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MASTER

GEOLOGICAL AND GEOCHEMICAL ASPECTS OF URANIUM DEPOSITS

A Selected Annotated Bibliography-- Vol. 2

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Information Division

**GEOLOGICAL AND GEOCHEMICAL ASPECTS OF URANIUM DEPOSITS
A SELECTED, ANNOTATED BIBLIOGRAPHY
VOL. 2**

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National Uranium Resource Evaluation Program
Ecological Sciences Information Center
Information Center Complex

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ABSTRACT

This bibliography, a compilation of 490 references, is the second in a series compiled from the National Uranium Resource Evaluation (NURE) Bibliographic Data Base. This data base is one of six data bases created by the Ecological Sciences Information Center, Oak Ridge National Laboratory, for the Grand Junction Office of the Department of Energy. Major emphasis for this volume has been placed on uranium geology, encompassing deposition, genesis of ore deposits, and ore controls; and prospecting techniques, including geochemistry and aerial reconnaissance. The following indexes are provided to aid the user in locating references of interest: author, geographic location, quadrangle name, geotectonic feature, taxonomic name, and keyword.

PREFACE

This publication of 490 references is the second in a series of bibliographies from the National Uranium Resource Evaluation (NURE) Bibliographic Data Base created by the Ecological Sciences Information Center (ESIC), Oak Ridge National Laboratory. Information support by ESIC to the NURE Program of the Department of Energy, Grand Junction Office, consists of six data bases: Bibliographic Information File, Quadrangle File, Contractor Report File, Uranium Mines File, Geounits File, and Numeric File. Major emphasis for the NURE Bibliographic Data Base has been placed on uranium geology, encompassing deposition, ore genesis, ore controls, lithology, and petrology; prospecting, including aerial reconnaissance, geochemistry, and geophysics; uranium reserves and resources; and universally applicable uranium studies. References cited in the Grand Junction Office contractors' reports on aerial reconnaissance surveys have also been abstracted and included when possible. This bibliography highlights select reports from the following International Atomic Energy Agency conferences: Nuclear Techniques in Geochemistry and Geophysics (1974), Uranium Exploration Methods (1972), Formation of Uranium Ore Deposits (1974), and Recognition and Evaluation of Uraniferous Areas (1975). The literature included was published between 1904 and 1977.

Geographic information is presented by state, county, section, township, range, and 15- or 7.5-minute quadrangle. The study areas are then categorized into one-degree by two-degree National Topographic Map Series quadrangles. Geologic formations, mines, claims, rivers, and regional structures located within the study site are named if they are applicable to the research.

Indexes provided for the purpose of simplifying search techniques are: author, geographic location, quadrangle name, geoformalional feature, taxonomic name, and keyword. The literature is sorted by subject category, as listed in the table of contents. Genesis of Ore Deposits, a new subject category, has been added to provide easier access to references on this subject. **All references in this bibliography are contained in the NURE Bibliographic Data Base and are available for searching upon submission of specific requests. The services of ESIC are free to all DOE-funded researchers. All inquiries for information services should be addressed to:**

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E. M. Eckerson of the Grand Junction Office of the Department of Energy and H. A. Pluderer and J. L. Ensminger of ESIC have provided assistance, guidance, and expertise in the establishment and compilation of the NURE data bases. Cathy Fore of ESIC and the staff of the Information Sciences and Operations Department of the Information Center Complex were responsible for the computer production of this document. Special thanks to Dr. W. E. Chenoweth for his constructive suggestions and contributions in the preparation of this document. This document was reviewed for its content and completeness by R. Floran and J. Kuhada.

national uranium resource evaluation

SAMPLE REFERENCE

A	Subject Category	F	Publication Description
B	Record Number (of reference)	G	Publication Date
C	Author	H	Abstract
D	Corporate Author	I	Abstracter's Initials
E	Title	J	Comments

(A) PROSPECTING

(B) (244)

(C) (D) Stuckless, J. S., and C. Pires Ferreira; USGS, Denver, CO; Comissao Nacional de Energia Nuclear, Rio de Janeiro, Brazil

(E) (F) **Labile Uranium in Granitic Rocks.** IAEA-SM-208 17, (pp. 717-730), 807 pp.; In Proceedings of the International Conference on Exploration for Uranium Ore Deposits, held in Vienna, Austria, March 29-April 2, 1976. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 717-730), 807 pp. (1976)

(H) Labile uranium in granitic rocks has been proposed as the source for many ore deposits. Tests of this hypothesis or development of commercial in-situ leaching of uranium from crystalline rocks will require analytical techniques that can be used to identify granites that contain labile uranium. U-Th-Pb isotopic systematics can be used to obtain quantitative or semi-quantitative data on the timing and extent of uranium mobilization, but the technique is limited to Precambrian rocks and is too expensive for general use as an exploration tool. Granite from the Granite Mountains, Wyoming, has been shown to contain labile uranium, and it is proposed that several characteristics of this granite may be typical of other granites that are possible uranium source rocks. Important characteristics for uranium source rocks are inferred to be (1) alkalic affinity and high (greater than 70%) silica content, (2) high Th content, and (3) disequilibria between pairs of long-lived radiogenic daughter products within the U-238-decay chain. This last characteristic may possibly be identified by comparing Rae/U values (radium equivalent uranium

(I) obtained by gamma-ray spectrometry) with chemical uranium contents. (Auth)

(J) Cited as a reference in NURE Contractor Reports.

GEOLOGY AND MINERALOGY

<1>

Isachsen, Y.W., T.W. Micham, and H.B. Wood; AEC. Grand Junction, CO

Age and Sedimentary Environments of Uranium Host Rocks, Colorado Plateau. Economic Geology. 50(2), 127-134. (1955)

Uranium deposits have been found on the Colorado Plateau in 32 sedimentary units that range in age from Pennsylvanian to Tertiary, and in a Tertiary monzonite porphyry. At least one example in each formation is briefly described. Ore has been produced from 22 of these units. Host rocks represent all major sedimentary environments except glacial. The wide variation in age and depositional environments of the host rocks suggests an epigenetic origin for uranium ore on the Colorado Plateau. (Auth)

<2>

King, J.W.; AEC. Grand Junction, CO

Geology and Ore Deposits of Mesa 5, Lukachukai District, Arizona. RMO-754. 17 pp. (1951)

Vanadium-uranium deposits on Mesa 5 are in the lower part of a fine-grained sandstone unit in the Salt Wash member of the Morrison formation of Jurassic age situated 65 to 95 feet above the base of the formation. The light tan, limonite-stained sandstone is from 15 to 25 feet thick and contains thin mudstone beds which are bleached to gray in the vicinity of the ore deposits. The ore minerals, principally carnotite and vanoxite, impregnate the sandstone and coat the sand grains. Fossil carbonaceous material is locally abundant and at places is mineralized. The ore bodies on Mesa 5 are small but numerous; the deposits on Mesa 4 and 2 are generally similar but are more numerous and of higher grade. (Auth)

<3>

King, J.W., and F.C. Ellsworth; AEC. Grand Junction, CO

Geology and Ore Deposits of Mesa 7, Lukachukai District, Arizona. RMO-803. 8 pp. (1951)

Carnotite and vanoxite impregnate a light tan sandstone at one place on the rim of Mesa 7. The sandstone bed is in the Salt Wash member of the Morrison formation of Jurassic age and is about 40 feet above the base of the formation. The ore exposure is less than a foot thick and is underlain by a green mudstone bed. The Salt Wash member on Mesa 7 is composed of predominantly pink, fine- to coarse-grained quartzose sandstone and interbedded red mudstone. (Auth)

<4>

Klemic, H., and R.C. Baker; USGS. Washington, DC

Occurrences of Uranium in Carbon County, Pennsylvania. USGS Circular: 350. 8 pp. (1954)

Uranium vanadates, carbonates, and silicates occur in coarse graywacke conglomerate near the base of the Pottsville formation, of Pennsylvanian age, on the north limb of the Panther Valley syncline; and on the south limb, autunite and uranium silicates occur in graywacke sandstones near the top of the Catskill formation of Devonian age. Uraniferous graywacke sandstone occurs in the upper part of the Catskill formation near Butcher Hollow and near Penn Haven Junction in minor anticlines of the Broad Mountain anticline. Small amounts of kasolite and palena occur in the vicinity of Penn Haven Junction. The three uranium deposits in the Catskill formation appear to be at about the same stratigraphic horizon. The uranium minerals coat fractures and are disseminated in the rock in lenses in discontinuously radioactive zones. The occurrences are all in gray or greenish-gray rock that contains finely divided carbonaceous material rather than in the red parts of the formations. (Auth)

<5>

Kelley, V.C.: University of New Mexico, Albuquerque, NM

Regional Tectonics of the Colorado Plateau and Relationship to the Origin and Distribution of Uranium. University of New Mexico Publications in Geology No. 5, 120 pp. (1955)

The relationship between regional structure and regional concentration of uranium deposits was studied. The report on this study consists of three principal parts: (1) a description and analysis of the regional tectonics, (2) a geologic history, and (3) a discussion of the tectonic influence on distribution and origin of uranium. In the first of these parts the structural elements are described. Tectonic subdivisions of the Colorado Plateau are established. Within the major tectonic subdivisions there are a host of minor structures such as folds, faults, joints, and intrusive centers; these are described and discussed from a regional point of view. In the second part of the report the sedimentational and tectonic histories of the Colorado Plateau are outlined as interpreted from sedimentary thickness, lithologies, and unconformities. In the third part of the report, dealing with the relationship between regional structure and uranium distribution on the Colorado Plateau, the conclusion is reached that little if any such direct relationship exists. However, tectonic events have had an important bearing on other geologic factors that may have contributed directly to the origin and distribution of uranium. These factors are (1) provenances and environments, (2) paleohydrology, (3) igneous activity, and (4) erosional history. (Auth)

See related paper in USGS Professional Paper 300, (pp. 171-178) by V.C. Kelley entitled "Influence of Regional Structure and Tectonic History upon the Origin and Distribution of Uranium on the Colorado Plateau".

<6>

Jobin, D.A.: USGS, Washington, DC

Regional Transmissivity of the Exposed Sediments of the Colorado Plateau as Related to the Distribution of Uranium Deposits. In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of

Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 317-320). 825 pp.: In USGS Professional Paper 300, (pp. 207-211), 739 pp. (1956)

A study of regional transmissivity of the sedimentary rocks of the Colorado Plateau has been made to relate differences in transmissivity to the position of ore deposits. Transmissivity is defined as the capacity of a sedimentary rock as a whole to transmit fluids. The coefficient of transmissivity for a sediment of a given locality is equal to the product of its thickness and mean permeability. Permeability is the capacity of a substance to transmit fluids under a hydraulic gradient and by definition is dimensionless. The sedimentary rocks on the Colorado Plateau may be divided into two groups on the basis of their transmissivity. Shales, mudstones, evaporites, and limestones are essentially non-transmissive by virtue of their extremely low permeability. Conglomerates, sandstones, and siltstones are permeable and, therefore, constitute the transmissive groups, which can be divided into two groups. One group consists of eolian sandstones which are characterized by uniform permeability and thickness. Changes in permeability and thickness are usually gradational and small in range, resulting in similarly small and gradual changes in transmissivity over large areas. The other group consists of fluvial sandstone, siltstone, and conglomerate and is characterized by great changes in permeability and thickness. This group contains most of the known uranium deposits in the Colorado Plateau. Owing to the frequency and range of permeability and thickness, the transmissive capacity of these sediments changes abruptly within short distances. The regional transmissive capacity of fluvial sediments as a whole is low relative to eolian sediments. Most of the known uranium deposits on the Colorado Plateau are in fluvial sediments. There is, however, no obvious correlation between position of ore deposits within a particular host rock and its regional permeability or transmissivity. (Auth)

<7>

Langford, F.F.: University of Saskatchewan, Department of Geological Sciences, Saskatoon, Saskatchewan, Canada

Surficial Origin of North American Pitchblende and Related Uranium Deposits. American Association of Petroleum Geologists Bulletin, 61(1), 28-42. (1977, January)

The ubiquitous association of pitchblende uranium deposits with terrestrial sediments is believed to be the natural result of formation of the orebodies by surficial processes operating under continental conditions. The major uranium deposits of North America illustrate this. The quartz-pebble conglomerate uranium deposits of Elliot Lake, Ontario, have thorium-rich uranium minerals that indicate a detrital origin. With the development of an oxygenic atmosphere before 1,700 m.y. ago, uranium was transported in solution in meteoric surface and near-surface ground water, and produced pitchblende veins in fractures in the basement and in lava flows in terrestrial environments. This accounts for the close association of fluvial sediments with the pitchblende deposits at Beaverlodge, Rabbit Lake, Baker Lake, and Great Bear Lake, Canada. The development of land plants about 300 m.y. ago produced favorable environments within the terrestrial sandstones themselves, and resulted in the tabular uranium orebodies of the Colorado Plateau. The close relation of tabular orebodies to sedimentation is apparent when compared to recent fluvial sedimentation. In Wyoming, the stratigraphic restriction of the boundary-roll deposits to a few zones in Eocene rocks results from their being remobilized tabular deposits. (Auth)

<8>

Keith, W.J.: USGS, Washington, DC

Geology of the Red Mountain Mining District, Esmeralda County, Nevada. USGS Bulletin 1423, 45 pp. (1977)

The Red Mountain mining district is in the central part of the Silver Peak Range near the west-central boundary of the Basin and Range province. The district consists of interlayered volcanic flows, breccias, and tuffs, and sedimentary rocks all of which are Miocene in age. The volcanic rocks form a continuous differentiation series that is alkali-calcic in composition. Structures in the district are predominantly high-angle northeast-trending normal faults that formed in

response to subsidence. Many of these faults were mineralized near the end of Miocene time to form sheeted quartz-calcite fissure veins that contain both precious and base metals. The district has produced mainly silver and gold with minor amounts of lead, zinc, and copper. (Auth)

<9>

Ayres, D.E., and P.J. Eadington: Commonwealth Scientific and Industrial Research Organization, Division of Mineralogy, Sydney Australia

Uranium Mineralization in the South Alligator River Valley. Mineralogica Deposita, 10, 27-41. (1975)

The South Alligator uranium deposits are located in the Northern Territory, Australia, south-west from the recent discoveries of Naharlek, Ranger, Koongarra and Jabiluka. All five deposits occur in intensely folded Early Proterozoic rocks around the perimeter of the Kombolgie Formation, a flat-lying Middle Proterozoic sandstone unit. It is proposed that during reconstitution (weathering or diagenesis) of acid volcanic rocks, groundwaters leached uranium and percolated down into the groundwater system of the permeable sandstone and conglomerate unit at the base of the sequence. Uranium as uranyl ion was stable in relatively high Eh groundwater conditions and was carried in solution until active reducing conditions were met with which resulted in reduction of uranyl ion to insoluble UO₂. Reduction occurred where faulting had brought underlying carbonaceous shales up against the sandstone aquifer, or where groundwater could percolate down permeable fault zones into the carbonaceous shales. These structural, chemical traps were sites of uranium accumulation. (Auth)

<10>

Anderson, J.J.: Kent State University, Department of Geology, Kent, Ohio

Geology of the Southwestern High Plateaus of Utah: Bear Valley Formation, an Oligocene-Miocene Volcanic Arcsite. Geological Society of America Bulletin, 82, 1179-1206. (1971, May)

The Bear Valley Formation was deposited in an extensive structural and physiographic basin within which faulting and volcanism were contemporaneous with sediment accumulation.

Little volcanism accompanied the early stages of sand deposition; the later stages, however, were marked by local eruptive activity which admixed a considerable quantity of glass shards in the sand and produced local ignimbrite and tuff strata. Deposition of the arenite was accomplished primarily by the wind, and took place under arid climatic conditions. This is indicated by the mineralogy and texture of the sand and by the large-scale cross-bedding throughout most of the section. After deposition and subsequent burial by renewed volcanism, the sand was cemented by clinoptilolite. The Bear Valley Formation crops out over an area of more than 1000 square miles and has a maximum exposed thickness in excess of 1000 feet. It may be described as moderately to well sorted, fine- to medium-grained, zeolite-cemented submaturation to mature volcanic arenite. No fossils have been recovered from this rock unit. (Auth)(M.B.)

<11>

McKnight, W.M., Jr.; Mobil Oil Corporation, Denver, CO

A Review of South Texas Uranium Geology. Gulf Coast Association of Geological Societies Transactions, 22, 97-103. (1972)

All production in the south Texas area is from Tertiary sandstone units representing marginal marine to continental depositional environments. These uranium accumulations are dominantly "roll front" type deposits which owe their existence to the geochemistry and stratigraphy of the sediments. Exploration techniques utilized in locating these deposits are similar to hydrocarbon techniques. Stratigraphic and structural controls of hydrocarbon and uranium accumulations have many common characteristics although trapping mechanisms are physical for hydrocarbon and chemical in the case of uranium. (Auth)(M.B.)

<12>

Stieff, L.R., T.W. Stern, and A.M. Sherwood; USGS, Washington, DC

Preliminary Description of Coffinite - A New Mineral. Science, 121(3147), 608-609. (1955)

A new radioactive black mineral has been discovered in several mines on the Colorado Plateau, and in Wyoming, Colorado, Arizona, and several foreign countries. The mineral, a uranous silicate with some hydroxyl substitution, has been named coffinite in honor of Reuben Clare Coffin. It is closely associated with carbonaceous material, uraninite, black vanadium minerals, pyrite, quartz and clay. Coffinite is best identified by its X-ray powder pattern, which is tetragonal, and similar to that of thorite, even though the mineral contains no thorium. (Auth)(MBW)

<13>

Trites, A.E., Jr., T.L. Finnell, and R.E. Thaden; USGS, Washington, DC

Uranium Deposits in the White Canyon Area, San Juan County, Utah. In USGS Professional Paper 300, (pp. 281-284), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 379-382), 825 pp. (1956)

The geology of approximately 560 square miles has been mapped in the White Canyon area, San Juan County, Utah. The area consists of sedimentary rocks, more than 4,000 feet thick, which range in age from Pennsylvanian to Jurassic and have a regional dip of 2 degrees - 3 degrees SW. Normal faults are present in the northwestern and southwestern parts of the area. The uranium deposits occur where the Shinarump conglomerate fills channels cut into beds of the Moenkopi formation. Most of these channels are within a broad band of Shinarump conglomerate ranging from 8 to 15 miles wide. All of the known high-grade deposits are in channels that are within 3,000 to 15,000 feet of the edge of the band of Shinarump conglomerate. The major control of the uranium deposition appears to have been lithologic; the most favorable bed is a clayey sandstone immediately overlying a bed of siltstone or mudstone and containing carbonized vegetal material. Branches and bends in channels, and

scours in the floor of channels, may have provided the conditions for the deposition of favorable rocks. In addition to uraninite, the uranium minerals include hydrous oxides, silicates, phosphates, and arsenates. (Auth)

<14>

Williams, G.O.: Not given

Radium-Bearing Silts of Southeastern Utah. *Engineering Mining Journal*, 119(5), 201-202. (1925)

Radium-uranium deposits have been found in Tertiary or Quaternary silt and clay beds on the floor of Montezuma Canyon in San Juan County, Utah. It is suggested that pre-existing carnotite deposits were eroded, washed downstream, and redeposited on the floor of the canyon. (Auth)

<15>

Witkind, I.J.: USGS, Denver, CO

Localization of Uranium Minerals in Channel Sediments at the Base of the Shinarump Conglomerate, Monument Valley, Arizona. *Economic Geology*, 49(7), 804-805; *Geological Society of America Bulletin*, 65(12), 1327. (1954)

Uranium ore bodies in the Monument Valley area are localized in the conglomeratic sandstone of the Shinarump conglomerate of Triassic age that fills channels scoured into the underlying Moenkopi formation, also of Triassic age. These channels range in cross section from 15 feet wide and 10 feet deep to 2,300 feet wide and 70 feet deep. Fragments of trees were deposited with Shinarump sediments in the channels. It is suggested that when the Shinarump conglomerate was invaded by mineralizing solutions, the uranium minerals were deposited mainly in and adjacent to decomposing plant material. It is suggested that short channels are more likely to contain ore than long channels. (Auth)

<16>

Witkind, I.J.: USGS, Washington, DC

Channels and Related Swales at the Base of the Shinarump Conglomerate, Monument Valley, Arizona. In USGS Professional Paper 300, (pp. 233-237), 729 pp.; In *Proceedings of the International Conference on the Peaceful Uses of Atomic Energy*, Vol. 6, *Geology of Uranium and Thorium*, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 368-370), 825 pp. (1956)

Vanadium-uranium ore deposits in Monument Valley are in channel sediments at the base of the Shinarump conglomerate of Triassic age. The channels range in width from 15 to 2,300 feet and are scoured as much as 75 feet into underlying strata. The relationship between channels and uranium deposits has been demonstrated so repeatedly that prospecting in the area has evolved to search for, and exploration of, these channels. In some localities, a channel occupies the axis of a broad elongate swale. The swales are too large for visual observation but are apparent on isopachous maps. The swales range in width from 1 to 3 miles, and have about 40 feet of relief. It may be possible to locate and outline concealed channels by exploration of the swales. (Auth)

<17>

Wright, R.J.: AEC, Grand Junction, CO

Ore Controls in Sandstone Uranium Deposits of the Colorado Plateau. *Economic Geology*, 50(2), 135-155; *Geological Society of America Bulletin*, 64(12), 1495. (1955)

Marked lithologic control characterizes most uranium deposits in sandstone formations of the Colorado Plateau. Deposits in rocks ranging in age from the Cutler formation of Permian age to the Wasatch formation of Eocene age are primarily in fluvial sandstones which contain carbonized plant matter, are light-colored or gray, rather than red, and contain feldspar or mica. In addition, sandstones that are interbedded with or interfinger with shales or mudstones are particularly favorable. These features are also characteristic of most sedimentary copper deposits. Most uranium deposits in sandstone formations show no immediate connection with tectonic features, but a general clustering of ore bodies around large

positive structures is noted. The reason for this is not clear. It is postulated that at least some of the uranium in the ores was derived from the same source as the host rocks. In this light the sandstone uranium deposits may be the continental analogue of uranium-rich marine black shales and phosphorites. Sedimentary copper deposits may have had a similar origin. Uranium moving seaward in streams, during erosion of a land mass, may be fixed on the continent in certain favorable fluvial environments. (Auth)

"Lithologic Ore Controls in Sandstone Type Uranium Deposits, Colorado Plateau" was published in 1953 as a Geological Society of America Bulletin abstract.

<18>

Zareski, G.K., AEC, Grand Junction, CO

Reconnaissance of Uranium Occurrences at Wray Mesa, San Juan County, Utah, and Montrose County, Colorado. RME-69 (Part I), 15 pp. (1954)

Uranium deposits are found in sandstone in the Brushy Basin and Salt Wash members of the Morrison formation on Wray Mesa. In all but two deposits, ore minerals are carnotite and black vanadium minerals. In one deposit in the Brushy Basin member, uranium is contained in an unidentified black mineral; in another deposit, the ore minerals are tyuyamunite and beta-uranotil. The orebodies are small in size. (Auth)

<19>

Not given; California Division of Mines and Geology, San Francisco, CA

Uranium, A Comparison of Its Geologic Occurrence in California and in the Colorado Plateau. California Division of Mines and Geology Mineral Information Service, 8(5), 1-7. (1955)

Uranium deposits are known in about 100 localities in California in igneous, sedimentary, and metamorphic rock types. In the Taft-McKittrick area, San Luis Obispo and Kern Counties, carnotite and other secondary uranium minerals have been found coating fractures in shale beds of

Tertiary age. In the Rosamond-Mojave area, Kern County, secondary uranium minerals occur along fractures and bedding planes and as disseminations in tuffaceous sedimentary and rhyolitic rocks of the Rosamond formation of Miocene age. In Kern Canyon, Kern County, autunite and other uranium minerals occur in and near shear zones in granitic rocks. Uranium deposits are also known in many other scattered areas in California. (Auth)(MBW)

<20>

Moench, R.H., and J.S. Schlee, USGS, Washington, DC

Geology and Uranium Deposits of the Laguna District, New Mexico. USGS Professional Paper 519, 117 pp. (1967)

Uranium deposits in the Laguna district are in the east end of the Southern San Juan Basin mineral belt. This belt is parallel to several controlling and definitive geologic features of Jurassic age but it widely divergent from major structural features of Tertiary age. Within the district most deposits are concentrated in elongate groups and apparently are controlled by Jurassic tectonic features and by sedimentary trends in the host rocks. The large uranium deposits in the Jackpile sandstone are composed of one or more semitabular ore layers. In plain view they range from nearly equant to strongly elongate. Viewed in section the layers are wholly within the host sandstone. The Jackpile deposit, the largest in the district, is nearly 6,000 feet long and averages about 2,000 feet in width; individual ore layers rarely exceed 15 feet in thickness, but several layers may aggregate 50 feet in thickness. The Woodrow deposit is small but contains high-grade ore. In the upper part of the deposit the ore is concentrated largely along the boundary ring faults. Deposits in the Entrada Sandstone and limestone of the Todito Formation in the Laguna district are small and rarely economic. A group of deposits in the limestone and sandstone in the sandy mine is localized along the crest and steep limb of a Jurassic fold. Coffinite and uraninite are the chief ore minerals of the relatively unoxidized parts of deposits and they are intimately mixed with carbonaceous matter, which is particularly abundant in deposits in the Morrison Formation. Other minerals associated with ore are vanadium clay, pyrite, and other sulfide minerals. The uranium deposits of the district may have formed in Jurassic time shortly after the

accumulation of the host rocks and perhaps when these rocks were exposed at the surface. Surface and ground waters flowing from the highland may have extracted uranium and vanadium from the rocks and transported them to the sites of deposition. Such waters could also have extracted soluble humic compounds from surficial or buried decaying plant debris. These substances could then have precipitated where the ground water flow was impeded by the stratigraphic and tectonic structural features that are recognized in the mineral belt. Impedance and partial stagnation might have invigilated aeration and enhanced the reduction of sulfate by anerobic bacteria. The resulting reducing environment might have effected a reduction and precipitation of uranium. In addition, weak acidification of the ground water might also have caused the precipitation of alkali-soluble humic compounds, which in turn might have extracted more uranium from solution. (JMT)

<21>

Not given; University of Texas, Bureau of Economic Geology, Austin, TX

Geologic Atlas of Texas, Amarillo Sheet, 1:250,000. University of Texas Map, I Sheet. (1969)

A geologic map of Amarillo quadrangle is presented. The scale of the map is 1:250,000. The map was prepared by the Army Map Service (BEPM), Corps of Engineers, and the U.S. Army in 1955. Horizontal and vertical control was provided by the USGS and the USC and GS. (JMT)

Cited as a reference in NURE Contractor Reports.

<22>

Not given; University of Texas, Bureau of Economic Geology, Austin, TX

Geologic Atlas of Texas, Perryton Sheet, 1:250,000. University of Texas Map, I Sheet. (1970)

A geologic map of the Perryton quadrangle is presented. The scale of the map is 1:250,000. The map was prepared by the Army Map Service (BEPM), Corps of Engineers, and the U.S. Army

in 1956. Horizontal and vertical control was provided by the USGS and the USC and GS. (JMT)

Cited as a reference in NURE Contractor Reports.

<23>

Not given; University of Texas, Bureau of Economic Geology, Austin, TX

Geologic Atlas of Texas, Plainview Sheet, 1:250,000. University of Texas Map, I Sheet. (1968)

A geological map of the Plainview quadrangle is presented. The scale of the map is 1:250,000. The map was prepared by the Army Map Service (BESM), Corp of Engineers, and the U.S. Army in 1955 by photogrammetric methods. Horizontal control and vertical control was provided by the USC and GS and the USGS. (JMT)

Cited as a reference in NURE Contractor Reports.

<24>

Reed, I.C., and O.M. Longnecker; University of Texas, Austin, TX

The Geology of Hemphill County, Texas. University of Texas Bulletin 3231, 98 pp. (1932)

The geologic report of Hemphill County, is the result of a detailed study of an area in the Southern High Plains. In Hemphill County the Canadian River emerges from its broad, deep valley which cuts entirely across the great plateau of the High Plains. The area is also in the Anadarko basin, which is the leading structural feature of western Oklahoma and of northwestern Texas Panhandle. Field work in the area lead to the discovery of one of the most prolific fossil fields of Lower Pliocene age yet discovered. The Cenozoic deposits of the High Plains were laid down after the latest major uplift of the mountain ranges to the west. Of the formations deposited clearly after, and as a result of, the mountain making movements, these deposits in Hemphill County have yielded fossils from which ages of the respective beds are determinable. The Santa Fe formation in the upper Rio Grande Valley in New Mexico has been

correlated with sediments in Hemphill County and the fossils closely agree in age, establishing the date of formation of the mountains. (JMT)

Cited as a reference in NURE Contractor Reports.

- 25 -

Matthews, W.H., III, University of Texas,
Bureau of Economic Geology, Austin, TX

**The Geologic Story of Palo Duro
Canyon** University of Texas Guidebook 8,
49 pp. (1969, August)

The report details the history of Palo Duro Canyon State Park and gives a general description of the geology of the park. The rocks which out crop in Palo Duro Canyon are sedimentary in origin and they represent four different geologic periods, Permian, Triassic, Tertiary, and Quaternary. The oldest formation exposed in the canyon is the Quartermaster Formation of Permian age. It is composed primarily of brick-red to vermillion shales which are interbedded with lenses of gray shales, clays, mudstones, and sandstones. Overlying the Quartermaster is the Tecovas Formation of Triassic age. The Tecovas Formation has a thickness of about 200 feet in the park area and consists largely of multicolored shales. The Trujillo Formation, also of Triassic age overlies the Tecovas Formation and consists of primarily sandstone. The Ogallala Formation overlies the Trujillo Formation. Between the two formations, lies a major unconformity. The Ogallala formation is of Pliocene age and consists of sandstone that is interbedded with conglomerate, siltstone, clay and marl. (JMT)

Cited as a reference in NURE Contractor Reports.

- 26 -

Maxwell, R.A., and J.W. Dietrich;
University of Texas, Bureau of Economic
Geology, Austin, TX

**Correlation of Tertiary Rock Units, West
Texas.** University of Texas Report of
Investigation No. 70, 34 pp. (1971)

Tertiary rocks, including sandstone, conglomerate, shale, pyroclastics, tuff, and lava, are preserved in

Big Bend National Park and in a much larger area to the west and northwest. Some of the rocks have distinctive characteristics that enable recognition by their lithology, but others are distinctly dissimilar, although they may have been deposited about the same time. This dissimilarity may be in part due to a different source of material as the normal behavior of the volcanic rock is to thin and disappear away from the source, also the volcanic rocks disappear by nondeposition and in other places by erosion, so that the casual observer would be unable to develop an orderly stratigraphic sequence over a large area. This has led to much confusion in stratigraphic correlation. Multiple names have been applied to the same rock unit in different areas and the same name has been applied to different rock units because of lithologic similarity. It was the object of this investigation to correlate these Tertiary rock units in a way so as to clarify these discrepancies, and the report details the results. (JMT)

Cited as a reference in NURE Contractor Reports.

- 27 -

Frye, J.C., A. Swinford, and A.B.
Leonard, University of Kansas, Lawrence,
KS, Kansas Geological Survey, Lawrence,
KS

**Correlation of Pleistocene Deposits of the
Central Great Plains with the Glacial
Section.** Journal of Geology, 56(6),
501-525. (1948)

Integration of Pleistocene chronologies of the central Great Plains and the glaciated area is a major problem of late Cenozoic stratigraphy in North America. Lenticular deposits of volcanic ash associated with fossil mollusks occur in both regions and furnish a widespread datum for interregional correlations. The ash lentils, collectively called Pearlette, can be differentiated petrographically from other late Cenozoic ash deposits of the Plains region and have been studied at localities extending from southeastern South Dakota to northwestern Texas. The associated molluscan fauna possesses an unforeseen degree of uniformity and stratigraphic significance. The Pearlette ash and faunal zone occurs above Kansas till and below Loveland loess and Iowa till in the Missouri Valley region and is judged to be early Yarmouthian in age. A modification of

stratigraphic names for Kansas contributes to uniformity of terminology in the Plains region. (Auth)

Cited as a reference in NURE Contractor Reports

- 28 -

Abou-Zied, S., and J.A. Whelan, Utah Department of Natural Resources, Salt Lake City, U.T. Utah Geological and Mineral Survey, Salt Lake City, Utah

Geology and Mineralogy of the Milford Flat Quadrangle, Star District, Beaver County, Utah. Utah Geological and Mineral Survey Special Studies 46, 23 pp. (1973, December)

Sedimentary and igneous rocks outcrop in the northwest corner of the Milford Flat quadrangle and the remainder are alluvium. Sedimentary rocks, excluding alluvium, range from Permian to Jurassic age. The Permian is represented by the Talisman Quartzite, Toroweap Formation and Kaibab Limestone, the Triassic by the Moenkopi Formation, Shinarump Conglomerate and the Chinle Formation, and the Jurassic by the Navajo Sandstone. The sedimentary rocks represent the east limb of a northeast-trending fold. They are cut by faults of several ages, the oldest being northeast-southwest normal faults. East-west cross-cutting faults are pre- and post-intrusion. Northeast-southwest normal faults are contemporaneous with the intrusion. Fissures on which no movement is evident trend east-west, north-east and northwest. Granodiorite, quartz monzonite and several lamprophyric and aplitic dikes intrude the sedimentary rocks. The granodiorite and quartz monzonite occur in separate masses and outcrop over an area of approximately one square mile. The igneous rocks are probably of Tertiary age. Lamprophyric dikes, several inches to 3 feet thick, are highly altered and have east-west or northerly trends. The aplitic dikes are a few feet thick and strike northwestward. Hydrothermal alteration of sedimentary rocks in the area include bleaching and recrystallization of limestones and dolomites and argillic, propylitic, siliceous and hematitic alteration of the igneous rocks. The mapped area has produced lead, zinc, silver, gold and copper. Mineralization is divided into: (1) deposits within the granodiorite mass, (2) contact metasomatic deposits, and (3)

hydrothermal replacement and fissure filling deposits. No distinct zonation of the mineralization is encountered. (Auth)

- 29 -

Ludwig, K.R., and E.J. Young, USGS, Denver, CO

Absolute Age of Disseminated Uraninite in Wheeler Basin, Grand County, Colorado Journal of Research of the USGS, 3(6), 747-751 (1975, November)

Uranium and lead isotopic analyses of monazite and uraninite from the disseminated uraninite occurrence at Wheeler Basin, Grand County, Colorado, indicate that these minerals formed 1,446 plus or minus 20 m.y. ago. This time correlates well with intrusion of the Silver Plume Granite. The uraninite and monazite were also affected by a later disturbance at 880 plus or minus 130 m.y., but show essentially no effects of subsequent events. This secondary disturbance may have been due to intrusion of dikes related to the Pikes Peak batholith, dated at 1,041 plus or minus 13 m.y. ago. (Auth)

- 30 -

Shoemaker, F.M., USGS, Washington, DC

Structural Features of the Central Colorado Plateau and Their Relation to Uranium Deposits. In USGS Professional Paper 300, (pp. 155-170), 739 pp. (1956)

The structural features of the central Colorado Plateau include broad uplifts and basins bounded on one or more sides by monoclinical folds and faults, complexly faulted salt anticlines, intruded igneous bodies of laccolithic and stocklike form, diatremes, and local areas of intense deformation of possible cryptovolcanic origin. Joints and small faults are associated with all major types of structures. The post-Cambrian tectonic history of the central Colorado Plateau includes major periods of deformation in early Pennsylvanian through Permian time, and in latest Cretaceous through Tertiary time. The major uplifts and basins have diverse histories. All of them underwent renewed deformation or were formed in latest

Cretaceous or Tertiary time, but the period of maximum deformation varies from one uplift to another, and for some uplifts it is not known. The salt structures were active from late Pennsylvanian or early Permian through Jurassic time and were subsequently modified during at least two periods of deformation, one in latest Cretaceous or early Tertiary and another in late Tertiary to Recent time. The main periods of igneous activity were probably latest Cretaceous and Pliocene. Lead and uranium age determination based on lead isotope analyses indicate a late Cretaceous or early Tertiary age for many uranium deposits of the Colorado Plateau, but the occurrence of uranium deposits in sedimentary and volcanic rocks of Eocene, mid-Tertiary and Pliocene age show that uranium ore-forming solutions also circulated, at least locally, since early Tertiary time. The great majority of uranium deposits show no readily apparent direct relation to regional structures such as faults and joints, though the structural relations at a number of deposits have been subject to diverse field interpretations. About a half dozen localities in the central part of the Colorado Plateau are known where the field evidence has been interpreted by nearly all observers as indicating a genetic relation between uranium deposits and faults. (Auth)

<31>

Vine, J.D.; USGS, Washington, DC

Geology of Uranium in the Basins of Tertiary Age in Wyoming and the Northern Great Plains. In USGS Professional Paper 300, (pp. 337-344), 739 pp. (1956)

Uranium deposits of commercial size and grade are being explored and mined in the Wyoming Basin and the Northern Great Plains physiographic provinces of Wyoming and adjacent parts of Colorado and North and South Dakota. These deposits occur in sedimentary rocks in or adjacent to basins of thick Tertiary deposits, in many places remote from metallic vein deposits. The concentration of uranium in sandstone, limestone, and coal is thought to be secondary in origin, and the deposition of uranium is thought to be from mineralizing solutions that travel through the strata, as evidenced by the cross-cutting relation between uranium minerals and the primary sedimentary structures. Tectonic structures,

primary sedimentary structures, and the gross variations in the permeability of the strata probably control the distribution of uranium by determining the direction and volume of flow of mineralizing ground water. Local variations in lithologic character provide physical and chemical conditions favorable for the deposition of uranium. Any apparent spatial relation between the distribution of uranium and petroleum is probably fortuitous. The lack of equilibrium of uranium and its radioactive-decay products in many localities and the occurrence of uranium in caliche, travertine, and pediment gravel suggest recent transportation and deposition of some of the uranium. Deposition of uranium probably took place in a moderate-to-low-temperature environment even though low-valence uranium minerals occur in some districts. Three hypotheses for the origin of the uranium are considered: thermal solutions genetically related to magmatic intrusions; the leaching and concentration of disseminated uranium in superjacent volcanic ash of Tertiary age; and reconcentration of disseminated uranium in rocks laterally equivalent or adjacent to the host formation. Available evidence indicates that all three hypotheses are permissible except for explaining the origin of the uraniferous Dakota lignite, in which the evidence for the leaching of the volcanic ash is preeminent. The following classification for the deposits, based on the immediate source of the uranium-bearing solutions and the environment of deposition, is suggested: surficial, vadose, and hydrodynamic. (Auth)

<32>

Conant, L.C., and V.E. Swanson; USGS, Washington, DC

Chattanooga Shale and Related Rocks of Central Tennessee and Nearby Areas. USGS Professional Paper 357, 91 pp. (1961)

The Chattanooga shale and Maury formation, which have a combined thickness of about 35 feet, outcrop on the steep slope between the Nashville Basin and the surrounding Highland Rim. Outside the basin, they are exposed in several river valleys and in folded areas. The Chattanooga shale, now considered to be of Late Devonian age, lies unconformably on many formations ranging in age from Middle Ordovician to Middle Devonian. The Chattanooga shale is part of a blanket of black

shale and other marine rocks that were deposited in a sea that covered large parts of North America in Late Devonian time. In Tennessee this sea covered most of what is now the Nashville dome, but a few areas appear to have been islands during Chattanooga time. The black shale contains about 20 to 25 percent quartz, 25 to 30 percent clay and mica, 10 percent feldspar, 10 to 15 percent pyrite, 15 to 20 percent organic matter, and 5 percent miscellaneous constituents. The shallow-water origin for the Chattanooga shale is indicated by several lines of evidence, but any deep-water hypothesis involves serious inconsistencies. The black mud that formed the Chattanooga shale probably accumulated in water 100 feet deep or less; some apparently accumulated close to shorelines in water only a few feet deep. The sediment is believed to have been transported by sea-bottom traction, by suspension, and by wind. Sedimentation appears to have been phenomenally slow, 30 feet of shale representing deposition during most of Late Devonian time. The uranium in the Chattanooga shale is believed to have been removed from the sea water by plant particles on the sea bottom. Its relative richness resulted from the extremely slow sedimentation. The Maury formation, overlying the Chattanooga shale, consists chiefly of green mudstone or glauconitic sandstone and in most places has a conspicuous bed of phosphate nodules at or near its base. The Maury is commonly only about 1 to 4 feet thick and represents most of Early Mississippian time. Its lower contact is fairly distinct; its upper contact is commonly abrupt where overlain by the Fort Payne chert but is gradational where overlain by the New Providence shale and its equivalents. The phosphate nodules are present chiefly as irregularly shaped nodules, balls, and plates, most of which are concentrated in a single layer and are embedded in black shale, glauconitic sandstone, or claystone. The nodules seem to have accumulated at a time when clastic sedimentation had almost ceased. Economically the rocks of the Chattanooga shale and Maury formation have thus far been of little importance. There are several possibilities for future utilization of the rocks, especially if the possible by-products are considered. The oil yield of the shale is about 10 gallons per ton, and other possible products that might be obtained are phosphate, sulfuric acid, uranium, and light-weight aggregate for concrete. (JMT)

<33>

Botinelly, L., and A.D. Weeks, USGS, Washington, DC

Mineralogic Classification of Uranium-Vanadium Deposits of the Colorado Plateau. USGS Bulletin 1074-A, 5 pp. (1957)

The uranium deposits of the Colorado Plateau vary widely in mineralogy, but similarities of the deposits becomes apparent when they are classified on the basis of the elemental composition of the deposit and the amount of oxidation. Thus the mineralogy is the result of the interaction of two factors - the oxidation process and the primary composition of the ores. The classification is based on composition and stage of oxidation, and comprises three groups and the oxidized varieties of each. (JMT)

<34>

Malin, R.C., and H.W. Ransport, AEC, Denver, Colorado

Geology of the Uranium Deposits in the Cochetopa District, Saguache and Gunnison Counties, Colorado. Economic Geology, 54(1), 1-19. (1959)

Vein-type uranium deposits of geologic interest and commercial significance occur in the Cochetopa mining district. The uranium minerals in these deposits have been precipitated from hypogene solutions probably related to Tertiary igneous activity in the district. Silicification and brecciation of the sedimentary rocks in the Morrison formation and the Dakota sandstone, in and adjacent to fault zones, controlled deposition of uranium minerals from hydrothermal solutions. The most important deposits in the district are at the Gunnison Mining Company's Los Ochos claims where substantial reserves of ore in pipelike and vertically tabular bodies have been blocked out. Pitchblende is the dominant uranium mineral, and it is associated with abundant clay and minor amounts of marcasite. As a result of studies carried out in the district, certain pertinent geologic criteria on ore localizing influences have been established. (Auth)(JMT)

<35>

Phair, G., and K.O. Shimamoto, USGS, Washington, DC

Hydrothermal Uranothorite in Fluorite Breccias from the Blue Jay Mine, Jamestown, Boulder County, Colorado
American Mineralogist, 37(7-8), 659-666, (1952)

In the course of thin-section and heavy-mineral studies of fluorite breccias from Jamestown, Colorado, the mineral thorite, variety uranothorite, was identified on the basis of chemical, spectrographic, optical, and x-ray data. This uranothorite is compared with uranothorite from South Westland, New Zealand, that was described by Hutton in 1950, and with similar material from an Alaskan placer sample studied by the writers. These uranothorites are in turn contrasted with the uranothorites described in the older literature, all of which represent hydrated material. Thorium halos in fluorite are described, probably for the first time. The uranothorite associated with the fluorite breccias is clearly of hydrothermal origin unlike all previously described thorites and uranothorites, with one very doubtful exception. (Auth)

<36>

Not given; AEC, Washington, DC

The Natural Occurrence of Uranium and Thorium. In Nininger, R.D. (Ed.), Exploration for Nuclear Raw Materials, D. Van Nostrand, Inc., New York, (pp. 7-51), 293 pp. (1956)

Uranium and thorium are found in a variety of rocks and formations. However, three broad source types stand out as the most productive: (1) belts of ancient Precambrian rocks, (2) widespread areas of permeable sediments, and (3) accumulations of detrital sands. Original sources to which uranium and thorium are attributed in the formation of deposits are (1) molten magma, (2) hot fluids, (3) ground water, (4) surface solutions, (5) sea water, (6) volcanic ash deposits, and (7) deposits exposed to erosion. (JMT)

<37>

Not given; AEC, Washington, DC

Uranium Provinces. In Nininger, R.D. (Ed.), Exploration for Nuclear Raw Materials, D. Van Nostrand, Inc., New York, (pp. 71-82), 293 pp. (1956)

As with many other metals, most of the world's important uranium deposits are clustered within broad, indefinitely defined areas or provinces. The initial concentration of uranium in these broad areas probably occurred during the formation of the earth's crust. Subsequently, owing to the interplay of geochemical and orogenic processes, the uranium in the original areas of concentration has been redistributed and in part concentrated to exploitable deposits. The formation of exploitable uranium concentrations in a uranium province depends on many geologic factors. The processes involved are largely geochemical, though to a large extent they are actuated by orogenic events. (JMT)

<38>

Morhouse, G.E.; AEC, Grand Junction, CO

Investigation of Thucholite Deposits near Placerville, Colorado. RM(910), 13 pp. (1951, July)

Near Placerville, Colorado, two somewhat unusual occurrences of uranium are found in an extensive fault zone which cuts the Dolores formation. The uranium mineral, which has been identified as uraninite, is intimately associated with asphaltic material. This combination of radioactive organic material has been considered to be thucholite. At the Black King prospect, thucholite is found in the fault associated with primary sulphides of copper, lead, zinc, molybdenum, and antimony; it is also found in the adjacent hanging-wall beds which have been highly altered. At the White Spar prospect, 1 1/2 mile southeast, the mineral assemblage and occurrence are similar to those of the Black King, but the exposed wall rock is less altered. A radiometric survey along the fault zone between the two deposits failed to indicate the presence of additional uranium-bearing material. (Auth)(M.L.B)

<39>

McKelvey, V.E.; USGS, Washington, DC

Uranium in Phosphate Rock. In USGS

Professional Paper 300, (pp. 477-481), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955, United Nations, New York, (pp. 499-502), 825 pp. (1956)

Marine phosphorites commonly contain 0.005 to 0.03 percent uranium. The uranium content increases roughly with increasing phosphate content but is generally low in rocks that contain more than a few percent CO₂. Aluminum phosphate deposits that have been derived from the weathering of marine phosphorites and phosphatic nodules in some marine black shale formations contain similar amounts of uranium. Most of the uranium in these materials does not occur as a separate mineral phase but substitutes for calcium in carbonate fluorapatite or crandallite. A few occurrences of tyuyamunite and torbernite have been reported from highly weathered marine phosphorites, however, and these and other secondary uranium minerals, such as carnotite and autunite, are not uncommon in fossil bones and teeth that have been exposed to uranium-bearing solutions after burial. Because the marine phosphorites are of wide extent they contain large tonnages of uranium, some of which can be recovered under favorable conditions as a byproduct of the manufacture of triple superphosphate. (Auth)

<40>

Fronzel, C.; USGS, Washington, DC;
Harvard University, Cambridge, MA

Mineralogy of Thorium. In USGS Professional Paper 300, (pp. 567-579), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955, United Nations, New York, (pp. 568-579), 825 pp. (1956)

The known minerals that contain thorium are divided into two groups: those that contain the element as an essential constituent, and those that contain thorium as a vicarious constituent. The first group contains 6 distinct species, of which only

the silicates, thorite and thortogummite, and the oxide, thoranite, are of importance, together with 16 minor chemical variants of these species that have been accorded varietal names. The second group, numbering more than 60 minerals, in places contains variable and usually small amounts of thorium in solid solution. Some of these minerals, notably monazite, are of economic interest because of their occurrence in relatively large amounts. (Auth)

<41>

Mackin, J.H., and D.E. Schmidt, USGS,
Washington, DC

Uranium- and Thorium-Bearing Minerals in Placer Deposits in Idaho. In USGS Professional Paper 300, (pp. 375-380), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955, United Nations, New York, (pp. 387-392), 825 pp. (1956)

Uranium- and thorium-bearing placer deposits sufficiently large to be worked by dredges have been studied in the northern Rocky Mountains. In the Bear Valley area, Valley County, Idaho, the higher grade parts of the placer deposits commonly contain the following quantities of heavy minerals in pounds per cubic yard: cuxenite 1.0; monazite 0.5; columbite 0.2; zircon 0.05; garnet 10; ilmenite 20; magnetite 5.0. In the Hailey area, Blaine County, Idaho, the higher grade parts of the placer deposits commonly contain the following minerals in pounds per cubic yard: uranothorite 0.5; zircon 0.5; sphene 1.0; garnet 0.1; magnetite 10. The principal uranium-bearing minerals, cuxenite and uranothorite, seem to be mutually exclusive in the two areas. The radioactive placer minerals were derived from quartz monzonite phases of the Idaho batholith. The cuxenite, uranothorite, and monazite occur as accessory minerals in the quartz monzonite. Segregations of these accessory minerals occur in parts of the quartz monzonite which are megascopically indistinguishable from surrounding rock having a much lower content of radioactive minerals. The grade of the placer deposits depends largely on the number and size of these segregations of the radioactive minerals in the quartz monzonite and on the physiographic history

of the drainage basin. (Auth)(M.I.B.)

<42>

Klepper, M.R., and D.G. Wyant; USGS, Washington, DC

Uranium Provinces. In USGS Professional Paper 300, (pp. 17-25), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955, United Nations, New York, (pp. 217-223), 825 pp. (1956)

Under the driving influence of orogenic forces, igneous processes tend to concentrate uranium in late-phase differentiates, notably in pegmatites, small alkalic plutons, and veins or other epigenetic deposits. Metamorphic processes may yield concentrations of uranium either by converting preexisting rocks to magma, which subsequently may yield uranium rich differentiates, or by "sweating" uranium out of weakly uraniferous rocks and concentrating it in favorable geologic settings. Weathering and sedimentary processes may either disperse or concentrate uranium, depending primarily on the climate. Some primary uranium-bearing minerals that are resistant to chemical and mechanical attack accumulate in placers. Other uranium-bearing minerals are dissolved, and the uranium is transported by ground and surface waters, from which it may be precipitated to form epigenetic deposits of a variety of types. Accordingly, the significant criterion for the recognition of a uranium province is the occurrence of a diversity of types of deposits. (Auth)(M.I.B.)

<43>

Cvancara, A.M.; North Dakota Geological Survey, Grand Forks, ND; University of North Dakota, Department of Geology, Grand Forks, ND

Geology of the Fox Hills Formation (Late Cretaceous) in the Williston Basin of North Dakota, with Reference to Uranium Potential. North Dakota Geological Survey Report of Investigation No. 55, 16

pp.; GJBN-21(76), 16 pp. (1976)

The Fox Hills Formation is a marine and brackish sequence of primarily medium and fine clastics within the Late Cretaceous Montana Group. In the Williston basin of North Dakota, four members (in ascending order) are recognized: Trail City, Timber Lake, Iron Lightning (with Bullhead and Colgate lithofacies), and Linton. The Fox Hills conformably overlies the Pierre Shale and conformably and disconformably underlies and interfingers with the Hell Creek Formation; it occurs in about the western two-thirds of the state. Principal lithology includes poorly consolidated sandy shale and siltstone (Trail City); fine to medium-grained, poorly consolidated and well-indurated sandstone (Timber Lake); interbedded, poorly consolidated sandstone and shale or siltstone (Bullhead lithofacies); medium-grained, poorly consolidated, muddy sandstone (Colgate lithofacies); and very fine- to fine-grained, indurated, siliceous sandstone (Linton). A conspicuous volcanic ash occurs in the formation and rises in the section from central Emmons County to southeastern Morton County. Lignite beds occur in the subsurface in part of southwestern North Dakota. Considerable lithologic variation occurs in the subsurface away from the main outcrop area in the south-central part of the state, and the members are difficult to trace. A barrier bar (or island)-deltaic model is followed for the deposition of Fox Hills sediments. The lower Fox Hills, of the Trail City and Timber Lake Members, is believed to represent the lower to upper shoreface of a barrier bar environment. The upper Fox Hills, of the Iron Lightning and Linton Members, suggests deposition within a deltaic complex as does the overlying Hell Creek Formation. Specific environments may have included tidal channel, bay, estuary, prodelta, and various environments associated with a delta-plain and the seaward part of a distributary system. Water depths may have been a few hundred feet and less. Since the Hell Creek, Fox Hills, and Pierre Formations are at least in part penecontemporaneous, a variety of depositional environments were in areal juxtaposition during Late Cretaceous time. Streams originating or passing through coastal plain bogs (of the Hell Creek) could have carried uranium ions (derived from volcanic materials) into bays, lagoons, or the open sea where they were deposited syngenetically. Epigenetic uranium may occur in finer clastics in the Fox Hills that directly underlie a volcanic ash bed. (Auth)(PAG)

<44>

Cvancara, A.M.: North Dakota Geological Survey, Grand Forks, ND; University of North Dakota, Department of Geology, Grand Forks, ND

Geology of the Cannonball Formation (Paleocene) in the Williston Basin, with Reference to Uranium Potential. North Dakota Geological Survey Report of Investigation No. 57, 22 pp.; GJBX-23(76), 22 pp. (1976)

The Paleocene Cannonball Formation is a marine, non-lignite-bearing clastic sequence in the lower part of the Fort Union Group. It is overlain by the lignite-bearing Ludlow Formation in places. The Cannonball crops out primarily in southwest-central North Dakota and probably occurs throughout the western one-half of the state. It occurs also in northwestern South Dakota and may extend into parts of Saskatchewan and Manitoba. Poorly consolidated, very fine- to fine-grained, light to medium brownish yellow-weathering sandstone and light gray-weathering, sandy mudstone are the principal types of lithology. Mudstone generally predominates in North Dakota whereas sandstone seems to predominate in South Dakota. Specific age assignments for the Cannonball vary from early to late Paleocene. The Cannonball sediments are interpreted to have been deposited adjacent to a lowland in a complex of environments, including tidal flat, lagoon, beach, shoreface, and shelf. Certain sandstones, underlain with gradational contact by sandy mudstones, are considered to be barrier island or regressive shoreline deposits. Although uranium in the Williston basin has been found almost entirely in lignite and nonmarine carbonaceous rocks, its occurrence in the marine Cannonball formation is possible. If the Cannonball, Ludlow, Tongue River, and Sentinel Butte Formations are at least partly penecontemporaneous, a variety of depositional environments were in areal juxtaposition during the Paleocene. Streams originating or passing through coastal plain bogs could have carried uranium ions (derived from volcanic materials) to the Cannonball sea where they were deposited syngenetically. Epigenetic uranium may occur in Cannonball mudstones or sandstones that directly underlie the Ludlow Formation, which is known to contain volcanic materials. (Auth)(PA(G))

<45>

Isaacs, A.F.: North Dakota Geological Survey, Grand Forks, ND; University of North Dakota, Department of Geology, Grand Forks, ND

Geology of the Upper Part of the Fort Union Group (Paleocene), Williston Basin, with Reference to Uranium. North Dakota Geological Survey Report of Investigation No. 58, 49 pp.; GJBX-24(76), 49 pp. (1976)

Lignite-bearing, sandy, silty, and clayey formations make up the Fort Union Group in the Williston basin, the upper part of which consists of the Tongue River Formation conformably overlain by the Sentinel Butte Formation. Two types of sandstone beds are present in the Tongue River Formation, one of which is elongate in plane view, trough shaped, and as much as about 300 m wide and 20 m thick. This type, which is most common, was deposited in low-sinuosity, non-braided channels typical of the seaward part of a high-constructive delta. The second type of sandstone bed in the Tongue River is elongate in map view (probably), tabular, in most cases about 3 m thick, and as much as several hundred metres wide. This type was deposited as lateral-accretion, point-bar deposits in high-sinuosity streams. Siltstone, claystone, lignite, and a small amount of limestone were deposited on natural leaves, crevasse splays, and in flood basins between the distributaries. The highest-grade uranium deposits in North Dakota are in the Sentinel Butte Formation in the area of the Little Missouri River escarpment in eastern Billings and northwestern Stark Counties. Little uranium has been found in the Tongue River Formation. Uranium may be more abundant in the Sentinel Butte Formation because of the abundance of glassy volcanic matter, which has now been largely altered to montmorillonite, and the abundance of fragments of volcanic rock. Weathering of the upper part of the Sentinel Butte Formation during formation of the Eocene paleosol in the northern Great Plains may have mobilized uranium that was deposited in the formation below the paleosol before deposition of the overlying Oligocene and younger sediment. The volcanic debris in the Oligocene, Miocene, and Pliocene formations may have contributed uranium to the deposits. Other Cretaceous and Paleocene formations that appear to contain significant amounts of volcanic matter, such as the Hell Creek

and Ludlow Formations, may contain important uranium deposits that formed probably at the time that the Eocene paleosol developed, or later by derivation from the volcanic matter in the Oligocene, Miocene, and Pliocene formations, or both. (Auth)(PAG)

<46>

Smith, G.E.; University of Texas, Austin, TX

Depositional Systems, San Angelo Formation (Permian), North Texas-Facies Control of Red-Bed Copper Mineralization. University of Texas Report of Investigation No. 80, 73 pp. (1974)

The San Angelo Formation is a mid-Permian sandstone and mudstone sequence about 100 feet thick that crops out in North Texas and dips westward into the Midland Basin; it is composed of two superposed members: the basal Duncan Sandstone Member and the overlying Flowerpot Mudstone Member. Depositional systems within the Duncan Member include the Copper Breaks deltaic system in the north, the Old Glory fluvial-deltaic system in the south, and the intermediate, strike-led Buzzard Peak sand-rich tidal-flat system. Gradationally above these systems is the Cedar Mountain mud-rich tidal-flat system which is coincident with the Flowerpot Member. Cedar Mountain facies include tidal channel-fill sandstone characterized by flaser bedding, red mudstone of tidal mudflat origin, and algal bound shale and dolomite. Cedar Mountain facies are overlain conformably by the Blaine Formation which was deposited within alternating sabkha and tidal-flat environments. Nodular gypsum beds comprise the framework of the Blaine sabkha and tidal-flat system. Copper mineralization occurs primarily within narrow, lenticular, organic-rich tidal channel-fill sandstone facies and thin, widespread algal mat shale facies. A sabkha-diagenetic model is used to explain the mineralization. Evaporative discharge from a sabkha creates an upward decrease in hydrodynamic potential with the result that primarily terrestrial ground water moves upward through the sabkha. Hydrogen sulfide, formed by bacteria, precipitates copper as ground water passes through chemically favorable facies. Calculations indicate that 100,000 to 200,000 years may be

necessary to form an economic deposit; alternate epigenetic models, involving diffusion over long distances, or movement of hydro-thermal solutions along faults and fractures, were evaluated. Copper minerals include chalcocite, covellite, and malachite. (Auth)

Cited as a reference in NURE Contractor Reports.

<47>

Brand, J.P.; University of Texas, Austin, TX

Cretaceous of Llano Estacado of Texas. University of Texas Report of Investigation No. 20, 59 pp. (1953, November)

Rocks of Cretaceous age crop out along the western margins of the deeper playa basins and along the southern and southeastern margins of the Llano Estacado. The Trinity group, containing only the Paluxy sandstone; the Fredericksburg group, consisting of the Walnut, Comanche Peak, Edwards, and Kiamichi formations; and the Washita group, containing only a portion of the Dick Creek formation, have been identified in the Llano Estacado. Formations of the Trinity and Fredericksburg groups are similar lithologically and paleontologically to equivalent units in the Calahan Divide and in the northern edge of the Edwards Plateau. Zonation, applicable to northern and central Texas and Pecos County, Texas, can be extended to the isolated Cretaceous exposures in the Llano Estacado. Cretaceous strata in the Llano Estacado dip to the southeast at the rate of 7 to 8 feet per mile. Structures in the underlying Triassic and Paleozoic do not appear to be governed by known structures in underlying units. (Auth)(PAG)

Cited as a reference in NURE Contractor Reports.

<48>

Robertson, D.S.; David S. Robertson and Associates Limited, Toronto, Ontario, Canada

Basal Proterozoic Units as Fossil Time Markers and Their Use in Uranium Prospection. In Proceedings of a Symposium on the Formation of Uranium

Ore Deposits, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 495-512), 748 pp. (1974, November)

Pyritic, uranium-bearing, quartz-pebble conglomerates have been found in Canada, South Africa, Brazil, and Australia. All are similar in lithology and mineralogy and all overlie a contorted graywacke-greenstone sequence and in turn, are overlain by rock units containing red clastics and shales. These uraniferous, sometimes gold-bearing, quartz-pebble conglomerate ores are considered to be a fossil expression of a limited period of geological time. Evidence suggests that these kinds of rocks were restricted to a time interval between 2.7 and 2.2 million years ago. The uranium content derives from detrital, heavy minerals carried to and preserved in the rocks because of an anoxygenic atmosphere prior to 2200 million years ago. Recognition of the environment of origin reflected by the conglomerate or the sequence of rock units permits assignment of an age range, frequently more meaningful than that obtainable from usual dating methods. The paper presents and compares the environments in which the conglomerates lie and comments on their age, their origin, their use as a stratigraphic marker at the base of the Proterozoic and the utility, in uranium prospecting, of recognition of their special environment. It is especially notable that the uraniferous conglomerate ores can only be found below the oldest red-colored rock units. (Auth)(JMT)

<49>

Dodson, R.G., R.S. Needham, P.G. Wilkes, R.W. Page, P.G. Smart, and A.L. Watchman: Australian Bureau of Mineral Resources, Geology and Geophysics, Department of Minerals and Energy, Canberra, Australia

Uranium Mineralization in the Rum Jungle - Alligator Rivers Province, Northern Territory, Australia. In Proceedings of a Symposium on the Formation of Uranium Ore Deposits, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 551-568), 748 pp. (1974, November)

In 1970, following the discovery of high-grade uranium ore in the Alligator River area, a start was made on semi-detailed mapping aided by geophysical surveys, isotopic dating, and stratigraphic drilling. With the exception of a few minor prospects, all known uranium deposits of the province occur in Lower Proterozoic sediments of the Pine Creek geosyncline. The deposits are concentrated in three areas: Rum Jungle, South Alligator River valley, and an area between the South Alligator River and Cooper Creek called the Alligator River area for convenience. The geology of the Alligator River area is dominated by two large complexes—the Nanambu and Nimbuwah metamorphic rocks which grade into unmetamorphosed sedimentary units of the Goodparla and South Alligator groups. Rb-Sr geochronical studies have demonstrated that the geological histories of the two complexes are different. The Nanambu complex consists of a core of granitoid rocks, leucogneiss, and migmatite, mantled by Lower Proterozoic sediments. Isotopic dating has revealed that the lower Proterozoic rocks that form the outer mantle of the complex were draped around a basement high. The granitoid core of the Nanambu complex has been dated at about 2500 million years (initial Sr 87/Sr 86=0.704 plus or minus 0.001). Other parts of the complex yield isochron ages of around 1800 and 2600 my. The Lower Proterozoic ages represent partial or complete resetting of the total rocks at the time of 1800 my metamorphism. Mica ages obtained by K-Ar and Rb-Sr methods, also reflect the 1800 my event. The Nimbuwah complex has been divided into zones which represent increasing degrees of migmatization and/or mobility towards the center. The zonation represents a classical gradation of migmatite types from incipiently migmatized schists to completely homogenized and mobilized granitoid anatectites in the center. An 1840 my Rb-Sr total rock isochron age obtained for the Nimbuwah complex represents the time at which Rb and Sr became fixed in the rocks shortly after the peak of migmatization and metamorphism. The orebodies occupy faults, shears, and breccias, or as at Rum Jungle Creek South deposit, are contained in a fold. This relation may be due to the squeezing-out of mineralized solutions from a sedimentary pile into centers of low stress during a tectonic event. The proximity of the major deposits to the mantled gneiss domes suggest that mineralization was also related to orogenic activity responsible for the rejuvenation of Archaean igneous masses and the intrusion of other

igneous masses at about 1800 my. Extensive zones of alteration, mostly chloritization and sericitization, around the deposits of the Alligator Rivers area in particular indicates a meso-thermal mineralization temperature range. Uranium-lead ages and lead isotopic compositions of ore from the Alligator Rivers area point to at least 4 pitchblende ages: 1800, 1700, 900, 500 my. These ages support the suggestion of syngenetic deposition of uranium in the Lower Proterozoic sediments before 1800 my and uranium concentration at 1700 my, perhaps by remobilization of pre-existing uranium accumulations, followed by periods of lead loss at 900 my and 500 my, ages which cannot be related to an igneous or tectonic event. (JMT)

<50>

Bohse, H., J. Rose-Hansen, H. Sorensen, A. Steenfelt, I. Lovborg, and H. Kunzendorf; University of Copenhagen, Institute of Petrology, Copenhagen, Denmark; Greenland Geological Survey, Copenhagen, Denmark; Danish AEC Research Establishment Ros, Roskilde, Denmark

On The Behavior of Uranium During Crystallization of Magmas - with Special Emphasis on Alkaline Magmas. In Proceedings of a Symposium on the Formation of Uranium Ore Deposits, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 49-60), 748 pp. (1974, November)

Uranium and thorium are usually enriched in the youngest, most felsic, most silicic, and most potassic members of comagmatic suites of igneous rocks. There is, however, a number of examples of uranium varying inversely to this rule. The Himaussaq intrusion of South Greenland, illustrates the decreasing content of uranium in the younger rock series. The most popular explanation of the decreasing uranium content is the oxidation of the uranium. Himaussaq rocks are rich in sodic pyroxenes and have high Fe^{3+}/Fe^{2+} ratios which might indicate a high oxygen fugacity of the magma. The silica-undersaturated and peralkaline rocks of the roof zone appear, however, to have crystallized at extremely low oxygen fugacities, as excess sodium stabilizes Fe^{3+} in the melt. The partitioning of uranium between gas phase and

magma also appears unlikely since theoretical and experimental data indicate that volatile components such as fluorine and chlorine are highly soluble in undersaturated peralkaline magmas characterized by a low silica activity. The authors favor the view that uranium and thorium have been retained in the halogen-rich magma during crystallization of the upper sequence of rocks. The possibility that the top sequence and the bottom sequence of rocks have been derived from separate magma masses is incompatible with the field relations. The trend demonstrated for the Himaussaq intrusion indicated that considerable concentrations of uranium and thorium may be built up during consolidation of undersaturated peralkaline magmas of aegiritic type. Peralkaline granitic magmas, which represent the end members of oversaturated differentiation series, will generally generate a fluid phase and expel chlorine and fluorine as crystallization proceeds. Metals may be extracted from magmas by such fluids, which may explain the successive release of uranium, thorium and other metals. (JMT)

<51>

Nitu, G.; Ministère des Mines, du Pétrole et de la Géologie, Entreprise des Métaux Rares, Bucharest, Romania

Les Conditions Tectono-Magmatiques de la Formation des Gisement D'Uranium de Roumanie. In Proceedings of a Symposium on the Formation of Uranium Ore Deposits, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 679-692), 748 pp. (1974, November)

The age relationships between different tectonic, magmatic and mineralization phenomena, the position of uranium deposits in the geological evolution of different regions, the relationship between Laramian magmatism and tectonics, and the paleotectonic conditions are analyzed. On the basis of this analysis, certain rules are derived and in part justify a number of hypotheses - concerning the role of magmatic and tectonic activity in the formation of Romania's uranium deposits, the depth at which they occur, the relief at the time of their formation, the reasons for the diversity of deposit types and for the occurrence of deposits including solid asphalts (anthraxolites), and the possible origin of the metals and asphalts. (Auth)

<52>

Ziegler, V.: Commissariat à l'Énergie Atomique, Chatillon, France

Essai de Classification Métallotectonique des Gisements D'Uranium. In Proceedings of a Symposium on the Formation of Uranium Ore Deposits, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria. (pp. 661-677), 749 pp. (1974, November)

The primary distribution of uranium and thorium is closely associated with the structural history of the sialic crust and hence with sialic magmatism. Accordingly, far from being distributed homogeneously, uranium should be associated preferentially with certain structural elements of the continental crust. Economic or subeconomic concentrations of uranium deriving for the most part from the primary distribution through hypogenic or supergenic remobilization should also be distributed in fairly close association with these structural elements. A metallogenic classification in the form of a table in which the deposits are grouped according to both the metallogenic type to which they belong and to the main structural element with which they are associated are proposed; the relative ages of the minerals are also indicated. From this table, which is based on the principal known occurrences of uranium in the world, it is possible to see the main characteristics of the distribution of uranium deposits. The chief purpose of the table is to indicate the principles of a method for studying the distribution of uraniferous deposits. Drawn up for a particular region, with appropriate structural and metallogenic distinctions, such a table should make it possible to discern the far more detailed regional patterns which are called for in the search for deposits. (Auth)

<53>

Wood, H.B.; AEC, Grand Junction, CO

Relations of the Origin of Host Rocks to Uranium Deposits and Ore Production in Western United States. In USGS Professional Paper 300, (pp. 533-541), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of

Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York. (pp. 307-316), 825 pp. (1956)

Compilation of data on 110 selected uranium deposits in the western part of the United States shows that their host rocks were formed in a wide range of petrogenic environments, that every unit of geologic time from Proterozoic to Recent except Devonian and Mississippian is represented, and that the deposits are widely distributed geographically. The environments represented include fluvial, igneous, littoral, marine, metamorphic, lacustrine, paludal, eolian, and terrestrial efflorescent. Fluvial sandstones and mudstones appear to be the most favorable host rocks. About 96 percent of the uranium ore that had been produced in the United States by June 30, 1955, came from fluvial and lacustrine sedimentary formations within the Colorado Plateau. It is expected that this source will continue to lead in production for some time. (Auth)

Extensive data are presented in tabular form: The conference paper was entitled "Age, Environment and Production of Uranium Host Rocks on the Colorado Plateau".

<54>

Butler, A.P., Jr., and R.W. Schnabel: USGS, Washington, DC

Distribution and General Features of Uranium Occurrences in the United States. In USGS Professional Paper 300, (pp. 27-40), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York. (pp. 224-230), 825 pp. (1956)

No igneous rocks other than a few pegmatites have a sufficient concentration of uranium in a distinct though disseminated mineral phase to be a submarginal source of uranium. Nearly all the vein and related deposits worked for uranium are of post-Jurassic age and are probably of Tertiary age. Most of them are closely associated with felsic intrusive or volcanic rocks of Tertiary age. The

largest deposits are fluorite bearing. Although some deposits are in the same small areas from which ores of other metals have been mined, most of the better deposits are not closely associated with deposits of other metals. The largest deposits of uranium in the United States are in impure sandstone and other terrestrial sedimentary rocks. All of the very large deposits are in rocks of Mesozoic age, but many recently discovered deposits, some of medium size are in rocks of Tertiary age. Most of these are in or closely underlie rocks that have abundant felsic volcanic debris. The areas of Tertiary rocks in the United States are large and have not been prospected and explored intensively. Widespread uraniferous coals and lignites have been known in Western United States for a number of years. The discovery of commercial deposits in them during the past suggests that they, too, are a promising environment for uranium deposits. Some marine phosphatic rocks and black shales are very large low-grade deposits of uranium, but only the phosphate deposits are presently a source of uranium. (MHB)

The conference paper was entitled
"Distribution of Uranium Occurrences in
the United States".

<55>

Adams, J.W., and F. Stugard, Jr.: USGS,
Washington, DC

**Summary of Wall-Rock Control of
Certain Pitchblende Deposits in Golden
Gate Canyon, Jefferson County,
Colorado.** In USGS Professional Paper
300, (pp. 113-116), 739 pp.; In Proceedings
of the International Conference on the
Peaceful Uses of Atomic Energy, Vol. 6,
Geology of Uranium and Thorium, held in
Geneva, Switzerland, August 8-20, 1955.
United Nations, New York, (pp. 279-282),
825 pp. (1956)

Carbonate veins cutting metamorphic rocks of Precambrian age in Golden Gate Canyon, Colorado, contain pitchblende and base-metal sulfides. The veins occupy extensive faults considered to be of Laramide age and normally contain pitchblende only where they cut hornblende gneiss. At the Union Pacific prospect, which was studied in detail, pitchblende, hematite, and some ankerite formed in advance of sulfides,

except possible for minor earlier pyrite. Base-metal sulfides and most of the ankerite vein-filling were deposited after the pitchblende. Chemical analyses show a high ferrous-iron content in the hornblende gneiss in contrast to low ferrous iron in the adjacent biotite gneiss. It is thought that ferrous iron released in alteration of hornblende was partly oxidized to hematite by the ore-bearing solutions and, contemporaneously, uranium was reduced and deposited as pitchblende. In other veins, which are not in hornblende gneiss, biotite or iron sulfides may have been similarly effective in precipitating pitchblende. Apparently both the ferrous ion and the sulfide ion can serve as reducing agents and control pitchblende deposition. Rocks rich in ferrous iron or preexisting sulfides are particularly favored sites for uranium deposition. (Auth)

The conference paper was entitled
"Wall-Rock Control of Certain
Pitchblende Deposits in Golden Gate
Canyon, Jefferson County, Colorado".

<56>

Twenhofel, W.S., and K.L. Buck: USGS,
Washington, DC

**Geology of Thorium Deposits in the
United States.** In USGS Professional
Paper 300, (pp. 559-566), 739 pp.; In
Proceedings of the International
Conference on the Peaceful Uses of
Atomic Energy, Vol. 6, Geology of
Uranium and Thorium, held in Geneva,
Switzerland, August 8-20, 1955. United
Nations, New York, (pp. 562-567), 825 pp.
(1956)

Thorium is a lithophilic and oxyphilic element closely related geochemically to zirconium, uranium, and the rare-earth metals. All its compounds are quadrivalent, and most of them are highly refractory. Available data indicate that many acidic rocks become enriched in thorium during magmatic differentiation. The principal thorium-bearing minerals are thorite, a thorium silicate, and monazite, a complex phosphate of the rare-earth metals and thorium. Other thorium-containing minerals-bastnaesite, thornthornite, thorianite, euxenite, and fluorapatite-are not now of economic importance as sources of thorium but are potential sources of byproduct thorium from certain localities. Thorium minerals are most abundant in igneous rocks,

pegmatites, veins, and placers. Placers are by far the most important commercial sources in the United States, although some veins may become important sources in the future. Nearly all the common and important thorium-bearing minerals resist natural decomposition and, hence, are not concentrated by secondary chemical processes. No important concentrations of thorium minerals, other than placers, have yet been found in sedimentary rocks. Most thorium in vein deposits is associated with barite, calcite, and rare-earth minerals, such as bastnaesite, rather than with base and precious metals, although lead and zinc minerals are found in some deposits. Many igneous and metamorphic rocks, particularly biotite-rich granite and granite gneiss, contain monazite. At a few places in the United States certain igneous and metamorphic rocks contain appreciable amounts of monazite. Some of these rocks have been the source for monazite-bearing placer deposits commonly occurring in the same terrane. Pleistocene and Recent placer deposits of monazite-bearing sands and gravels are the source of most of the thorium produced in the United States. (Auth)(MLB)

<57>

Thurlow, E.E.; AEC, Salt Lake City, UT

Uranium Deposits at the Contact of Metamorphosed Sedimentary Rocks and Granitic Intrusive Rocks in Western United States. In USGS Professional Paper 300, (pp. 85-89), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 288-292), 825 pp. (1956)

On the Spokane Indian Reservation in northeastern Washington, autunite and uranophane occur at the contact of the Loon Lake granite of Cretaceous age which intrudes the Deer Trail argillite of late Paleozoic age. Uraninite and pyrite have been found in diamond-drill holes which penetrated the contact zone at depth. Loon Lake granite is a coarse-grained, holocrystalline, somewhat porphyritic intrusive rock with aplitic and pegmatitic facies. No primary uranium mineral has been identified in the granite, but secondary

minerals are found as much as 20 feet from the contact. Although it is termed argillite, Deer Trail is composed of schists and phyllites with quartzite lenses in the vicinity of the deposit. Mineralization extended at least 40 feet into the metamorphosed sedimentary rocks along shear zones parallel with the contact with no apparent replacement of the host rock. A similar deposit occurs near Austin in Lander County, Nevada, where uranium minerals are found in fractures in Jurassic monzonite and metamorphosed sedimentary rocks. Uranium is associated with mineralized fractures resembling dikes which are composed of finely divided sericite with varying amounts of vein quartz.

Concentrations of autunite and metatorbernite occur in both the intrusive and the metamorphosed sediments but are confined to fractures near the contact zone and small roof pendants of metamorphosed sediments. The metamorphic rocks include hornfelses, quartzites, and phyllites. Uranium deposits closely associated with the contact of granitic intrusive rocks and metamorphosed Paleozoic sedimentary rocks show a decided preference for the metamorphosed sediments. (Auth)(MLB)

The conference paper was entitled "Uranium Deposits at the Contact of Meta-Sediments and Granitic Intrusives in the Western United States".

<58>

Osterwald, F.W.; USGS, Washington, DC

Relation of Tectonic Elements in Precambrian Rocks to Uranium Deposits in the Cordilleran Foreland of the Western United States. In USGS Professional Paper 300, (pp. 329-335), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 293-298), 825 pp. (1956)

The Cordilleran foreland is a large area immediately east of the main folded and thrust belts of the Middle Rocky Mountains. Within the foreland a series of simple folded mountains alternates with broad asymmetric basins. Most of the structures are caused by vertical movements of blocks in the Precambrian basement rocks that are

expressed at the surface by flexures and high-angle normal and reverse faults. Most uranium deposits in the Cordilleran foreland, irrespective of the type of deposit, are related to the tectonic pattern. They are clustered where large northwestward-trending structures, such as major basins and mountain ranges, are intersected by later more subdued northeastward-trending structures; where large northwestward-trending structures are intersected at acute angles by in-echelon faults or folds, or near the axial parts of major basins. The relation is thought to be caused by repeated deformation along old structures influencing sedimentation, or, intersections of major tectonic elements where energy levels are changed; or, margins of major tectonic elements changing energy levels; or, repeated deformation causing relatively young Tertiary rocks to be slightly deformed and jointed, thereby providing a favorable structural environment for uranium deposition. (Auth)(MLB)

<59>

Neuerburg, G.J.; USGS, Washington, DC

Uranium in Igneous Rocks of the United States. In USGS Professional Paper 300, (pp. 55-64), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 231-239), 825 pp. (1956)

Uranium is an ubiquitous and very small component of all igneous rocks. The uranium content of igneous rocks largely reflects the chemistry of the rock-felsic igneous rocks generally contain more uranium than do the mafic igneous rocks within any given petrographic association. Uranium occurs in six different ways in igneous rocks: uranium minerals; uranium disposed in the structure of the rock minerals by diadochy and in structural defects in crystals; uranium held in cation-exchange positions; uranium in unknown form absorbed on surfaces of crystals; uranium dissolved in fluid inclusions within rock minerals; and uranium dissolved in intergranular fluids. The uranium in the six environments displays differing degrees of reactivity toward and accessibility to solutions passing through the rock. The total uranium content of an igneous rock is the sum of the amount of uranium fixed in the rock at the time

of final consolidation and the amount of labile uranium, which probably was changed after consolidation of the rock. Study of the occurrence and quantity of uranium in igneous rocks are important for two reasons: these rocks are potential low-grade ores, and uranium in currently minable concentrations has originated both directly and indirectly from igneous activity. (MLB)

<60>

Overstreet, W.C., N.P. Cuppels, and A.M. White; USGS, Washington, DC

Monazite in Southeastern United States. In USGS Professional Paper 300, (pp. 597-601), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 593-596), 825 pp. (1956)

Monazite is a minor accessory mineral in some crystalline rocks occurring in two narrow belts in the Southeastern United States. It is widely but sparsely distributed as a detrital mineral in Cretaceous, Tertiary, and Quaternary sedimentary rocks exposed across the Coastal Plain. The detrital monazite was derived from crystalline sources in the interior and was deposited with alluvial and littoral sediments between these sources and the Atlantic Ocean. Except in rare areas where the deposits have been reworked, monazite constitutes less than 0.1 percent of the sediments. The apparent preferential precipitation of monazite in quartz monzonite and associated injection gneiss in areas where regional metamorphism has attained the highest grade of the amphibolite facies suggests that monazite will be found elsewhere in areas of injection gneiss that are in the sillimanite-garnet subfacies, no matter whether they are sillimanitic or isofacial sillimanite-free gneisses. (MLB)

<61>

Not given; USGS, Washington, DC; AEC, Washington, DC

Natural Occurrence of Uranium in the United States. In Proceedings of the

International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 211-216), 825 pp. (1956)

In the United States, uranium deposits are classed according to their host rocks or their controlling structure, as deposits in igneous rocks, veins, terrestrial clastic rocks, precipitates and evaporites, lignites, coal, and asphaltic materials, marine black shales, and phosphorites. Most of the ore deposits of uranium occur in the orogenic belt between the 100th and 120th meridian of west longitude. Some igneous rocks contain much more uranium than most granites. The uranium in igneous rocks occurs as discrete uranium minerals, disposed in the structure of the rock-forming minerals by diadochy and in structural defects, in cation exchange positions, adsorbed on surfaces of grains, and dissolved in fluid inclusions and intergranular fluids. Felsic extrusives and intrusives are the most common host rocks of uraniferous veins. The principal source of uranium in the United States is in terrestrial sandstones, mudstones, and limestones in which the uranium minerals occur as pore fillings and impregnations. Uranium occurrences in coals, marine sedimentary rocks, and petroliferous rocks are discussed, also. (M.L.B.)

<62>

Moore, W.L.; University of North Dakota, Department of Geology, Grand Forks, ND; North Dakota Geological Survey, Grand Forks, ND

The Stratigraphy and Environments of Deposition of the Cretaceous Hell Creek Formation (Reconnaissance) and the Paleocene Ludlow Formation (Detailed), Southwestern North Dakota. University of North Dakota Report of Investigation No. 56, 40 pp.; GJBX-22(76), 40 pp. (1976)

The Cretaceous Hell Creek and Paleocene Ludlow Formations of southwestern North Dakota, with the exception of the included lignite beds and minor amounts of concretions and nodules, are almost exclusively clastic sediments and sedimentary rocks. Massive clays, clays alternating with silts and sands, sandstones filling channels and other depressions, sheet sandstones, and lignites are

the dominant sediment and rock types present. Lignites, a few feet thick, and which occasionally exceed ten feet in thickness, are spaced out over intervals of a few tens of feet throughout the Ludlow Formation. The formation is cyclic in the sense that the lignite beds are repetitive, but the beds associated with the lignite indicate that the swamps were drowned (lacustrine clays) or were buried (alluvial sands or clay and coarser clastic alternations). Channel and depression fill sandstones of the Ludlow Formation have a relatively low permeability and a high organic content at the surface and, for this reason, are considered poor prospective uranium host rocks. The lighter colored yellow winnowed sheet sandstones of the Ludlow are more permeable and relatively free of organic matter. They are considered as possible host rocks for uranium occurring in association with an oxidation reduction interface at shallow depths. The uranium potential is enhanced where the latter sandstones occur along paleodivides which have been overlain by the Oligocene White River Formation, or in local areas where the latter formation is still preserved. Light yellow winnowed sheet sandstones are rare in the Hell Creek Formation, and the chances for uranium prospects in this interval seem correspondingly reduced. (Auth)

<63>

Conant, L.C.; USGS, Washington, DC

Environment of Accumulation of the Chattanooga Shale. In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 435-438), 825 pp.; In USGS Professional Paper 300, (pp. 463-467), 739 pp. (1956)

The black Chattanooga shale in Southeastern United States accumulated slowly on an extensive peneplain that was gradually inundated by a sea that had an irregular shoreline, scattered islands, a gently sloping bottom, and distant connections with the ocean. Some of the shale must have accumulated soon after submergence in shallow water, for it is separated from the underlying formations of Ordovician and Silurian age only by a basal sandstone a few millimeters thick, and

locally even that is absent. Other considerations suggest that the sea was shallow at all times. Studies of the conodonts indicate that the 30 to 35 feet of shale represents most of Late Devonian time. The presence of the conodonts and of assorted other marine fossils shows connections with the ocean. Abundant plant remains, a pyrite content of 10 percent, and the absence of calcareous detritus indicate a reducing environment. Sluggish streams from surrounding lowlands, gentle sea drift, and winds probably brought only small amounts of sediment to the area. The plant matter is a mixture of planktonic marine organisms and land plants, and includes spores, macerated particles of *FOERSTIA*, and logs of *CALLIXYON* several feet long and a few millimeters thick. The uranium was probably abstracted from the sea water by the organic matter, presumably the plants, which had ample time to become uraniferous before burial. The uranium concentration is believed to result from the abundant plant matter and relatively small amount of mineral matter. Some of the logs, which are now films of high-volatile bituminous coal, contain as much as 0.02 percent uranium, which is several times the uranium content of the shale, probably because of longer exposure to the sea water and the absence of mineral matter.
(Auth)(PAG)

- 64 -

Brookins, D.G.; University of New Mexico, Albuquerque, NM

Clay Mineralogy. In AT(05-1)-1636-1, (pp. 50-87), 153 pp.; In GJBX-16(76), (pp. 50-87), 153 pp. (1975)

The overall clay mineral paragenesis in the Morrison Formation is discussed. The concept of a terrigenous and fluvial origin for the Morrison Formation is sustained by the clay mineralogy. Many of the upper Morrison Formation sediments in the Grants Mineral Belt are believed to be first-cycle and during periods of prolific volcanic activity the amount of ash far exceeded detrital clay minerals. This can be evidenced by the generally sparse illite in the Morrison Formation. The hydrolysis of volcanic ash developed an abundant montmorillonitic assemblage shortly after the deposition. Coagulation of humic acid in the sediment caused local dissolution of previously-formed montmorillonite releasing much

Al, Mg, Fe and to a lesser degree Si. Since other detrital silicates were also affected by the humic acid, the water present must have been enriched in dissolved silica. Much of this silica was probably consumed later in the formation of collinite *c.* precipitated in the form of quartz overgrowths outside the ore body. The close spatial relationship of chlorite with the humate-rich ore body suggests that the former mineral was developed at the time of encroachment of humic acid. This is further evident since chlorite is also enriched in the barren and bleached reduced sandstones in the northern Ambrosia Lake district. Two types of kaolinite can be recognized in the Morrison Formation: residual kaolinite, such as in Jackpile Sandstone that was formed by weathering and remained in place; and the diagenetic variety that was formed from resilication of aluminum-rich materials such as the next-type of kaolinite commonly found in the Westwater Canyon Member Sandstone. Compared to the disseminated matrix kaolinite, the "next-type" kaolinite is definitely secondary and appears to represent a post-ore process since it occurs widely both in mineralized and barren sandstones. (JMT)

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Brookins, D.G.; University of New Mexico, Albuquerque, NM

Geology of the Grants Mineral Belt. In AT(05-1)-1636-1, (pp. 1-34), 153 pp.; In GJBX-16(76), (pp. 1-34), 153 pp. (1975)

Some six thousand feet of sedimentary rocks, are present in the general area of the Grants Mineral Belt (GMB). They range in age from Pennsylvanian to Cretaceous and overlie the crystalline Precambrian rocks of the Zuni Uplift. The sedimentary rocks generally dip north to northeastward into the San Juan Basin except in the Laguna district where northwestward dips are common. Of the sedimentary rocks, continental varieties are most common in the Cretaceous rocks. Late Cretaceous and Tertiary sediments of both marine and continental origin are exposed in the interior of the San Juan Basin to the northeast of the GMB. The area between the Laguna and the Ambrosia Lake districts is extensively covered with volcanic rocks of the Mt. Taylor volcanic field. These rocks range in age from Miocene to Recent with a wide range in composition. K-Ar age determinations on obsidian, perlite and sanidine

from the Mt. Taylor rocks yield ages ranging from 1.5 to 3.0 m.y. The outcropping Precambrian rocks in the Zuni Uplift are composed mostly of leucocratic granitic, aplite, granitic gneiss, metarhyolite and schists. The absolute isotopic ages of these rocks have not been reported. In the GMB the Morrison Formation can be divided into four members. These are, in ascending order, the Salt Wash, Recapture, Westwater Canyon, and Brushy Basin members. In addition, two sandstone bodies located in the upper part of the Brushy Basin Member, of economic usage, are recognized: the Poson Canyon Sandstone of the Ambrosia Lake district and the Jackpile Sandstone of the Laguna district. In the Four Corners region, the Salt Wash Member intertongues extensively with the Recapture Member and contains many groups of uranium deposits in the Shiprock district. Unlike the other deposits in the Morrison Formation, these deposits are high in vanadium content, with an average U/V ratio of 1.7. To the south in NE Arizona and NW New Mexico, the Salt Wash Member pinches out by grading into the Recapture Member. In some localities the Salt Wash Member grades into the Cow Springs Sandstone, and to the north over a large part of eastern Utah and western Colorado, it replaces the Recapture Member and constitutes the lower half of the Morrison Formation. The Recapture Member conformably overlies the Bluff Sandstone in the GMB. No significant uranium deposits have been found in the Recapture Member in the GMB. The Westwater Canyon Member generally overlies the Recapture Member. It may represent a continuous depositional process from Recapture deposition with a rejuvenation of the source area, but it has been argued that an unconformity exists between the Westwater Canyon and Recapture members. The Brushy Basin Member conformably overlies the Westwater Canyon Member and is unconformably overlain by the Dakota Sandstone of Cretaceous age. The contact of the Brushy Basin Member with the Westwater Canyon Member is gradational and intertonguing so that the selection of the contact in many places is arbitrary. (JMT)

<66>

Rich, R.A., H.D. Holland, and U. Petersen; Harvard University, Cambridge, MA

The Distribution of Uranium. In AT(05-1)-1640, (pp. 2-13), 383 pp.; In

GJO-1640, (pp. 2-13), 383 pp. (1975)

In most subsurface environments, U is present in the tetravalent (+4) state because the hexavalent (+6) state is stable only under oxidizing conditions. The combination of the relatively large size and high charge of U+4 prevents it from entering the crystal lattices of the major rock-forming minerals except in trace amounts. Significant quantities of U are frequently found in accessory minerals such as thorite, thorianite, thorogummite, allanite, xenotime, zircon, fluorite, apatite, and barite. Much of the U in rocks is loosely held and probably occurs in adsorbed films coating the grains of rock-forming minerals, where it can be easily leached by dilute acids. The leaching of U from weathered outcrops is rapid and is enhanced by the formation of complex uranyl ions with carbonate and sulfate ions. In nature, reduction is most frequently due to the presence of sulfide, ferrous iron, carbonaceous matter or hydrocarbons. U can also be removed from aqueous solutions by adsorption on clays, organic matter, and iron hydroxides. Uraninite is the most abundant U mineral and the only commonly occurring tetravalent U mineral. In addition, coffinite $[U(SiO_4)]_x(OH)_4x$ in minor amounts is found in some vein-type U deposits. There are, however, many minerals containing hexavalent U. Pitchblende, the fine-grained, massive, botryoidal, or sooty variety of uraninite, is the most common U ore mineral of vein-type deposits. The ideal formula for pitchblende is UO_2 , but in nature some hexavalent U is always present. Natural pitchblende exhibits compositions ranging up to $UO_{2.6}$. It is not known at present whether the compositional variation of pitchblende reflects differences in the conditions of primary deposition or the operation of post-depositional oxidation processes. Magmatic and pegmatitic uraninite usually contains large amounts of Th and rare earth elements, but hydrothermal pitchblendes do not. Uranium tends to be enriched in the late stage members of igneous differentiation series. High U concentrations usually correlate well with high concentrations of K and SiO_2 , but it has been suggested that igneous rocks with anomalously high U concentrations are characterized by unusually high U/K ratios. Granitic and alkalic rocks usually contain 2-4 ppm U, but felsic rocks (and especially their pegmatitic derivatives) containing more than 10 ppm U are not uncommon. The average sedimentary rock contains essentially the same amount of uranium as the average igneous rock, but the distribution of U in

sediments is quite variable. Clean sandstones and pure limestones are usually rather poor in uranium, but uranium enrichment in sedimentary rocks can be pronounced, particularly in shales and phosphorites. The uranium concentration in shales correlates with their clay content and with their concentration of organic carbon. The U content of metamorphic rocks is also quite variable and it tends to reflect the U concentration of their protoliths. Some very high grade metamorphic rocks are apparently depleted in U relative to their lower grade and unmetamorphosed equivalents, however, and it is likely that U moves upward in the crust during granulite grade metamorphism. (JMT)

<67>

Rich, R.A., H.D. Holland, and U. Petersen; Harvard University, Cambridge, MA

Characteristics of Vein-Type Uranium

Deposits. In A1105-1-1640, (pp. 14-32). 383 pp.; In G30-1640, (pp. 14-32). 383 pp. (1975)

In the United States, a strong correlation exists between the occurrence of U veins and granitic rocks. In one study, of 548 US vein-type U occurrences, it was found that no less than 83% of these deposits occurred in, or closely associated with Pre-Tertiary granitic rocks and Tertiary intrusives. Non-igneous host rocks usually contain carbonaceous matter, clays, carbonates, ferrous silicates, sulfides, or phosphates. Hydrothermal U deposits are epithermal or mesothermal in character, and most often, they are fracture fillings in faults, joints, or fracture zones. The age of the known vein-type deposits range from Middle Precambrian to Late Tertiary. The absence of hydrothermal U deposits of Archean age is striking. In the United States, the major deposits have Late Mesozoic to Tertiary ages. Pitchblende ages from a single deposit often show a broad range due to the presence of more than one generation of deposition. Such multiple age deposits are thought to reflect the apparent ease with which early pitchblende can be remobilized and redeposited. In virtually all deposits, pitchblende is the only important hypogene U mineral present. In some hydrothermal U deposits with simple mineralogy, pitchblende is the only mineral present, but most veins contain at least some gangue, usually quartz

or calcite, and small amounts of sulfides. Pyrite and marcasite are particularly common. Hematite is present either as wall rock alteration or vein mineral in most hydrothermal U deposits.

Pitchblende precipitated alone at some point in the depositional sequence was found in 58% of the deposits studied. Where pitchblende was reported to have been deposited simultaneously with one or more other minerals, the assemblages found in more than 10% of the deposits were pitchblende + pyrite marcasite, pitchblende + quartz, pitchblende + pyrite marcasite + quartz, pitchblende + base metal sulfides, and pitchblende + quartz + hematite + pyrite marcasite. All of the deposits studied contain pyrite marcasite, although not always in the stage of pitchblende deposition, and most of the deposits contain base metal sulfides (90%), quartz (83%), hematite (76%), and carbonate (51%). Fluorite occurs in 34% and barite in 20% of the deposits considered, but not in the stage of uranium deposition. In 90% of the deposits the first appearance of pitchblende in the paragenetic sequence is early. In 77% of the deposits reporting the presence of hypogene hematite, pitchblende is first deposited with or after the initial deposition of hematite, and in 82% of the deposits containing quartz, pitchblende deposition was preceded by quartz. In 68% of the deposits studied, the initial pitchblende stage occurs with or before the deposition of pyrite marcasite, and in 94% of the deposits containing a base metal sulfide stage, the earliest pitchblende is deposited before or with the sulfide stage, the earliest pitchblende is deposited before or with the sulfide stage. (JMT)

<68>

Walker, G.W., and J.W. Adams; USGS, Washington, DC

Mineralogy, Internal Structures and Textural Characteristics and Paragenesis of Uranium-Bearing Veins in the Conterminous United States. USGS Professional Paper 455-D, (pp. 55-90). (1963)

Fifty-five species of minerals that contain uranium as either an essential or nonessential constituent have been reported from uraniumiferous veins in the conterminous United States. Among these are a few simple oxides or silicates of uranium, a few multiple oxides of uranium in combination with other elements, and a large number of brightly

colored uranyl vanadates, phosphates, arsenates, silicates, carbonates, and hydroxides. The minerals that contain nonessential, extrinsic or vicarious uranium include fluorite, opal, rutile, pyromorphite, thorite, magnetite, and possibly hematite, and probably several of the rare-earth minerals. The nonuraniferous minerals associated with uranium-bearing veins are those commonly found in metalliferous deposits, and no particular species appears to be distinctive. Dominant among the metallic minerals of uranium-bearing veins are pyrite or marcasite, galena, chalcopyrite, sphalerite, jordanite, or molybdenite, arsenopyrite, argentite, stibnite, magnetite, hematite, and many of their oxidation products. The common nonmetallic minerals are fluorite, quartz, chalcedony, opal, barite, adularia, chlorite, and several varieties of calcium, magnesium, or iron carbonate minerals. In some deposits, radiation damage to some gangue minerals has created distinctive characteristics including changes in internal crystallinity, thermoluminescent properties, and colorations. Uranium-bearing veins in the conterminous United States are similar in internal structural and textural characteristics to those epithermal and mesothermal vein deposits in which the introduced minerals fill open epigenetic pore spaces or cavities. Cataclastic textures are common, whereas replacement textures, specifically between uranium and nonuranium minerals, have been reported in only a few places. Texturally, primary uranous oxide in virtually all veins is the colloform or sooty variety of uraninite called pitchblende. Many metals are associated with uranium in vein deposits, but only a few metals, (molybdenum, manganese, beryllium, tungsten, vanadium, niobium, yttrium, and zirconium), seem to show a positive and geologically significant correlation to uranium in some deposits, districts, or areas. The other metals associated with uranium, such as lead, zinc, copper, silver, and possibly cobalt, seem to be associated with uranium only in the sense of occurring within the same favorable geologic environment. Primary pitchblende is one of the earliest metallic minerals to form during any single stage of vein formation in most veins in the United States. However, the early pitchblende may be subject to partial solution and reprecipitation during later mineralization stages. This younger pitchblende may be represented by a hard, highly lustrous colloform variety or by the sooty variety and it can be expected to show apparently anomalous paragenetic relations. (Auth)(JMT)

<69>

Walker, G.W.; USGS, Washington, DC

Host Rocks and Their Alterations as Related to Uranium-Bearing Veins in the Conterminous United States USGS Professional Paper 455-C, 37-53 pp. (1963)

Many different kinds and ages of igneous, metamorphic, and sedimentary rocks are the host for uranium-bearing veins in the conterminous United States. In mineralogic and chemical composition, these host rocks show a wide variation and include some composed dominantly of silic minerals and others composed dominantly of mafic minerals. Some of the host rocks are characterized by an abundance of graphitic carbon, by clay minerals, by calcium or magnesium carbonate minerals, by iron oxide minerals, or by phosphate minerals. Even though nearly all textural, chemical, and mineralogic types of rocks have been reported as the host for uraniferous vein deposits, the veins are most abundant in holocrystalline, commonly equigranular, igneous and metamorphic rocks characterized by a moderate to high silica content and by physical properties that are somewhat alike. Similarities in physical properties are related largely to the behavior of these rocks under stress. In general, they lack any important plastic-flow phenomena under near-surface conditions of pressure and temperature and are more apt to rupture under stress than other kinds of rocks. Most of the host rocks of uranium-bearing veins have been modified, reconstituted, or mineralized either before, during, or after the introduction of the uranium. Consequently, the physical, chemical, and mineralogic character of the petrologic environment of uranium deposition is poorly known. Many of the uranium-bearing veins in the conterminous United States are enclosed in alteration halos commonly consisting of three principal zones characterized by sericitized, argillized, and chloritized wallrocks. Hematite in uranium-bearing veins or hematitic alteration of adjoining wallrocks is not particularly common and, consequently, seems to have limited usefulness as a diagnostic feature of uranium mineralization. (Auth)

<70>

Vine, J.D.; USGS, Washington, DC

**Geology of Uranium in Coaly
Carbonaceous Rocks.** USGS Professional
Paper 365-D, 113-170 pp. (1962)

Coaly carbonaceous rocks characteristically contain non-marine indigenous humic plant remains that accumulate in swamps. Uranium is only one of many inorganic constituents of these rocks. The average abundance of uranium in coaly carbonaceous rocks may normally be less than 0.001 percent. Deposits in the United States containing at least 0.005 percent uranium occur in five general rock types: unconsolidated peaty material; lignite and subbituminous coal; bituminous and anthracitic coal; impure lignite and lignitic shale; and carbonaceous shale. The uranium in alpine-meadow peaty soils is evidently introduced continuously by spring waters and becomes concentrated in the living plants and especially in the decaying plant debris that accumulates in the meadow soil. Lignite and subbituminous coal in the Rocky Mountain and Great Plains regions contains a number of large deposits of uranium, but the tenor for large tonnages rarely exceeds 0.015 percent. Bituminous and anthracitic coal in the United States is not known to contain more than a few small, low-grade deposits of uranium. In the bituminous coal fields of the United States, the highest concentrations of uranium are commonly found in the marine black shale that overlies coal beds or in the underlay directly below the coal beds. Unconsolidated peaty material is capable of being greatly enriched in uranium, but only rarely are deposits found in peat. Lignite and subbituminous coal have the capacity to take up abundant uranium, but the physical properties of these rocks are apparently less favorable for concentrating uranium than are those of impure lignite and of lignitic shale. Bituminous and anthracitic coals are generally unfavorable host rocks for uranium. Carbonaceous shale seems to be a chemically favorable but physically unfavorable host rock. The structural position, size, shape, and type of epigenetic uranium deposit is largely determined by whether the mineralizing ground water is thermal, artesian, unconfined in saturated ground, or vadose. The physical and chemical form of uranium in coaly carbonaceous rocks is obscure because uranium minerals are rarely visible and never account for all the metal present. Even where plants grow in a uraniferous environment the sorption of uranium on decaying plant materials far exceeds the contribution from living organisms. Uranium is directly associated with carbonaceous matter but shows no pronounced preference for

specific carbonaceous rock constituents except possibly for layers of translucent attritus containing abundant amorphous humic matter and yellow waxy matter. The geochemical enrichment of uranium in coaly carbonaceous rocks is the result of cation exchange in humic or coaly carbonaceous matter, a unique geologic process which uranium does not share with any of the major elements in a sedimentary environment. (JMT)

A great number of geologic formations are mentioned in the paper.

<71>

Walker, G.W., and F.W. Osterwald;
USGS, Washington, DC

**Introduction to the Geology of
Uranium-Bearing Veins in the
Conterminous United States.** USGS
Professional Paper 455-A, 1-28 pp. (1963)

Most of the known uranium bearing veins are in the western United States in such areas as the Front Range mineral belt of Colorado; the Boulder batholith area, Montana; the Sierra Ancha region, Arizona; and the Marysvale district, Utah.

Uranium-bearing veins are tentatively divided into eight classes on the basis of mineralogy. These types are: (1) fluorite-bearing veins; (2) base-metal sulfide veins; (3) veins dominantly of uranium minerals but which may contain minor amounts of other introduced metallic minerals; (4) magnetite or other iron oxide bearing veins, excluding deposits in gossan derived from supergene alteration of base-metal sulfide deposits but including those uraniferous deposits characterized dominantly by magnetite, hematite, or limonite; (5) veins dominantly of thorium or rare earths minerals; (6) brannerite-bearing quartz or siliceous veins; (7) davidite-bearing veins; and (8) hydrocarbon-rich uranium-bearing veins. Each of these vein types are discussed, and a list of uranium-bearing vein deposits in the conterminous United States is included. (JMT)

<72>

Colton, R.B.; USGS, Washington, DC

**Geology of the Otter Creek Quadrangle,
Montana.** USGS Bulletin 1111-G, 230-287

pp. (1962)

Sedimentary Paleozoic and Mesozoic rocks, at least 8,700 feet thick, underlie the Otter Creek quadrangle but are not exposed. Overlying these rocks and partly exposed are about 1,200 feet of the Fort Union formation of Paleocene age. The Fort Union formation is unconformably overlain by the Flaxville formation of Miocene or Pliocene age that consists mainly of quartzitic gravel. Erosion of the Flaxville formation and redeposition of the gravel resulted in the formation of part of the Wiota gravels of Pleistocene age. The Wiota gravels and their erratics are the only evidence of an earlier glaciation. The quadrangle was glaciated a second time during the Tazewell or Iowan substages of the Wisconsin stage, and till was deposited. Outwash deposits and melt-water channels formed during the retreat of the Tazewell or Iowan ice front. During the Cary substage of the Wisconsin, glacial ice advanced to within 5 miles of the north edge of the area and probably entered the southeast corner of the quadrangle. A valley train of outwash, the Plentywood formation, was deposited in the valley of Big Muddy Creek. As the ice sheet melted, the Plentywood formation was trenched to a depth of 170 feet. In postglacial time the valley of Big Muddy Creek was filled with 150 feet of outwash and alluvium. Other deposits of Recent age include clay deposits in closed depressions in the ground moraine, colluvium, dune sands, and thin loess. The chief structural feature of the area is a homocline dipping southeastward into the Williston structural basin. Many linear features in the area suggest the presence of small faults, fractures, or jointing in the bedrock. Mineral resources consist of lignite, riprap, sand and gravel, till, and soil. No favorable structures for the accumulation of oil and gas were found. Measured, indicated, and inferred reserves of several lignite beds in the Fort Union formation total 416 million short tons. (Auth)(MBW)

<73>

Witkind, I.J., and R.E. Thaden: USGS.
Washington, DC

**Geology and Uranium-Vanadium
Deposits of the Monument Valley Area,
Apache and Navajo Counties, Arizona.**
USGS Bulletin 1103, 163 pp. (1963)

Uranium-vanadium ore deposits in the Monument

Valley area are in the Shinarump member of the Chinle Formation (Late Triassic), a light-gray crossbedded conglomeratic sandstone. The Shinarump is commonly conglomeratic at the base, grading upward into finer sedimentary rocks, with medium- to coarse-grained sandstone near the top. The Shinarump caps most of the isolated mesas and buttes and normally appears as a cliff about 50 feet thick. It rests unconformably on top of the Moenkopi formation of Triassic age. The unconformity is marked by elongate shallow depressions, termed "swales", cut in the top of the Moenkopi. These swales are as much as 3 miles wide and have a relief of about 50 feet. Local relief on the unconformity does not exceed 5 feet except where symmetric and asymmetric channels are scoured as much as 75 feet into the underlying strata. These channels range from about 15 feet to as much as 2,300 feet in width. Sixty-two channels and channel segments were noted, and of these, 18 have mineralized exposures. Nine of the channels are described, including the Monument No. 1 and Monument No. 2 channels, which have been and are being mined (1953). The Monument No. 2 channel, one of the richest uranium-vanadium deposits in the Monument Valley area, is a short channel that ranges in width in its central part from 400 to 700 feet, and has been cut about 50 feet into the underlying strata. During mine mapping, four types of ore bodies were noted: rods, tabular ore bodies, corvusite-type ore bodies, and rolls. The rods are cylindroidal bodies about 3 to 5 feet wide, 2 to 3 feet high, and are 3 to 5 feet thick. The corvusite-type ore bodies are irregular-shaped masses within which the rock is thoroughly penetrated by vanadium minerals. Sedimentary rocks of both the Shinarump member of the Chinle formation and the De Chelly sandstone member of the Cutler deposits are mineralized in this type of ore body. The "rolls", the fourth type of ore body, are similar to those mined in the Morrison formation. Not all the channel strata that fill the Monument No. 2 channel contain ore; weakly mineralized ground alternates at irregular intervals with richly mineralized ground, both laterally and vertically. Swales and channels are important prospecting guides in the Monument Valley area. Other useful guides are (1) observable uranium minerals, (2) abnormal radioactivity, (3) channel fill, and (4) channel conglomerate containing carbonaceous water. (Auth)(JMT)

<74>

Sims, P.K., and D.M. Sheridan; USGS, Washington, DC

Geology of Uranium Deposits in the Front Range, Colorado. USGS Bulletin 1159, 113 pp. (1964)

The Colorado Front Range is one of the principal regions of uranium vein deposits in the United States. The uranium deposits are mostly in the Precambrian crystalline rocks that form the core of the Front Range, but a few are in bordering sedimentary rocks. The deposits are typically fissure veins in faults. Within the mineral belt the mineralized faults are discontinuous and form a complex intersecting network. In the foothills area, they are long, persistent, have undergone repeated movements, and are called breccia reefs. The deposits in the mineral belt generally are in sulfide-quartz veins that are chiefly valuable for gold and silver, whereas those in the foothills area are in veins that have a gangue of carbonate minerals and potassic feldspar and are valuable primarily for uranium. In the Jamestown district of Boulder County, uranium occurs in fluorite veins and breccias. The uranium minerals are dominantly pitchblende and coffinite, but include uranothorite, uraniferous hydrocarbon, and, in the oxidized zone, autunite, tobernite, uranophane, kasolite, bassettite, and rarely other highly colored secondary uranium minerals. The primary uranium minerals typically occur as fillings, either in openings in the fissure veins or in the interstices of breccias. Generally both pitchblende and coffinite were deposited early in the vein-forming sequence, or at least early in any particular stage of vein filling. They were preceded at places by iron sulfides and gangue. The uranium deposits appear to be arranged zonally with respect to the mineral belt. The largest, most valuable ore bodies are marginal to the mineral belt and are of epithermal character. Those within the mineral belt are of mesothermal character. (JMT)

<75>

Rich, E.I.; USGS, Washington, DC

Reconnaissance Geology of Hiland-Clarkson Hill Area, Natrona County, Wyoming. USGS Bulletin 1107-G, 447-539 pp. (1962)

The Hiland-Clarkson Hill area lies in the eastern

third of the Wind River structural basin and includes about 860 square miles of the west-central part of Natrona County, Wyoming. Areas of anomalous radioactivity occur in the Wind River and White River formations. Small amounts of uranium have been found in two places within Hiland-Clarkson Hill area. In general, the percent of uranium found in rock samples collected from the areas of anomalously high radioactivity is less than the equivalent uranium. A few water samples contain more uranium than average and those with the highest amount, exclusive of those from the mineralized areas, are at or near the structurally low synclinal axis of the Wind River Basin. (JMT)

<76>

Brokaw, A.L., J. Rodgers, D.F. Kent, R.A. Laurence, and C.H. Behre, Jr.; USGS, Washington, DC

Geology and Mineral Deposits of the Powell River Area Claiborne and Union Counties, Tennessee. USGS Bulletin 1222-C, 55 pp. (1966)

The Powell River area is in northeastern Tennessee in the Valley and Ridge province. The occurrence of zinc and lead minerals in the area has been known for more than a century, but commercial production has come from only three small mines. The mines and prospects are in gently folded Cambrian and Ordovician sedimentary rocks exposed in the upper plate of the Pine Mountain (Cumberland) thrust block. The main part of the district, 6-7 miles wide, extends northeast along the crest of the Powell River anticline. This anticline is a compound fold at the surface and involves formations chiefly of the Knox Group, of Cambrian and Ordovician age. The area is within a trapezoidal block whose boundaries are tectonic features related to movement on the Pine Mountain thrust fault. The southeast edge of the trapezoid is a northeast-trending Speedwell flexure; the northwest side is the sharply upturned flank of the Middlesboro syncline; and the northeast edge is the north-trending Rocky Gap flexure. The part of the Powell River anticline within the trapezoid is about 2 miles narrower than the part outside the block. Superimposed on the primary folds are secondary folds that trend northeast or northwest, and strike-slip faults that trend northwest. These secondary features apparently are related to rotational stresses that were activated when the

forward motion of the Pine Mountain thrust was retarded between the Speedwell and Rocky Gap flexures. The larger ore bodies are localized in openings along steeply dipping strikeslip faults which terminate at depth against bedding planes or bedding-plane faults. The most productive deposits are in the Maynardville Limestone Member of the Nolichucky Shale where it has been cut by the northwest-trending strike-slip faults. Deposits of lesser economic importance, which may represent chimneys from richer deposits below, are along faults and fractures that cut the younger rocks, mostly the Copper Ridge Dolomite. The localization of these deposits is clearly related to tectonic features formed during the Appalachian orogeny. Therefore, the deposits are probably post-Pennsylvanian in age. (Auth)

<77>

Boucot, A.J.; USGS, Washington, DC

Stratigraphy of the Moose River Synclinorium, Maine. USGS Bulletin 1111-E, 153-186 pp. (1961)

The Moose River synclinorium of west-central Maine contains the greatest thickness of relatively unmetamorphosed upper Lower Devonian strata known in the Appalachian belt. These strata, which have a total average thickness of about 10,000 feet, are chiefly dark sandstone and slate, with subordinate amounts of rhyolite. Strata of Oriskany and early Onondaga age form the trough of the synclinorium. On the flanks of the synclinorium they are unconformably underlain by erosional remnants of Helderberg, Late Silurian, possible Silurian, Middle Ordovician, Cambrian or Ordovician, and possible Precambrian age. The strata of Silurian through Helderberg age consist chiefly of calcareous sandstone, calcareous siltstone, conglomerate and arkose containing granitic and volcanic debris, limestone conglomerate, and limestone, with a maximum thickness of about 4,000 feet. The pre-Silurian strata consist of light and dark volcanic rocks, slate, phyllite, dark sandstone, graywacke, gneiss, and granitic rocks, with unknown stratigraphic thicknesses. Intrusive rhyolitic rocks of Early Devonian age and intrusive granitic rocks of post-Early Devonian age are present. The granitic intrusive rocks are bordered by contact metamorphic aureoles. (Auth)

<78>

Williams, J.R.; USGS, Washington, DC

Geologic Reconnaissance of the Yukon Flats District, Alaska. USGS Bulletin 1111-H, 289-329 pp. (1962)

Shale, coal, and lignite of early Tertiary age crop out in a few places within the marginal upland of the Yukon Flats district. The early Tertiary and older rocks of the marginal upland are covered by high-level alluvium of late Tertiary or early Quaternary age. These deposits were laid down (a) by the Yukon River and its large tributaries and are now preserved as high terraces, and (b) by the numerous small streams that drain the highlands and now are coalescent piedmont alluvial fans. The high-level alluvium is mantled in most places by eolian sand and loess of Quaternary age. The Yukon Flats is underlain by more than 290 feet of quiet water (lacustrine?) silt and silty sand of late Tertiary to early Quaternary age which probably extends below present sea level. The quiet-water deposits are overlain by alluvial deposits, which form the alluvial fans, terraces, and flood plains of the Yukon Flats. These deposits range in age from early or middle Pleistocene to Recent. The alluvial fans of the Chandalar, Christian, and Sheenjek Rivers were formed, in part, of glacial outwash deposited during Pleistocene glaciation of the southern Brooks Range. The oldest glaciation, the deposits of which are preserved only in isolated patches, probably extended in the Yukon Flats through the Chandalar, Marten, and possibly the Sheenjek Valleys in early Pleistocene time. Three younger glaciations ranging in age from early or middle Pleistocene to late Pleistocene are represented by glacial drift and moraines in the valleys of the Chandalar River and the East Fork of the Chandalar River. The oldest of these moraines in the Chandalar River valley lies 6 miles from the northern edge of the Yukon Flats. The alluvium of the Yukon Flats locally is mantled by eolian sand and loess of Pleistocene and Recent age. The deposits of the flood plain and low terraces and of the small alluvial fans that border the marginal escarpment are of Recent age. (Auth)(MBW)

<79>

Maclay, R.W.; USGS, Washington, DC

Geology and Ground-Water Resources of the Elizabethton-Johnson City Area, Tennessee. USGS Water-Supply Paper 1460-J. 47 pp. (1962)

The western two-thirds of the Elizabethton-Johnson City area lies within the Valley and Ridge province and the remainder in the Blue Ridge province. Most of the area is underlain by consolidated sedimentary rocks ranging from Precambrian to Ordovician. Unconsolidated deposits of late Tertiary and Recent age are present in the stream valleys and beneath terraces along these valleys. The Shady and Honaker formations and the Knox group are the principal water-bearing rocks of the area. Wells drilled into these formations yield an average of about 10 gallons per minute (gpm) in most places. Perched water is common in the residuum of the Shady dolomite and in the Rome formation. Wells that tap perched water generally yield less than 2 gpm and many of them go dry in the late summer or early fall. The Honaker dolomite is the most productive aquifer. Near the Watauga River, wells of two rayon plants at Elizabethton yield as much as 2,500 gpm each. These plants use about 17 million gallons of water per day, of which 12 million gallons is pumped from the wells. The ground water in the area is suitable for most purposes, except that the water from the Sevier shale commonly is highly mineralized. Most of the ground water has a hardness of more than 100 parts per million (ppm). Data relating to 141 springs and 235 wells within the area are listed in the report. (Auth)

<80>

Sighinolfi, G.P., and T. Sakai; Federal University of Bahia, Institute of Geosciences, Salvador, Brazil; Federal University of Bahia, Institute of Physics, Salvador, Brazil

Uranium and Thorium in Potash-Rich Rhyolites From Western Bahia (Brazil). Chemical Geology, 14, 23-30. (1974)

The U and Th distribution in K-rich acid metavolcanics affected by postmagmatic processes has been studied. Th(20 ppm) and U(2.41 ppm) average abundances are well within the normal ranges for granitic rocks, but the Th:U values are appreciably higher than most of the values reported. Since the rhyolitic magma is supposed to

have been formed by partial melting of pre-existing rocks, the high Th:U ratios may be due: (1) to an extreme magmatic fractionation towards a K-rich trend in the magma chamber or during magma displacement; and (2) to high Th:U ratios in the original material, probably ancient crystalline basemental rocks depleted in U with respect to Th during previous cycles. The possible influence of postmagmatic processes on U and Th distribution is discussed, and evidence of U mobilization and redistribution within the formation is set forth. (Auth)

<81>

Gross, E.B.; California Division of Mines and Geology, San Francisco, CA

A Unique Occurrence of Uranium Minerals, Marshall Pass, Saguache County, Colorado. American Mineralogist, 50, 909-923. (1965, July)

In 1956 several unusual uranium deposits were uncovered in the Marshall Pass district, Saguache County, Colorado. Two of the ore bodies occurred in alluvium at an elevation of about 10,000 feet. The largest of these, on the Lookout No. 22 claim, produced about five tons of high-grade uranium ore. The bedrock at the deposit is a quartz-hornblende-feldspar-schist which has been altered adjacent to a fault zone. Small areas of the schist have been completely replaced by uranium and sulfide minerals, producing "rich" ore bodies that have been found in situ in the alluvium above the fault. Ore pieces are tabular to rounded yellow masses measuring from a few inches in diameter to large slabs 2 feet by 1 foot by 8 inches thick and weighing as much as 140 pounds. Nearly all contained a yellow oxidized coating around a black interior of pitchblende and sulfides. Geochemical sampling of soils surrounding the deposit indicate that uranium has migrated less than 100 feet downslope from the ore body. Radioactive minerals include pitchblende, schoepite, ianthinite, epi-ianthinite, becquerelite, soddyite, boltwoodite, uranophane, zeunerite, metazeunerite, and a hydrated autunite. Other minerals are tetrahedrite, chalcocite, sphalerite, chalcocite, covellite, galena, pyrite, and marcasite. Pitchblende occurs in concentrically banded and colloform masses showing fractures and microfaults rehealed by later pitchblende. Secondary uranium minerals and sulfides transect the pitchblende and occur

interstitially between banded masses. The uranium deposit was probably formed under epithermal conditions during early Tertiary time. (Auth)

<82>

Norris, S.E., and H.C. Spicer; USGS.
Washington, DC

**Geological and Geophysical Study of the
Pegglacial Teays Valley in West-Central
Ohio.** USGS Water-Supply Paper 1460-E.
33 pp. (1958)

Earth-resistivity methods were used to locate the buried Teays Valley and to trace its course before test drilling was begun. The apparent resistivity of the earth was computed by the Wenner formula; interpretation of the three resistivity curves obtained for each depth profile was by methods based on the theory of images. Computed resistivity values for the unconsolidated deposits ranged between 1,670 and 69,000 ohm cms; for the consolidated rocks the range was between about 2,500 and 41,000 ohm cms. Test holes drilled later at critical sites revealed the depth of the buried valley, its gradient and configuration, and the character of the valley-fill deposits. The Teays River was the master stream for the drainage from a large part of the Appalachian region in late Tertiary time. In the area of glacial drift the course of the buried Teays Valley has been traced, largely from well records, across western Ohio, northern Indiana, and Illinois to the Mississippi embayment. The Teays was a mature stream. Its valley in southern Ohio, where it is cut into shale and sandstone of Mississippian age, averages about 1 1/2 miles in width, has a flat floor and steep sides, and is about 200 to 300 feet below the general level of the uplands. In west-central Ohio, where it is cut into limestone and dolomite of Silurian age, the buried Teays Valley is about 3,000 feet wide in the narrowest place, the valley walls are steep, and the valley floor is 400 feet or more below the general level of the bedrock surface. The gradient of the Teays Valley in southern Ohio is about 9 inches per mile; its gradient in the area of this investigation is about 10 inches per mile. The buried valley declines in altitude from 568 feet in south-central Madison County to 538 feet in southern Champaign County, over a channel distance of about 35 miles. The fine-grained, unconsolidated deposits in the buried Teays Valley in west-central Ohio are not important as a source of ground water. (M.L.B)

<83>

Downs, G.R., and A.G. Bird; Cotter
Corporation, Denver, CO

**The Schwartzwalder Uranium Mine,
Jefferson County, Colorado. The
Mountain Geologist, 2(4), 183-191 (1965)**

The Schwartzwalder uranium mine has been the largest vein-type producer of uranium ore in Colorado and ranks among the six largest of this type in the United States. Ore shipments of 133,000 tons of 0.78 percent average grade ore have yielded more than 2,000,000 pounds of U₃O₈. Unmined reserves are believed to exceed the amount already produced. The ore body is classed as a typical hydrothermal vein-type ore deposit. Primary pitchblende is the principal ore mineral. The host rocks are units of the Idaho Springs Formation of Precambrian age. Deposition of the ore occurred during early Tertiary time. The fissure veins are parallel to and located about four hundred yards southwest of the Rogers breccia reef, a northwest-trending Laramide fault of large displacement. Repeated movement along the major fault resulted in fracturing and rebrecciation of the tectonically related fissures of the mine area. These fissures provided channels for the entry of contemporaneous and subsequent mineralizing fluids. Ore deposition was controlled not only by the fracture porosity and permeability afforded by the brecciated fissures, but also by favorable chemical reactions which took place between the host rocks and the hydrothermal fluids. The garnetiferous biotite gneiss and phyllitic schist units of the Idaho Springs Formation were particularly effective host rocks for pitchblende ore deposition and concentration. (Auth)

<84>

Childers, M.O.; Power Resources
Corporation, Denver, CO

**Uranium Occurrences in Upper
Cretaceous and Tertiary Strata of
Wyoming and Northern Colorado. The
Mountain Geologist, 11(4), 131-147. (1974)**

Uranium deposits of economic significance are known to occur in the Laramie, Lance and Fox Hills Formations of Late Cretaceous age; in the Fort Union Formation of Paleocene age; and in the

Wind River, Wasatch, and Battie Spring Formations of early Eocene age. The best known deposits occur in the lower Eocene strata which, when taken in their entirety, contrast sharply with the underlying strata of Cretaceous and Paleocene age. The Cretaceous and Paleocene strata are reducing throughout, except where altered, and show evidence of deposition under influence of a uniformly humid tropical climate, whereas the Eocene formations are bifacies in character showing influence of a savanna climate. These facies are an oxidized red-banded mudstone facies, and a reduced gray carbonaceous sandstone and mudstone facies. The oxidized facies was deposited by small intermittent tributary streams, and the reduced facies was deposited by large permanent streams. The savanna climate actually persisted into early Oligocene time, influencing the deposition of the Chadron Formation in eastern Wyoming. It is proposed that the savanna climate was a very important factor in the origin of Wyoming uranium deposits, and that the deposits were actually emplaced during Eocene and Oligocene time under the influence of the savanna climate. Uranium was soluble in both surface water and ground water of the oxidizing facies during the incipient arid phases of the savanna climate, but uranium was precipitated from ground water which invaded the reduced large-stream facies. Also, when uranium-bearing surface water stagnated in swampy environments, low-grade syngenetic deposits resulted. The source of the uranium was probably the granitic rocks from which the arkosic sands were derived. Uranium was leached from these granitic source rocks during weathering and erosion. (Auth)

<85>

Swenson, F.A.; USGS, Washington, DC

Geology and Ground-Water Resources of the Lower Marias Irrigation Project, Montana. USGS Water-Supply Paper 1460-B, 56 pp. (1957)

A succession of sandstones and shales of Cretaceous age underlies the entire report area. These rocks consist of the Colorado shale, Telegraph Creek formation, Eagle sandstone, Claggett shale, and Judith River formation and have an aggregate thickness of about 3,300 feet. All but the Colorado shale are exposed in the area. Mantling the bedrock are unconsolidated deposits

of Quaternary age. These deposits consist principally of ground moraine deposited by one or more continental glaciers that advanced over the area during Pleistocene time, of outwash deposits laid down by glacial melt water, of paludal or lake deposits in depressions, and of alluvium deposited by postglacial streams. The deposits of Quaternary age range in thickness from a little more than 250 feet where they fill buried valleys to a featheredge where they border exposures of bedrock. The Virgelle sandstone member of the Eagle sandstone and the Judith River formation are the two principal bedrock aquifers. The Virgelle sandstone member is about 450 feet below land surface in the western part of the area and about 750 feet in the northeastern part. Faulting 3-5 miles north of the Big Sandy has raised the Virgelle close to the surface, and relatively shallow wells drilled close to the faults on the upthrown side would reach this aquifer. Water in the Virgelle is highly mineralized, except possibly near the faults. The mineralization increases northward and eastward down the dip of the formation. The Judith River formation is present only in the eastern part of the area and is tapped by many relatively shallow wells. The water in this formation is of good quality and is preferred wherever it is available. Fairly large supplies of water of moderately good quality can be obtained from the alluvial fans along the base of the Bearpaw Mountains at the eastern edge of the area and from the deposits filling the buried valleys of the ancestral Missouri and Marias Rivers. Small supplies of water are available at shallow depth from lenses of permeable material in the ground moraine. Unless only small amounts of water are used for irrigation or unless provision is made for the disposal of irrigation water in excess of crop needs, many parts of the Lower Marias irrigation project are likely to become waterlogged. (Auth)(M.L.B)

<86>

Kunkel, F., and F.S. Riley; USGS, Washington, DC

Geologic Reconnaissance and Test-Well Drilling, Camp Irwin, California. USGS Water-Supply Paper 1460-F, 37 pp. (1959)

The area of study covers five alluvial-filled structural basins herein called the Camp Irwin, Bicycle, Langford, Coyote, and Dry Gulch basins. These basins lie northeast of the town of Barstow

within or near the Camp Irwin Military Reservation. The geologic units are grouped in two categories: consolidated rocks and unconsolidated deposits. The consolidated rocks are mostly hard and impervious; and, except for minor amounts in cracks and fractures, they are generally not water bearing. The unconsolidated deposits are porous and generally more permeable, and as a group are potentially capable of storing, transmitting, and yielding significant quantities of ground water. The consolidated rocks, as mapped, include the crystalline basement complex of pre-Tertiary age, a series of volcanic and associated continental sedimentary rocks of Tertiary age, and two groups of volcanic rocks of late Tertiary to early Quaternary age. The unconsolidated deposits, as mapped, comprise six units of alluvial deposits ranging in age from late Tertiary to Recent, as follows: granitic gravel of unknown origin, older fan deposits, older valley-floor alluvium, alluvial-fan deposits, valley-floor alluvium, and wash deposits. There are also two units of lake deposits, ranging in age from late Pleistocene to Recent as follows: lacustrine and playa deposits, and dune sand of Recent age. Four test wells were drilled in connection with this study. The logs of materials penetrated, the summaries of test pumping, and the chemical analyses of the waters are included; also given are similar data for seven wells drilled by the Army from 1941 to 1944. The geologic reconnaissance and well data indicate that the valley-floor areas of Camp Irwin, Bicycle, Langford, and Coyote basins are favorable for the development of ground water. Wells in these four basins yield from 115 to 1,700 gpm. One well in Dry Gulch basin that was drilled to a depth of 335 feet bottomed in basalt above the water table. (Auth)

<87>

Ruppel, E.T.; USGS, Washington, DC

**Geology of the Basin Quadrangle
Jefferson, Lewis and Clark, and Powell
Counties, Montana.** USGS Bulletin 1151,
121 pp. (1963)

The Basin quadrangle, in the northern part of the Boulder Mountains between Butte and Helena, Montana, is underlain principally by igneous rocks that include Upper Cretaceous quartz latitic and andesitic Elkhorn Mountains volcanics, quartz monzonite and related rocks of the Boulder

batholith, Oligocene quartz latitic volcanic rocks, and late Miocene-early Pliocene rhyolitic volcanic rocks. Sedimentary rocks of the Upper Jurassic Morrison formation, the Lower Cretaceous Kootenai formation, and the Lower Cretaceous lower part of the Colorado formation, crop out in the northwest part of the quadrangle. The

batolithic rocks include early-stage quartz monzonite, quartz monzonite and granodiorite of the Butte quartz monzonite, and late-stage aplite and alaskite. The rocks of the Butte quartz monzonite are in discontinuous layers approximately conformable to the folded Elkhorn Mountains volcanics that form the roof of the batholith, and may be part of a sill-like body rather than of a batholith in the classic sense.

Metamorphic changes in the roof rocks are not conspicuous except in one stratigraphic unit that probably was especially susceptible to thermal reorganization. The batholithic rocks and the Elkhorn Mountains volcanics are jointed, and are cut by faults. The east-trending faults are most abundant, especially in the eastern part of the quadrangle, and cut only the batholithic and older rocks; many of the faults of other trends cut Tertiary volcanic rocks, and a few cut Pleistocene glacial deposits. The Elkhorn Mountains volcanics are folded into a series of shallow anticlines and synclines that trend about N. 35 degrees E. A surface of moderate relief was cut before eruption of the Lowland Creek volcanics of Oligocene age, and the late Miocene-early Pliocene volcanic rocks covered a deeply weathered surface of low relief. By Pleistocene time a landscape almost like that of today had been formed, and during the one period of Pleistocene glaciation, valley glaciers and a mountain ice sheet modified the earlier landforms and left extensive deposits of till and outwash. These deposits have been modified in many places by mass-wasting processes that have dominated postglacial erosion. Mineral deposits in the quadrangle include deposits of disseminated auriferous pyrite, base- and precious-metal bearing quartz veins in some of the east-trending fault zones, placer deposits of gold and tin, and a few nonmetallic deposits, chiefly stone, gravel, and dumortierite. Nearly all the metallic minerals mined in the quadrangle have come from the east-trending quartz veins and from the placer deposits. (Auth)

<88>

Woodmansee, W.C.; AEC, Grand Junction, CO

Relationship Between Sandstone-Type Uranium Deposits and Ground Water in Some Uranium-Producing Areas. In *Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Vol. 2, Survey of Raw Material Resources, held in Geneva, Switzerland, September 1-13, 1958*. United Nations, New York, (pp. 351-357), 843 pp (1958)

Many uranium deposits in clastic sedimentary host rocks are associated with present-day water tables or are considered to have been related to past groundwater conditions. Geologic and geochemical evidence suggests that some of these "sandstone-type" deposits were formed and are forming epigenetically by the precipitation and concentration of uranium from groundwater solutions, migrating laterally through permeable Mesozoic and Cenozoic strata. Uranium deposits are commonly localized in and adjacent to paleo-fluvial drainage channels, which are characteristic features in clastic sediments of uranium-mining areas throughout the western United States. Uranium was introduced into these channel systems either during channel filling or at some later date. The contact zone between oxidized and unoxidized host sandstones is well defined in many open-pit uranium mines. The unoxidized sandstone is typically blue gray, due to the abundance of finely disseminated microscopic grains of pyrite; sandstone largely or completely oxidized is buff colored to brown. Due to alteration of pyrite to limonite. Oxidized ore bodies are generally relatively small and irregular in shape and variable in grade because of redistribution of uranium. Unoxidized ore bodies are generally relatively large, continuous, and well defined. The oxidized-unoxidized contact is above the water table in most places. The depth of the contact is determined primarily by climatic factors and bedrock conditions, and it essentially represents the depth to which atmospheric oxygen penetrates, or the upper limit at which sufficient oxygen-free moisture is present in the sandstone to retard oxidation. Fluctuations of the water table, at present as well as in the past, are believed to influence the character of mineralized horizons. Uranium ore bodies are closely related to the oxidized-unoxidized contact and the present water table. Deposits are characterized by the formation of multiple mineralized horizons, which range from the surface to depths of 200 feet. The Maybell district of Colorado is cited specifically as an area

in which sufficient data are available to consider the possible influence of groundwater on the genesis of known ore bodies. Oxidized ore minerals are chiefly phosphates, with minor silicates and carbonates. Both oxidized and unoxidized ore bodies are concentrated in the contact zone above the water table. The oxidized-unoxidized contact is a highly irregular, undulating surface, with local domes and depressions and abrupt variations in depth. These variations are due to recent small-displacement faults, differential oxidation, local perched water tables above clay and hard carbonate beds, and "perched" unoxidized zones below impermeable beds. Comprehensive groundwater studies are of value in exploration for uranium in districts where ore bodies occur in zones of water tables or in water-bearing host rocks and where circulating ground waters are considered the major ore solutions. (JMT)

<89>

Hagmair, J.L.: University of North Dakota, Grand Forks, ND

Groundwater Flow, Hydrochemistry, and Uranium Deposition in the Powder River Basin, Wyoming: Geology. In Ph.D. Dissertation, Groundwater Flow, Hydrochemistry, and Uranium Deposition in the Powder River Basin, Wyoming. Chapter 2, (pp. 7-21), 166 pp. (1971)

The Powder River Basin is underlain by sedimentary rocks that were deposited during the Cenozoic Era. The Wasatch Formation of Eocene age is exposed throughout most of the central part of the basin. The Fort Union Formation of Paleocene age underlies the Wasatch Formation and outcrops in a band around the periphery of the Wasatch exposures. The White River Formation of Oligocene age is the only Tertiary rock unit in the basin that is younger than the Wasatch Formation. It occurs locally in the basin as a caprock on the Pumpkin Buttes. The Fort Union Formation conformably overlies the Lance Formation of late Cretaceous age. It generally has a thickness of between 3000 and 3800 feet, and it contains three distinct facies: a sandstone facies, a siltstone-clay facies, and a lignite-shale facies. The three facies are interpreted to be a fluvial channel deposit, a river levee and floodplain deposit, and a floodbasin deposit, respectively. The Wasatch Formation unconformably overlies the Fort Union Formation.

and it ranges in thickness from 1000 feet to about 3000 feet. Like the Fort Union, the sediments of the Wasatch Formation may be divided into three distinct sedimentary facies, the sandstone facies, the silt-stone-clay facies, and the lignite-shale facies. These facies are completely intertongued, and montmorillonite clay is common in all. The clay was apparently derived from volcanic ash. The facies environments are interpreted to be the same as were the facies in the Fort Union facies. The White River Formation on the Pumpkin Buttes unconformably overlies the Wasatch Formation, and consists of coarse-grained sandstone. Volcanic ash was a significant sediment source for this formation, and the rocks of the formation are interpreted to have once covered the entire Powder River Basin, but have been almost completely removed by erosion since the Pliocene Epoch. The Powder River Basin is structurally related to the Laramide Orogeny. An angular unconformity that separates the Wasatch and Fort Union Formations indicates substantial uplift near the end of the Paleocene Epoch. Contemporaneously with the surrounding uplift, subsidence in the basin was apparently rapid enough to maintain a coastal plain which persisted northward into Montana and North Dakota where a large Tertiary lake existed in the Williston Basin. During the Oligocene Epoch the Powder River Basin was filled with sediment derived from the volcanic centers in the Yellowstone-Absaroka region to the west and the surrounding highlands. The climate became more arid during this time and a prairie environment developed. Presumably, sedimentation in the basin continued into the Miocene and Pliocene Epochs. Erosion during the Pleistocene and Holocene Epochs removed all the late Cenozoic sediments that may have been present and most of the Oligocene sediments. (JMI)

—90—

De Nault, K.; Stanford University.
Stanford, CA

Cenozoic History of Wyoming. In Ph.D.
Dissertation, Origin of Sandstone Type
Uranium Deposits in Wyoming, Chapter
2, (pp. 7-24), 352 pp. (1974)

During much of Mesozoic and Paleozoic time Wyoming was covered by epicontinental seas, but toward the close of the Cretaceous Period the western half of the state became an emergent

swampy coastal plain. In the Late Cretaceous, the sea withdrew nearly completely, and mountains and basins formed during the Laramide Orogeny. Two main areas of subsidence developed a northern trough extending from the southern border of Yellowstone Park into the present site of the Wind River Basin and on toward the Black Hills, and a southern trough extending from the present Great Divide Basin to the Hanna Basin. Of particular note to uranium geology is the emergence of the juvenile Granite Mountains in the center of the state. By the close of the Cretaceous Period, deformation had produced a number of present-day structural units in ancestral form. The Beartooth, Owl Creek, Washakie, Wind River and western Gros Ventre Mountains appeared in juvenile form and the incipient Medicine Bow Mountains, Sierra Madre, Rock Springs Uplift, and Granite Mountains were further accentuated. A broad area in southeastern Wyoming was uplifted, but the Bighorn Mountains and Black Hills had not yet appeared. During the Paleocene Epoch uplift of mountains and subsidence of basins continued. A variety of sediments were deposited in the basins, fine-grained clastics derived from soft Cretaceous shales and sandstones, local conglomerates deposited principally along the flanks of the ancestral Wind River, Medicine Bow, and Granite Mountains, and coals deposited in swamps which formed when drainages became slowed or blocked by uplifts. As uplift continued, lakes formed in some basins. In the Wind River Basin over 2000 feet of dark carbonaceous shales was deposited in Waltman Lake and these lake beds may be the source of some of the Tertiary oil and gas found in Wyoming. By the close of the Paleocene Epoch the northern Bighorn Mountains and Black Hills had begun to emerge. Early Eocene time marked the crescendo of Laramide deformation. Strong folding and thrust faulting took place over most of the state and vertical relief probably reached a maximum. Mesozoic and Paleozoic sedimentary rocks had been eroded from the mountains, and basins were being filled by detritus primarily derived from Precambrian granitic cores. The change of source material from recycled sediments to Precambrian igneous and metamorphic rocks is reflected by a marked change in heavy mineral species between the Paleocene Fort Union Formation and lower Eocene sediments. Along mountain flanks, coarse-grained arkosic sands and conglomerates were deposited in alluvial fans and aggrading stream channels. The sands are the host unit for uranium mineralization in all the major uranium districts. Basinward, lower

Eocene coarse-grained sediments become finer and in places grade into lacustrine deposits. The Granite Mountains near the center of the state supplied the host sands in the Gas Hills, Crooks Gap, and Shirley Basin Districts. In the Powder River Basin host sands were derived from the Laramie Range and Granite Mountains. In the Wind River Basin and Shirley Basin the lower Eocene unit is called the Wind River Formation. In the Wind River Basin most of the uranium deposits occur in the Puddle Springs arkose member of the Wind River Formation, which represents a main drainage channel off the northwest flank of the Granite Mountains. In the Powder River Basin lower Eocene sediments are called the Wasatch Formation and uranium deposits occur in this unit and to a limited extent in the underlying Fort Union Formation. In the Crooks Gap District uranium is found in the Battle Spring Formation. In middle Eocene time major uplift of mountain masses ceased and the temperate climate of the Paleocene changed to a humid subtropical climate. At this time, major volcanic activity commenced in the Absaroka area, and wind-blown ash was deposited throughout the state filling basins throughout the Oligocene, Miocene, and Pliocene. The beginning of Oligocene time was marked by inauguration of a depositional cycle that continued through the Miocene and into the Pliocene epochs. Deposition of Oligocene sediments began with the filling of larger valleys, reducing relief which resulted in slow accumulation of stream-laid deposits. In Pliocene the collapse of the Granite Mountains began and this area became a large graben bounded on the north and south by normal faults. At the close of Pleistocene time Wyoming underwent regional uplift and a new cycle of erosion was initiated. (JM1)

- 91 -

Wilson, C.W.; Vanderbilt University,
Nashville, TN

**Stratigraphy and Geology History of
Middle Ordovician Rocks of Central
Tennessee.** Geological Society of America
Bulletin, 73, 481-504. (1962, April)

The major facies of the Nashville and Maysville groups (Middle and Upper Ordovician) in Central Tennessee are laminated argillaceous limestone to the west and limestone with varying amounts of silt to the east; granular phosphatic limestone and

dove-colored limestone lie between the western and eastern facies. The distribution of these four rock types was controlled by activity of the Cincinnati arch. Typical of the regional history was the pattern of deposition of the various lithologies in the Bigby-Cannon Limestone. During deposition of this formation a relatively deep sea to the east received normal limy ooze with varying amounts of silt. Between these two provinces was a north-south belt of shallow water - the Central Tennessee Bank - which was the expression of the Cincinnati arch, and which for short periods of time was above sea level to form a north-south strip of mud and sand. The great concentration of organisms on the western part of the bank resulted in "in situ" reef detritus and the limy phosphatic "sand" of the fore reef slope off the bank, which together formed the granular phosphatic limestone. The eastern part of the bank was a tide-level shelf lagoon in which fine limy ooze accumulated to form the Dove-colored limestone. During the deposition of the Hermitage Formation there were three uplifts of the then narrow Cincinnati arch. During deposition of the Bigby-Cannon Limestone the arch remained high. At the beginning of deposition of the Catheys Limestone the arch was low, but it was uplifted for a short period of time during early Catheys deposition. Uplifts were recurrent during deposition of the Leipers and the arch at this time was a broad domal bulge - the Nashville Dome. (Auth)(JM1)

<92>

Divis, A.F.; University of California, San
Diego, CA

**The Geology and Geochemistry of the
Sierra Madre Mountains, Wyoming.**
Ph.D. Dissertation, University of
California, Geology Department, 200 pp.
(1975)

Geochronologic evidence indicates that a profound discontinuity separating two discrete Precambrian age provinces parallels the Wyoming-Colorado border. This boundary transects the Sierra Madre Range in southern Wyoming adjacent to a sequence of folded Middle Precambrian sediments. Precambrian rocks of the Sierra Madre Mountains represent a series of igneous and sedimentary events which occurred near the edge of the Archean continental nucleus between 2600 and 1600 m.y. B.P. Quartz-biotite gneiss, probably 2800 to 2900

m.y. old, occupies the northern part of the range and grades eastward into a N.W. trending antiform of microcline augen gneiss and granite. The Rb-Sr isochron of the granite gneiss complex yields an age of 2650 m.y. with an initial Sr 87/Sr 86 intercept of 0.7000. Geochemical evidence suggests the quartz-biotite gneiss may have evolved from a supracrustal dacitic protolith formed by anatexis of a basaltic amphibolite. Calc-alkaline volcanic flows, tuffs, and volcanogenic sediments and a 4 km thick sequence of conglomerate, quartzite and limestone were deposited on the gneiss basement subsequent to 2650 m.y. B.P. A period of igneous activity and tectonism between 1650 and 1900 m.y. B.P. resulted in the metamorphism and folding of the sediments into a E-W trending anticlinorium of isoclinal folds. The Sierra Madre south of this metasedimentary structure consists principally of a composite batholith of plutons ranging from gabbro to granite. The Encampment River Granodiorite, the oldest intrusion, is a gneissic unit which isotopic and REE data suggest was derived by partial melting and remobilization of the polycyclic quartz-biotite gneiss. This thermal reactivation probably occurred between 1900 and 2000 m.y. B.P. The majority of the batholith is made up of a distinctive red granite with an isochron age of 1680 m.y. and an initial Sr 87/Sr 86 ratio of 0.7024. Trace and rare earth element data suggest that this Sierra Madre Granite was derived by partial melting of amphibolite gneiss under conditions of low pH and $P_{total}=7-10$ kb. A white quartz monzonite discordantly intrudes the granite and hornblende gneiss country rock. Isochron ages and initial Sr 87/Sr 86 intercepts of the monzonite and gneiss are respectively: 1680 m.y., 0.7020; and 1880 m.y., 0.7015. At least three distinct generations of mafic dikes are present in the Sierra Madre; field relations with dated units indicate ages of approximately 2700 m.y., 1800 to 2650 m.y. and 1680 m.y. The persistence and evolution of the Sierra Madre Range as a locus of magmatic activity and possible plate boundary through 1000 m.y. makes several important implications with respect to the growth of continental crust with time. The synchronization of magmatic and thermal events in relatively narrow time frames of 200 m.y. or less, over continental and planetary dimensions, implies the existence of large scale processes possibly related to primary mantle dynamics. These events show a crude episodicity with a period of 600 to 800 m.y. and may represent intervals of rapid continental accretion separated by quiescent "no growth" periods. No significant plutonism is apparent

between 2600 and 1800 m.y. B.P. in the Sierra Madre Range, but during the 200 m.y. period following, granitic plutons were intruded in an 800 km wide area to the south, from the Colorado-Wyoming border to northern Mexico. (Auth)(JMT)

<93>

Archbold, N.J.; University of Michigan, Geology Department, Ann Arbor, MI

Relationship of Carbonate Cement to Lithology and Vanadium - Uranium Deposits in the Morrison Formation in Southwestern Colorado. Economic Geology, 54, 666-682. (1959)

Sandstone from the top (ore-bearing) unit of the Salt Wash sandstone member of the Morrison formation contains an average of 2.5 to 3.0 percent carbonate regardless of whether or not it has been epigenetically altered, mineralized, or weathered (oxidized). The lower, generally barren, sandstone lenses of the Salt Wash sandstone member contain several times more carbonate than those of the upper sandstone. It appears that the ore-bearing sandstone originally contained less carbonate cement. Altered mudstone contains slightly less carbonate than unaltered mudstone and the process of mudstone alteration probably involved some leaching of carbonate. Altered and unaltered sandstone have about the same amount of carbonate, and possibly the mudstone and sandstone were altered by different agents. Carbonate-rich zones adjacent to contacts with mudstone are probably syngenetic or early diagenetic, whereas carbonate-rich zones which are closely associated in space with ore bodies may be genetically related to ore deposits. Where the ore-bearing sandstone has been subjected to weathering and associated oxidation, the average carbonate content has apparently not been greatly changed nor has carbonate been appreciably redistributed. If certain carbonate-rich zones or types of carbonate are genetically associated with ore bodies, they might be useful as ore guides. (M.B)

<94>

Brookins, D.G.; University of New Mexico, Department of Geology.

Albuquerque, NM

Position of Uraninite and/or Coffinite Accumulations to the Hematite-Pyrite Interface in Sandstone-Type Deposits. *Economic Geology*, 71(5), 944-948. (1976)

In the Grants Mineral Belt, New Mexico (and elsewhere), are found accumulations of reduced uranium (IV) as coffinite and/or uraninite, not only in the immediate proximity of the hematite-pyrite redox interface but in the oxidized hematitic rocks upgradient from the interface and well removed from the interface in pyritic sandstone downgradient from the interface. The upgradient deposits in the hematitic rocks have been noted in several mines in the Ambrosia Lake District, but the downgradient deposits have received less attention. The location of this interface is problematical, but it does serve as a convenient ore guide more often than not throughout at least the Ambrosia Lake District. This interface is roughly parallel to the southwestern margin of the San Juan Basin. Ore-bearing rocks of the Morrison Formation (Jurassic) dip into the basin to the northeast and are unconformably overlain by the Dakota Formation (Cretaceous). (MEB)(PAG)

<95>

Page, L.R.: USGS, Washington, DC

Uranium in Pegmatites. *Economic Geology*, 1, 12-34. (1950, January)

Uranium and rare-earth minerals are common accessory minerals in pegmatite deposits. No domestic pegmatites have been found that are rich enough to support an economic mining operation for uranium alone; however, small quantities of uranium minerals may be recovered as by-products of feldspar or mica mining. It has been shown that the uranium and rare earth minerals generally occur in pegmatites or pegmatite units rich in potash feldspar. Mineralogical and structural studies of pegmatites by the USGS indicate that, on the basis of geologic mapping, these units can be projected laterally and in depth with reasonable accuracy. In most places the mineral content of these units can be estimated with sufficient accuracy for development purposes. (Auth)

Cited as a reference in NURE Contractor

Reports.

<96>

McKelvey, V.E., and L.D. Carlsell, USGS, Washington, DC

Uranium in the Phosphoria Formation. In USGS Professional Paper 300, (pp. 483-487), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, *Geology of Uranium and Thorium*, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 503-506), 825 pp. (1956)

The Permian Phosphoria formation and its close stratigraphic correlatives consist of two overlapping couplets, each composed of a lower carbonaceous phosphatic unit, overlain by a cherty or carbonate-bearing unit. Phosphate deposits are found in the formation in Montana, Idaho, Wyoming, Utah, and Nevada. Nearly all the phosphatic beds are uraniferous, but their uranium content ranges from about 0.001 to 0.065 percent. Although some highly phosphatic beds are only weakly uraniferous, the phosphate beds that are more than 3 feet in thickness and that contain more than 31 percent P₂O₅ generally contain 0.01 - 0.02 percent uranium. Beds composed of pellets and oolites are more uraniferous than those composed of fish scales, brachiopod shells, and other organic remains; and highly weathered phosphate beds contain less uranium than their unweathered equivalents. Most of the uranium seems to occur in carbonate-fluorapatite, where it probably substitutes for calcium; but tyuyamunite has been discovered in one area where the rocks are highly weathered. (Auth)(MEB)

<97>

Pierce, A.P., J.W. Mytton, and G.B. Gott; USGS, Washington, DC

Radioactive Elements and Their Daughter Products in the Texas Panhandle and Other Oil and Gas Fields in the United States. In USGS Professional Paper 300, (pp. 527-532), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, *Geology of Uranium and Thorium*, held in

Geneva, Switzerland, August 8-20, 1955.
United Nations, New York. (pp. 494-498).
825 pp. (1956)

Uranium has been redistributed and concentrated within the interstices of rocks through which petroleum has migrated or in which it has accumulated. The concentration and redistribution of uranium has been associated in time with structural and diagenetic events including recrystallization, solution, concentration, and adsorption of metalliferous surface-active fractions of migrating petroleum. The result has been to make uranium and its daughter products easily accessible to fluids and gases. It is believed that a large part of the helium present in natural gases may have been derived from the radionuclides that have been distributed in this manner. More information about the geochemistry of uranium in petroleum waters, however, is necessary for a complete understanding of the genesis of the helium and the associated uraniferous asphaltites. (Auth)(MI.B)

98

Pipiringos, G.N.: USGS, Washington, DC

Uranium-Bearing Coal in the Central Part of the Great Divide Basin Sweetwater County, Wyoming. In USGS Professional Paper 300. (pp. 433-438). 739 pp.: In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York. (pp. 484-488). 825 pp. (1956)

Uranium-bearing coal of early Eocene age underlies about 750 square miles of the Great Divide Basin, Sweetwater County, Wyoming. The uranium content of the ash of these coal beds range from 0.003 to 0.023 percent. In the central part of the Great Divide Basin, the thickest coal beds underlie a relatively narrow belt in the trough and on the west flank of the northwest-trending Red Desert syncline; those containing the most uranium are thinner and on the east flank. The dominant structural feature of the area is a graben which trends about N. 70 degrees W. The schroekingite deposits in the north-central part of the Great Divide Basin occur within and along the southern

edge of the graben. The source of uranium in the coal and in the schroekingite deposits is probably the tuffaceous beds in the Browns Park formation localized in its present sites by ground water circulation guided by the structure and the interfingering of sedimentary facies. (MI.B)

99

Shoemaker, E.M.: USGS, Washington, DC

Occurrence of Uranium in Diatremes on the Navajo and Hopi Reservations, Arizona, New Mexico, and Utah. In USGS Professional Paper 300. (pp. 179-185). 739 pp.: In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York. (pp. 412-417). 825 pp. (1956)

Uranium deposits are localized in diatremes in widely separated parts of the Navajo and Hopi Reservations, but the bulk of the known deposits are in the Hopi Buttes area. One deposit in the northern part of the reservation comprises small podlike concentrations of uranyl-vanadates and copper carbonates in sandstone adjacent to a mica-serpentine tuff dike radiating from a diatreme. In another vent in the northeastern part of the area, uranium minerals are associated with minette tuff and in-fallen blocks of the Morrison formation of Jurassic age. In the Hopi Buttes area, uranium is widespread in the limestones and in some fine-grained clastic beds in the diatremes, but most of the known deposits are below ore grade. Some of the highest concentrations of uranium known occur in laminated siltstone and shale overlying sedimentary unconformities within the diatremes. These relations suggest that the uranium is syngenetic in the fine-grained clastic and carbonate sediments and that one of the factors governing the concentration of uranium may have been the rate of sedimentation. If uranium-bearing solutions were being supplied more or less continuously from depth, the uranium may have been concentrated in the beds that were deposited at the slowest rate. A few qualitative chemical tests suggest that uranium is present in the sediments in part as a phosphate, which suggests the possibility that in the Hopi Buttes area the uranium was

introduced by solutions derived from the hydrous phosphate-rich monchiquite magma. (Auth)(M.I.B)

- 100 -

Staatz, M.H., and F.W. Osterwald, USGS, Washington, DC

Uranium in the Fluorspar Deposits of the Thomas Range, Utah In USGS

Professional Paper 300, (pp. 131-136), 739 pp., In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 275-278), 825 pp. (1956)

Uranium-bearing fluorspar deposits on Spors Mountain in the western part of the Thomas Range, Juab County, Utah, constitute the largest known reserve of uraniferous fluorspar in the United States. Spors Mountain is made up largely of a thick sequence of conformable Ordovician to Devonian sedimentary rocks, most of which are limestone and dolomite; the fluorspar deposits are in dolomite of Middle Silurian age. Many small volcanic plugs and dikes intrude the sedimentary rocks. The rocks of the district are cut by close-spaced and complex faults. The uraniferous fluorspar deposits have three structural habits: (1) oval to irregular pipes, (2) veins, and (3) disseminated deposits. The fluorspar occurs chiefly in the pipes. These differ considerably in size and are adjacent to faults or intrusive breccia bodies. The ore, containing 65-94 percent fluorite, closely resembles brown, white, or purple clay, and forms either soft pulverulent masses or boxworks. The pipelike ore bodies commonly become smaller and lower in grade with depth. Uranium contents of 155 fluorite samples range from 0.003 to 0.33 percent. The uranium content of some individual deposits varies systematically vertically and nonsystematically horizontally. Other deposits show no systematic vertical variation. At most deposits uranium is enriched near the surface, presumably as a result of leaching of uranium from the upper part of the deposit and redeposition by adsorption in the dry underlying fluorite a few inches to as much as 30 feet below the position from which it was removed. The fluorspar is believed to have been formed from fluorine-rich fluids carrying minor amounts of uranium, which

rose along faults and shattered zones in the dolomite. These fluids probably were derived from the same source that formed abundant topaz in rhyolites that make up most of the eastern half of the Thomas Range. The uranium was originally dispersed throughout the fluorite, probably within the crystal structures. (Auth)

< 101 >

Vine, J.D., USGS, Washington, DC

Uranium-Bearing Coal in the United States. In USGS Professional Paper 300, (pp. 405-411), 739 pp., In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 452-457), 825 pp. (1956)

Large potential reserves of uranium are contained in coal and lignite, particularly in Cretaceous and Tertiary sedimentary rocks in some parts of the Rocky Mountains and northern Great Plains regions of the United States. The concentration of uranium in the ash of coal provides a possible means of recovering uranium as a byproduct. Ore-grade uranium in lignite is present locally in the northern Great Plains. Uranium-bearing lignite occurs in the Fort Union formation of Paleocene age in the northern Great Plains, in the Salt Lake formation of Pliocene age in southern Idaho, and in Tertiary sediments in Nevada and western California. Uranium-bearing coal is present in the Wasatch formation of Eocene age in Wyoming, in the Laramie formation of Cretaceous age in Colorado, in the Mesaverde formation of Cretaceous age in New Mexico, and in the Bear River formation of Cretaceous age in southeastern Idaho. Bituminous coal and anthracite of Paleozoic age in North Central and Eastern United States contain only very small quantities of uranium. The distribution of uranium in coal is erratic. In many areas uranium is preferentially concentrated at the top of the stratigraphically highest coal beds. In the Red Desert area of Wyoming, uranium is concentrated in coal beds adjacent to permeable units of the enclosing strata. Uranium is thought to be held in coal as a fixed adventitious constituent of epigenetic origin. When more uranium is available in the coal than can be chemically combined with the organic matter, uranium

minerals including carnotite, autunite, torbernite, metazeunerite, and coffinite may form. In the northern Great Plains uranium is thought to be introduced into coal by ground water that leached uranium from unconformably over-lying volcanic rocks. (Auth)

<102>

Walker, G.W., and F.W. Osterwald.
USGS, Washington, DC

Relation of Secondary Uranium Minerals to Pitchblende-Bearing Veins at Marysvale, Piute County, Utah. In USGS Professional Paper 300, (pp. 123-129), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 283-287), 825 pp. (1956)

Concentrations of hexavalent uranium minerals at Marysvale are the near-surface extensions of pitchblende- and fluorite-bearing veins at depth. The veins, emplaced in faults and shear zones in Tertiary volcanic and intrusive rocks, are probably of early to middle Pliocene age. Some of the richest ore, which is about the same grade in the oxidized and unoxidized parts of veins, occurs in steeply plunging shoots at intersections of different fault sets or at places where faults change strike; some ore is concentrated at the contact of the quartz monzonite and the overlying rhyolite. Hydrothermally altered wall rock accompanies some of the uranium-bearing structure, but in general, the zones of alteration thin with depth and are absent adjacent to veins exposed in lower mine workings. Although most hexavalent uranium minerals are thought to have been derived essentially in place from oxidation of primary pitchblende, some of the uranyl minerals, notably umohite, and part of the uranophane, autunite, and torbernite, and some of the sooty pitchblende are thought to have resulted from the action of thermal solutions either by direct precipitation or by hydrothermal alteration of primary pitchblende. (M.B.)

<103>

Wallace, S.R., and J.C. Olson; USGS, Washington, DC

Thorium in the Powderhorn District, Gunnison County, Colorado. In USGS Professional Paper 300, (pp. 587-592), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 582-586), 825 pp. (1956)

Two principal types of thorium-bearing deposits occur in the Powderhorn district: silicified and iron-stained mineralized shear zones in Precambrian rocks; and carbonate-rich veins, filling persistent fissures, which are especially abundant in and near the Iron Hill composite stock. Both types of deposits contain relatively high concentrations of several or all of the following elements: U, P, Ba, Sr, Th, Nb, and rare earths; carbonate- and alkali-bearing minerals are common in many of the deposits. The veins are associated with alkalic igneous rocks of pre-Jurassic age that contain abnormal amounts of the elements listed above as characteristic of the veins. The content of minor elements in both the igneous rocks and the thorium-bearing deposits is reflected in their similar accessory mineral assemblages. The spatial and geochemical associations of the alkalic igneous rocks of the district with the thorium-bearing deposits indicate a genetic relationship between them. The Little Johnnie vein, the most promising thorium deposit known in the district, is a mineralized shear zone, in foliated Precambrian rocks, that can be traced discontinuously for a distance of more than 3,500 feet; in this distance it ranges from less than 6 inches to be about 5 feet in width. The thorium-bearing material occurs as irregular veinlets and thin films along the fault zone. (Auth)(M.B.)

<104>

Hall, W.J., Jr., A.T. Myers, and C.A. Horr; USGS, Washington, DC

Uranium in Asphalt-Bearing Rocks of the Western United States. In USGS Professional Paper 300, (pp. 521-526), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of

Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 489-493), 825 pp. (1956)

Host rocks containing the asphalt include sandstone, arkose, conglomerate, limestone, diatomite, and alluvium. The asphalt was extracted from the host rock, reduced to dry ash, analyzed chemically for uranium, and analyzed spectrographically for other elements by semiquantitative methods. Significant amounts of uranium in the ash of the extracted oil, whose average uranium contents range from 0.028 to 0.376 percent, were found in samples from 7 of the 45 areas examined. All except 1 area contain large estimated reserves of asphalt-bearing rock, ranging from 15 million to almost 2 billion tons. The average uranium content of samples from 13 additional areas ranges from 0.02 to 0.68 percent uranium in the ash of the extracted oil. Many of these areas contain very large reserves of asphalt-bearing rock. It is believed that most of the uranium was present either as an original constituent of the oil or was introduced during the migration of the oil. Chemical analyses of the extracted asphalt and of the rock residue show that the uranium is concentrated as an organo-uranium complex in the asphalt and not in the host rock. Preliminary evaluation of the field data indicates that the amount of uranium in the asphalts may be closely related to the mineralogical composition of the sediments in which the oil originated, or the rocks through which the oil migrated. (Auth)(M.I.B)

The conference paper is entitled "Uranium in Asphalt-Bearing Rocks".

<105>

Sharp, B.J.: AEC, Salt Lake City, UT

Uranium Deposits in Volcanic Rocks of the Basin and Range Province. In USGS Professional Paper 300, (pp. 79-83), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 252-256), 825 pp. (1956)

Vein-type uraninite deposits in granitic rocks in the Marysvale district are closely associated with volcanic rocks. Uranium minerals occur in red rhyolite agglomerate and in felsitic to glassy dikes. Uraninite has been identified in the rhyolite agglomerate in close association with fluorite. Other uranium minerals identified are autunite, meta-autunite, torberite, and uranophane. In the Kings River area, uranium occurs along a northward-trending fault which displaces Miocene volcanic rocks. The volcanic sequence was extruded upon an old erosion surface of granodiorite of Jurassic age which crops out north of the ore deposit and is also exposed in working mines. Uranium minerals include autunite, torberite, and possibly gummite and uraninite. Gangue minerals are pyrite, quartz, fluorite, and clays. Elsewhere in Nevada and California uraninite and secondary uranium minerals have been found in volcanic rocks varying from rhyolitic tuff and agglomerate to andesite. (Auth)(M.I.B)

<106>

Coats, R.R.: USGS, Washington, DC

Uranium and Certain Other Trace Elements in Felsic Volcanic Rocks of Cenozoic Age in Western United States. In USGS Professional Paper 300, (pp. 75-78), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 248-251), 825 pp. (1956)

In the Cordilleran region of Western United States very few uranium deposits are remote from surficial manifestations of Cenozoic volcanic activity. On the other hand, broad areas of volcanic rocks are completely lacking in known uranium deposits. To determine whether this lack of known uranium deposits is due to insufficiency of exposures, of prospecting, or of both, or to a real scarcity of uranium, rhyolitic and dacitic volcanic rocks, nearly all of which were glassy or partly glassy were sampled. All these samples were analyzed fluorimetrically for uranium, chemically for fluorine, and spectrographically for boron, beryllium, lanthanum, lithium, niobium, tin, lead, and zirconium. The geographic distribution of uranium and some of the other elements studied is

not random; rather high and low values tend to fall into provincial groups, which have been tentatively delineated. The content of uranium has a significantly high positive correlation with that of fluorine, lithium, niobium, tin, and beryllium; a negative correlation with that of lanthanum; and the correlation with lead, boron, zirconium or manganese is not significant. The provincial distribution may have resulted from the generation of magmas in parts of the crust that differed significantly in their content of the elements studied because of regional differences in the effectiveness of upward transport of these elements. A study of the correlations suggests that these elements were concentrated in rhyolitic rest magmas following removal of other elements by crystallization of early-forming minerals. (Auth)(M.L.B)

The conference paper is entitled "Distribution of Uranium and Certain Other Trace Elements in Felsic Volcanic Rocks of Cenozoic Age of the Western United States".

<107>

Derzay, R.C.: AEC, Denver, CO

Geology of the Los Ochos Uranium Deposit, Saguache County, Colorado. In USGS Professional Paper 300, (pp. 137-141), 739 pp.: In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 468-472), 825 pp. (1956)

In the mine area a major high-angle reverse fault (the Los Ochos fault), trending easterly is traceable for several miles. A deeply dipping northeast-trending pitchblende-bearing zone, intensely sheared at the contact of the granite and the Morrison formation, intersects the Los Ochos fault. The two faults form tubes of an ore deposit that is triangular in horizontal cross section and essentially a steeply plunging "pipe". The ore body measures 82 feet along the northeast-trending shear, 85 feet in width, and 120 feet along the Los Ochos fault. It extends at most 60 feet above the drift and downward for an undetermined distance. Although exploitation of this deposit and exploration work at nearby prospects indicate that the intersections of northeast-trending shear zones

with east-trending faults are more obvious controls of the uranium ore bodies, fractures trending in other directions may also have been channelways for mineralizing ore solutions. (M.L.B)

The conference paper is entitled "The Los Ochos Uranium Deposit".

<108>

Swanson, V.E.: USGS, Washington, DC

Uranium in Marine Black Shales of the United States. In USGS Professional Paper 300, (pp. 451-456), 739 pp.: In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 430-434), 825 pp. (1956)

The most uraniferous shales are those rich in organic matter (mainly plant debris), pyrite, and phosphatic matter. They are also low in calcium carbonate content, and yield oil by destructive distillation. Most uraniferous black shale units are thin blanket-like deposits of Paleozoic age that have very little variation in thickness or lithology over wide areas and were deposited at an exceedingly slow rate. Both field and laboratory studies show that uranium is evenly disseminated throughout the black shale and is believed to have accrued contemporaneously with the deposition of the enclosing organic-rich muds. Areal variations in uranium content are related directly to regional paleogeographic trends; vertical variations are related directly to lithologic changes, particularly in the ratio of organic matter to detrital minerals. The form of the uranium in the shale is not completely known and no uranium-bearing minerals have been identified; however, laboratory studies indicate that uranium ions in the sea water were adsorbed by the organic matter. In order to evaluate the uranium potential of marine black shales, they may be classified by the tectonic and paleogeographic setting of the area during time of accumulation of organic-rich muds. Thus, four general categories are considered: epicontinental areas similar to the Chattanooga, geosynclinal-fringe areas similar to the Marcellus, miogeosynclinal areas similar to the Normanskill, and eugeosynclinal areas similar to the Mariposa. As inferred from geologic studies, each is characterized by definite water conditions

(chemistry, depth, circulation, life regimen), climatic conditions, rate and amount of subsidence, and relation to the source of sediments (distance, topography and drainage, rock composition). The more uraniferous shales known in the United States were deposited in epicontinental seas. (Auth)(MLB)

<109>

Singewald, Q.D., and M.R. Brock, USGS, Washington, DC

Thorium Deposits in the Wet Mountains, Colorado In USGS Professional Paper 300, (pp 581-585), 739 pp. In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp 578-581), 825 pp (1956)

The thorium-bearing veins are zones of shattered rock, most are less than 10 feet wide, but locally as much as 50 feet wide, which have been extensively feldspathized and locally silicified. They are heavily impregnated with red and yellow iron oxide minerals. Many vein rocks emit a strong, stinking odor when freshly broken. Quartz, barite, carbonate minerals, and minor amounts of fluorite and sulphide minerals may or may not be present. The veins are most abundant along sinuous belts of faults, but many are scattered erratically elsewhere. Veins do not seem to be localized either by lithology or structure in the crystalline complex, but where the same vein crosses both granite and metasedimentary gneisses, the most intense local radioactivity anomalies are apt to be found in granite. Thorium-rich concentrations occur erratically along the veins as pockets, pods, or lenses. A reddish-brown thorite-like mineral, probably thorogummite, is visible as blebs and veinlets at only a few places. Elsewhere the thorium-rich minerals, indicated by limonite, can be detected only by their radioactivity. (Auth)(MLB)

<110>

Sims, P.K., and E.W. Tooker; USGS, Washington, DC

Pitchblende Deposits in the Central City

District and Adjoining Areas, Gilpin and Clear Creek Counties, Colorado In USGS Professional Paper 300, (pp 105-111), 739 pp. In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp 265-269), 825 pp (1956)

Pitchblende, a local constituent of the ores, is associated with veins of all types, but it is most abundant in composite and galena-sphalerite veins. Pitchblende, characteristically showing colloform texture, was the first ore mineral to form; it was deposited contemporaneously with quartz and was followed closely by rutile, chalcopyrite, sphalerite, tennantite, and galena. Carbonate minerals locally form a part of the gangue. The pitchblende occurs in shoots, small pods or lenses that are systematically arranged in some veins and erratically distributed in others. The shoots are small, the largest being about 40 feet high, 20 feet long, and a maximum of a foot thick. The ore ranges from less than 1 percent to as much as 65 percent U₃O₈. The pitchblende was leached and altered by acid meteoric waters in the oxide portions of the veins. In veins of the galena-sphalerite type, however, where the supergene solutions were only slightly acid, some of the uranium was reprecipitated as torbernite and other secondary minerals in the lower part of the zone of oxidation. The torbernite was preferentially deposited in biotite-quartz-plagioclase gneiss and amphibolite wall rocks that had been altered largely to montmorillonite. Locally the torbernite replaced these rocks. (Auth)(MLB)

<111>

De Nault, K.; Stanford University, Stanford, CA

Origin of Sandstone Type Uranium Deposits in Wyoming: Mineralogy In Ph.D. Dissertation, Origin of Sandstone Type Uranium Deposits in Wyoming, Chapter 7, (pp. 145-181), 352 pp. (1974)

Mineralogical changes in samples of the Battle Spring Formation from the Red Desert area of Wyoming, were observed among heavy mineral species, particularly ilmenite, hornblende, pyrite,

and zircon. In altered ground, ilmenite is replaced by anatase; hornblende and zircon have been almost completely removed. Hornblende crystals in fresh ground some distance in front of the roll display etch features. In fresh ground, pyrite is found in three morphologic forms, discrete octahedra, framboids, and small massive grains, whereas in mineralized ground, framboids have preferentially grown. In altered ground pyrite is removed or replaced by iron oxide. Framboids are composed of discrete tetrahedra. Hornblende, pyrite and some chlorite grains in fresh ground some distance in front of the roll, contain sufficient uranium to give a pronounced positive uranium test when reacted with Bowie's flux. No mineralogic differences among the mineralogic constituents, quartz and feldspar, were observed between samples of fresh, altered and mineralized ground other than coatings of iron oxide in altered ground. (JMT)

<112>

De Nault, K.; Stanford University,
Stanford, CA

**Origin of Sandstone Type Uranium
Deposits in Wyoming: Red Desert Area,
Wyoming.** In Ph.D. Dissertation, Origin
of Sandstone Type Uranium Deposits in
Wyoming, Chapter 5, (pp. 111-123), 352
pp. (1974)

The Red Desert is a loosely defined portion of the Great Divide Basin, Wyoming. The host unit for sandstone-type uranium mineralization in the area is the Battle Spring Formation of early and perhaps middle Eocene age. In the Red Desert, the formation is a coarse grained to pebbly arkose containing lesser amounts of claystone. The assemblage appears to have been deposited in deltaic sheets, and the sediments have a minimum thickness of 3500 feet in the area. Except for recent dry-lake deposits, alluvium, and sand dunes, there are no sediments younger than the Battle Spring Formation in the area of sandstone mineralization. The Bridger Formation of middle Eocene age, and sediments of Oligocene, Miocene, and Pliocene age are preserved to the north and west, and the important aspect of these younger formations is that they are composed predominantly of volcanic ash. The volcanic ash may have been the source for the uranium in the host units that they once overlaid. Occurrence of uranium in the Red Desert

of Wyoming was first discovered at Lost Creek in the early 1930's. The deposit was composed of schroëckingerite that was apparently precipitated in a desert playa. The deposit was not extensive enough to be mined profitably. Mineralization in the Lost Creek Schroëckingerite Deposit is found in the Cyclone Rim Fault zone and in immediately adjacent sediments. Schroëckingerite occurs as rounded prosolites, flaky crystals, and tabular masses associated with gypsum in caliche-type deposits. The source of the uranium is not known, although several hypotheses have been put forth. Local concentrations of uranium occur in coal and carbonaceous shale of the Wasatch and Green River Formations in the Red Desert. Uranium minerals have not been identified and the concentrations are low, ranging from 0.01 to 0.02 percent uranium. Sandstone-type uranium mineralization was discovered in the Battle Spring Formation about 20 miles south of Crooks Gap, Wyoming. These deposits consist of at least three rolls lying in different stratigraphic intervals and extend laterally for several miles. The occurrence is unusual because the Battle Spring Formation is the host unit for uranium rolls at Crooks Gap up dip to the north. Extensive exploration drilling has been done on the property but to date no mining has begun. The area is consequently ideal for study because there has been no change in existing groundwater conditions caused by mining activities which might affect the mineralogy of fresh, mineralized, and altered ground. (JMT)

<113>

De Nault, K.; Stanford University,
Stanford, CA

**Origin of Sandstone Type Uranium
Deposits in Wyoming: Petrography.** In
Ph.D. Dissertation, Origin of Sandstone
Type Uranium Deposits in Wyoming,
Chapter 6, (pp. 124-144), 352 pp. (1974)

Samples were obtained from seven core holes drilled under the direction of Minerals Exploration Company. A sand bed containing a uranium roll and known to be continuous from numerous drill holes was selected for this study. Thin and polished sections were prepared for each sample from coherent pieces of core. The fresh sand consists mainly of poorly sorted grains of angular quartz and feldspar, some of which are frosted. Accessory minerals include chlorite, pyrite, pale red to rose

garnet, zoisite, clinozoisite, hornblende, zircon, and a very fine grained poorly coherent white material that is possibly drilling mud or a zeolite. Fragments of granitic rock are present in the coarsest size fraction, and there is very little clay matrix. The rock is porous and permeable and very poorly consolidated. Altered sand is similar to fresh sand except that quartz and feldspar grains are commonly covered with a thin layer of orange, red, or green material. There is a distinct color difference between fresh and altered ground. Fresh ground is very light gray with a light bluish cast. Coloration darkens approaching the roll and changes abruptly to yellow and orange in altered ground. Colors of ground specimens were also compared and they showed a similar, though more subdued, color pattern. (JMT)

<114>

Sheridan, D.M., C.H. Maxwell, and A.L. Albee; USGS, Washington, DC

Geology and Uranium Deposits of the Ralston Buttes District, Jefferson County, Colorado. USGS Professional Paper 520, 121 pp. (1967)

The Ralston Buttes uranium mining district is the richest in Colorado east of the Continental Divide. The bedrock in the district is predominantly Precambrian (90%), and it consists of a thick, apparently conformable succession of complexly folded and metamorphosed sedimentary and volcanic (?) rocks, which were intruded by less abundant Precambrian igneous rocks. In the northeastern part of the district, the Precambrian rocks are overlain unconformably by Paleozoic and Mesozoic sedimentary rocks, including, from oldest to youngest, the Fountain Formation, Lyons Sandstone, Lykins Formation, Ralston Creek Formation, Morrison Formation, Dakota Group, Benton Shale, Niobrara Formation, and Pierre Shale. A few dikes and sills of Laramide age intrude the Precambrian rocks and the younger sedimentary rocks. The uranium deposits are in two main areas within the district. Deposits in the Ralston Creek area are along the Rogers fault system and include those in the famous Schwartzwalder mine; those in the Golden Gate Canyon area are along the southeastern extension of the Hurricane Hill fault system. The typical uranium deposits in the Ralston Buttes district are hydrothermal veins occupying openings in fault

breccias and fractures that cut the Precambrian rocks. Ore shoots range from tens of tons to several thousand tons. Pitchblende and lesser amounts of secondary uranium minerals are associated with generally sparse base-metal sulfide minerals in a gangue of carbonate minerals, potassic feldspar, and, in some veins, quartz. Coffinite has been identified in one of the largest deposits. Less common deposits of pitchblende and secondary uranium minerals occupy fractures cutting pegmatites and quartz veins. Pitchblende was deposited early in the paragenetic sequence, and base-metal sulfides were deposited later. The age of a pitchblende sample from one of the vein deposits was found to be 73 plus or minus 5 m.y. by lead-uranium age determination. Some of the uranium deposits have the structural, textural, and mineralogic features of epithermal deposits. Others appear to be transitional between mesothermal and epithermal. The uranium deposits were located by (1) a favorable structural environment, and (2) favorable host rocks. Deposits in each of the two major areas formed where a northwest-trending fault system splits into a complex network of faults and fractures. Most of the deposits seem to be localized where the faults cut Precambrian rocks rich in hornblende, biotite, or garnet and biotite. Features observed in the Ralston Buttes district that may be useful as guides to undiscovered deposits include: (1) associations of the deposits with breccia-reef fault systems, (2) localization of deposits in certain favorable Precambrian rocks, such as amphibolite, hornblende gneiss, biotite-quartz-plagioclase gneiss, layered calc-silicate gneiss, and garnetiferous biotite-quartz gneiss, (3) common association of pitchblende with copper minerals and other base-metal sulfides, and (4) abnormal radioactivity at the outcrop and the presence of secondary uranium minerals. (Auth)(JMT)

<115>

Wyant, D.G., W.N. Sharp, and D.M. Sheridan; USGS, Washington, DC

Reconnaissance Study of Uranium Deposits in the Red Desert Sweetwater County, Wyoming. USGS Bulletin 1030-I, 237-308 pp. (1956)

The largest known deposit of schroederite, a secondary uranium mineral, and uraniferous lignite occur in part of the Red Desert in northeastern

Sweetwater County, Wyoming. Schroeckingerite was discovered on Lost Creek in 1936 and lignite between Lost Creek and Wamsutter was found to be uraniferous in 1945. An area of 650 square miles in the Red Desert of the Great Divide Basin was studied in reconnaissance in 1949 by a combination of photogeologic and field methods. The surface rocks in the Red Desert are intertonguing beds of sandstone, claystone, lignite, oil shale, and arkose of the Wasatch, Green River, and Bridger formations and the Continental Peak Formation, all of Eocene age, and shale, derived from volcanic ash of the Chadron Formation of the Oligocene. Several units of the Green River Formation are the only Eocene rocks whose formation may be identified readily. The Tertiary rocks are covered in part by Pleistocene lake and stream terrace deposits. Most of the rocks in the Red Desert are abnormally radioactive. The uranium content of the lignite beds ranges from 0.002 to 0.007 percent. The Lost Creek schroeckingerite deposit is within the Cyclone Rim fault zone north of the outcrops of uraniferous lignite. Minerals other than detrital quartz and feldspar, that are commonly associated with schroeckingerite are clay, gypsum, aragonite, opal, and efflorescent white salts. The uranium content of the deposit ranges from 0.013 to 0.28 percent. Schroeckingerite crystallizes near the surface from ascending alkaline groundwaters, preferentially in moist claystone, shale, or in siltstone beds. The source of the uranium is not certain. It is possible that uranium transported by ascending groundwaters circulating within the Cyclone Rim fault zone, and derived from uraniferous lignite, may have been deposited above the low water table prevailing at times in the Pleistocene epoch. Later, the rise of the water table may have caused the uranium mineral to be dissolved, transported, and recrystallized as schroeckingerite. Schroeckingerite may now be forming from migrating groundwater at about the same rate that it is being dissolved and removed by surface water. (JMI)

<116>

Phoenix, D.A.: USGS, Grand Junction, CO

Uranium Deposits Under Conglomeratic Sandstone of the Morrison Formation, Colorado and Utah. Bulletin of the Geological Society of America, 69, 403-418. (1958, April)

In southwestern Colorado and southeastern Utah, strata of conglomeratic sandstone are localized at the base of the Brushy Basin Member of the Morrison Formation of Jurassic age. These discrete lithologic units contain sedimentary structures oriented in a prevailing easterly direction. They are believed to cover about one-third of the underlying Salt Wash Member in southwestern Colorado and southeastern Utah, and they locally rest on ore-bearing sandstone in the Salt Wash Member. Eastward-trending planar cross-stratification and trough cross-stratification and a general westward coarsening of sediments in the conglomeratic sandstone strata suggest that they are the products of stream aggradation from western source areas. Uranium-vanadium deposits in the uppermost, almost continuous, layer of sandstone of the Salt Wash Member are classified according to their association with the conglomerate strata. Of the 363 deposits studied in the uppermost sandstone layer of the Salt Wash Member 101 are known to be directly beneath conglomeratic sandstone strata, 211 are below the projected extension of conglomerate sandstone strata, 33 are beyond the same limits of such projection, and 18 are lateral to the margins of conglomeratic sandstone strata. At places, near clusters of deposits in the uppermost sandstone of the underlying Salt Wash Member, conglomeratic sandstone strata of the Brushy Basin Member are also mineralized. It is postulated that ground-water movement during deposition of the Morrison Formation in Late Jurassic time localized the uranium and vanadium. The direction of this ground-water movement is believed to have been related to streams that deposited the conglomeratic strata, so that in the ore-bearing sandstone metal ions contained in the ground water were localized in places of high transmissibility and in the vicinity of decaying organic debris. According to the age of the ores, precipitation of the metals was much later than their localization, probably during Late Cretaceous or early Tertiary time. (Auth)

<117>

Lee, M.J.: University of New Mexico, Albuquerque, NM

Geology of the Grants Mineral Belt. In Ph.D. Dissertation, Geochemistry of the Sedimentary Uranium Deposits in the Grants Mineral Belt, Southern San Juan Basin, New Mexico. (pp. 6-30), 241 pp. (1976)

The Grants Mineral Belt (GMB) forms a southeasterly trending linear belt of uranium deposits at the southern margin of the San Juan Basin. Within the Belt four major uranium districts are recognized. They are the Laguna, Ambrosia Lake, Smith Lake, and the Church Rock Districts. Some 6000 feet of sedimentary rocks are present in the general area of the GMB. They range in age from Pennsylvanian to Cretaceous and they overlie the crystalline Precambrian rocks of the Zuni Uplift. Of the sedimentary rocks, continental varieties are most common in the Jurassic and older rocks. Late Cretaceous and Tertiary sediments of both marine and continental origin are exposed in the interior of the San Juan Basin. The outcropping Precambrian rocks are composed mostly of leucocratic granite, aplite, granite gneiss, metarhyolite, and schists and basic rocks. The area between the Laguna and the Ambrosia Lake districts is extensively covered with the volcanic rocks of the Mt. Taylor volcanic field. The rocks range in age from Miocene to Recent with a wide range in composition. Potassium-argon age determinations on obsidian, perlite, and sanidine from the Mt. Taylor rocks yield ages ranging from 1.5 to 3.0 my. The host rock for the uranium deposits in the GMB is the Morrison Formation. In the GMB and vicinity the Morrison can be divided into four members. These are the Salt Wash, Recapture, Westwater Canyon, Brushy Basin members from lower to upper Morrison. In addition, two sandstone bodies located in the upper part of the Brushy Basin member, are of economic usage: the Poison Canyon sandstone of the Ambrosia Lake district and the Jackpile sandstone of the Laguna district. The Recapture Member conformably overlies the Bluff Sandstone in the GMB; to the southwest it intertongues with and grades into the Cow Springs Sandstone. The Recapture Member generally consists of interstratified pale-red to dusty red, silty to sandy mudstone and light-brown fine-to-medium grained sandstone. No significant uranium deposits have been found in the Recapture Member in northwestern New Mexico. The Westwater Canyon Member generally overlies the Recapture Member. It is mostly a gray or reddish-brown, medium-to-coarse grained, arkosic sandstone interbedded with mudstones. Deposition of the Westwater Canyon Member may represent a continuous process from Recapture Member deposition with a rejuvenation of the source area as seen by the coarser material plus a greater abundance of fossil plants, logs, and dinosaur bones. The Brushy Basin Member conformably

overlies the Westwater Canyon Member and is unconformably overlain by the Dakota Sandstone of Cretaceous age. The contact with the Westwater Canyon Member is gradational and intertonguing. The Brushy Basin Member in New Mexico consists primarily of greenish, variegated silty and sandy mudstone. The mudstone contains an abundance of montmorillonite and is interbedded with sandstone lenses which are similar to the sandstones of the Westwater Canyon Member. The Westwater Canyon Member is the major uranium host rock in the Grants Mineral Belt. (JMT)

<118>

Lee, M.J.; University of New Mexico,
Albuquerque, NM

Clay Mineralogy. In Ph.D. Dissertation,
Geochemistry of the Sedimentary Uranium
Deposits in the Grants Mineral Belt,
Southern San Juan Basin, New Mexico,
(pp. 79-120), 241 pp. (1976)

The distribution of clay minerals in outcrops, ore zones, and remote bleached sandstone was studied. In all outcrop sections analyzed, the sandstone and siltstones of the Recapture Member are characterized by abundant montmorillonite followed by subordinate kaolinite, minor amounts of illite and illite-montmorillonite. In the Brushy Basin Member, montmorillonite is frequently the only clay mineral present with occasionally abundant kaolinite. Montmorillonite and kaolinite are the predominant species in the Westwater Canyon Member. In all sections studied the Westwater Canyon Member contains minor amounts of chloritic clay in the middle part. Much of the montmorillonite in the entire Morrison is believed to be authigenic, formed by devitrification and hydrolysis of the volcanic ashes. Potassium treated montmorillonite contracts to 11 angstroms but fully expands to near 17 angstroms indicative of volcanic origin. In the ore zones, one of the distinctive features of ore-zone alteration is the enrichment of chloritic minerals relative to montmorillonite. Chemical analysis and microprobe study reveal that chlorite is highly vanadiferous, with V₂O₄ content ranging from 1.5 to 3.3%. In addition to chlorite, variable amounts of kaolinite, montmorillonite, and illitic clay minerals are present in the ore zone. Clay mineral analyses were also carried out for bleached or unoxidized Westwater sandstones from 8 core holes

farther north in the Ambrosia Lake District. Here the Westwater Canyon Member is mostly light gray and no mineralization has been reported. Two features are distinctive compared to the clay mineral assemblage in the outcrops: the presence of well-crystalline chlorite and regularly interstratified illite-montmorillonite. The chlorite is persistent in all sandstone samples studied whereas the mixed-layer illite-montmorillonite is somewhat sporadically distributed. (JMT)

<119>

Hawley, C.C., R.C. Robeck, and H.B. Dyer. USGS, Washington, DC

Geology, Altered Rocks and Ore Deposits of the San Rafael Swell, Emery County, Utah. USGS Bulletin 1239, 115 pp. (1968)

The San Rafael Swell is a large asymmetric anticline in which sedimentary rocks ranging in age from Pennsylvanian to Cretaceous are exposed. The oldest rocks exposed in the San Rafael Swell are probably of Early Permian and Pennsylvanian age. Younger strata exposed more extensively consist of the Coconino Sandstone and Kaibab Limestone of Permian age, the Moenkopi Formation of Early and Middle Triassic age, the Chinle Formation of Late Triassic age, and the Glen Canyon Group of Triassic and Jurassic age which contains the Wingate Sandstone, the Kayenta Formation and the Navajo Sandstone. The Moenkopi Formation underlies most of the Sinbad Country; it ranges from less than 500 feet to more than 800 feet in thickness. The formation can be divided into three units; a lower part consisting largely of siltstone and subordinately of fine-grained sandstone, thin-bedded carbonates, and a basal chert-pebble conglomerate. The Moenkopi Formation is overlain with probably slight angular unconformity by the Chinle Formation. The Chinle consists of four members: the Temple Mountain, Moss Back, Monitor Butte, and Church Rock. The formation ranges from about 215 to 370 feet in thickness. The Temple Mountain, Monitor Butte, and Church Rock Members are predominantly varicolored siltstone which was probably deposited on flood plains and in shallow lakes; the Moss Back Member, largely light-colored sandstone was deposited by a great northwest-flowing-river system. The Wingate Sandstone overlies the Chinle with apparent conformity but with a marked break in lithology.

The Wingate is almost entirely fine grained, white to pale-orange sandstone deposited in large-scale crossbeds. The uranium deposits of the San Rafael Swell occur principally in the three areas termed the South, North, and Temple Mountain mineral belts. The Temple Mountain belt lies wholly within the swell, but the other two belts probably continue in a northwest-southeast direction into the deeply buried rocks on the flanks of the swell. The uranium deposits occur mostly in the Monitor Butte and Moss Back Members of the Chinle Formation. Uranium deposits in the South mineral belt are mostly tabular ore bodies that are localized in isolated "scours" in channels of the Moss Back Member and in lenticular sandstone bodies of the Monitor Butte Member. The ore bodies are spotty in distribution and, with the exception of the Delta mine, contain less than 12,000 tons of ore with most ore bodies containing less than 4000 tons. Grade of deposits is variable but generally low and averages about 0.20% U₃O₈. Deposits in the North belt are smaller and are found in channels in the Moss Back Member or in the Temple Mountain Member. The major ore bodies of the Temple Mountain district differ from most other ore bodies of the swell by being partly roll-like in character, as well as by generally occurring above the basal unit of the Moss Back Member. Most of the ore deposits were localized by channel structures, small scale sedimentary structures, and bedding-plane and related low-angle slips that are common at or near sandstone-mudstone contacts. The deposits formed by filling pores and by replacement of interstitial cement, carbonaceous material, and, more rarely, detrital grains. The uranium is mainly contained in the mineraloid commonly termed asphaltite and in uraninite. Oxidized minerals of hexavalent uranium are locally abundant. Small amounts of chalcopyrite, galena, sphalerite, chalcocite, molybdenite, montroselite, and other unoxidized metallic minerals accompany the uraninite or asphaltite. (JMT)

<120>

Bell, H., and W.E. Bales: USGS, Washington, DC

Uranium Deposits in Fall River County, South Dakota. USGS Bulletin 1009-G, 211-231 pp. (1955)

In 1951 uranium deposits containing carnotite were discovered in the southern Black Hills near

Edgemont, Fall River County, South Dakota. Many carnotite deposits have since been found in sandstones in the Inyan Kara group of Early Cretaceous age, and uranium-bearing material has been discovered in the Minnelusa sandstone of Pennsylvanian age and the Deadwood formation of Cambrian age in the southern Black Hills. Ore has been produced only from the Inyan Kara group, mostly within an area of about 30 square miles along the southwest flank of the Black Hills uplift between Dewey and Hot Springs, in Custer and Fall River Counties. In addition, occurrences of uranium in other parts of the Black Hills and the surrounding area are known and reported in sedimentary, igneous, and metamorphic rocks of pre-Cambrian to Tertiary age. The lowermost and uppermost formations of the Inyan Kara group—the Lakota and Fall River sandstones—contain the productive uranium deposits. These terrestrial formations are composed predominantly of massive sandstone lenses with thin units of thinly bedded sandstone and mudstone, but locally they contain abundant mudstone and thinly bedded sandstone. The massive sandstone lenses commonly overlap and truncate underlying lenses. Iron stain, carbonaceous material, thin seams of gypsum, ripple marks, concretions, and fossil roots are common in the mudstone and thinly bedded portions of these formations. Some high-angle normal faults of small displacement are found in the area containing the largest number of uranium occurrences in the Inyan Kara group. Although no ore deposits seen were cut by faults, high-angle fractures parallel to and at right angles to the faults contain carnotite for short distances. The productive uranium deposits are most common where the Lakota and Fall River sandstones locally contain a large portion of mudstone and thinly bedded sandstone. Other deposits are in the massive sandstone lenses of the Lakota sandstone and in the thin units between the lenses. Although carnotite is the most conspicuous and important mineral in most deposits, corvusite is an important constituent of some deposits. Other uranium minerals in the deposits are tyuyamunite, rautite, and autunite. Ore produced in 1952 from the Fall River and Lakota sandstones contained about 0.2 percent of U_3O_8 and 0.6 percent of V_2O_5 . In general, deposits in the Fall River and Lakota sandstones contain about the same percentage of U_3O_8 , but the deposits in the Fall River sandstone appear to have a higher percentage of vanadium. The grade of individual deposits, however, is highly variable. Most deposits are small, but a few have yielded as much as a thousand tons of ore. (Auth)

<121>

Adams, J.W., and F. Stugard, Jr.; USGS, Washington, DC

Wall-Rock Control of Certain Pitchblende Deposits in Golden Gate Canyon, Jefferson County, Colorado.
USGS Bulletin 1030-G, 187-209 pp. (1957)

Carbonate veins cutting metamorphic rocks of Precambrian age in the Golden Gate Canyon area, Colorado, contain pitchblende and base-metal minerals. The veins occupy extensive faults considered to be of Laramide (earliest Tertiary) age, but normally contain pitchblende only where they cut hornblende gneiss. At the Union Pacific deposit, which was studied in detail, pitchblende, hematite, and some ankerite formed before the sulfide minerals, except possibly for minor earlier pyrite. Base-metal minerals and the bulk of the ankerite vein filling were deposited after the pitchblende. Chemical analysis show a high ferrous iron content in the hornblende gneiss in contrast to low ferrous iron in the adjacent biotite gneiss. It is thought that ferrous iron released by alteration of hornblende was partly oxidized to hematite by the ore-bearing solutions and, contemporaneously, uranium was reduced and deposited as pitchblende. In other veins that are not in hornblende gneiss, biotite or iron sulfide may have been similarly effective in precipitating pitchblende. Apparently both the ferrous iron and the sulfide ion can serve as reducing agents and control pitchblende deposition. Conditions that seem favorable for uranium deposition include those where uranium-bearing solutions had access to rocks rich in ferrous iron or preexisting sulfide minerals. (Auth)

<122>

Taylor, A.O., T.P. Anderson, W.L.
O'Toole, G.G. Waddell, A.W. Gray, H.
Douglas, C.L. Cherry, and R.M.
Caywood; AEC, Salt Lake City, UT

Geology and Uranium Deposits of Marysvale, Utah. RMO-896, 30 pp. (1951, September)

Rocks within the currently known area of uranium ore deposits at Marysvale, herein designated as the "central" area, are exclusively of igneous origin. In order of first appearance, they include: (a)

quartz-monzonite; porphyry; (b) porphyritic quartz-monzonite; (c) quartz-monzonite; (d) granite. These, all intrusives, are overlain by (e) the late Tertiary extrusive Mt. Belknap rhyolite. All of the intrusives invaded the early Tertiary Bullion Canyon volcanic series, but all except a few traces of this older group were eroded before the rhyolitic effusion. Faulting and fissuring later than the rhyolite flow gave rise to extensive alteration of the fractured rocks and mineralization by uranium, though it is not yet proved that the two effects were simultaneous. Shear zones with a northeasterly trend have thus far been the most productive of uranium ores, but fractures in other directions show increasing possibilities. The primary uranium mineral is pitchblende, most commonly soft and pulverulent, occasionally the hard, botryoidal variety. It is associated with calcedonic silica, adularia, pyrite, calcite, jordisite, purple to black fluorite, hematite, magnetite, and tentatively identified siderite and marcasite. Deposition is believed to have been epithermal, possibly solfataric or fumarolic. Some of the sooty pitchblende found at depths less than 60 feet may be secondary, but much of it is associated with minerals which show no evidence of oxidation except near the boundary between primary and secondary uranium mineralizations. Alteration of primary oxides has yielded a considerable variety of secondary uranium minerals, including autunite, torbernite, schroëckingerite, uranophane, and a few others not yet identified. Uranophane is most abundant near outcrop, but the others, apparently more susceptible to atmospheric decomposition, occur 5 to 10 feet deeper. A red, hematitic zone, resulting from rock alteration, is almost invariably associated with uranium minerals in the primary zone, sometimes persisting up into the zone of supergene alteration. Its usefulness as a guide to ore, however, is somewhat diminished by reason of its small and inconspicuous size in proportion to the mass of mineralized material. (Auth)

<123>

Lee, M.J.; University of New Mexico, Albuquerque, NM

Geochemistry of the Sedimentary Uranium Deposits of the Grants Mineral Belt, Southern San Juan Basin, New Mexico. Ph.D. Dissertation, Geochemistry Department, University of New Mexico, 241 pp. (1976)

The mineralogical and geochemical aspects of the sandstone-type uranium deposits which occur in the Jurassic Morrison Formation of northwestern New Mexico are discussed in detail in the dissertation. (JMT)

This thesis is divided into six parts and each part is abstracted separately.

<124>

Derzay, R.C.; AEC, Denver, CO

Uranium Occurrence at the Cherokee Mine, Queen Mineral Ranch, Gilpin County, Colorado. RME-4041, 7 pp. (1953, January)

Pitchblende-bearing vein material was found on the Cherokee dump. Radioactivity on the dump ranges from 0.05 to 10 MR per hour. Grab samples from the most radioactive portions of the dump assayed 1.06 percent, 1.48 percent, 0.40 percent, and 1.97 percent U_3O_8 , respectively. The mineralogic assemblage is favorable for an occurrence of pitchblende. Principal ore minerals are chalcopyrite, galena, pyrite, and sphalerite, and the gangue consists of quartz and altered schist. Uranium occurs as pitchblende in veinlets from 1/32 inch to 2 inches wide. The country rock is predominantly pre-Cambrian quartz-biotite schist and schistose gneiss, with lenses and injections of pegmatitic materials. (MIB)

<125>

Myerson, B.L.; AEC, Salt Lake City, UT

Uranium Occurrence Near Panaca, Lincoln County, Nevada. RME-2052, 12 pp. (1956, May)

Carnotite was found in a carbonaceous layer 0.5 to 2.0 feet thick in the late Pliocene or early Pleistocene Panaca tuff. Some investigative drilling was done to aid in the study of a small, low-grade uraniferous zone. Assays range from 0.004 percent to 0.12 percent U_3O_8 and average about 0.05 percent U_3O_8 . Meteoric or warm spring waters percolating through the tuffaceous rocks of this formation may have mobilized uranium ions already present and reconcentrated them in a more favorable horizon. (Auth)(MIB)

<126>

Vine, J.D., and R.F. Flége, Jr.: USGS.
Washington, DC

**Reconnaissance During 1952 for
Uranium-Bearing Carbonaceous Rocks in
Parts of Colorado, Utah, Idaho, and
Wyoming.** TEI-336. 19 pp. (1953, June)

A reconnaissance for uranium-bearing carbonaceous rocks was made in 23 areas in Colorado, Utah, Idaho, and Wyoming. Uranium in small amounts occurs in several of the areas examined, but no deposits were found that might have commercial possibilities. As much as 0.03 percent uranium is in the ash of coal in the Caribou Mountains area in southeastern Idaho; 0.012 percent in the ash of coal in the Burnt Fork area of southwestern Wyoming; and 0.009 percent in the ash of coal in eastern Idaho. Seven additional areas were examined in which beds of coal or carbonaceous shale contained more than 0.002 but less than 0.007 percent uranium in the ash. Unweathered samples of bituminous sandstone from the Vernal area, Utah, contain minor quantities of uranium. (Auth)(MIB)

<127>

Keenmon, K.A.: University of Michigan,
Geology Department, Ann Arbor, MI

**The Geology of the Blacktail-Snowcrest
Region, Beaverhead County, Montana.**
Ph.D. Dissertation, Geology Department,
University of Michigan, 206 pp. (1950)

The report discusses the physiography; metamorphic, sedimentary, and igneous rocks; structure; and economic geology of the area. Geologic history is also discussed. Numerous area maps, tectonic maps, and structural maps are included. Also, photographs of the geologic formations are presented. (MIB)

<128>

Bierwagen, E.E.: Princeton University,
Geology Department, Princeton, NJ

**Geology of the Black Mountain Area,
Lewis and Clark and Powell Counties,**

Montana. Ph.D. Dissertation, Geology
Department, Princeton University, 166 pp.
(1964)

Over 40,000 feet of sedimentary rocks ranging in age from Precambrian to Late Tertiary are exposed in the map area. The Precambrian Belt Series, which is more than 28,000 feet thick, is represented by the red bed and gray carbonate Ravalli group, the gray carbonate Piegan group, and the red bed and gray carbonate Missoula group. An analysis of the lithology and sedimentary structures of the Belt rocks indicates: (1) the dark-colored clastic and carbonate rocks below the Ravalli group and above the Missoula group were deposited in a barred basin or a series of barred basins; (2) the red beds and gray carbonate rocks of the Ravalli, Piegan, and Missoula groups were deposited in shallow water, frequently above wave base or in the intertidal zone. The structural relationships and sedimentary structures of the latter rocks suggest that they were deposited in a northwest-trending seaway through which moved northwest-flowing oceanic currents. The Paleozoic section consists of about 4000 feet of Cambrian, Devonian, Mississippian, Pennsylvanian, and Permian rocks. The Mesozoic section contains over 3000 feet of Middle and Upper Jurassic and Lower Cretaceous rocks. Tertiary colluvial-alluvial deposits overlie Paleozoic limestones at Mullan Pass and high-level Tertiary and or Quaternary boulder deposits occur locally. Pleistocene morainal debris of two ages can be recognized. Dikes and sills, plutons, and volcanics of predominantly intermediate composition are abundant. Late Cretaceous and or Early Tertiary folding formed a broad, southeast-plunging syncline with steeply west-dipping fracture cleavage. Normal faulting connected with magma emplacement and Oligocene to Pliocene regional uplift has greatly complicated the structure in the area. (Auth)(MIB)

<129>

Cohenour, R.E.: AEC, Grand Junction,
CO

**Geology and Uranium Occurrences Near
Lakeview, Oregon.** RME-2070, 33 pp.
(1960, July)

The possibility of finding additional epithermal uranium deposits in the volcanic rocks of the Lakeview area is fair to good. Additional detailed

geologic mapping will be necessary to evaluate the area adequately. Investigations show that the uranium mineralization was closely related to intrusive rhyolites. The intrusive rhyolites within the Lakeview area trend in a belt 1 mile in width diagonally through the area for at least 15 miles from southeast to northwest. Basaltic rocks, both intrusive and extrusive, are not known to contain any significant amounts of uranium minerals within the area. However, faulting of basalts to the zone of vadose (practically no circulation) waters may afford an environment whereby uranium deposits may form. Physical and chemical characteristics of the rocks and fault zones that form the conduits through which the metal-bearing magmatic waters passed were most important in the localization of the ore bodies. Originally, the rocks must have been sufficiently competent to fracture, and to have been of such mineral composition to allow formation of an abundance of clay clogging material to restrict and force percolating ore solutions into various routes. This situation coupled with relatively rapid temperature and pressure (hydrostatic) changes promoted the dispersal of uranium minerals into many, small, usually widely separated bodies. The foregoing conditions emphasize the futility of correlation and outlining or extending ore bodies by a drilling program. Drill-hole spacing would by necessity have to be so closely spaced as to become an economic impossibility relative to the size of ore bodies which may be expected. Ore bodies may be of a fair size up to several thousand tons but continuity of the ore should not be expected. Cooling and shrinkage of rocks within the area that has undergone extensive volcanism will further cause disruption of strata and enclosed ore bodies. In prospecting for uranium in a volcanic area with an average rainfall similar to the Lakeview area, anomalies may be expected in siliceous and silicified rocks, but the best ore bodies are most likely to be found in soft tuffaceous rocks. Siliceous rocks tend to stand in relief and are more readily accessible to surficial radiometric detection, whereas tuffaceous rocks erode readily and the contained ores are deeply covered by alluvium and soil. (M.I.B)

<130>

Haglund, D.S., G.M. Friedman, and D.S. Miller; Rensselaer Polytechnic Institute, Department of Geology, Troy, NY

The Effect of Fresh Water on the Redistribution of Uranium in Carbonate Sediments. *Journal of Sedimentary Petrology*, 39(4), 1283-1296. (1969, December)

Interpretation of the relationships of uranium concentration in whole carbonate sediment samples with established fresh water alteration indicators form converging lines of evidence demonstrating the effect of fresh water alteration on the redistribution of uranium. Synthesis of the interpretations leads to the following chain of events concerning the uranium concentrations. After initial incorporation in marine carbonate sediments, uranium retains a stable concentration level as long as the system is in contact with marine water. On exposure to fresh water, mineralogical changes begin with the replacement of Mg-calcite and the dissolution of aragonite. This process allows uranium held in these two phases to become mobilized. Since corals contain the greatest amount of uranium and are composed of aragonite, their dissolution produces the most significant change in the total sample uranium content. The Mg-calcite phase contains less uranium than the aragonite phase and has less effect on the total system. Precipitated and replaced calcite, the mineralogical end products of fresh water alteration, do not incorporate uranium at the original concentration levels. The removal of uranium from the carbonate minerals is a continuous change resulting in a loss of, approximately 50 percent of the initial uranium concentrations, as indicated by the Bermuda and Israeli suites studied. (M.I.B)

<131>

Barrett, D.C., and N. Mallory; AEC, Salt Lake City, UT

Airborne Reconnaissance in the Valley of Fire-Muddy Mountains Region, Nevada. RME-2040, 14 pp. (1955, September)

Uranium was found at three sedimentary horizons in the Valley of Fire-Muddy Mountains region. The lowest horizon is the Shinarump zone, which contains moderately radioactive carbon trash beds. Uranium minerals are not visible at any of the exposures in this zone except possibly in the radioactive petrified logs in the Valley of Fire State Park. At the middle are the unnamed beds between the Aztec sandstone and the Willow Tank

formation. Here the uranium is associated with cherty limestone and a carbon trash bed. The most promising uranium showing in the area is in this sequence. The uppermost formation known to carry uranium is the thin siliceous limestone bed near the base of the Horse Spring formation. All exposed rocks in the area, ranging in age from Cambrian to Miocene, were given approximately 25 percent airborne coverage. The rock types differ considerably. They include massive limestone; massive crossbedded column sandstone; fluvialite shale; sandstone and conglomerate, which contain minor amounts of lacustrine limestones and mudstone; and some Cenozoic lake beds. Uranium was known to occur at two sedimentary horizons at the time the airborne program began. One new uranium-bearing sedimentary horizon was discovered by the airborne reconnaissance. Of 15 anomalies detected, only 11 were posted as the remainder were claimed at the time of the survey. The type of topography controlled the method of flying; rim-type coverage was employed almost exclusively. (M.I.B)

<132>

King, R.E., R.L. Bates, J.M. Hills, B.G. Martin, and S.J. Taylor; Not given

Resume of Geology of the South Permian Basin, Texas and New Mexico. Bulletin of the Geological Society of America, 53, 539-560. (1942, April)

In the South Permian Basin the Permian rests on an irregular surface of folded older rocks. On the east side of the basin the exposed Permian is sparsely fossiliferous. The lower part is largely limestone and the upper is red clastic sediment with layers of gypsum. In the mountains west of the Pecos River the Permian is fossiliferous limestone, sandstone, and shale except for the highest formations, which are largely gypsum and redbeds. In the subsurface the Permian strata pass through a succession of changes in lithologic facies, which are related to the regional structure. Two broad negative areas subsided during the Permian more rapidly than the platforms bordering them. Limestone reefs and banks on the margins of the platforms grade into clastic rocks in the intervening negative areas. On the platforms, between the marginal reefs, are lagoonal dolomites, evaporites, and clastic rocks. The Permian Basin was probably connected with the open sea by way of a

geosyncline crossing northern Mexico. Because of the narrowness of the entrance to the basin and barriers to free circulation of ocean water within the basin, the salinity of the water probably varied greatly from place to place. Evaporites were deposited in areas where the salinity of the water was abnormally high. Permian oil reservoirs are in porous dolomites, and to a lesser extent in sandstone layers. Production is obtained from several of the pre-Permian formations. (Auth)

<133>

King, R.U.; USGS, Washington, DC

Vein Deposits of Uranium at the Caribou Mine, Boulder County, Colorado.
TEM-13A, 18 pp. (1952, February)

Examinations have been made of the Caribou Mine, Boulder County, Colorado, by the USGS for the purpose of evaluating the possibilities of the deposit as a source of uranium. These examinations included radiometric traversing of accessible levels, as well as detailed geologic mapping and sampling of the radium vein in the east drift of the 1,040 level. The radium vein contains pitchblende, as small, hard lenses, and as sooty, porous streaks. The uranium content of the vein ranges from 0.001 percent to 1.45 percent. On the 1,040 level the exposed part of the Radium vein contains only a small tongue of uranium, but the silver and lead that accompany the pitchblende may be sufficiently abundant to repay further prospecting of the vein to the east or above and below the 1,040 level. (M.I.B)

<134>

Hardy, C.T., and H.D. Zeller; USGS, Denver, CO

Geology of the West-Central Part of the Gunnison Plateau, Utah. Bulletin of the Geological Society of America, 64, 1261-1278. (1953, November)

A detailed study of the west-central part of the Gunnison Plateau, Utah, has disclosed stratigraphic and structural relations important in the geological history of central Utah. The area mapped includes the eastern half of the Axtell No. 2 quadrangle, Manti area (U.S. Dept. of

Agriculture, Soil Conservation Service). The bedrock ranges in age from the Arapian shale (Upper Jurassic) to the Green River formation (Eocene). The North Horn formation (Cretaceous-Tertiary), the Flagstaff limestone (Paleocene-Eocene), and the Green River formation (Eocene) successively overlap the Arapian shale and the Indianola group in the northern part of the area. In the southern part of the area, the North Horn formation and the Flagstaff limestone successively overlap the Price River conglomerate with angular discordance. The latter relation establishes a post-Price River and pre-North Horn orogenic movement in Central Utah. A conspicuous west-dipping monocline, broken by many high-angle faults and a graben, extends along most of the western margin of the area. This structure is similar to the monocline and graben in the Wasatch Plateau to the east. At one point in the northern part of the area, the North Horn and the overlying Flagstaff oppose the Arapian shale across a high-angle fault. The Green River formation extends across the fault and overlaps the Arapian. This relation suggests faulting between Flagstaff and Green River, cannot be differentiated in this immediate area. Numerous small intrusive masses of monzonite porphyry of post-Upper Jurassic age occur in the Arapian shale. (Auth)(MLB)

<135>

Anderson, T.P., and G.G. Waddell: AEC.
Salt Lake City, UT

**Examination of the Stalin's Present Mine,
Pershing County, Nevada. RMO-927. 11
pp. (1952, February)**

The uranium mine described is located in Pershing County, Nevada. The area is on the west flank of the Humbolt Range, a fault-block mountain range. The topography in the vicinity is steep and rugged. Stalin's Present claims are located on the west slope, near the crest line, of the Range. Host rock in the area is a medium-to-course-grained, white to gray granite. In addition to quartz and feldspar, there is between 5 and 10% of ferromagnesian minerals, mostly shiny euhedral biotite crystals. Mine workings consist of a 41-foot adit driven on a uranium-bearing vein at about 25 to 30 feet below the discovery cut exposing the vein. Pitchblende has been identified in material from the prospect which assayed 0.70% eU3O8. Near the portal of the

adit several joint surfaces in the granite were observed to be coated in irregular patches by thin crusts of radioactive amorphous yellow-green secondary mineral. The pitchblende-bearing mineralized zone extends from the portal to the breast, a distance of 41 feet. Channel samples range in grade from 0.009% to 0.19% U3O8. (MLB)

<136>

Milton, C., B. Ingram, J.R. Clark, and
E.J. Dwornik: USGS, Washington, DC

**McKelveyite, a New Hydrous Sodium
Barium Rare-Earth Uranium Carbonate
Mineral from the Green River Formation,
Wyoming. American Mineralogist, 50(56).
593-612. (1965, May)**

McKelveyite, a new mineral, occurs in 4 subsurface localities in Sweetwater County, Wyoming. It is the first known mineral with considerable uranium (4.6 percent as UO2) from the Green River Formation. Two types are known, one (very rare) in apple green crystals and simple morphology and a more abundant type, dark green or black, massive and in crystal aggregates. The density of mckelveyite in the massive aggregate is 3.58 and in the crystals 3.47 g cm (E-3). McKelveyite with essentially yttrium rare earths occurs together with burbankite, a cerium rare-earth mineral. (PAG)

<137>

Not given: Not given

**Uranium Core - Green River Basin. In
Glaze, R.E. (Ed.), Wyoming Geological
Association, Twenty-Fifth Annual
Symposium and Core Seminar on the
Geology and Mineral Resources of the
Greater Green River Basin, 1973. (pp.
12-14). 178 pp. (1973)**

Nine core samples from uranium-bearing rock in the Green River Basin, Wyoming are described in the paper. Eight of the samples are sandstone, while one is a siltstone. The core depths range from 200 to 220 feet. (JMT)

<138>

Hallier, R.L.: AEC, Salt Lake City, UT

Preliminary Report on the Uranium Occurrence of the Jeep No 2 Claim, Clark Mountain Mining District, San Bernardino County, California.
RME-2011, 10 pp. (1954, June)

Anomalous radioactivity and visible uranium minerals occur in small replacement bodies in limestone at Jeep No. 2 claim, Clark Mountain mining district, San Bernardino County, California. Carnotite coating brown jasper is associated with oxidized copper, zinc, lead, and manganese minerals. Situated a few miles west of the thorium and rare earth deposits of the Mountain Pass area, the claim is in typical barren, rugged desert terrain. The deposits appear to be small, spotty, and low-grade though a certain amount of exploration may be warranted to determine the possibilities of finding more substantial mineralized zones in this area. (Auth)

<139>

Barton, P.B., Jr., and C.H. Behre, Jr.:
Columbia University, New York, NY

Interpretation and Evaluation of the Uranium Occurrences near Goodsprings, Nevada. RME-3119, 105 pp. (1954, December 31)

The uranium occurrences near Goodsprings, Clark County, Nevada are divided into two distinct types which differ from each other in geographic distribution, localization of mineralization, mineralogy, and origin. None of the known deposits are of present commercial significance. Carnotite is found as thin films and specks on fractures in late Paleozoic sedimentary rocks and in Tertiary and later tuff and gravel. The carnotite was probably deposited above the water table from groundwater that derived uranium and vanadium from a tuff which formerly covered the region. The tuff remnants carry about 10 ppm uranium, or about two and one half times that of the average granite. Structural control of groundwater circulation appears to be the principal feature in the localization of this mineralization. Many of the base metal mines in the Goodsprings district exhibit anomalous radioactivity attributable to uranium and its decay products. Most commonly, the radioactivity is localized by limonite,

hydrozincite, or chrysocolla. Secondary uranium minerals are found in three mines, but primary uranium minerals have not been identified. The radioactivity from these materials which are free from visible uranium minerals is attributed to the adsorption of uranium from solution by colloidal materials during oxidation of primary sulfide ore bodies. Laboratory studies show that the uranyl carbonate, uranyl hydroxide, and uranyl ions are adsorbed by colloidal hydrous ferric oxide or basic zinc carbonate. Upon crystallization of the adsorbent, the uranium either is returned to solution or forms discrete uranium minerals. The source of the uranium is believed to have been a primary uranium mineral (presumably pitchblende) which was associated more closely with the primary copper and iron sulfides than with those of zinc and lead. The volcanic rocks which once covered much of the area possibly could have contributed small amounts of uranium to the oxidizing base metal ores, but this effect was probably of minor importance. No geographic limits of uranium mineralization could be established, but there is a tendency for the more western mines to have more uranium. (JMT)

Cited as a reference in NURE Contractor Reports.

<140>

Mrak, V.A.: Mrak Mining Company,
Douglas, WY

Uranium Deposits in the Eocene Sandstones of the Powder River Basin, Wyoming. In Ridge, J.E. (Ed.), *Ore Deposits of the United States, 1933-1967*, Vol. 1. The American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, (pp. 838-848), 991 pp. (1968)

The Powder River Basin encompasses an area of about 12,000 square miles in northeastern Wyoming. It is a broad structural and topographic basin, open to the north and terminated on the west by the Bighorn Mountains and the Great Pine Ridge Escarpment, on the south by the Laramie Mountains and the Hartville Uplift, and on the east by the Black Hills and related structures. All of the known uranium deposits in the Powder River Basin are in the Wasatch Formation of Early Eocene age. The Wasatch is underlain by the Fort Union Formation of Paleocene age and overlain by the

White River Formation of Oligocene age. The uranium deposits may be broadly classified into three general types on the basis of size and grade, mineralogy, and their association with red sandstone. The first type comprises small high-grade concretionary or roughly tabular deposits usually containing less than 35 tons of uranium ore with an average grade of 1 per cent or more uranium. The minerals are uraninite associated with manganese or iron oxides and surrounded by uranophane and/or secondary uranium vanadates. These isolated high-grade pods are found within the red beds and generally are considered to be of little economic importance. The second type of deposit is composed of intermediate size deposits containing as much as 5000 tons of ore averaging about 0.40 per cent U₃O₈. Uranium vanadates are the dominant ore minerals; however, small high-grade uraninite pods associated with pyrite are found. Calcite is the prevalent gangue mineral. The third type of deposit is characteristic of the Monument Hill district. They average more than 150,000 tons of ore with grades running between 0.20 and 0.25 percent U₃O₈. Uranium deposits of this type are similar to the intermediate type deposit with the notable exception that the ore bodies are located several hundreds of feet down-dip from the predominantly red-colored zone. The author believes the deposits are epigenetic and that the source of uranium was the tuffaceous Oligocene and Miocene rocks that overlie, or once overlaid the area. Circulating ground water was the ore-bearing medium, and the uranium was precipitated on contact with a reduction zone in the sediments. (JMT)

Cited as a reference in NURE Contractor Reports.

<141>

Hart, O.M.; Homestake Mining Company, Lead, SD

Uranium in the Black Hills. In Ridge, J.E. (Ed.), *Ore Deposits of the United States, 1933-1967*, Vol. I. The American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, (pp. 832-837), 991 pp. (1968)

Uranium ores occur in the Lower Cretaceous Inyan Kara Group in the Black Hills of western South Dakota and northeastern Wyoming. The host rock group has been divided into two formations. The

lower is the Lakota formation. It is composed of dominantly sandy sediments of non-uniform continental facies, lithogenetically related to the underlying Morrison Formation. The upper part of the group is the Fall River Formation. It is composed of predominantly sandy sediments of marginal marine facies, and it is related lithogenetically to, and is gradational with, the overlying marine Skull Creek Shales. The black unoxidized ore minerals of the Black Hills uranium deposits are uraninite and coffinite with associated vanadium minerals, paramontrosite and haggite (V₂O₃-V₂O₄-3H₂O). These minerals impregnate the interstices of sandstones and are intimately associated with pyrite, marcasite, calcite, and rarely jordanite and isemannite. Vanadium to uranium ratios of the unoxidized ores average 1.5:1.0. Oxidized ores are of two general types: (1) those that are predominantly yellow and (2) those that are mainly purplish black to reddish brown. Yellow ores have carnotite and tyuyamunite as the principal minerals. The purplish black to reddish brown oxidized ores contain carnotite and tyuyamunite with the vanadium minerals corvusite and rauvite in sufficient quantity to impart the darker coloration. A pink hematite staining accompanies most of the uranium deposits in the Black Hills area. It borders or partly encloses the deposits and terminates abruptly against the zone containing visible uranium and/or vanadium minerals. There is little evidence on the source of the uranium in the Black Hills, but a great deal of evidence indicates ground water as the principal distributing agent. The most likely source of uranium is thought to be the Oligocene and younger sediments in the area. These sediments contain much devitrified volcanic ash and tuffaceous sandstones. They have been reported to contain up to 0.0015 per cent uranium. The uranium and vanadium minerals are thought to have been precipitated from the ground water as primary oxides in a reducing environment produced and controlled by physiochemical characteristics of the Inyan Kara host formations but only at spatially favorable locales. (JMT)

<142>

Harshman, E.N.; USGS, Denver, CO

Uranium Deposits of Wyoming and South Dakota. In Ridge, J.D. (Ed.), *Ore Deposits of the United States, 1933-1967*, Vol. I. The American Institute of Mining,

Metallurgical, and Petroleum Engineers, Inc., New York, (pp. 815-831), 991 pp. (1968)

The major uranium-mining districts of Wyoming and South Dakota are located in the Black Hills, the Powder River Basin, the Shirley Basin, the Gas Hills, and at Crooks Gap. The deposits are generally concordant with the bedding of the host rocks, and many deposits host ore rolls. Uraninite and coffinite are the principal low-valence uranium minerals in the unoxidized sandstone-type deposits. Pyrite, marcasite, hematite, molybdenum (probably as jordisite), and selenium (in part as ferrocite) are associated with the uranium minerals. They are all believed to be epigenetic and to have been deposited during the ore-forming processes. Calcite cement is present in and near the ore bodies. It is genetically related to the ore. Oxidized uranium and/or uranium-vanadium minerals are present above the water table in some of the Wyoming districts. The most common minerals are hydrous uranium carbonates, phosphates, and sulfates and hydrous uranium and/or vanadium silicates. In unoxidized ore, uranium and sulfate minerals coat sand grains, fill interstices between grains, and, to a minor extent, replace the grains. The principal uranium deposits in Wyoming are in arkosic sandstones and conglomerates of continental origin and of early Eocene age. The ore-bearing sandstone units range in thickness from a few tens of feet to several hundred feet. Generally these units contain interbedded siltstones or shales, and in many districts they are underlain and overlain by thick sequences of fine-grained rocks. Epigenetic concepts of origin of sandstone-type deposits can be divided into two broad categories based upon the source of the uranium and the character of the solutions in which it was transported to the site of original deposition. Advocates of the magmatic hydrothermal or hypogene concept propose that uranium and the associated elements were expelled from a magma in fluids that passed upward into zones of progressively lower temperatures and pressures. These fluids entered the gently dipping permeable sedimentary rocks, comingling with ground water, and eventually reaching a place where temperature and pressure conditions caused deposition. The hypogene concept of origin has been rejected by most geologists working on the Wyoming deposits. Proponents of the supergene concept advocate that: (1) percolating vadose water leached uranium and associated elements from various source rocks and transported them basinward through transmissive ore-bearing

formations and (2) deposition occurred when these solutions entered an environment conducive to precipitation of the transported elements. The Wyoming deposits, occurring as they do in rocks of early Eocene age, are less than 55 million years old; how much less is questionable. The Powder River Basin deposits, as interpreted from lead-lead and lead-uranium ratios range from 7 to 13 million years in age. Studies on the distribution of Th-230 and Pa-231, and on the fractionation of U-234 suggests a minimum age of 250,000 years for deposits in the Shirley Basin. There are no definite guides to buried sandstone-type deposits in Wyoming and South Dakota, but a number of general guides exist and when combined with broad geologic and hydrologic studies, they should lead to more successful and less costly exploration programs. (JMT)

Cited as a reference in NURE Contractor Reports.

<143>

Motica, J.E.; Union Carbide Corporation, Grand Junction, CO

Geology and Uranium-Vanadium Deposits in the Uravan Mineral Belt, Southwestern Colorado. In Ridge, J.D. (Ed.), *Ore Deposits of the United States, 1933-1967, Vol. I. The American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, (pp. 805-813), 991 pp. (1968)*

Ores containing uranium and vanadium minerals have been mined from the Salt Wash Member of the Morrison Formation from many localities in the Colorado Plateau region since about 1900. The most productive deposits are in a relatively small area in Southwestern Colorado referred to as the Uravan mineral belt. The ore deposits occur principally in the uppermost sandstone unit of the Salt Wash. This unit consists of sandstone lenses formed by a system of aggrading braided streams flowing in an easterly direction generally normal to the mineral belt. These lenses, referred to as channels, are as much as one mile in width and average about 50 feet in thickness and can be traced for several miles along their courses. Areas favorable for such deposits are recognized principally by the following criteria: (1) a host sandstone thickness of over 30 feet, (2) the presence of carbonaceous material in the host sandstone,

and (3) gray mudstones and clays associated with ore-bearing sandstone. The ore minerals are believed to have been precipitated from laterally migrating solutions; there is no apparent genetic relationship between ore deposits and tectonic structural features. Exploratory and development drilling from the surface is conducted in three phases: first, wide-spaced drilling to find and outline favorable channels; second, moderate-spaced drilling in favorable ground to locate ore deposits; and third, close-spaced drilling to black-out ore. Long-hole drilling from underground stations is used to find and delineate extensions of ore bodies being mined. Due to intense production since 1948 from shallow deposits, best potential for new deposits exists in areas where the ore-bearing unit is 600 to 800 feet deep. (Auth)(JMT)

<144>

Mahn, R.C.; AEC, Grand Junction, CO

The Uranium Mining Industry and Geology of Monument Valley and White Canyon Districts, Arizona and Utah. In Ridge, J.D. (Ed.), *Ore Deposits of the United States, 1933-1967*, Vol. I. The American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, (pp. 790-804), 991 pp. (1968)

The Monument Valley and White Canyon districts are in northeastern Arizona and southeastern Utah. Exploration and mining for uranium has been conducted in these districts since the late 1940's. Nearly 5000 feet of Permian, Triassic, and Jurassic sedimentary rocks, mainly of continental origin, are exposed in these districts. All the important uranium deposits are in the Shinarump, the basal member of the Chinle Formation of Triassic age. The Shinarump lies on a widespread unconformity. It is composed of fluvial sediments, generally less than 100 feet thick, that were deposited by streams flowing from a source to the south. Most of the deposits are in an arcuate belt, convex to the west. This belt, 3 to 12 miles wide, extends from Monument Valley northward nearly 130 miles. The uranium deposits contain variable amounts of copper and vanadium. In the unoxidized parts of the ore, uraninite and coffinite are associated with vanadium minerals, and these are the dominant ore minerals. The uranium deposits are most

commonly localized in the more deeply scoured portions of Shinarump channels. These deeper scours occur on the outside of bends and in relatively straight portions of channel in those places where the less resistant beds of the Moenkopi were present. The uranium in the deposits may have been derived from: (1) erosion and leaching of large masses of granitic rocks, arkose, and tuffaceous sediments or (2) from hypogenic fluids generated by magmatic activity. The author favors the first theory. (JMT)

<145>

Kelly, V.C., D.F. Kistel, and P.E. McMahon; University of New Mexico, Albuquerque, NM; Anaronda Company, Grants, NM; Homestake-Sagin Partners, Grants, NM

Uranium Deposits of the Grants Region. In Ridge, J.D. (Ed.), *Ore Deposits of the United States, 1933-1967*, Vol. I. The American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, (pp. 767-789), 991 pp. (1968)

Uranium in the Grants region occurs mainly in the upper part of the Jurassic Morrison Formation, but significant lesser deposits are found in limestone of the Jurassic Todilto Formation and in the black shale of the Cretaceous Dakota Formation. The deposits are disseminations that form runs ranging from a few hundred tons to several million tons. The ore contains mainly of uraninite, vanadiferous carbonaceous material, coffinite, and such secondary oxidized minerals as tyuyamunite, carnotite, and uranophane. In sandstone, the ore runs were localized by mudstone, interstitial carbonaceous material, and primary sand channel trends. In limestone, ore deposition was related to folds and fracture zones. The great bulk of production has come from the Ambrosia Lake mines in the Grants district and the Jackpile and Paguate mines in the Laguna district. The ores generally range between 0.20 and 0.30 percent U₃O₈. Since their discovery in 1930, the deposits have yielded concentrated values in excess of \$800,000,000. Since the deposition of the Jurassic host rocks, a geologic history involving tilting, faulting, erosion, changing ground-water environments, and oxidation has considerably influenced the existence and character of the

deposits. A degree of agreement appears probable for a pre-Dakota age for the original ore runs and, at Ambrosia Lake, two principal stages of ore formation, separated by Laramide faulting, are recognized. All earlier ores have been modified by Quaternary oxidation, solution, and enrichment during which time much secondary tyuyamunite, metatyuyamunite, and carnosite were formed. (Auth)(JMT)

<146>

Wood, H.B.: AEC, Grand Junction, CO

Geology and Explanation of Uranium Deposits in the Lisbon Valley Area, Utah. In Ridge, J.D. (Ed.), *Ore Deposits of the United States, 1933-1967, Vol. 1.* The American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, (pp. 778-789) 991 pp. (1968)

Uranium ore deposits in the Lisbon Valley area are in an arcuate belt, 15 miles long by one-half-mile wide, on the southwest flank of the Lisbon Valley anticline. They range in size from 500 to 1,500,000 tons and by mid-1965 had yielded 6,147,800 tons containing 48,530,000 pounds of U₃O₈. Ore bodies average 6 feet in thickness and are tabular masses, concordant to the bedding. They are in the thickest, lowest sandstone unit of the Moss Back Member of the Chinle Formation of Triassic age. The host rock is predominantly a fluvialite, calcareous, fine-grained to conglomeratic sandstone. Uraninite, the principal ore mineral, fills the pores in the sandstone and partly replaces sand grains and fossil wood fragments. During the Late Permian and Early Triassic time, pre-Chinle Formations were arched to form the ancestral Permian anticline. Moss Back streams truncated Moenkopi and Cutler beds which capped the ancestral anticline and then covered it with fluvialite clastics, which were subsequently covered by thousands of feet of Triassic, Jurassic, and Cretaceous sediments. Uranium, probably derived from the Chinle Formation by diagenetic processes, was transported in connate ground waters, moved by compaction or hydrostatic forces, and deposited under reducing conditions. Uranium was emplaced around the crest of the ancestral anticline, prior to the Laramide orogeny. During the orogeny, the Tertiary-Lisbon valley anticline was superinduced on the Permian anticline and,

penesynchronous with uplift, was faulted parallel to its longitudinal axis. The Big Indian ore belt on the southwest flank footwall block was elevated to approximately its present position, and the northeast flank hanging wall block was elevated only slightly. An extension of the Big Indian ore belt around the northeast flank of the ancestral Permian anticline may exist in the Moss Back sandstone in the downthrown block northwest of the Lisbon Valley fault. (Auth)(JMT)

<147>

Sims, P.K.; USGS, Washington, DC

Geology of Uranium and Associated Ore Deposits Central Part of the Front Range Belt Colorado. USGS Professional Paper 371, 119 pp. (1963)

The Central City district and adjoining mining areas in the central part of the Front Range mineral belt have supplied small quantities of uranium ore intermittently since the discovery of pitchblende at Central City in 1871. The mining districts are in a terrain of complexly folded Precambrian crystalline rocks, which constitute the core of the Front Range. The Precambrian rocks are interlayered with a generally conformable sequence of metasedimentary rocks, migmatites, and intrusive igneous rocks, some of which are metamorphosed. The Tertiary igneous sequence of the region is one of the most radioactive groups of intrusive rocks in the world. The ore deposits of the region are gold-, silver-, copper-, lead-, zinc-, and uranium-bearing veins that formed as hydrothermal fissure fillings in the faults. The structure, mineralogy, and texture of the veins are similar to those described by Lindgren as mesothermal. Uranium occurs locally in veins of different mineralogic types throughout much of the region, but is abundant in only a few veins. Although the uranium-bearing veins are widely scattered, a large proportion of the occurrences and most of the occurrences of economic importance are in an area less than one square mile in the Central City district. Pitchblende is the primary uranium mineral in the veins. Oxidation of the pitchblende has yielded a limited variety of hexavalent uranium minerals, which are hydrous uranium phosphates, silicates, sulfates and carbonates. The most abundant secondary minerals are torbernite, autunite, and kasolite. The discovery of uranium-bearing ore bodies larger than those

previously mined in the area is doubtful. As a result, future production of uranium from this region will probably come from scattered small pods and ore shoots distributed throughout the uranium-bearing veins. These bodies can be recovered most economically during the mining of precious- and base-metal ores. (Auth)(JMT)

<148>

Fischer, R.P.; USGS, Denver, CO

The Uranium and Vanadium Deposits of the Colorado Plateau Region. In Ridge, J.D. (Ed.), Ore Deposits of the United States, 1933-1967, Vol. 1. The American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, (pp. 735-746), 991 pp. (1968)

Through 1964, the uranium-bearing deposits of the Colorado Plateau region have yielded about 70% of the uranium recovered from domestic ores, about 90% of the recovered vanadium, and nearly all of the recovered radium. Typically, the deposits are in sandstone and form tubular ore bodies that are nearly concordant with bedding. Most of these deposits are in beds of the Chinle Formation of Triassic age or in the Morrison Formation of Jurassic age. A few deposits are in collapsed breccia pipes, and a few form veins along fractures. Accumulations of uranium have also been found in beds of shale and coal and in igneous rocks in this region, but deposits of these types have been virtually unproductive. There are twenty ore minerals below the zone of oxidation in these deposits. The are low-valent oxides and silicates of uranium and vanadium. The accessory minerals are mainly sulfides; pyrite and marcasite are common, and tract amounts of galena and sphalerite are widespread. Minerals containing molybdenum, selenium, chromium, nickel, cobalt, and silver are also present in certain areas. The peneconcordant uranium deposits of the Colorado Plateau are uniform in grade and consistent in habits, though they vary greatly in size. The ore produced has averaged about 0.25% U₃O₈. On the basis of geologic evidence alone, the peneconcordant uranium deposits can be dated only vaguely. The ore was obviously introduced at some time after the host sandstone beds were deposited, but most of the ore bodies have been displaced by faulting. Based on the geologic history of the area, it is reasonable to assume that not much of the faulting

occurred before Laramide time; many faults, however, may be younger. Isotopic dating of the ore has not yielded results that appear more definitive than the geologic evidence alone; in fact, the possible age range can be even greater, depending upon what interpretations are made. Various theories have been proposed that attempt to explain the origin and source of the ore metals. Syngeneisis has been proposed, but never strongly supported. Epigenesis is requisite, but is divided into two major concepts - hypogene and supergene - relating to the nature of the ore-bearing solutions and the source of the ore metals. (JMT)

<149>

King, J.W.; AEC, Grand Junction, CO

Reconnaissance of Red Rock District, Cove Mesa, and Kinesta (Tree) Mesa, Arizona. RMO-755, 11 pp. (1951)

All known vanadium-uranium ore deposits in the Red Rock district and the Cove and Kinesta Mesa areas are in the lower part of the Salt Wash member of the Morrison formation of Jurassic age. The Salt Wash member is about 200 feet thick and is composed of gray to brown, fine-grained quartzose sandstone interbedded with red or green mudstone lenses up to five feet thick. The ore bodies are small and are as much as three feet thick. Carnotite is the principal uranium mineral. (Auth)

<150>

Keys, W.S., and R.L. White; AEC, Grand Junction, CO

Investigation of the Temple Mountain Collapse and Associated Features, San Rafael Swell, Emery County, Utah. In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 371-378), 825 pp.; In USGS Professional Paper 300, (pp. 285-298), 739 pp. (1956)

The Temple Mountain collapse was drilled to investigate the genesis of its structure and its

relation to the uranium ores and to test for ore at zones deeper than those locally productive. Two other smaller collapses were also drilled. The Temple Mountain collapse is about 500 feet wide by 2,000 feet long; the maximum subsidence is 300 feet. The collapse is characterized by a synclinal depression, with a brecciated and bleached center. Drilling shows that the rock has undergone damage, brecciation, and alteration at depth. Minerals identified include pyrite, galena, arsenopyrite, realgar, uraninite, and abundant asphalt. Limestone, normally present in the stratigraphic section are missing in most of the holes, thus supporting the hypothesis that solution of carbonate rocks was at least partly responsible for the collapse of overlying sediments. A new ore horizon, consisting of chert remnants of the Kaibab limestone cemented by asphaltic sandstone, was found immediately above the Coconino Sandstone. More than 95 percent of the uranium production of the Temple Mountain region has come from an area about 2,000 feet south of the collapse. (Auth)

The conference paper was entitled "Deep Drilling in the Temple Mountain Collapse, San Rafael Swell, Utah", and authored by W.S. Keys.

<151>

Blair, R.G.; AEC, Denver, CO

Preliminary Report on Radioactive Mineral Deposits in the Gulf Coastal Plain of Texas and Louisiana, North and East of the Guadalupe River. TM-D-5-2. 15 pp. (1959, March)

Approximately thirty radioactive mineral deposits are known to occur in the Gulf Coastal Plain of Texas and Louisiana, north and east of the Guadalupe River. A preliminary field examination and sampling of each deposit has been made. The host rocks range in age from lower Eocene to Miocene. Only localities in northern Gonzales, Fayette, and western Washington Counties, Texas, are likely to produce uranium ore. In these counties, five scattered properties have produced select samples containing more than 0.10% U₃O₈. These samples are from small mineralized lenses within sandy silty lignite beds and sandstone strata of the upper Jackson formation of Eocene age and the lower Catahoula formation of Miocene age. (Auth)(MLB)

<152>

Finch, W.I.; USGS, Washington, DC

Geology of Epigenetic Uranium Deposits in Sandstone in the United States. USGS Professional Paper 538, 121 pp. (1967)

Epigenetic uranium deposits in sandstone and related rocks are formed by the precipitation of uranium minerals from solutions. These deposits are widespread in the United States; they have yielded most of the uranium ore produced in this country and contain nearly all the domestic ore reserves. Most deposits are tabular layers that lie nearly parallel to the bedding and for that reason are called *penconcordant* deposits. In these, the ore minerals mainly fill the pore spaces of the host rocks, but they partly replace the sand grains, plant fossils, and accessory and cementing minerals of these rocks; in some deposits the uranium occurs in asphaltic material that impregnates and partly replaces the sandstone. Other deposits are mainly localized along fractures that are discordant to bedding and are referred to as *vein* deposits. In these, the ore minerals occupy the fracture partings and impregnate the adjacent wallrock. Nearly all *penconcordant* deposits are in beds of Devonian age or younger and correlate with the evolutionary development of woody land plants, which occur in abundance as fossils in most of the host rocks. *Vein* deposits, however, occur in beds ranging in age from Precambrian to Tertiary, and are nearly as abundant in sandstone of marine origin as in that of fresh-water origin. Ore bodies range from small masses only a few feet across to those that are hundreds of feet across and contain a million tons or more of ore. Most deposits seem to have formed before regional deformation and have since remained stable, but others are believed to represent the redissolved and reprecipitated materials of those early deposits that became unstable owing to changes in environmental conditions. Some *vein* deposits are probably of hydrothermal origin from a hypogene source. (Auth)(MLB)

Tables summarizing geographic distributions, stratigraphic distributions, character, hypotheses of origin, and favorable areas and formations of uranium deposits are included; Cited as a reference in NURE Contractor Reports.

<153>

Saen, C.A., G.P. Dix, Jr., S.W. Hazen, Jr., and R.R. McLellan: US Bureau of Mines, Washington, DC

Uranium-Mining Operations of the Utah Exploration Company in the Big Indian District, San Juan County, Utah. US Bureau of Mines Information Circular 7669, 13 pp.; Mines Magazine, 44(4), 16-28. (1954)

A major uranium-vanadium ore deposit was discovered on the Mi Vida claim in the Big Indian mining district, San Juan County, Utah. The district lies on the southwest flank of the faulted, northwest-trending Lisbon Valley anticline; in the vicinity of the Mi Vida mine the rocks dip about 15 degrees SW. The deposit is in the Chinle formation of Triassic age; the Chinle formation is underlain by the Cutler formation of Permian age and overlain by the Wingate sandstone of Jurassic age. The rocks of the Chinle formation consist of variegated mudstones and siltstones, intraformational conglomerates, and fine- to medium-grained cross-bedded sandstones. The ore-bearing unit, in the lower part of the Chinle formation, is characteristically grey while the upper part of the formation is red. The ore body is irregularly tabular in shape and ranges from 10 to 23 feet thick. The deposit lies in a channel scoured into the Cutler formation to a depth of about 50 feet; the channel axis trends about N. 30 degrees W. Abundant carbonaceous trash in the channel is replaced by pyrite or uraninite or preserved as carbon. The highly variable lithology of the channel provides a favorable host rock. It is believed that the deposit was emplaced by hydrothermal solutions derived from Late-Cretaceous or Early-Tertiary intrusive igneous rocks such as are exposed in the La Sal Mountains, but there is a possibility that the solutions could have been ground-water or a mixture of both. The location of the deposits may have been controlled by the Lisbon Valley anticline. Exploration and development, the surface and underground plants, the mining methods, and production are described. (Auth)

US Bureau of Mines Information Circular 7669 was published in 1953.

<154>

Williams, F.J., and D.C. Barrett; AEC.
Salt Lake City, UT

Preliminary Report of Reconnaissance in the Cameron Area, Arizona. RME-4802, 10 pp. (1953, June)

Ground and airborne reconnaissance for uranium was conducted in the Cameron area, Coconino County, Arizona. The largest and best deposits are in the Petrified Forest member of the Chinle formation of Triassic age, but uranium also occurs associated with fossil logs in the Shinarump conglomerate, also of Triassic age. The uranium deposits in the Petrified Forest member are in silty mudstone and clay which contain scattered sand and carbonaceous material. The normally gray color of the rocks has been changed to light tan or yellowish brown in the vicinity of the deposits. Uraninite and secondary uranium minerals are associated with carbonaceous material, pyrite, smaltite, calcite, and gypsum. The deposits contain negligible amounts of copper or vanadium. (Auth)

<155>

Winterhalter, E.C.; AEC, Denver, CO

Preliminary Reconnaissance for Uranium in the Green River Basin and the Rock Springs Uplift, Sweetwater and Fremont Counties, Wyoming. RME-1045, 10 pp. (1954)

Reconnaissance for uranium deposits in part of southwestern Wyoming disclosed two areas of anomalous radioactivity. One area is northwest of Oregon Buttes in the southwest corner of Fremont County. Anomalous radioactivity is present in some micaceous and arkosic sandstones of the Tipton tongue of the Green River and the Cathedral Bluffs tongue of the Wasatch formation, both of Eocene age. No visible uranium minerals were found. The other area, the Red Creek, Basin is south of Rock Springs, Wyoming, near the Utah-Wyoming border. Some shale, carbonaceous shale, coal, and limestone beds in the Tipton tongue of the Green River formation in the area are anomalously radioactive. (Auth)

<156>

Wood, H.B., and W.D. Grundy; AEC.
Grand Junction, CO

Techniques and Guides in Exploration for

Uranium in Shinarump Channels on the Colorado Plateau. In USGS Professional Paper 388, (pp. 651-657), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 701-703), 825 pp. (1956)

Detailed studies have been made of three areas on the Colorado Plateau in which uranium ore deposits occur under similar geologic conditions in the Shinarump conglomerate of Late Triassic age: Circle Cliffs and White Canyon regions of southeastern Utah, and Monument Valley region of Utah and Arizona. In these areas, large asymmetric anticlines with irregular axes are the dominant structural features. Commercial uranium deposits occur in fluvial sediments which fill ancient stream channels incised in the pre-Shinarump erosion surface. These paleostream channels are widespread and variable in size and shape. In White Canyon, 22 channels, 6 containing ore, were located by recognition of certain geologic criteria and traced by drilling based on information provided by paleotopographic maps. The formations involved are continental in origin and include the Moenkopi formation, the Shinarump conglomerate, and the Chinle formation, all Triassic in age. The following are recommended as guides to ore in the regions: (1) uranium ore is confined to the bottoms and sides of channels and scours; (2) ore is most likely to occur in a poorly sorted permeable, argillaceous, arkosic sandstone or conglomerate interbedded with mudstone lenses and clay galls; (3) irregular channels with deep and narrow cross sections and with variations in depth of scour are favorable for the occurrence of this type of lithology; (4) the presence of carbonaceous material and some clay lenses is important for uranium concentration; (5) an appreciable thickening of the zone of bleaching in the underlying Moenkopi may indicate a mineralized channel; (6) the nearby presence of copper sulfides, sulfates and carbonates; iron sulfides, sulfates and hydrous oxides; and cobalt arsenate. The reconstruction of the paleotopography is desirable in exploration to determine the presence and trend of a buried channel. (Auth)

The conference paper, entitled "Techniques and Guides for Exploration of Shinarump Channels on the Colorado

Plateau", is not as complete as the USGS Professional Paper 388.

<157>

Zeller, H.D., and E.H. Bultz, Jr.; USGS, Washington, DC

Uranium-Bearing Copper Deposits in the Coyote District, Mohave County, New Mexico. USGS Circular 334, 11 pp. (1954)

Uranium-bearing copper deposits occur in steeply dipping beds of the Sangre de Cristo formation of Pennsylvanian and Permian age south of Coyote, New Mexico. The deposits occur in lenticular carbonaceous zones in shales and arkosic sandstone. Samples from these zones average 3 percent copper and contain as much as 0.067 percent uranium. Metatyuyamunite is disseminated in some of the copper sulfide nodules occurring in the shale. The sulfide nodules are composed principally of chalcocite with some bornite and covellite, as well as pyrite and malachite. Some nodules replace wood. The copper and uranium were probably deposited with the sediments and concentrated into zones during compaction and lithification. Carbonaceous material in the Sangre de Cristo formation provided the environment that precipitated uranium and copper from mineral-charged connate waters forced from the clayey sediments. (Auth)

<158>

Kozlov, I., University of Sofia, Sofia, Bulgaria

Crystallochemical Differentiation and Localization of Uranium Ore Deposits in the Earth's Crust. In Proceedings of a Technical Committee Meeting on Recognition and Evaluation of Uraniferous Areas, held in Vienna, Austria, November 17-21, 1975. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 15-33), 295 pp.; IAEA-TC-25/2, (pp. 15-33), 295 pp. (1977)

Uranium is one of the 5f elements with 5f3, 6d1, and 7s2 electrons influencing its valency. Although known as U2+, U3+, U4+, U5+, and U6+ ions, in its natural occurrences, uranium is invariably

quadrivalent or hexavalent. Quadrivalent uranium is about 1 angstrom in size and has a cation anion ratio with oxygen of 0.82, which is slightly higher than that characteristic for the ideal cubic coordination, typically representing the fluorite type of structure. The most widespread uranium mineral, uraninite, possesses this type of structure. Hexavalent uranium is the most awkward ion as far as atomic substitution in the crystal structures of minerals is concerned, being invariably found as uranyl group, UO_2^{2+} , a dumb-bell with dimensions of 2.64 angstroms $\times$ 6.04-6.84 angstroms, its axial length depending on the particular crystal structure. Uranium possesses amphoteric or slightly alkaline properties, and in both the quadrivalent and the hexavalent state has a pronounced tendency to form complexes with water, organic compounds, and a number of oxygen compounds (i.e. CO_3^{2-} , PO_4^{3-} , SO_4^{2-} , VO_4^{3-} , etc.). The average contents of uranium in ppm for some salient rock types are: chondritic, 0.015; ultramafic, 0.03; mafic, 0.5; intermediate, 1.8; acidic, 3.5; and sedimentary, 3.2. Uranium migration is carried out mostly by alkaline carbonate solutions forming complex ions with the uranium. Fluorine can also be an important mobilizing agent, forming uranyl fluorides (UF_4 , UO_2F_2). The most amenable sites for uranium accumulation in the earth's crust can be assumed to be as follows: (1) Uplifted protocontinental geoblocks of greater primeval thickness, which have undergone granitization and alkalinization processes; (2) Boundaries between geoblocks and tectonic zones in them, tracing mainly vein-type uranium deposits; (3) Unconformities (basal conglomerates of the classic Precambrian type) and permeable beds within formations of all geological ages, facies and tectonic settings. The permeable rocks of smaller closed basins within geoblocks deserve special interest. The sites in permeable beds typify "sedimentary" uranium deposits in the widest sense; (4) Areas adjacent to evaporitic and petroliferous deposits. These are generally areas between orogenic belts and platforms (geoblocks); (5) Areas enriched with rocks bearing graphite, coal, bitumens and/or pyrite (sulphide in general), subjected to post-depositional deformation and alteration; (6) Sites of intensive low-temperature hydrothermal rock alterations and especially zones of alkalinization and zeolitization. Attention should be paid to zonality exhibited not only when a drastic change in pH-Eh conditions occur, but also within one and the same physico-chemical formation. (7) Specific studies on degeneracy

marks, of micro-and microfossils, abounding in former water basins with an influx of uranium may serve eventually as an additional criterion for separating syngenetic from epigenetic uranium deposits and thus for tracing sites of abnormal ecology, which might give hints regarding the original concentration of uranium in a particular basin. (JMT)

<159>

King, J.W., and S.R. Austin; AEC, Grand Junction, CO

Some Characteristics of Roll-Type Uranium Deposits at Gas Hills, Wyoming. Mining Engineering, 18(5), 73-80. (1966, May)

The Gas Hills district in Wyoming, is the site of approximately 12% of the known uranium in the US. The ore deposits are confined to a permeable sandstone unit, up to 350 ft. thick, at or near the base of the upper Wind River formation of early Eocene age. The major uranium deposits of the Gas Hills can be considered in three categories: oxidized, blanket and roll. Most important economically, and most illuminating genetically, are the roll deposits, which contain most of the uranium of the district. Rolls in the Gas Hills are tongue-shaped in plane and crescentic in vertical section with elongated horns of the crescent corresponding to the upper and lower limbs of the roll. The most productive rolls occur where the solution front curves most sharply. All rolls observed in Gas Hills are confined at the top and bottom by clayey beds, and the peak concentration of uranium is usually within a few feet of the front. The pyrite of the barren ground of the rolls occurs predominantly as discrete and nearly euhedral crystals. In zones of mineralization, the pyrite occurs mainly as aggregates of very fine crystals and in the ore zones, the pyrite is characteristically tarnished. Magnetite and other heavy detrital accessory minerals appear in remote barren ground, but most of these minerals, except garnet and zircon have apparently been removed from the mineralized zones in the course of mineralization. The pattern of sulfur isotope variation is one of the most enlightening of any of the plotted values. The extreme enrichment in S^{32} in the barren interior and the lesser enrichment in the mineralized ground plot as relatively smooth curves separated by an abrupt break at the solution front. The curves show

secondary minima corresponding to secondary peaks of iron and sulfur. The abrupt rise in per mil values begins at the solution front and continues in the rich ore without relation to peak values of uranium, iron, and sulfur. The per mil values increase further in the protore section to near meteoritic values. The sharp break in the delta S34 curve suggests that the front defines a zone of increase bacterial activity and that the fractionation is related primarily to the front, but whether bacteriogenic or not, the pattern of sulfur isotope distribution found cannot be produced by fractionation alone, but requires differential transport of fractions enriched in one isotope or the other. Several working hypotheses might serve to explain the observed isotopic and chemical distribution about the front. Some might be based on the assumption that the front is merely an interface between fluids of different original chemical and isotopic composition. Others might involve bacterial reduction and fractionation of sulfur at the front. These might be more satisfactory because bacteriogenic hydrogen sulfide is enriched in S32 over the parent sulfate and the residual sulfate is depleted accordingly. Results of the present study do not indicate a satisfactory hypothesis. The source, original composition, and history of fractionation of the sulfur are among the foremost problems to be resolved. (JMT)

<160>

Brown, G.H., III; AEC, Grand Junction, CO

Uranium Deposits of the Vegas Cluster
Rio Arriba and Sandoval Counties, New Mexico. RME-84, 13 pp. (1955, June)

Uranium mineralization found in the Vegas Cluster has been restricted to the upper arkosic limestone member of the Madera formation and to the lower portion of the Cutler formation (Abn formation). Generally, the mineralization is of the copper-uranium type and occurs as impregnations in (1) light gray arkosic lenses and (2) mudstone or siltstone beds underlain or overlain by arkosic lenses. The mineralization is commonly associated with carbon in the form of trash or logs, and green mudstone galls. There is no intimate relation between the copper and uranium mineralization, but it was noted that copper mineralization was found only when carbon was present. Scour fillings of light gray arkose or arkosic sandstone, with a

grain size ranging from medium to very coarse, have been the best guides to ore. The various red colored sands appear to be unfavorable hosts. (Auth)

<161>

Weir, G.W., and W.P. Puffett; USGS, Washington, DC

Similarities of Uranium-Vanadium and Copper Deposits in the Lisbon Valley Area, Utah-Colorado, USA. In Proceedings of the International Geological Congress, Report of the Twenty-first Session, Part 15, Genetic Problems of Uranium and Thorium Deposits, held in Copenhagen, Denmark, 1960. (pp. 133-148), 164 pp. (1960)

The geologic similarities of uranium-vanadium and copper deposits and the occurrence together of uranium, vanadium, and copper minerals in the Lisbon Valley area, a uranium-mining district on the Colorado Plateau, suggest that these deposits have a common origin. The uranium-vanadium deposits are in sedimentary rocks of Permian, Triassic, and Jurassic age. The copper deposits are chiefly in sandstone of Cretaceous age but also are in older formations and in brecciated igneous rock of Tertiary age. The geologic habits of the deposits differ somewhat in each host rock but practically all the deposits are tabular bodies in virtually unaltered sandstone. Most uranium-vanadium deposits are remote from faults, but the copper deposits are generally found only in fractured rock near faults. The ore minerals impregnate sandstone and carbonaceous material; the copper minerals also occur in small fractures. Uranium and vanadium minerals occur in a few copper deposits, and copper minerals occur in many uranium deposits. The copper ores were deposited from low-temperature hypogene solutions moving along faults in Tertiary time. The uranium-vanadium ores were probably deposited from the same or similar solutions moving laterally through favorable beds. (Auth)

<162>

Bates, T.F., and E.O. Strahl; Pennsylvania State University, University Park, PA

**Mineralogy, Petrography, and
Radioactivity of Representative Samples
of Chattanooga Shale. Bulletin of the
Geological Society of America, 68,
1305-1314. (1957)**

The Chattanooga Shale is a massive chocolate-brown sediment which displays faint indications of lamination. Some pyrite lenses, nodules, and crystals and a few mica flakes are large enough to be seen with a hand lens. In thin section, the rock is seen to consist of grains of quartz and feldspar in a matrix of yellow to red-brown organic material, which incorporates sheaths of mica and probably clay particles and is dotted with small clusters of pyrite. Larger organic fragments with associated pyrite are common and take various forms. Individual mineral particles range from pyrite cubes less than 0.15 micron on a side to quartz and feldspar grains as large as 0.10 mm. X-ray studies show the clay minerals to be illite, kaolinite, and chlorite in decreasing order of abundance. Tourmaline, zircon, and apatite are the characteristic heavy minerals of the sediment. Quantitative studies, accomplished by a combination of chemical and mineralogical methods, have shown the composition of a batch sample of this rock to be approximately: 22% quartz, 9% feldspar, 31% illite and kaolinite, 22% organic matter, 11% pyrite and marcasite, 2% chlorite, 2% iron oxides, and 1% tourmaline, zircon, and apatite. Alpha-track studies of emulsion-covered thin sections indicate that no uranium mineral is present. Approximately 70% of the uranium atoms are randomly distributed throughout the fine-grained matrix of the rock, whereas another 25% is concentrated in organic-pyrite-clay complexes such as pyrite nodules and discrete organic bodies. In unweathered samples there is no relationship between uranium distribution and textural features such as bedding. The data indicate that the uranium was precipitated from sea water under reducing conditions and has not been redistributed following compaction of the sediment. (JMT)

<163>

Bell, R.G.; USGS, Washington, DC

**Deposition of Uranium in Salt-Pan
Basins. USGS Professional Paper 354-G,
(pp. 161-169). (1959)**

Drainage waters carry minute quantities of uranium into oceans, inland seas, and lakes. When such bodies of water evaporate completely in desiccating salt-pan basins, the uranium must be deposited together with all other dissolved materials. The ratio of uranium to total evaporite sediments is approximately $1:2 \times 10(E+7)$. The distribution of uranium in salt-pan basin sediments is not completely known. Some organic-rich muds and phosphatic sediments deposited in desiccating basins may contain uranium in amounts as large as 0.0X percent. Uranium may be adsorbed on clays that are deposited with some evaporite sediments. These muds, phosphatic sediments, and clays may remove nearly all of the dissolved uranium from the water of some of the basins. Anhydrite, gypsum, halite, and potassium bearing evaporite minerals probably are the least uraniferous of all rocks in the earth's crust; their uranium contents generally are less than 0.00001 percent. Within salt-pan basins, where oxidizing conditions tend to prevail, and no significant amounts of organic-rich muds, clays, and phosphatic sediments are deposited, highly soluble uranium salts remain in solution and are deposited only as the basin finally is completely desiccated. These final highly soluble evaporite sediments are not likely to be preserved because they are subject to wind erosion and leaching. (Auth)(JMT)

<164>

Walker, G.W.; USGS, Washington, DC

**Supergene Alteration of Uranium-Bearing
Veins in the Conterminous United States.
USGS Professional Paper 455-E. (pp.
91-103). (1963)**

Virtually all uranium-bearing veins in the conterminous United States show some evidence of super-gene alteration, but the degree and products of alteration vary markedly. The hypogene uranium minerals within these deposits, many of the associated nonuraniferous vein minerals, and locally some wallrock minerals have been altered at or near the ground surface into minerals that tend to be more stable in an oxygenated environment. In some deposits, the transformation of primary minerals into secondary ones has occurred for the most part in place. In many other deposits, some of the elements have been redistributed to form enriched or impoverished zones. Where the altering meteoric waters were moderately to strongly acidic,

particularly in some deposits containing abundant sulfide minerals, considerable leaching and removal of materials has resulted. Thus, three patterns of distribution, (or redistribution), for uranium in the oxidized parts of veins can be demonstrated. These are enriched zones, impoverished zones, and unchanged zones in which alteration has occurred essentially in place. In general the causal chemical processes and the resultant geologic expression of supergene alteration of uranium-bearing veins are similar to those described for copper and other base-metal sulfide deposits. The products of supergene alteration of uraniferous veins are many and include not only hydrated hexavalent uranium minerals, but locally uranyl ions adsorbed on several alteration products and, in some places where reduction has occurred, on several supergene quadrivalent uranium minerals. Commonly, in those vein deposits characterized by several uranyl compounds, a zoning of the uranium-bearing alteration products has been demonstrated in which hydrated oxides and hydroxides occur closest to unaltered pitchblende; uranyl silicates, phosphates, vanadates, molybdates, and arsenates occur in an intermediate position; and uranyl carbonates and sulfates are found farthest from ground waters are characteristic of most uranium-bearing veins subjected to supergene processes and are most common at or near the ground surface. In a few veins, supergene alteration occurs essentially in place and shows no marked tendency toward uranium enrichment or depletion in the more oxidized parts of the veins. In still other veins, supergene alteration has resulted in enrichment of uranium in zones of decreased oxidation potential; commonly, the enriched zones characterized by mostly or regenerated pitchblende. (JMT)

<165>

Russell, R.T.: AEC, Grand Junction, CO

Relationship of Uranium Ore Deposits to Petroleum- and Gas-Bearing Structures.

In Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Vol. 2, Survey of Raw Material Resources, held in Geneva, Switzerland, September 1-13, 1958. United Nations, New York, (pp. 358-366), 843 pp. (1958)

The uranium deposits related to petroleum- and gas-bearing structures, as discussed in this paper

are divided into two types. One group consists of uranium mines on productive oil or gas structures or so situated that oil or gas from depth could migrate into the uranium ore zone; the other group comprises oil-type traps from which oil or gas has escaped leaving an asphalt-like substance intimately associated with the uranium ore. It was concluded that while petroleum can transport minor amounts of uranium, the process was not important in the formation of uranium ore deposits. Natural gas, too, fails to transport enough uranium to be considered an important agent in the transportation of uranium. There is evidence, however, that natural gas acts as a precipitating agent on the uranium ore solutions. Studies at the Colorado School of Mines Research Foundation on the ability of various natural gases to precipitate uranium from solution, have shown that natural gas from which all traces of hydrogen sulfide has been removed, give little or no precipitation. Hydrogen sulfide, however, produced a very large yield of precipitate. It was noted that the reaction and formation of uraninite apparently took place at the solution-atmosphere interface. Oil type structures may play a dominant role in the localization of uranium ore even in cases where oil-type structure may produce reactions resulting in the deposition of uranium and other elements. This process has been noted to take place at the present time in the oil fields of southeastern Kansas. The techniques as developed by mining companies in Wyoming has two variations. The first, as used in the Gas Hills, consists of mapping the areal extent of the Frontier formation beneath the overlying Wasatch formation. The Frontier formation in this area is a gas producer; therefore, if natural gas tends to precipitate uranium from solution, the Wasatch formation above and adjacent to the beveled Frontier sandstone is a logical unit to explore. The second, as used in the Shirley Basin, Wyoming consists of making a subsurface map of the Pre-Tertiary surface and drilling over oil-type structures. Success in finding uranium ore in the overlying Tertiary sediments is ascribed to using this exploration approach. (JMT)

<166>

Fischer, R.P., and J.H. Stewart; USGS, Denver, CO; USGS, Menlo Park, CA

Copper, Vanadium, and Uranium Deposits in Sandstone—Their Distribution and Geochemical Cycles.

Economic Geology, 54, 509-520. (1961)

Deposits of copper, vanadium, and uranium in nonmarine sandstones are numerous and widespread. Copper deposits, with or without uranium, are mainly resident in first-generation arkosic sandstones derived from granitic rock terrains; deposits rich in vanadium, with or without much uranium are dominantly in second-generation sandstones, many of which are associated with beds containing volcanic debris. All three metals are dispersed in igneous rocks but not in close association. Copper and uranium enter the hydrothermal environment, but the record of vanadium in hydrothermal solutions and veins is scant. Some of the uranium and most of the copper minerals in igneous rocks and veins oxidize readily and the metals go into surface-and ground-water solutions, but the vanadium in igneous rocks is not so easily mobilized—under normal geologic conditions, conceivably it may require diagenetic reactions and a second period of weathering to solubilize much vanadium. All three metals precipitate from solutions in the presence of a reducing agent, such as carbonaceous material or associated sulfide ions, either in sediments as they accumulate or in existing rocks. These geochemical habits permit the concept that copper and uranium are made available by weathering of igneous rock terrains and hence might accumulate in first-generation sediments, whereas vanadium would be commonly available only after a second period of weathering. Perhaps the oxidation or devitrification of volcanic debris may contribute uranium to ground waters as does the weathering of igneous rocks. (Auth)

<167>

Butler, A.P., Jr.; USGS, Washington, DC

The Geological Survey's Work on the Geology of Uranium and Thorium Deposits. GEI-207, 26 pp. (1952, April)

The Geological Survey has been studying the geology of uranium and thorium continuously since 1939, when it began a comprehensive investigation of the vanadium-uranium deposits of the Colorado Plateau. Greatly increased demand for uranium arising from the advent of controlled fission in 1942 resulted in widening of the study in 1944 to include other possible sources and in further expansion on behalf of the US Atomic Energy Commission since

1947. The wide variety of materials investigated in this study are embraced by five somewhat arbitrary groups of related types of deposits as follows: (1) Igneous rocks, pegmatites, veins, and related deposits; (2) Deposits in sandstone of carnotite, copper-uranium, and other minerals; (3) Other consolidated sedimentary rocks; (4) Placers; and (5) Natural fluids. Much of the work has been concentrated in geologic study and exploration of the carnotite deposits in sandstone, but hundreds of occurrences of uranium have been examined since 1944. Several bodies of igneous rock among at least 100 tested contain 0.005 to 0.01 percent equivalent uranium. Although none offer a large volume of rock from which uranium might be concentrated by simple means. The small size and low average grade of numerous pegmatites examined suggest that pegmatites constitute only an inconsequential source of byproduct uranium or thorium. The study of uraniferous vein deposits has included examination of scores of metalliferous veins and few fluorite veins, mainly in eight western states. Concentrations of carnotite and other uranium minerals associated with vanadium or copper minerals in sandstones of the Colorado Plateau region are the principal domestic source of uranium. Comprehensive study of ore deposits in the Morrison formation in this region was greatly expanded in 1947 to include extensive exploration by drilling. Preliminary investigations have also been made of recently discovered deposits in the southern Black Hills, South Dakota, and near Pumpkin Buttes, Wyoming. Intensive study of uraniferous parts of the Chattanooga shale, some Florida and western phosphatic rocks, and some western lignites has been completed. Monazite-bearing placers in Idaho have been studied and the monzonite source rocks in the Carolinas are also being outlined. In Alaska, investigations for uranium and thorium have consisted mainly of reconnaissance of areas containing types of rock thought to be possibly favorable for uranium. (JMT)

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Eargle, D.H., and A.D. Weeks; USGS, Austin, TX; Temple University, Philadelphia, PA

Geologic Relations Among Uranium Deposits, South Texas, Coastal Plain Region, USA. In Proceedings of the Eighth International Sedimentological

Congress, Ores in Sediments, held in Heidelberg, West Germany, 1971, (pp. 101-113). (1971)

Uranium in the South Texas Coastal Plain occurs in tuffaceous sandy sedimentary rocks of late Eocene to Pliocene age. The uranium ore contains small amounts of molybdenum and selenium. Deposits range from small irregular bodies of highly oxidized "yellow ores" near the outcrop to unoxidized "black ores" at depths of 60 feet (18.3 meters) to at least several hundred feet. The oxidized ore is highly susceptible to leaching accompanied by migration down dip of permeable sand. The deep unoxidized deposits exhibit well developed roll-type ore bodies along oxidation-reduction boundaries. Genetic factors presumed to be common to these deposits are: (1) a source of uranium from the diagenetically altered tuffaceous sedimentary rocks, (2) dissolution and transportation of uranium by the alkaline carbonate pore-waters of the ash, (3) precipitation of uranium in reducing environments caused principally by hydrogen sulfide and in part by organic matter where waters were retarded by lenticular, clayey or structural barriers, and (4) preservation from leaching by such features as a caliche cap developed during an arid climate. Four principal geologic environments of uranium ore in South Texas are: (1) in nearshore sandstones sandwiched between less permeable beds and overlain unconformably by tuffaceous deposits, (2) in sandstones interfingering with claystones along the sides of major paleo-stream-channel deposits, (3) in sandstone near faults along which natural gas containing hydrogen sulfide has migrated, and (4) in sandstone above the sulfurous caprock of a salt dome. (JMT)

<169>

MacKevett, E.M., Jr.; USGS, Menlo Park, CA

Geology of the Ross-Adams Uranium-Thorium Deposit, Alaska. In *Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Vol. 2, Survey of Raw Material Resources*, held in Geneva, Switzerland, September 1-13, 1958. United Nations, New York, (pp. 502-508), 843 pp. (1958)

The Ross-Adams deposit is an uncommon type of uranium-thorium deposit which forms a gently inclined crudely fusiform body in which uranothorite and uranoan thorianite constitute the chief ore minerals. In general, the Ross-Adams ore body consists of a core of high-grade ore that contains greater than 0.50% U₃O₈ enveloped by a uraniferous zone from 2 to 20 feet thick that contains less than 0.50% U₃O₈. The ore minerals occur both in veinlets and scattered throughout the alkali granite of the lode. Besides the uranium-thorium minerals, the veinlets contain abundant hematite, and less amounts of calcite, fluorite, pyrite, galena, quartz, and chlorite. Pyrite and galena are locally abundant in veinlets near the crosscutting faults. Secondary uranium minerals occur in minor amounts in near-surface environments. They include gummite, sklodowskite, beta-uranophane, bassettite, and novacchite. The formation of the Ross-Adams deposit is believed to be attributable to two processes, a local concentration of late-stage accessory uranothorite and uranoan thorianite in the alkali granite, followed by the emplacement of numerous uranium- and thorium-bearing veinlets at the site of the lode. The causes of the local concentration of the accessory uranium-thorium minerals are not well understood. Except for the quantity of the uranium-thorium minerals, the numerous veinlets, and the lack of potassium, the properties of the host alkali granite of the lode are similar to its unmineralized counterparts. There are no recognizable structural features that would favor the accumulation of the accessory uranium-thorium minerals at the site of the deposit. One or both of the crosscutting faults probably acted as channel-ways from which the ore-bearing veinlets emanated. It is postulated that these faults had at least two periods of activity, and that they were open channels for the active hydrothermal solutions which formed the ore-bearing veinlets. Later movements on them offset the ore body. Indications that these faults may have been channel-ways are that the ore deposit attains its widest dimension near the faults, that finely crushed ore and vein mineral are found along them, and that local small deposits of uranium-thorium minerals, fluorite, hematite, and rare earths occur along similar faults nearby. (JMT)

<170>

Stephens, J.G.; USGS, Washington, DC

Geology and Uranium Deposits at Crooks Gap, Fremont County, Wyoming. USGS Bulletin 1147-F, 87 pp. (1964)

Commercial uranium deposits were found in the Crooks Gap area in 1954 and by 1955 three mines were producing uranium ore in the area. The near surface deposits are erratically distributed, generally less than 20 feet across, only a few feet thick, and generally concordant with bedding. Exposed rock containing uranium in commercial quantities is confined to the lower folded member of the Battle Spring formation of Eocene age. It consists of sandstone impregnated with uranophane, autunite, minor amounts of uraninite, coffinite, and metatyuyamunite, and sandstone having no visible uranium minerals. Uranium also occurs in gouge along thrust faults at the northeast side of Crooks Gap. Rocks exposed in the area range in age from Precambrian to Recent. The Precambrian rocks, consisting predominantly of granite, crop out in a discontinuous band trending eastward across the central part of the area. Paleozoic rocks, about 2,065 feet thick, consist of limestone and sandstone containing some shale and are exposed only adjacent to faults in the central and east-central parts of the area. Rocks of Mesozoic age, exposed in the central and east-central parts of the area, consist largely of shale and beds of sandstone and are about 8,900 feet thick. Rocks of Cenozoic age are present over most of the Crooks Gap area. The Fort Union formation of Paleocene age is 0 to 540 feet thick and consists mostly of mudstone and some lenticular beds of conglomerate and sandstone in the lower part. The formation unconformably overlies the Cody Shale of Late Cretaceous age and is unconformably overlain by the Battle Spring formation of Eocene age. Oligocene age deposits of tuffaceous clayey siltstone are exposed in an area of about half a square mile near the north end of Crooks Gap. Miocene rocks (Split Rock Formation) consisting of at least 950 feet of poorly consolidated tuffaceous sandstone and lenses of arkose cover most of the northern half of the area. Two factors are suggested as controls that influenced uranium deposition: (1) carbonaceous siltstone beds provided a local reducing environment where uranium might have been precipitated from uranium-bearing ground water; and (2) abrupt changes in permeability (caused by impermeable gouge along fault zones or by facies change from coarse-grained to fine-grained material) effectively controlled the pattern of circulation of the uranium-bearing ground water.

(JMT)

<171>

Not given; AEC, Washington, DC

Influence of Regional Structure on Uranium Occurrence in the Western United States. In Ninninger, R.D. (Ed.). *Exploration for Nuclear Raw Materials.* D. Van Nostrand, Inc., New York, (pp. 83-98), 293 pp. (1956)

The Cordilleran Foreland is a region containing distinctive structural elements that forms a broad north-south belt parallel to and east of the Cordilleran anticline. Uranium deposits within the Foreland are widely distributed throughout the region as disseminated uranium and uraniferous lignites in the sedimentary rocks of the basins, and as veins in the crystalline cores of mountain ranges. The lithology of some Mesozoic rocks of the Foreland exhibits a close relation to structure on both regional and local scales. Most of the known uranium districts within the Foreland are in four structural environments: (1) areas near major basin axes along northwest-trending large-scale structures; (2) areas in which northwest- and northeast-trending intermediate-scale structures intersect; (3) areas in which groups of an echelon, northwest-trending intermediate-scale structures are superimposed on northeast-trending large-scale structures; and (4) areas over or near large faults or fault zones in Precambrian rocks, associated with northeast-trending large-scale structures. The regional tectonic pattern has only little direct relationship to the distribution of uranium and related deposits in the Colorado Plateau. Tectonic events of the past, probably as far back as Permian time, have had a most important bearing on the distribution of the ore. The principal factors of direct control are (1) provenances and environments of sedimentation, (2) paleohydrology, (3) igneous activity, and (4) erosional history. Although mineralization occurs in almost every formation of the stratigraphic section, the great preponderance of known commercial reserves and output of ore are from three relatively thin stratigraphic intervals within the Morrison, Chinle, and Shinarump formations. Most of the deposits have been oxidized or modified to some extent by ground water, and there are few deposits on the Plateau that are unquestionably hydrothermal by reason of being on fissures or connected directly to

mineralized fissures. (JMT)

<172>

Beecraft, G.E.; USGS, Washington, DC

Uranium Deposits of the Boulder Batholith, Montana. In USGS Professional Paper 300, (pp. 117-121), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 270-274), 825 pp. (1956)

Uranium minerals and radioactivity anomalies occur in silver-lead veins and chalcedony veins in the Boulder batholith of southwestern Montana. Many silver-lead veins in the batholith contain radioactive material, and pitchblende has been identified in a few. No anomalous radioactivity or uranium minerals have been found in similar veins in prebatholithic rocks of the area. Chalcedony veins, some of which are uraniferous, are distinctly different from the silver-lead veins and with a single exception are known only in the batholith. The veins consist of one or more discontinuous stringers or veins of chalcedony and slightly coarser grained quartz in silicified and sericitized quartz monzonite, granodiorite, and in less strongly altered alaskite. Only small amounts of silver ore have been produced from these chalcedony veins. All of the veins are early Tertiary in age, but the silver-lead veins are probably older than the chalcedony veins. Uranium is closely associated with chalcedony in both types of veins. The association suggests that all of the uranium in the area is of the same age. If so, some of the silver-lead veins must have been reopened during the period of chalcedony vein formation. (Auth)(MBW)

<173>

Adler, H.H.; AEC, Washington, DC

Concepts of Uranium-Ore Formation in Reducing Environments in Sandstones and Other Sediments. In Proceedings of a Symposium on the Formation of Uranium Ore Deposits, held in Athens, Greece, May 6-10, 1974. International Atomic Energy

Agency Publications, Vienna, Austria, (pp. 141-168), 748 pp. (1974, November)

Sandstones contain nearly a third of the world's resources and in excess of 95% of the US reserves. Uranium mobility in solution in permeable sediments is governed by the stability of its two natural valence states, U4+ and U6+. In its two most important ore minerals, uraninite and coffinite, uranium occurs largely in the tetravalent state. These compounds are stable under reducing conditions, but under oxidizing conditions, they are rendered soluble. In the presence of vanadium ions or ionic complexes, stable uranyl vanadates such as carnotite and tyuyamunite are likely to form, but if reducing conditions are re-encountered, the uranyl ions may be re-reduced from U6+ to U4+, causing uranium precipitation and renewed accumulation. In the absence of suitable reductants or absorbents, uranium may move through the ground water system to be dissipated. Sandstones containing coalified plant remains, humate substrates, pyrite, or hydrogen sulfide make suitable host rocks for uranium ore deposits. The major deposits in sandstone are classifiable into peneconcordant and roll types on the basis of morphological relationships. From a genetic standpoint, roll-ore deposits may be divided into four principal types. These are the Wyoming-type, which is associated with a prominent redox interface created by oxidation of indigenous stone; the Entrada- or Rifle-type, which attributes to diffusion of H2S and ore-forming cations towards a stationary interaction zone separating a trapped oil or gas pool from wedges of fresh water which press against and confine the location of the hydrocarbon-H2S-bearing medium and its reaction interface; and the Texas-type, which is formed by H2S introduced along faults into the host sands from underlying gas and oil deposits. Redistribution deposits formed by reworking of pre-existing tabular deposits in the Grants, New Mexico area are genetically classified with the Wyoming-type rolls. Ore deposits in eolian sandstones are identified with a bleached zone overlying the normally red facies of the host rock. At Grants and Placerville, and in the intervening San Juan Basin, the bleaching appears to be related to H2S development in the Todilto sea immediately following the end of Entrada deposition. Tabular (peneconcordant) deposits are also classifiable according to the nature and source of the reductant controlling ore deposition. Deposits associated with introduced humate substances make up a substantial part of US resources. Sandstones and

other classic sediments may play a role in uranium-ore formation by serving as paleoquifers which conduct uraniumiferous ground waters in adjoining less permeable sediments containing suitable reductants. (Auth)(JMT)

Cited as a reference in NURE Contractor Reports.

<174>

Augustinidis, S.S., E. Mposkos, and A. Vgenopoulos; National Technical University of Athens, Athens, Greece

Geochemical and Mineralogical Studies of Euxenite and Its Alteration Products in Graphitic Pegmatites from Harar, Ethiopia. In Proceedings of a Symposium on the Formation of Uranium Ore Deposits, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria. (pp. 61-71), 748 pp. (1974, November)

Metamictic euxenite occurs in a graphitic pegmatite from Harar, Ethiopia. Owing to differential leaching by chemical weathering of the euxenite, an alteration margin has been produced, which is relatively depleted in Nb and U in comparison with the unaltered euxenite. In this alteration margin there is relatively more Y and Ti. Mineralogically the alteration margin includes relics of euxenite, anatase and perhaps ampaugheite. Additional studies showed that by heating the metamictic euxenite to 580 degrees C, some lattice restoration occurred; however, complete euxenite lattice restoration occurred at 770 degrees C. (Auth)

<175>

Smith, E.E.N.; Eldorado Nuclear Limited, Ottawa, Ontario, Canada

Review of Current Concepts Regarding Vein Deposits of Uranium. In Proceedings of a Symposium on the Formation of Uranium Ore Deposits, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria. (pp. 515-529), 748 pp. (1974, November)

The primary uranium mineral filling cracks,

fractures, pore spaces, breccias and stockworks is pitchblende, a thorium-deficient variety of uraninite. A wide range of rocks may contain vein uranium suggesting that, in some cases, it is the structural trap created by the rock rather than its chemical composition which makes it a suitable host. Vein deposits form an integral part of the uranium geochemical cycle which includes all types of uranium deposits, and which governs the repeated transport and deposition of uranium from one geological setting to another. Because of this cyclic interdependence, different types of deposits may be found together within a specific uranium province. In Canada, uranium in veins, pegmatites and sediments may all be found in the geosynclinal belts surrounding provinces and sub-provinces of the Precambrian shield. More than one type is invariably present within a small area, although all types may not form one bodies. Age determinations on several deposits within a specific setting often indicate a long period of repeated concentration, transportation and redeposition such that the same uranium may have occupied different deposits during different periods of the cycle. Two major periods of the earth's geological history appear to have provided the original setting for most of the world's deposits of uranium in veins. These are the Carboniferous-Permian period and the Middle Proterozoic period. In both cases the first vein pitchblende was deposited during a period of long and intense weathering. Some geologists feel that repetition of these exogenic conditions has moved and redeposited the uranium several times up to the present. Other geologists consider that the uranium is carried to its host from a fertile source by thermal waters which may originate from late stages of granitic evolution or from acid volcanism. (Auth)

<176>

Martin-Delgado Tamayo, J., and J.A. Fernandez Polo; Junta de Energia Nuclear, Madrid, Spain

Analogías y Diferencias de Conductas de Favonibilidad en Distintos Terranos Sedimentarios de la Cordillera Iberica. In Proceedings of a Symposium on the Formation of Uranium Ore Deposits, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria. (pp. 479-491), 748 pp. (1974, November)

The paper describes the geological features of the Iberian cordillera and its adjacent zones where prospecting and exploration of uranium deposits in sedimentary formations are now in progress. The most significant data and the standards which can serve as a guide in evaluating the nature and degree of favorability are specified. A description is given of the best-known types of deposits and their similarities to, and differences from, other localized anomalies. Thus the Picoñeres type in the Lower Cretaceous of Spain, the Mazarette type in the Lower Triassic, the Miocene paleochannels of Palencia and the lignite-containing basins are defined. (Auth)

<177>

Rich, R.A., H.D. Holland, and U. Petersen; Harvard University, Cambridge, MA

Vein-Type Uranium Deposits.
AT(85-1)-1640, 383 pp.; GJO-1640, 383 pp. (1975)

The report is a critical review on the mineralogy, paragenesis, geochemistry, and origin of vein-type uranium deposits. During the formation of vein-type and sandstone-type deposits uranium seems to have been dissolved by and transported in oxidized solutions, and deposited where these solutions encountered reducing agents such as carbon, sulfides, ferrous minerals and hydrocarbons. Granitic rocks abnormally enriched in uranium have apparently been the most common source for uranium in vein-type deposits. Surface solutions saturated with atmospheric oxygen have frequently passed through red bed or clear sandstone conduits on their way to and from uranium source rocks. Deep solutions of non-surface origin have apparently become sufficiently oxidizing by passage through and equilibrium with red beds. (Auth)(MBW)

Cited as a reference in NURE Contractor Reports.

<178>

Young, P., and D.G. Mickle; Bendix Field Engineering Company, Grand Junction Operations, Grand Junction, CO

Uranium Favorability of Tertiary Rocks

in the Badger Flat-Elkhorn Thrust Area, Park and Teller Counties, Colorado.
GJRX-54(76), 30 pp. (1976, October)

Uranium potential of Tertiary rocks in the Badger Flats - Elkhorn Thrust area of central Colorado is closely related to a widespread late Eocene erosion surface. Most uranium deposits in the area are in the Eocene Echo Park Alluvium and Oligocene Tallahassee Creek Conglomerate, which were deposited in paleodrainage channels on or above this surface. Arkosic detritus within the channels and overlying tuffaceous sedimentary rocks of the Antero and Florissant Formations of Oligocene age and silicic tuffs within the volcanic units provide abundant sources of uranium that could be concentrated in the channels where carbonaceous debris facilitates a reducing environment.

Anomalous soil, water, and stream-sediment samples near the Elkhorn Thrust and in Antero basin overlie buried channels or are offset from them along structural trends; therefore, uranium-bearing ground water may have moved upward from buried uranium deposits along faults. The area covered by rocks younger than the later Eocene erosion surface, specifically the trends of mapped or inferred paleochannels filled with Echo Park Alluvium and Tallahassee Creek Conglomerate, and the Antero Formation are favorable for the occurrence of uranium deposits. (Auth)

<179>

Keller, W.D.; USGS, Washington, DC

Clay Minerals in the Morrison Formation of the Colorado Plateau. USGS Bulletin 1150, 90 pp. (1962)

More than 500 samples of mudstone and sandstone were collected from 23 selected stratigraphic sections of the Morrison formation on the Colorado Plateau, so that the clay minerals in the formation could be studied. The purposes of the investigation were to determine: (1) whether the clays were related to the genesis of the ore deposits, (2) whether the clays could be used as guides to uranium deposits, and (3) what the clays might contribute to the understanding of the geologic history of the Morrison formation. The stratigraphic sections were chosen to include some from which uranium ore was produced, some that were nonproductive although within a mining

district, and some from presumably barren areas which might serve as controls. Within the Morrison formation, the Salt Wash sandstone member is characterized predominantly by the illite, or hydrous mica, group of clay minerals. In northwestern New Mexico, the Recapture shale member of the Morrison and the underlying Bluff sandstone correlate and intertongue with the Salt Wash member. The Recapture member contains illite in the northwest corner of the state, an abundance of montmorillonite at Thoreau, New Mexico, and commonly, mixed-layer clay minerals east of Thoreau. These clay-mineral changes are interpreted as facies variations resulting from different source rocks. The Bluff sandstone, although scanty in clay content, yields montmorillonite in its clay-size fraction. The Brushy Basin shale member of the Morrison is characterized in the northwestern part of the Colorado Plateau by a predominance of montmorillonite, but illite, chlorite, and mixed-layer clay minerals increase relatively in amount and become prominent toward the south. Illite, chlorite, and mixed-layer clay minerals are prominent as well in the Westwater Canyon sandstone member of the Morrison, which intertongues with the Brushy Basin member in New Mexico. The similarity in clay-mineral composition of the two members leads to the interpretation that part of the mudstone of the Brushy Basin is a clay facies of the Westwater Canyon member. (JMT)

<100>

De Nault, K.: Stanford University,
Stanford, CA

Sandstone-Type Uranium Deposits in Wyoming. In Ph.D. Dissertation, *Origin of Sandstone Type Uranium Deposits in Wyoming*, Chapter 3. (pp. 25-93), 352 pp. (1974)

The principal uranium-producing districts in Wyoming are the Gas Hills, Crooks Gap, and Shirley Basin districts. These districts are situated around the flanks of the Granite Mountains: Gas Hills along the north, Crooks Gap along the south, and Shirley Basin along the east. The host rock for the uranium mineralization in both the Gas Hills and Shirley Basin districts is the Wind River Formation, a coarse-grained arkosic sandstone. The host rock in the Crooks Gap district is the Bottle Spring Formation, a unit that is

lithologically similar to the Wind River Formation, but one that was deposited somewhat earlier. Uranium mineralization occurs in a particular geometric shape called a roll in all the districts in Wyoming. In cross section the roll is a crescentic area of mineralization in which the concave side encloses altered ground and the convex side points toward unaltered or "fresh ground". There is usually more than one roll in each district. There are two major rolls in the Shirley Basin, several in the Gas Hills, and many in the Powder River Basin. Color differences between fresh and altered ground were early recognized as an important prospecting tool. Color contrasts vary from district to district and the cause of these color changes is not completely understood. In surface outcrops, color contrast is often spectacular, but unoxidized deposits found at depth commonly have color differences only in shades of gray, which are difficult or impossible to distinguish in rotary drill cuttings. Below the water table, uraninite, sometimes accompanied by minor amounts of coffinite, is the primary uranium bearing mineral in the rolls. It is found as fine-grained to sooty coatings on sand grains, filling interstices between grains and occasionally filling fractures in grains. Uranium mineralogy is quite simple as long as the deposit remains below the water table, but if the deposit is exposed to surface oxidation, a host of secondary uranium-bearing minerals may form. Selenium is a characteristic associate of uranium in sandstone-type uranium deposits in Wyoming. It may occur in the native state, as ferroselite, as a substitute for sulfur in pyrite, or some combination of the three. Pyrite is usually present in fresh ground, absent in altered ground, and concentrated in the roll with uranium. Calcite, along with selenium and pyrite, is also a characteristic associate of uranium in the roll-type deposits. Organic matter consisting of plant debris locally concentrated or dispersed through the sediments constitutes a small but important fraction of the host units. In fresh ground, organic matter is generally coalified but in altered ground this material has been partly or completely decomposed. In places, uranium rolls are located in areas of highest organic carbon content. In the principal districts, the time of ore precipitation within the host sands is known with various degrees of certainty. One problem is that both uranium and its daughter products may be mobilized, creating difficulties in obtaining radiometric age dates. The youngest district is apparently the Gas Hills with an age of 150,000 to 170,000 years for primary uraninite and 11,000 to 16,000 years for secondary

minerals. On the basis of geologic data, it has been postulated that mineralization at Crooks Gap occurred following subidence of the Granite Mountains in Pliocene or post-Pliocene time. In the Shirley Basin, attempts to obtain an age using total lead-uranium ratios have given ages from 10 to 40 million years with an average of 18 million years. Three sources of the uranium in the Wyoming deposits have been proposed: (1) hydrothermal solutions, (2) the Granite Mountains, and (3) volcanic ash. At the present time, only the latter two postulated sources are considered viable. Theoretically, the Granite Mountains have been leached of sufficient uranium to account for all known Wyoming deposits but the range is not now yielding uranium to groundwater even in areas of known Precambrian uranium mineralization. Springs and wells in Miocene and younger tuffaceous sediments have anomalously high uranium concentrations of uranium, and in the opinion of the author, present data strongly favors volcanic ash as the primary source of uranium in these deposits. From whatever its source the transportation of uranium to sites of deposition, is almost universally believed to have been accomplished by meteoric groundwaters. (JMI)

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Altschuler, Z.S., E.B. Jaffe, and F. Cuttitta; USGS, Washington, DC

The Aluminum Phosphate Zone of the Bone Valley Formation, Florida, and Its Uranium Deposits. In USGS Professional Paper 300, (pp. 495-504), 739 pp., 1. Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 507-513), 825 pp. (1956)

The Bone Valley Formation was altered by weathering and ground water, and the vertical changes through the aluminum phosphate zone show a progressive change in mineralogy and texture. Much apatite and clay have been leached and replaced in the aluminum phosphate zone, and its rock is generally white, friable, and highly porous; however, its character has been greatly influenced by the Bone Valley petrography. Thus, where graded bedded pebbly rock is altered, coarse,

frequently graded vesicularity results, where massive clayey sand is altered, fine porosity prevails, and aluminum phosphates are more common. The uranium content of unaltered rock of the lower part of the Bone Valley is approximately 0.004 percent, its P_2O_5 content is about 15 percent. Unaltered rock of the upper part of the Bone Valley contains much less uranium and P_2O_5 . By contrast, a well-developed section of aluminum phosphate zone typically has 0.012 percent uranium and approximately 8-10 percent P_2O_5 . Within the aluminum phosphate zone, uranium increases as calcium does, and the more calcic phosphates are more uraniferous. In addition, supergene process have caused a subzone of basal enrichment in the aluminum phosphate zone in which individual apatite specimens contain as much as 0.8 percent uranium. Except for a single trace occurrence of autunite, no uranium minerals have been found in the Bone Valley formation. (Auth)(JMI.B)

<182>

Denson, N.M., and J.R. Gill, USGS, Washington, DC

Uranium-Bearing Lignite and Its Relation to Volcanic Tuffs in Eastern Montana and North and South Dakota. In USGS Professional Paper 300, (pp. 413-418), 739 pp., 1. Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 464-467), 825 pp. (1956)

Field evidence indicates leaching of uranium from the tuffs and concentration in the underlying lignite. Lignites are believed to have acted as receptors that extracted uranium by ion exchange or by formation of organometallic compounds. Chemical analyses of water from the tuff show abnormal concentrations of uranium in association with arsenic, vanadium, molybdenum, and copper. An epigenetic theory of origin of the uranium in the lignite is supported by the fact that the mineralized beds, irrespective of their ages, closely underlie the unconformity at the base of the Oligocene and that greater uranium concentrations occur in the upper parts of the stratigraphically highest lignites. Analyses of approximately 500 surface and 1,000 core samples indicate that the

mineralized lignites contain 0.005-0.02 percent uranium with concentrations of 0.05-0.1 percent uranium in the lignite ash. Molybdenum is also closely associated with uranium in the lignite in concentrations ranging from 0.01 to 1.0 percent in the lignite ash. Although the uranium content is generally only 0.00%, the tonnages of lignite are great. The discovery of autunite- and meta-autunite-bearing lignite containing as much as 5 percent uranium in beds 18-30 inches thick in the Cave Hills area of northwestern South Dakota increases interest in lignite as an economic source of uranium and indicates other deposits of comparable grade may be discovered (Auth:MI B).

The conference paper is entitled "Uranium-Bearing Lignite and Its Relation to Volcanic Tuffs in Eastern Montana and the Dakotas".

<183>

Lee, M.J., University of New Mexico,
Albuquerque, NM

Mineralogy and Genesis of the Ore Deposits. In Ph.D. Dissertation, Geochemistry of the Sedimentary Uranium Deposits in the Grants Mineral Belt, Southern San Juan Basin, New Mexico, (pp. 31-78), 241 pp. (1976)

The mineralogy of the ore deposits in the Morrison Formation is discussed in some detail, and the minerals identified are divided into two categories: the authigenic minerals occurring within or close to the ore bodies, and the detrital minerals. Coffinite is the major uranium-bearing mineral in the Grants Mineral Belt (GMB). It is always closely associated with organic carbonaceous material in the deposits and is especially abundant in the black, vitreous, primary ore bodies. Coffinite has been synthesized in the laboratory in the pH range 7.5 to 10.7; below pH 7.5 only uraninite is produced, and uraninite is very rare in the GMB. A variety of other uranium bearing minerals have been found in the GMB. Most frequently found are uranium carbonates and sulfates, all in the hexavalent state. Included among these minerals are andersonite, schwetzingite, bayleyite, uranophane, tyuyamunite, and carnotite. No low-valence vanadium minerals, other than the clay minerals, were detected optically or from x-ray patterns in this study, but their occurrence has been reported in some unoxidized, redistributed ore

bodies. Amorphous black jordanite, MoS_2 , is commonly present in association with primary ore bodies, coating sand grains and mudstone and siltstone layers. No appreciable amount of molybdenum is found in the redistributed ore. Two iron sulfide minerals are found in the Morrison Formation of the GMB, pyrite and marcasite. Pyrite is the most common authigenic mineral in the formation, being commonly present in ore, in bleached sandstones, and in green mudstone pebbles and galls. Locally, marcasite aggregates are formed in fractures, and in or near ore as in intergrowths with pyrite. The marcasite is obviously a metastable transitional phase to pyrite, and it is not commonly found in the GMB. Two titanium minerals, anatase and rutile, have been microscopically identified in a few samples. Organic carbonaceous matter of probable lignin-derived parent origin is noted everywhere in the uranium deposits, usually in direct association with the ore. Two types of calcite found near the ore bodies bear probable genetic relationships to the chemical processes responsible for the ore formation. Layers of dense, calcite-cemented sandstone are particularly common a few feet below and above the lenticular ore pods. The other type of calcite is the so-called "buckshot calcite" which forms conspicuous spherules or shells near the edge of and within the primary ore bodies. The overall distribution pattern of the two calcites indicate that they are the product of probable buffering reactions associated with primary mineralization. Goethite and hematite coatings on sand grains cause the yellow and red colors in the sandstones of the Westwater Canyon Member, but most of the primary deposits are present in non-iron oxide bearing sandstones. Other authigenic minerals that have been found near the ore deposits are radiobarite and gypsum. The barite is mostly present in fracture zones associated with redistribution ore. The detrital minerals discussed are quartz, the feldspars, and the heavy minerals. It is believed that the mineralization occurred essentially at low pressure and temperature. Authigenic mineral assemblages, such as calcite, quartz over growth, and chlorite, indicate a low temperature process, and it has been shown that uranium solubility in carbonate solutions decrease considerably above 120 degrees C. The ore solution involved in transporting the uranium is believed to be groundwater. It has been shown that groundwater from volcanic and tuffaceous sediments may contain 250 ppb (approx. 10^{-6} molar) uranium. Thus if one considers the bentonitic mudstones of the Westwater Canyon

and Brushy Basin Members, or the arkosic material in them, as potential source rocks. 1000-4) metal of uranium would be a fair estimate for the ore-forming solutions. Water present in the Morrison Formation typically has pH values in the range of 7 to 9. Unless there was appreciable amounts of organic material, initial ore solution entering the Morrison sediments probably had a similar pH. Ore deposits occur in channel sandstones which are deposited in irregular depressions cut into bentonitic claystones and mudstones. Ore occurs in argillaceous sandstones in many places in preference to cleaner sandstones above or below, and mudstone and siltstone units nearly always underlie and frequently overlie the host sandstone units. Generally, the closer the mudstone layers, the higher the ore grade. The role of mudstone layers and partings in the host sandstones have been considered primarily as a plumbing system controlling the flow of groundwaters including the ore solution. Field observations, however, suggest that the argillaceous units played a major role in the precipitation of the organic carbonaceous materials and the uranium in the primary deposits (JMT).

- 184 -

Larsen, E.S., Jr., G. Phair, D. Gottfried,
and W.L. Smith; USGS, Washington, DC

Uranium in Magmatic Differentiation. In USGS Professional Paper 300, (pp. 65-74), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, *Geology of Uranium and Thorium*, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 240-247), 825 pp. (1956)

By means of fluorimetric uranium analyses of successive rock types, the path of uranium in differentiation has been traced throughout a wide variety of North American magma series. These include 4 plutonic calc-alkalic series—the southern California batholith, the Idaho batholith, the Sierra Nevada batholith, and the Boulder Creek batholith of Colorado; 1 predominantly hypabyssal calc-alkalic series having alkalic end products—the porphyry series of the Colorado Front Range; and 1 predominantly volcanic calc-alkalic series—the volcanic rocks and related small stocks of the San Juan Mountains. In addition, less complete

information has been obtained on rocks belonging to the so-called Modoc lavas of California and the alkalic rocks of the Highwood and Bearpaw complexes of Montana, Colorado, New Jersey and of the White Mountains of New Hampshire. With the exception of the Boulder Creek batholith all rocks studied are younger than Precambrian. Each such series has the structures and textures thought to be typical of magmatic rocks. In each of these comagmatic series the average uranium content is low (about 0.3 ppm) in the mafic rocks, increases steadily (about 20 ppm) in the rocks of intermediate composition, and reaches a maximum (about 50 ppm) in the granite. In some highly differentiated series the uranium content became enriched at least twofold and not uncommonly as much as twentyfold (100 ppm) over the average for calc-alkalic granite, an example is the porphyry sequence of the Front Range in which the differentiation did not cease at the granite stage but proceeded toward an end product extremely (CaO poor (as little as 0.0 ppm CaO) and rich in alkalis. Moderately radioactive accessory minerals such as zircon, sphene, and apatite together probably contribute less than 25 percent of the total uranium to any one rock. Sparse thorium-rich and uranium-rich accessory minerals—thorite, xenotime, monazite, and uraninite—have been found to be more widespread than formerly supposed and account for an appreciable part of the total uranium content in certain granites. According to the present data, however, the rock-forming minerals themselves contain most of the uranium found in the rock. The uranium content of the quartz and feldspar is about half as much as the rock, and the dark minerals—hornblende, biotite, and magnetite—are enriched many times, much, but not all, of this uranium can be leached from the rock-forming minerals by weak acid. The fact that the maximum uranium enrichment in any one rock series is found in the youngest member, coupled with the ready leachability of much of the uranium, indicate that a substantial part of the uranium is "late". The same data show that not only the total uranium content but the amount of leachable uranium change in a roughly systematic way with rock composition and point to a predominantly petrogenetic control. In contrast to the rocks already described, the one Precambrian complex studied, the Boulder Creek batholith, shows maximum enrichment in uranium in the early quartz diorites, less in the rocks of intermediate composition, and a minimum in the granites. The uranium-rich quartz diorites are largely concentrated along the outer margins of the

batolith and there is considerable evidence of reaction with and assimilation of metasedimentary wall rocks (Auth)

- 185 -

Patterson, F. D., USGS, Washington, DC

**Radioactivity of Part of the Bituminous
Coal Region of Pennsylvania** H-479, 44
pp (1954, November)

Samples of the commercially important coal beds and associated rocks in the Pottsville, Alleghany, Conemaugh, and Monongahela series of the Pennsylvania series were collected from 104 localities in western Pennsylvania. The coal and associated rocks examined and sampled at 103 places were nearly nonradioactive and are interpreted to contain essentially no uranium. Radioactive coal was found at only one locality in Clearfield County where the upper 0.4 foot of the Lower Freeport coal bed (32 feet in thickness) contains an average of 0.019 percent uranium (Auth)

PROSPECTING

<186>

Wantland, D., U.S. Bureau of Reclamation, Washington, DC

Geophysical Investigations for United States Atomic Energy Commission in the Colorado Plateau Area U.S. Bureau of Reclamation Geologic Report G-119, 151 pp. (1952)

Geophysical field investigations were conducted at King Tuttle Mesa, Apache County, Arizona and at Bull Canyon, Montrose County, Colorado. The resistivity method was used in both areas, and the potential drop ratio method was unsuccessfully tried in a part of the Bull Canyon area. Areas of high resistivity can be correlated with areas of ground favorable for the occurrence of uranium deposits. The field procedures employed are described, and resistivity depth curve plots are included. (Auth)

<187>

Wantland, D., and R.D. Casey, U.S. Bureau of Reclamation, Washington, DC

Field Tests for the United States Atomic Energy Commission on the Use of the Seismic Geophysical Method for Tracing "Buried Channels" in the Monument Valley Area, Arizona U.S. Bureau of Reclamation Geologic Report G-123, 68 pp. (1952)

Seismic methods of geophysical prospecting as applied to the mapping of buried channels in which uranium ore might occur were investigated. It was tentatively concluded that the seismic refraction method could be usefully applied in connection with and in advance of drilling to outline these channels. The seismic reflection method proved unsuitable for this purpose. (Auth)

<188>

Kamiyama, T., S. Okada, and Y. Shimazaki, Power Reactor and Nuclear Fuel Development Corporation, Tokyo, Japan, Japan Geological Survey, Tokyo, Japan

Exploration of Uranium Deposits in Tertiary Conglomerates and Sandstones in Japan In Proceedings of a Panel on Uranium Exploration Methods, held in Vienna, Austria, April 10-14, 1972. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 45-54), 320 pp., IAEA-PI-490/31, (pp. 45-54), 320 pp. (1973, November)

In Japan there are two uranium mines, the Ningyo-toge mine and the Iino mine, which occur as percolant uranium concentrations in the basal part of Neogene formations immediately overlying a Mesozoic granitic basement. The uranium concentrations occur in the depressions of the granite surface which are considered to be former river channels. These deposits were discovered as a result of an extensive airborne radiometric survey designed to cover the entire country; subsequent exploration employed various methods. Detailed mapping coupled with geophysical methods provided data on the extent of the ore-bearing horizons and the topography of the basement surface. Drilling was carried out extensively. A large-size-diameter, mud fluid method was applied to produce maximum core recovery and succeeded in obtaining perfect core samples even in hard sedimentary rock. Exploratory tunneling provided the final dimensions and the grade of the ores. Basic studies of the geochemistry and mineralogy of the ores, and of the petrology of the granitic rocks which are considered to be the source of the uranium, proved invaluable for exploration, since they yielded detailed understanding of the nature of the deposit and the ores. (Auth)(M.I.B.)

<189>

Ketola, M., and R. Sarikola, Outokumpu Company, Tapiola, Finland

Some Aspects Concerning the Feasibility of Radiometric Methods for Uranium Exploration in Finland In Proceedings of a Panel on Uranium Exploration

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Methods, held in Vienna, Austria, April 10-14, 1972. International Atomic Energy Agency Publications, Vienna, Austria, (pp 31-43), 320 pp., IAEA-PI-490 11, (pp 31-43), 320 pp. (1973, November)

Systematic exploration for uranium has been carried out on a rather small scale, and has been concentrated mainly on extensive quartzitic areas. The exploration has been based mainly on the search for boulders, a method in which the boulders loosened from the bedrock by glacier ice or frost are traced and used for the localization of the outcropping mineralization. To localize the source of the boulders or radioactive anomaly, systematic radiometric mapping, radon measurements or geological detail mapping are employed. Also, the feasibility of employing airborne radiometric methods as well as radon determinations has been evaluated without very positive results. (MI.B)

[190]

Ristic, M., Institute of Geological and Mining Exploration and Investigation of Nuclear and Other Mineral Resources, Materials, Belgrade, Yugoslavia

The Discovery and Investigation of Blind Deposits of Uranium. In Proceedings of a Panel on Uranium Exploration Methods, held in Vienna, Austria, April 10-14, 1972. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 249), 320 pp.; IAEA-PI-490 8, (pp. 249), 320 pp. (1973, November)

In many parts of the world there are no more outcropping deposits, but it is probable that blind deposits exist. Such deposits are located using methods very different from conventional ones. To discover economic but blind uranium deposits, the prospective areas should first be examined by metallogenic analysis. In the case of endogenous deposits, structural maps, lithological maps and maps showing the level of erosion must be prepared. Following this the dispersion haloes of U, Hg, I, Li and other chemical elements and the alteration zones of the country rock should be investigated in relation to geology and structure. In the case of exogenous deposits, geological maps and maps of the extent of erosion of the overall petrogenic complex are drawn up. Subsequently,

maps showing the distribution of the facies and paleogeographical reconstruction are produced. The paleorelief, circulation of subterranean water, location of the water table and sedimentological structures are studied, and the position of the shore line and the direction in which clastic material is transported are determined. Insofar as the results of these investigations indicate the possible existence of uranium-bearing petrogenic complexes, research is then carried out on the dispersion of U, Ra and Rn in the water, alluvium and rocks. The radioactive pattern associated with the lithostratigraphic column of the rocks is determined. Finally, an attempt is made to discover the depth of host structures by means of geophysical prospecting, and also any evidence of uranium recycling. On the basis of such results prognostic maps are compiled and the work required to discover and investigate a blind deposit of uranium is determined. Such work may consist of drilling, mining exploration and associated operations. (Auth)

[191]

Dall'Agnol, M., Laboratorio Geomineralogico del CNEN, Geochemical Group, Casaccia, Rome, Italy

Geochemical Exploration for Uranium In Proceedings of a Panel on Uranium Exploration Methods, held in Vienna, Austria, April 10-14, 1972. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 189-208), 320 pp.; IAEA-PI-490 10, (pp. 189-208), 320 pp. (1973, November)

Geochemical prospecting has to do mainly with detecting secondary dispersion haloes, which are formed around mineral deposits during the disintegration of the elements concentrated there. In the zones under investigation it is possible that deposits in the stage of supergene dispersion are present. In this case geochemical prospecting can easily detect the secondary dispersion haloes. But it is just as likely that minerogenetic processes are occurring. Even though detecting active minerogenetic processes are not as easy as detecting secondary haloes, geochemistry applied to mineral exploration definitely has to deal with this problem also. In planning the application of the various geochemical techniques of exploration, keep in mind the following characteristics of this method:

(a) polymetallic surveys are the most logical and convenient type of application of geochemical exploration. (b) each of the various geochemical techniques must be employed using a sampling grid density proportioned to the dimensions of the various types of the dispersion haloes. In particular, the best application of geochemical exploration is in large scale surveys. (c)

geochemical prospecting is an essentially direct exploration technique. Geochemical exploration is the only direct approach to the problem of mineral exploration because its subject matter is precisely the distribution and circulation of the elements searched for. This method of exploration permits the most direct link of ore genesis studies with exploration. (M.I.B.)

< 192 >

Adler, H.H., AEC, Washington, DC

Exploration for Uranium in Sandstones: Geochemical, Remanent Magnetic, and Sulphur-Isotope Applications In

Proceedings of a Panel on Uranium Exploration Methods, held in Vienna, Austria, April 10-14, 1972. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 155-169), 320 pp., IAEA-PL-490 1, (pp. 155-169), 320 pp (1973, November)

Most of the uranium ore mined in the United States has been deposited at reduction-oxidation interfaces in fluvial sandstones as a result of oxidation of pyritic carbonaceous facies. The ore-forming process produces large tongues of oxidative alteration which extend from the surface downward to the redoxite facies. Radioactivity and spotty mineralization at the surface reflect the presence of ore bodies at depth, but where these manifestations are absent other characteristics measurable in the outcrop of red or drab sandstones may be useful in evaluating favorability for ore. Natural remanent magnetic properties, such as anomalous pole orientations or absence of remanent magnetism in Eocene or older fluvial red-bed sandstones, may conceivably reflect relatively recent oxidation leading to ore formation at depth. The observed absence of magnetite and maghemite in presently oxidized sandstone can be attributed to reduction or leaching of these iron oxides by ore-forming processes. Unusually negative delta S 34 values for sulphate sulphur in

surface gypsum, whole-rock samples or groundwater may indicate the presence at depth of S 32-enriched pyrite with which uranium deposits are associated. (Auth)(M.I.B.)

< 193 >

Lovborg, L., Danish AEC Research Establishment Risø, Roskilde, Denmark

Future Development in the Use of Gamma-Ray Spectrometry for Uranium Prospecting on the Ground In

Proceedings of a Panel on Uranium Exploration Methods, held in Vienna, Austria, April 10-14, 1972. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 141-153), 320 pp., IAEA-PL-490 4, (pp. 141-153), 320 pp (1973, November)

The significance of a uranium anomaly can often be most readily estimated from gamma spectrometric measurements of the ratio between the concentration levels of uranium, thorium, and potassium. This technique lends itself to remote sensing from aircraft, surveying by car or on foot, and examination of collected material. Although gamma spectrometric prospecting for uranium is most economically carried out from aircraft, ground surveying must also be considered an expedient technique, especially where aeroradiometric surveying is impracticable. The future field gamma spectrometer will be easily carried and capable of measuring radionuclide concentration levels, expressed in ppm U, ppm Th, and % K, in the course of a few minutes. Statistically meaningful radionuclide determinations can only be made if sufficiently large scintillation crystals are used, so there is a lower limit to the size and weight of any usable gamma spectrometer. Successful use of portable gamma spectrometers depends on the future availability of suitable calibration standards at strategic places in or near the world's major uranium districts. Future possibilities for fast interpretation of uranium anomalies are largely dependent on the efficiency in the use of digital computers for the processing of gamma spectrometric data. (Auth)(M.I.B.)

< 194 >

Matolin, M., Charles University, Faculty of Science, Prague, Czechoslovak Socialist Republic

Artificial Standards for Calibration of Airborne, Field Portable and Logging Gamma Spectrometers. In *Proceedings of a Panel on Uranium Exploration Methods*, held in Vienna, Austria, April 10-14, 1972. International Atomic Energy Agency Publications, Vienna, Austria, (pp 125-139), 320 pp., IAEA-PI-490 6, (pp 125-139), 320 pp. (1973, November)

Gamma spectrometers used in prospecting for uranium ores are calibrated at calibration stations which may be located on natural geological structures, or constructed by artificial standards. Artificial standards should fulfill the physical and geometrical conditions of calibration of field gamma spectrometers. The shapes and dimensions of the standards for airborne, field portable and logging spectrometers are different. The shape of the gamma spectrum, the intensity of gamma radiation and the influence of the composition of the standard on the values measured in calibrating the apparatuses are discussed. Problems concerning the standards containing loose material with a suitably chosen concentration of U, Th, and K, which is enclosed in a firm envelope, are presented and dealt with. The choice of material for manufacture of the standards, the radioactive equilibrium in the standards, the effect of the envelope of the standard and the dimensions and locations of the standards are treated separately. To enhance the accuracy of calibration, the radioactivity of the standards is chosen higher than that in rocks. The specified parameters of the standards for calibration of field gamma spectrometers can be applied in constructing a calibration base in an area where gamma-spectrometric measurements are to be carried out. (Auth)(M.I.B)

<195>

Davis, J.F.; Union Pacific Mining Corporation, Denver, CO

A Practical Approach to Uranium Exploration Drilling from Reconnaissance to Reserves. In *Proceedings of a Panel on Uranium Exploration Methods*, held in Vienna,

Austria, April 10-14, 1972. International Atomic Energy Agency Publications, Vienna, Austria, (pp 109-123), 320 pp., IAEA-PI-490 3, (pp 109-123), 320 pp. (1973, November)

Geological knowledge gained from the development of large uranium reserves in sandstone-type deposits, increased understanding of geochemical and sedimentary controls, low drilling costs and advanced logging techniques have led to the use of a relatively unusual combination of mineral exploration procedures. Guided by proven concepts, and hampered by lack of meaningful surface evidence, drilling has emerged as the primary means of providing access to data in all phases of exploration, from early reconnaissance to the final outlining of an ore body. With proper geological guidance, the drill hole and its samples provides stratigraphic, lithologic, structural, alteration, and geochemical data that is unattainable by any other means. Use of the rotary non-core drill in the early stages of exploration can eliminate much of the uncertain theorizing based on meager evidence, thus permitting rapid and relatively definitive evaluation of a potential area. Drill hole information provides definitive, three-dimensional evaluation at a relatively low cost for reserves established. Portable drill rigs capable of drilling over 600m per shift permit a total exploration cost of less than \$10 m. In the United States of America this type of exploration, guided primarily by continuing geological analysis, has led to the discovery of large amounts of uranium at a cost of less than \$2 kg. (M.I.B)

<196>

Miller, J.M., and D. Ostle; Institute of Geological Sciences, Radioactive and Metalliferous Minerals Unit, London, England, United Kingdom

Radon Measurement in Uranium Prospecting. In *Proceedings of a Panel on Uranium Exploration Methods*, held in Vienna, Austria, April 10-14, 1972. International Atomic Energy Agency Publications, Vienna, Austria, (pp 237-247), 320 pp., IAEA-PI-490 16, (pp 237-247), 320 pp. (1973, November)

All radon prospecting techniques are based on the

natural alpha radioactivity of radon and its immediate daughter elements, and the equipment employed to date detects either the alpha emissions themselves or the degree of ionization caused by these emissions. By far the majority of methods measure the alpha-sensitive phosphor.

silver-activated zinc sulphide. Radon-bearing soil gas, or gas samples stripped from water, are drawn into these by some form of pneumatic system and alpha radioactivities determined by viewing the scintillations produced in the phosphor by means of a photomultiplier. Signals are fed to a ratemeter or scaler. The methods of obtaining the sample and introducing it into the measuring chamber vary with individual equipment but soil air measurement instruments can be classified into alpha probes and pump monitors, while radon in water

measurements can be made only with pump monitors. Radon in ground air surveys have their greatest potential value in areas where promising indications of uranium mineralization already exist but in which the bedrock gamma radioactivity is masked by a layer of inactive overburden. Ground air radon determinations are most effective where this layer is of dry porous material and less than 10m thick. The measurement of radon

concentrations in ground, air, and surface waters is now an established uranium exploration technique. In the simple circumstances of a thin layer of dry arenaceous material overlying bedrock of low relief, the radon pattern obtained is a direct guide to the distribution of sub-outcropping uranium mineralization. Such specific and precise delineation of sub-outcropping uranium is outside the capability of any other technique. The most meaningful measurements are obtained in the deepest sampling holes and in this respect the vehicle-borne equipment, using power augers, has an advantage over portable instruments. The principal disadvantage of all radon equipment lies in their susceptibility to contamination by radon daughter elements. It must be emphasized that radon prospecting is concerned with a dynamic system depending upon a number of variables and it is therefore hazardous to attempt to arrive at an absolute basis for the interpretation of results. (M.I.B)

<197>

Faeth, H.: Bundesanstalt für
Bodenforschung, Hannover-Buchholz,
Federal Republic of Germany

**Hydrogeochemical Reconnaissance
Prospecting.** In Proceedings of a Panel on
Uranium Exploration Methods held in
Vienna, Austria, April 10-14, 1973.
International Atomic Energy Agency
Publications, Vienna, Austria, (pp
209-218), 320 pp, IAEA-PI-490 2 (pp
209-218), 320 pp (1973 November)

Hydrogeochemical reconnaissance prospecting by the chemical determination of uranium in springs, streams, and wells has the advantage that it can indicate uranium enrichments not only at the surface but also at depth. By modifying the procedure, this method was so improved as to be quicker and cheaper than airborne and carborne prospecting. The water samples are collected in 2-litre polyethylene bottles and are analyzed in the laboratory trailer by the following method: precipitation of the uranium by ferric hydroxide, separation from the disturbing elements by tributyl-phosphate, and determination of the uranium using a cathode-ray polarograph. About 70-90 analyses can be made per man and working day. Depending on the number of samples (max. 300/day) the mobile laboratory must be operated by one to four people of whom at least one must be an assistant chemist. The laboratory costs per sample is about US \$1. The costs of sampling depend mainly on conditions in the survey area, \$1.0 per sample under the most favorable, \$10.0 under the least. In all cases, only a qualitative evaluation of the general results is possible since, as a rule, there is no relation between the height of the uranium water anomaly and the size or degree of enrichment of the corresponding uranium deposit. For this reason this method is good, first of all, as a relatively certain negative indicator. This means that over a large region, using a widely spaced grid of sample points, areas are quickly demarked in which there is only a small chance of finding uranium. The areas which remain after this should be investigated intensively using radiometric and geological methods. (Auth)(M.I.B)

<198>

Bowie, S.H.U.: Institute of Geological
Sciences, London, England, United
Kingdom

**Methods, Trends and Requirements in
Uranium Exploration.** In Proceedings of a
Panel on Uranium Exploration Methods,

held in Vienna, Austria, April 10-14, 1972. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 57-65), 320 pp.; IAEA-PI-490 12, (pp. 57-65), 320 pp. (1973, November)

The main requirement of the future is the development of methods of detecting hidden ore bodies. Existing techniques will gradually improve through the normal processes of development: electronic miniaturization, for example: thus, making scintillation counters smaller, lighter, and more robust. Similar evolution will take place in the case of gamma spectrometers, whether portable or transportable. Geochemical and biogeochemical measurements both on the ground and from the air are likely to increase in importance in detecting ore bodies beneath overburden. For deeply buried ore, radon measurements, possibly combined with those of helium, offer the best hope. Further study is required in the use of novel techniques such as indicator elements, the measurement of radiogenic lead in non-radioactive minerals, and in the measurement of radiogenic heat. (MLB)

<199>

Martin-Delgado Tamayo, J., R. Arteaga Rodriguez, and J.A. Fernandez Polo; Junta de Energia Nuclear, Direccion de Geologia y Mineria, Madrid, Spain

Programa de Prospeccion de Yacimientos Uraniferos en Espana: Evolucion de Tecnicas y Metodos. In Proceedings of a Panel on Uranium Exploration Methods, held in Vienna, Austria, April 10-14, 1972. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 23-30), 320 pp.; IAEA-PI-490 5, (pp. 23-30), 320 pp. (1973, November)

The paper presents significant information on all aspects of radiometric prospecting, geochemical prospecting, surface studies, and studies carried out by means of boreholes, probes, and shafts. The paper also describes the main features of Spain's present program and its four-year plan for the immediate future. (Auth)(MLB)

<200>

Not given. International Atomic Energy Agency, Vienna, Austria

Uranium Exploration Methods. Proceedings of a Panel on Uranium Exploration Methods held in Vienna, Austria, April 10-14, 1972. International Atomic Energy Agency Publications, Vienna, Austria, 320 pp. (1973, November)

The International Atomic Energy Agency convened a Panel in Vienna, Austria, from 10 to 14 April 1972 with the objectives of reviewing available information on uranium exploration methods and formulating recommendations on future research and development of exploration techniques. The requirements of developing countries were also considered, including policy, types of programs, costs, and the application of the most appropriate exploration techniques to specific environments. Uranium exploration geologists from various parts of the world, with experience in using different types of exploration techniques, participated (MLB)

Cited as a reference in SURF Contractor Reports.

<201>

Cameron, J.; International Atomic Energy Agency, Vienna, Austria

The Exploration of Uranium Ore Deposits. Report on the International Symposium Held in Vienna from 29 March to 2 April 1976. Atomic Energy Review, 14(2), 415-420, (1976, June)

Papers of general interest pertaining to the major topics of exploration techniques, preliminary evaluation techniques, and research and development of exploration techniques were presented at the symposium. Working Group discussions were also considered to be of considerable success to the symposium. The highlights of new techniques and advances which have either been achieved in the last few years or are at the developing stages were presented and put into the major categories of remote sensing, technological advancements, and research and development efforts. (MLB)

<202>

Wright, R.J.; AEC, Grand Junction, CO

Prospecting with a Counter. U.S. Government Printing Office Publication, 68 pp. (1954)

Information is summarized on the operation and use of portable radiation detection equipment, such as Geiger counters and scintillation counters, suitable for prospecting for uranium. (Auth)

<203>

Not given, AEC, Washington, DC; USGS, Washington, DC

Techniques for Prospecting for Uranium and Thorium. In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp 752-755), 825 pp. (1956)

Successful prospecting and physical exploration for uranium and thorium requires a thorough knowledge of geologic, geochemical and geophysical techniques. The favorability of each distinct geological unit, within large areas not previously known to contain deposits of these elements, can be evaluated on the basis of existing knowledge. Preliminary geophysical reconnaissance of the favorable areas is best made by gamma radiation detectors carried by the geologist-prospector on the ground or in low-flying aircraft. These techniques locate only exposed or slightly buried deposits, but they commonly result in opening up new districts where concealed deposits are found by other methods. When ore minerals are not exposed soil, rock, water, and plant sampling, and panning are useful supplements to radiation and geologic criteria. In the search for deeply buried deposits useful structural, lithologic, and mineralogic guides have been determined for most major districts in the United States. Some of these, such as favorable structural and lithologic hosts, are effectively outlined by geophysical techniques. (Auth)

<204>

Bowie, S.H.U., and J. Cameron; Institute

of Geological Sciences, London, England, United Kingdom; International Atomic Energy Agency, Vienna, Austria

Existing and New Techniques in Uranium Exploration. In Proceedings of a Symposium on Exploration for Uranium Ore Deposits, held in Vienna, Austria, March 29-April 2, 1976. The International Atomic Energy Agency Publications, Vienna, Austria, (pp 3-13), 807 pp.; IAEA-SM-208/60, (pp 3-13), 807 pp. (1976)

A brief review is presented of the existing techniques and, of techniques which have not yet been used on an appreciable scale. Some fourteen techniques used over the last 30 years are identified and their appropriate application, advantages and limitations are briefly summarized and the possibilities of their further development considered. The aim of future research on new techniques, in addition to finding new ways and means of identifying surface deposits, should be mainly directed to devising methods and instrumentation capable of detecting buried ore bodies that do not give a gamma signal at the surface. (Auth)(PA6)

<205>

Bowie, S.H.U.; Institute of Geological Sciences, London, England, United Kingdom

Where to Prospect for Uranium. In Proceedings of a Technical Committee Meeting on Recognition and Evaluation of Uraniferous Areas, held in Vienna, Austria, November 17-21, 1975. International Atomic Energy Agency Publications, Vienna, Austria, (pp 151-164), 295 pp.; IAEA-TC-25/12, (pp 151-164), 299 pp. (1977)

A survey of some of the world's more important uranium deposits is presented and a number of deductions are drawn as to where the best area for uranium exploration are presented. The deposits discussed briefly include: (1) the oligomictic and polymictic conglomerates of the Witwatersrand, (2) the quartz-pebble conglomerates of Elliot Lake-Blind River, (3) the Kum Jungle-Arghar River province, (4) the Colorado-Wyoming

uranium province, (5) the uranium province of Agades (Niger), (6) the uranium province of Lake Frome-Yarramba (Australia), and (7) the uranium deposits associated with the Hercynian and Alpine orogenies. From the comparison of these deposits, it was concluded that the initial concentration of the lithophile elements, such as U, Th, Rb, and K, and the thickening of the crust in the environs of ancient cratons resulted in further additions from the mantle. This resulted in widespread remobilization of granitic rocks both by way of formation and deformation and the introduction of basic dykes. The latter are symptomatic of favorable uranium country since they are indicative of further crustal differentiation and of possible uranium metasomatism. The distribution of uranium in the silicic crust would not be expected to be uniform because of early crust mantle mixing by convective motion. Hence, provinces can be expected in which uranium is enriched and others in which uranium is depleted. Rock-forming minerals in uranium provinces may be enriched in radiogenic lead and, with modern high-throughput mass spectrometric equipment, isotopic determinations could throw some light on regions of uranium enrichment. Carbonaceous material has an almost ubiquitous association with uranium in sediments and as a result, all carbonaceous sediments occurring near an igneous source area are to be considered favorable for uranium development. Once a uranium province has been recognized, favorable tectonic or sedimentary features that permitted enrichment to ore grade need to be identified. The most important of these are major faults; unconformities; tectonic traps; trough and ancient stream channels; interfaces between different sedimentary facies such as shales and sandstones or sandstones and grits; the presence of more than usual abundances of carbonaceous material, particularly if forming continuous horizon; the presence of sulfides; and the existence of oxidation-reduction boundaries in sediments. Continental sediments, lacustrine, fluvio-lacustrine, fluvial, fluvio-deltaic, deltaic sediments and aeolian sandstones are more favorable host rocks than marine sediments; miogeosynclinal are more favorable than eugeosynclinal sediments; and the presence of redoxates is particularly indicative of suitability of the environment for uranium development. (JMT)

<206>

Not given; AEC, Washington, DC

Geophysical Prospecting. In Nininger, R.D. (Ed.), *Exploration for Nuclear Raw Materials*. D. Van Nostrand, Inc., New York, (pp. 193-201), 293 pp. (1956)

The US Geological Survey has tested a wide variety of geophysical methods on the Colorado Plateau to determine which could be used to aid in exploration for uranium deposits. The seismic-refraction and the electrical-resistivity methods have proved particularly applicable to uranium exploration. Magnetic and natural potential methods have as yet proved to have no direct application to uranium exploration. Shallow seismic reflection, electric logging, and surface-inhole electrical methods have been tested, but not enough information has been obtained to determine fully their application to uranium exploration. Induced polarization, radio-frequency, and electromagnetic-induction methods appear promising and will be further developed in the future. (JMT)

<207>

Not given; AEC, Washington, DC

Geophysical-Geochemical Prospecting. In Nininger, R.E. (Ed.), *Exploration for Nuclear Raw Materials*. D. Van Nostrand, Inc., New York, (pp. 202-212), 293 pp. (1956)

Geochemical and geophysical exploration methods are based upon determination of variations in some physical or chemical property associated with a mineral deposit. The unique property of radioactive disintegration of thorium and uranium has aided immeasurably in surface prospecting for these metals. However, a thin (two feet or less) rock cover absorbs such radiation, and when the deposit is buried, other geophysical and geochemical techniques must be applied. Proven aids in the search for radioactive materials are seismic reflection and refraction, continuous interval velocity logging, electromagnetic induction, electrical well logging, surface-resistivity, surface-radiometry, and geochemical determinations of trace elements and associated anions. Decisions on the kind and sequence of geophysical and geochemical techniques which may be most suitable for a given area are based upon reconnaissance. To this end and also for interpretational purposes, representative soil,

water, or rock samples are analyzed for physical property variations and chemical content. Inherent variations attributable to topographic, geographic, and climatic effects are considered. Their effects may be evaluated empirically or statistically by means of extensive laboratory and field data. (JMT)

<208>

Not given; AEC, Washington, DC

A Systematic Method of Exploration for and Evaluation of Uranium Deposits in France. In Ninninger, R.D. (Ed.), *Exploration for Nuclear Raw Materials*. D. Van Nostrand, Inc., New York, (pp. 131-138), 293 pp. (1956)

The method of exploration used by the Commissariat à l'Energie Atomique of France is discussed. Preliminary prospecting is carried out with light equipment, with one geologist and two or three prospectors. The aim is to locate the occurrences or the radioactive anomalies which will determine the zones worth being explored in detail. Once the preliminary program is completed, semisystemic prospecting begins. This represents an intermediate step between preliminary prospecting and systematic prospecting and it is used where preliminary prospecting fails to define with sufficient accuracy the zone to study in systematic prospecting. Once these two steps are completed systemic prospecting begins. In the first stage of systematic prospecting "counter maps" are prepared on which the activities are shown by isorads. When the counter map has furnished all the desired data on the configuration of a mineralized zone, trenching is begun in order to confirm the existence of deposition at points of maximum activity; to define its geometry; to permit the collection of samples from rocks in situ in order to study the mineralization and to estimate the grade of the surface zone; and to define the pattern of the faults which displaced the deposits. If the results of the prospecting stage are favorable from a geologic and mining point of view, the next step is to extend the information obtained at the surface to various depths, first by drilling and then by underground work if the results of drilling confirm the first indications. (JMT)

<209>

Not given; AEC, Washington, DC

Radiometric Prospecting. In Ninninger, R.D. (Ed.), *Exploration for Nuclear Raw Materials*. D. Van Nostrand, Inc., New York, (pp. 139-149), 293 pp. (1956)

The principal instruments used to prospect for radioactive minerals are the Geiger-Muller counter and the scintillation counter. The portable scintillation counter has several advantages over the Geiger-Muller counter: (1) higher efficiency for gamma-ray detection, (2) lower relative cosmic-ray background, and (3) relatively short resolving time. Comparative disadvantages of the scintillation counter are: (1) the present high cost and scarcity of large thallium-activated sodium iodide crystals, (2) the small pulse output from the photomultiplier, requiring a better amplifier circuit than for the Geiger-Muller counter tube, and (3) a high-voltage regulation for the photomultiplier which is far more critical than regulation for the Geiger-Muller counter tube. Essentially all field techniques for radiometric prospecting are based on gamma radiation. Supplemental detection of beta radiation is useful in picking out the highly radioactive rock and mineral fragments from mineralized outcrops. Because of the short range of alpha radiation, its detection has not proved to be practical in the field. Calibration in absolute units is usually based on direct quanta from a radium source, and is then expressed as milliroentgens per hour. Theoretically, if all portable Geiger and scintillation instruments are correctly calibrated in terms of milliroentgens per hour, measurement made with different instruments should be directly comparable, provided the spectral energy distribution of the gamma radiation measured is effectively the same as from radium. Several difficulties arise in the large-scale quantitative calibration of instruments. Gamma radiation from natural sources is always much scattered, so that the effective energy spectrum is greatly enriched on the low-energy end. Instruments calibrated with first-flight quanta from a point radium source will not show the correct intensity in milliroentgens per hour when the measured radiation is partly scattered. The gross readings will still be comparable from counter to counter of the same energy response, but units such as milliroentgens per hour are essentially meaningless in field practice, where many instruments of different types may be used. (JMT)

<210>

Not given; AEC, Washington, DC

Surface Radiometric Techniques. In Nininger, R.D. (Ed.), *Exploration for Nuclear Raw Materials*. D. Van Nostrand, Inc., New York. (pp. 150-154), 293 pp. (1956)

Surface techniques used in radiometric prospecting include local surveys or spot examinations, detailed surveys, and regional surveys. Local surveys are planned either to find localities of anomalously high radioactivity or to evaluate reported occurrences of radioactive raw materials. To indicate possible economic concentrations of radioactive materials a radioactivity anomaly must show at least a several-fold increase over the local background radiation. The minimum increase is frequently considered fourfold for measurements made with a portable Geiger counter and twentyfold for measurements made with a scintillation counter. Detailed surveys are made to determine accurately the distribution of radioactivity within an area ranging from a few thousand square feet to many square miles. The objectives may be specific, such as locating and evaluating radioactive ore deposits, or may be general, such as locating fissures, veins, and other structures or determining the variation of radioactivity in and among rock types. Regional surveys, usually covering several thousand square miles, have been successful in locating radioactivity anomalies for detailed investigations and in providing basic data on the surface distribution of radioactivity. Normally, such surveys are made with car-mounted scintillation counters of the continuously recording type. (JMT)

<211>

Not given; AEC, Washington, DC

Geologic Prospecting. In Nininger, R.D. (Ed.), *Exploration for Nuclear Raw Materials*. D. Van Nostrand, Inc., New York. (pp. 108-130), 293 pp. (1956)

All major areas of relatively high-grade uranium deposits in the United States contain intrusive or extrusive igneous rocks of alkalic or calc-alkalic affinity. Within these broad regions, the search for epigenetic deposits can be narrowed down to the smaller districts characterized by large faults, shear zones, folds, cryptovolcanic structures, diatremes,

and buried and exposed intrusives. The problem of finding new districts in permeable sedimentary terrains is one of finding large areas where physical traps favorable for the precipitation of uranium are numerous. Various guides have been successfully used in this phase of prospecting. These are the presence of favorable structures, host rocks, and chemical environment. Especially favorable are anticlinal or terrace structures - tectonic, erosional, or depositional in origin - or other structures that might cause the accumulation of gases or liquids such as CO₂, H₂S, natural gas, and oil that could result in direct precipitation of uranium, or in the precipitation of other solutes that in turn would reduce the solubility of uranium compounds. Some of these structures are places where fractures may allow the escape of dissolved gases and result in precipitation. Fault, shear, and fracture zones crossing sedimentary horizons at an angle to the direction of flow of solutions and primary sedimentary structures, such as channel, cross-bedding, and interfingering porous and less porous beds may change the velocity and pressure relationships and thereby result in precipitation. Once a district has been found to contain abnormal concentrations of uranium, various guides can be applied in the search for ore deposits. These can be grouped as structural, lithologic, mineralogic, and chemical. Alteration effects associated with uranium mineralization in igneous or metamorphic rocks appear to be more readily detected than those in sediments. Few if any of the alteration criteria associated with uranium deposits differ appreciably from those of copper, zinc, tungsten, and other metals, however their applicability to uranium is selective. Significant alteration features in hydrothermal uranium deposits appear to include: ferrugination, fluoritization, chloritization, alunitization, and dolomitization. (JMT)

<212>

Not given; AEC, Washington, DC

Survey of Prospecting. In Nininger, R.D. (Ed.), *Exploration for Nuclear Raw Materials*. D. Van Nostrand, Inc., New York. (pp. 101-107), 293 pp. (1956)

Geologic prospecting for epigenetic deposits of uranium, whether of direct or indirect magmatic origin, should emphasize areas of deep-seated major structures, particularly those related to (1) near-surface intrusions, (2) basins containing

terrestrial sediments (3) areas of metamorphosed clastic sediments, and (4) granitic batholiths. Syngenetic deposits should be sought in (1) marine black shales and phosphorites, (2) terrestrial and marine placers, (3) alkaline igneous stocks, sills, and dikes, and (4) granitic pegmatites.

Iso-abundance maps of specified grain sizes, diagnostic heavy minerals, base metals, and lithologic types can be used as prospecting guides. Contour maps of the water table, indicating abundance of critical elements such as fluorine in the water, are helpful in areas of caliche-type mineralization. Mapping of clay minerals and hematitic alteration zones in proximity to veins in igneous and metamorphic rocks have also proved useful. Geochemical prospecting techniques are also being rapidly adapted to uranium exploration. The uranium and radon content of surface and ground waters may serve as an approximate index of the uranium concentration in the rocks with which the water has been in contact. These analyses depend upon such variables as water pH, temperature, rock composition and permeability. Geobotanical prospecting has shown that uranium deposits under as much as 20 meters of cover may be reflected chemically in surface vegetation. The uranium content of the ash of plants growing in unmineralized sandstone is generally less than 1 ppm; a content of several parts per million is common in the ash of plants rooted over ore. Uranium deposits have not proved susceptible to direct detection by geophysical means. (JMT)

<213>

Bisby, H., E. Franklin, and D. Taylor:
Atomic Energy Research Establishment,
Harwell, England, United Kingdom

Instrumental Developments in the Prospecting, Mining and Chemical Processing of Nuclear Materials. In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York. (pp. 704-711), 825 pp. (1956)

This paper describes some of the instrumental developments by the Electronics Division at the Atomic Energy Research Establishment, Harwell, England, since 1946, and deals specifically with

instruments required in connection with the prospecting, mining, and chemical processing of fissionable material, in particular, uranium. (MLB)

<214>

Pittman, R.K., P.H. Dodd, and C.W. Tom:
AEC, Grand Junction, CO

Subsurface Techniques for Outlining Favorable Zones by Widely Spaced Core Drilling. In USGS Professional Paper 300. (pp. 641-645), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York. (pp. 695-700), 825 pp. (1956)

Subsurface mapping techniques for outlining zones favorable for the occurrence of uranium-vanadium ores were tested in the Cottonwood Wash mining area, San Juan County, Utah, by holes spaced 500 to 1,000 feet apart. This is considered wide spacing in the search for small uranium deposits in the Morrison Formation. This technique appears to be useful in areas where outcrops are few or nonexistent. (Auth)(MLB)

<215>

Amiel, S., and I. Winsberg; Weizman
Institute of Science, Israel Atomic Energy
Commission, Rehovoth, Israel

Measurements on Natural Water Sources as an Aid in Prospecting for Underground Deposits of Uranium. In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York. (pp. 792-793), 825 pp. (1956)

In prospecting for underground deposits of uranium considerable help may be derived from a detailed examination of radioactive materials brought up by water or gases. Further aid may also be obtained from the study of the isotopic composition of non-radioactive elements. Among

the radioactive elements which are of importance in this connection are uranium, radium, radon, krypton-85, xenon-133, and tritium. Among the properties of non-radioactive elements, of special significance are changes in the isotopic abundance of deuterium, oxygen, nitrogen, helium, and argon. The paper is devoted mainly to work involving the radioactive elements and helium. Work involving the stable isotopes, other than helium, is only mentioned in passing. (MLB)

<216>

Malojevic, A., V. Kostic, and M. Petrovic;
Institute of Nuclear Sciences "Boris
Kidric", Vinca, Yugoslavia

**Radiation Detectors with Halogen
Counters for Use in Prospecting.** In
Proceedings of the International
Conference on the Peaceful Uses of
Atomic Energy, Vol. 6, Geology of
Uranium and Thorium, held in Geneva,
Switzerland, August 8-20, 1955. United
Nations, New York, (pp. 712-713), 825 pp.
(1956)

In the study of different instruments for radiation detection with halogen self-quenching counters, detectors were constructed, running from the low-level radiation to the highest value of radiation intensity registered by the halogen counters. The detectors were developed without using thermionic vacuum tubes, and the registration can be recorded acoustically, optically or through normal microamp instruments, according to the purposes and radiation intensities. Detectors with instruments, or perhaps with acoustical or similar warning signal devices for greater radiation intensities, were developed especially for the continuous technical services of radiation survey. Improvements of the sensitivity of such kinds of instruments can be achieved by developing detectors using scintillation substances in association with a photosensitive Geiger-Muller counter, instead of halogen self-quenching counters, which would yield more effective methods for routine prospecting and radiometric survey. Further improvement in electronics can be expected through further development and application of transistors, instead of ionic valves. (MLB)

<217>

Chester, W.; AEC, Grand Junction, CO

**Drilling Techniques in Search of
Uranium.** In Proceedings of the
International Conference on the Peaceful
Uses of Atomic Energy, Vol. 6, Geology of
Uranium and Thorium, held in Geneva,
Switzerland, August 8-20, 1955. United
Nations, New York, (pp. 685-687), 825 pp.
(1956)

Drilling patterns employed on the Colorado Plateau are generally either a grid or a "fence" (row) of holes. The grid pattern is used where little is known about the area, and it is desired to make subsurface favorability criteria studies. It is also used in testing for ore bodies not confined to a linear paleostream channel, and having random distribution as well as variable size and shape. As information is gained through drilling on a grid, definite trends of either favorable ground or ore deposits alignment are established and a fence drilling pattern oriented perpendicular to such trends is used. Hole spacing is greater when searching for favorable ground than when looking for orebodies within a favorable ground. There is a great difference between the size of orebodies and the size of favorable areas, hence no definite rule can be set for spacing of holes in the search for either. The quest for purely geological information may not require definite spacing. In areas of rapidly changing structure or lithology, hole spacing must be rather close to permit subsurface correlation. In the Shinarump formation, orebodies are found in paleostream channels. In most cases these channels show on the outcrop and the problem is to follow the concealed channel back from the outcrop by drilling. A fence pattern is usually most economical, and once the trend of the channel is determined by the first row of holes behind the outcrop or from any two adjacent rows of holes, spacing between fences can be increased. Once the channel is located, further drilling within the channel-the area of favorable ground-in search of orebodies may be on a grid pattern for uniform coverage. This may be followed by closer spaced offsetting of mineralized grid holes in order to outline any orebodies. (MLB)

<218>

Cannon, H.L., and F.J. Krimhampl;
USGS, Denver, CO

Botanical Methods of Prospecting for Uranium. In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 801-805). 825 pp.: In USGS Professional Paper 300, (pp. 681-686), 739 pp. (1956)

Botanical methods of prospecting are based on the premise that concealed mineral deposits may be reflected chemically in surface vegetation. Results indicate that ore bodies under a cover of barren sandstone many feet thick may be detected by testing plants growing above them for uranium and associated elements. Two methods of such prospecting for uranium have been developed. The first method is based upon the presence of uranium in all plants in small but measurable amounts. The uranium content of plants rooted in ore, however, is detectably greater than the uranium content of plants rooted in barren ground. In semiarid country, similar parts collected from identical species of trees or deep-rooted shrubs shows differences in uranium content, which may indicate mineralized ground buried to a maximum depth of 60 feet. Plant ash is analyzed directly for uranium by the fluorimetric method. The uranium content of the ash of plants rooted in unmineralized sandstone is generally less than 1 part per million. A content of several parts per million is common in the ash of plants rooted in ore. A second method of prospecting, that of mapping the distribution of indicator plants, has been used in ecologically favorable areas. A plant may be used as an indicator plant in prospecting if its distribution is controlled by any factor related to the chemistry of the deposit. Carnotite ore and other oxidized uranium ores contain appreciable amounts of available selenium and sulfur. The distribution patterns of plants requiring one of these elements in quantity may indicate favorable ground. Which species of plants are useful as indicators in an area depends directly upon the chemical composition of the ore and the position of the ground-water table. Experimental studies show that the availability of selenium is greatly increased in the presence of carnotite. *ASTRAGALUS PATTERSONI*, the most reliable indicator of uranium ore, is deep rooted and capable of extracting selenium directly from ore bodies as deep as 75 feet. In some ores soluble salts have migrated upward into the surface soil and there become available to plants that have shallow roots. Ore has been found as much as 25

feet below the surface in ground indicated as favorable by the distribution of onions and other sulfur-absorbing ephemerals. Prospecting by both plant analysis and indicator-plant mapping in widely separated areas of the Colorado Plateau has shown a positive correlation between botanically favorable ground and major ore deposits. (Auth)

<219>

Denson, M.E.; AEC, Grand Junction, CO

Geophysical-Geochemical Prospecting for Uranium. In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 772-781). 825 pp.: In USGS Professional Paper 300, (pp. 687-703), 739 pp. (1956)

Exploration for uranium can be made more effective by combining geophysical and geochemical surveys. Physical and chemical data not only help to clarify geological problems, but also provide information useful in guiding an exploration or evaluation program. Examples of surface survey data, or of logging data and sample analysis data demonstrate the usefulness and significance of information obtainable by geophysical and geochemical techniques. Combined methods of exploration indicate variations in the uranium-bearing rocks which appear to be both directly and indirectly related to mineralization. Preliminary though incomplete data indicate that differences in permeability, porosity, and degree of kind of cementation of the enclosing rocks, controlled in part by sedimentary depositional factors and modified by structure, are significant. Surface surveys (electrical, geochemical, seismic, or radiometric), subsurface logging (electrical and velocity) and water analyses can, with certain reservations, be used successfully to detect these differences. (Auth)(PAG)

<220>

Foot, R.S., and L.R. Page; AEC, Grand Junction, CO; USGS, Washington, DC

Techniques For Prospecting for Uranium and Thorium - A Summary. In USGS

Professional Paper 388. (pp. 621-625), 739 pp. (1956)

Preliminary geophysical reconnaissance of the favorable areas is best made by gamma-radiation detectors carried by the geologist-pro prospector on the ground or in low-flying aircraft. Self-recording gamma-detection equipment, capable of measuring increments in radiation rates of 0.5 micro-roentgens per hour, mounted in a variety of mobile carriers has been effective in radiometric reconnaissance. These techniques locate only exposed or slightly buried deposits, but they commonly result in opening up new districts where concealed deposits are found by other methods. Where ore minerals are not exposed anomalous radioactivity is a less effective guide to ore, but soil, rock, water, and plant sampling, and panning, are useful supplements to radiation and geologic criteria. In the search for deeply buried deposits useful structural, lithologic, and mineralogic guides have been determined for most major districts in the United States. Some of these such as favorable structural and lithologic hosts are effectively outlined by geophysical techniques. Lithologic logging of drill holes supplemented by gamma-ray and electric logging is essential to prospecting in depth. Gamma-ray logging techniques in drill holes give accurate thickness and position of uranium mineralization intersected, and, with chemical assay control, give the approximate grade of ore surrounding the hole. Iso-radiation maps of subsurface units are used to guide drilling exploration. Electric logs supply valuable lithologic information and can be interpreted as indicating favorable zones in specific formations. Seismic refraction methods have successfully delineated well-developed paleo-channels favorable for ore localization. Some new and promising experimental techniques are coming into use. Electrical-resistivity measurements indicate unique electrical characteristics associated with ore in some sedimentary formations. Shallow-reflection high-resolution seismic methods and acoustical logging may help outline subsurface geologic guides. (Auth)(PAG)

<21>

Not given; AEC, Washington, DC

Botanical Prospecting. In Nininger, R.D. (Ed.), *Exploration for Nuclear Raw Materials*. D. Van Nostrand, Inc., New

York. (pp. 224-231), 293 pp. (1956)

Two methods of botanical prospecting have been developed and used by the U.S. Geological Survey to locate uranium deposits on the Colorado Plateau. One method currently used is based upon the uranium content of the plants; another is based upon the distribution of indicator plants (those that are dependent either directly or indirectly upon the presence of abnormal amounts of uranium and associated elements). Plant ash normally contains 0.2 to 1.0 ppm uranium, but uranium content of plants rooted in ore may range from 1 to 100 ppm. The uranium content of trees and herbaceous plants varies slightly with the seasons and the amount of rainfall. A large part of the uranium absorbed by the plant root is precipitated within the root cells. A lesser amount is transported to the leaves and branches, and is in direct proportion to the total amount of uranium absorbed by the roots. The amount of plants is dependent also upon the amount of water-soluble uranium in the vicinity of the plant roots, which is due in part to the interaction of uranium with other ions present in unusual amounts and does not necessarily reflect the total amount of uranium present. The roots of junipers, pinyons, and desert shrubs penetrate 15 to 25 meters through cracks and crevices connected with an ore-bearing aquifer and act as ground-water plants or phreatophytes. A plant may also be used as an indicator plant in prospecting for uranium deposits if its distribution is affected by the availability of chemical constituents present in the ore. The plants used in prospecting for a particular type of deposit may not all be controlled by the same factor. They are usually common rather than unusual plants, and the indicator plants for uraniferous sandstone deposits are controlled not only by the presence of unusual amounts of selenium and sulfur but by an increased availability of these elements in water-soluble form and by the increased availability of the major plant nutrients, calcium and phosphorus. (JMT)

<22>

Not given; AEC, Washington, DC

Hydrogeochemical Prospecting. In Nininger, R.D. (Ed.), *Exploration for Nuclear Raw Materials*. D. Van Nostrand, Inc., New York. (pp. 232-255), 293 pp. (1956)

Hydrogeochemical prospecting for uranium deals with the detailed examination of radioactive materials brought up by water or gases. Among the radioactive elements of importance in hydrogeochemical prospecting are: (1) uranium, (2) radium, (3) radon, (4) krypton 85, (5) xenon 133, and (6) tritium. In order for radium to be present, the water must have passed through the deposit. This need not be the case for radon since it is a chemically inert gas and can therefore be transported by other gases or move by means of its own diffusion. Because the half-life of radon is short, water that contains it probably passes close to a deposit. Lack of radon does not necessarily mean the absence of a deposit in the vicinity, since the intervening structures may not be sufficiently permeable to permit the passage of radon in an order of its half-life. A value for the minimum size of a deposit associated with a well being continuously pumped can be calculated from the radon content and the rate of flow. The actual size of a deposit calculated by this method is almost always greater than the calculation, and is helpful to have other evidence to support this point. Among the various decay products of uranium, the rare gases are most useful for this purpose. These are helium and radon from alpha decay and krypton 85 and xenon 133 from spontaneous fission of uranium 238 and from neutron-induced fission of uranium 235. Uranium deposits seldom occur under simple geochemical conditions, and as a result, a hydrogeochemical search for them involves appraisal of the net relative effect of such complex variables as the mineralogy of the deposit; the oxidation of associated sulfide-minerals; the geology of the area; the pH, chemical composition, oxidation-reduction potential, temperature and content of colloids, clays, and organic matter of the waters; the climate; the relationship between stream underflow and surface flow; and the circulation pattern of the ground water. (JMT)

<223>

Not given; AEC, Washington, DC

Subsurface Radiometric Techniques. In Nininger, R.D. (Ed.). *Exploration for Nuclear Raw Materials*. D. Van Nostrand, Inc., New York. (pp. 268-276). 293 pp. (1956)

Subsurface radiometric techniques include gamma-ray and neutron logging of exploratory

drill holes and measurement of the radon content of gases issuing from soils, springs, and drill holes. The Geiger counter is used in logging small-diameter drill holes. The scintillation counter and the ionization chamber are widely used where the hole diameter is sufficiently large. Most logging instruments are installed in heavy-duty trucks, but lightweight portable equipment has been developed for logging shallow holes in remote locations. Measurements of radon in gas samples are made with ionization-chamber equipment in mobile laboratories. In exploration for radioactive raw materials, the gamma-ray log of small diameter drill holes has provided highly valuable information. Gamma-ray logs are used for (1) correlating stratigraphic horizons, (2) preparing lithologic logs where core recovery is poor or lacking, (3) determining depth and thickness of ore-bearing horizons, and (4) estimating semi-quantitatively the thickness and grade of radioactive ores. Neutron logging techniques have been widely applied in the petroleum industry but have not been specifically developed to assist in exploration for radioactive materials. Measurement of the natural neutron flux in drill holes and neutron-gamma and neutron-neutron logging have been considered. In gamma-ray logging of exploratory drill holes on the Colorado Plateau, small sharp anomalies detected several hundred feet down dip from carnotite ores are presumably caused by radon migrating in ground waters along permeable channels. Radon concentrations in helium-bearing natural gases is being investigated, both to determine whether abnormally high radon concentration might indicate significant localized concentrations of uranium and radon at depth, and to clarify the relationship between radon and uranium. (JMT)

<224>

Not given; AEC, Washington, DC

Exploration Drilling. In Nininger, R.D. (Ed.). *Exploration for Nuclear Raw Materials*. D. Van Nostrand, Inc., New York. (pp. 256-267). 293 pp. (1956)

Exploration drilling for uranium usually involves a grid pattern of holes. The grid pattern is used where little is known about the area and it is desired to make subsurface favorability criteria studies. It is also used in testing for ore bodies not confined to a linear paleostream channel and

having random distribution as well as variable size and shape. In the case of ore bodies in paleostream channels, the problem is to follow the concealed channel back from the outcrop of drilling. A fence pattern is usually most economical, and once the trend of the channel is determined by the first row of holes behind the outcrop or from any two adjacent rows of holes, spacing between fences can be increased. This may be followed by closer-spaced offsetting of mineralized grid holes in order to outline ore bodies. Three types of drilling methods are usually used: diamond drilling, rotary drilling, and percussion drilling. The diamond core drill is the type most frequently used in search of uranium on the Colorado Plateau. Rotary drills are used chiefly when the core is not desired. They result in faster, more economical drilling.

Percussion drills are usually mounted on a truck and can attain a maximum depth of 350 feet. They are economical to use, and the capital expenditure for such drills is low. (JMT)

<225>

Davidson, C.F., and S.H.U. Bowie: Great Britain Geological Survey, London, England, United Kingdom

Methods of Prospecting for Uranium and Thorium. In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York. (pp. 659-662). 825 pp. (1956)

The first essential step towards making a systematic exploration for radioactive mineralization in any circumscribed region is a comprehensive study of the existing geological information on the area in question, by one or more geologists who are well acquainted with the literature describing the geological, geochemical and structural environments in which such mineralization is most likely to occur. From such preliminary research it may be possible to postulate what are potentially the most favorable localities in field operations. All known occurrences of mineralization, particularly sulphide mineralization, should be systematically listed, for more uranium ore has been found in old prospects and in working on derelict mines than anywhere else; and attention should be specifically directed to formations which bear an apparent

petrological similarity to known uranium provinces elsewhere. Concurrent with this work, the prospectors to be engaged in the field work should receive training in the recognition of radioactive minerals—especially traces of secondary minerals. Also, electronic aids to prospecting and geochemical methods for prospecting are discussed. (MLB)

<226>

Chew, R.T., III; USGS, Washington, DC

Study of Radioactivity in Modern Stream Gravels as a Method of Prospecting. USGS Bulletin 1030-E, 20 pp. (1956)

Traverses along some streams of the Colorado Plateau in areas known to contain mineable uranium deposits show that anomalous radiation in the stream gravels can be detected with a suitable counter downstream from the deposits. Intensity of radiation is influenced by the size of the uranium deposit, the size of the drainage area, of the stream, the grain size of the sediments, and the lithology of the rocks over which the stream flows. The spacing of the stations where readings are taken is controlled by the size of the stream, and special readings are also taken just downstream from important tributaries. An anomaly is empirically defined as a 10 percent rise over background. Radioactive material from large uranium deposits has been detected as much as 1 mile downstream. Radioactive material from smaller deposits is detectable over shorter distances. The method is slow but appears to be a useful prospecting tool under certain conditions. (Auth)

<227>

Mitcham, T.W.; AEC, Grand Junction, CO

Discovery Planning for Uranium in Monument Valley, Arizona and Utah. RME-50, 12 pp. (1953, September)

The paper reports on phase one of an exploration program undertaken by the AEC in the Monument Valley area of Arizona and Utah. Phase one is an exhaustive search for ore guides in the Shinarump Member. Twenty-six possible ore guides are listed. The guides fall into the main categories of

sedimentary structure, diagenetic structure, tectonic structure, mineral distribution-cause or effect of ore emplacement, and supergene activity. (MLB)

<228>

Kratzmann, J.; AEC, Washington, DC

Regional Exploration Criteria for Uranium. In Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Vol. 2, Survey of Raw Material Resources, held in Geneva, Switzerland, September 1-13, 1958. United Nations, New York, (pp. 325-329), 843 pp. (1958)

Hundreds of uranium deposits have been discovered in many geologic environments. However, significant deposits or districts which have produced large quantities of uranium, or which contain noteworthy reserves, are relatively few. It is these few deposits and their geologic relationships which may hold the clues for major future discoveries. The largest and most important uranium districts are in Precambrian shield areas. Uranium concentrations in sedimentary basins are second in importance; ore bodies in silicic intrusions of orogenic belts are third. Because geologic data are not available for vast areas of the earth, it is necessary to use regional or generalized criteria in selecting areas for exploration. (MLB)

<229>

Hilsley, C.T.; AEC, Denver, CO

Evaluation of Hydrogeochemical Techniques in the Mt Spokane Area, Washington. RME-1098, 25 pp. (1957, August 26)

Chemically the waters in the Mt. Spokane area are of the carbonate type and divided into three groups according to the amount of total dissolved material. These three groups correspond to an arbitrarily selected grouping of geologic environments: intensely decomposed granitic rocks; fresh granitic rock; and sedimentary lake bed deposits and Columbia River lavas. The areal background analysis for uranium in surface waters was determined to be approximately 1.5 ppb as compared with the regional background of 0.2 ppb.

The areal background for spring waters was found to be about 4.5 ppb. Several springs in the area are radioactive and can be easily detected with a hand scintillation counter. Anomalies in the amount of 100 ppb were detected. Comparisons of uranium with the pH and bicarbonate content of surface waters showed that uranium occurs in anomalous concentrations only where the bicarbonate content is greater than 25 parts per million and the pH is greater than 6.5. Limitations of the hydrogeochemical method in the Mt. Spokane area are similar to those encountered elsewhere. Waters with abnormally high uranium do not always indicate the presence of uranium ore deposits. The major factor of distance between an ore deposit and the surface openings of adjacent springs needs further evaluation. Other significant limitations are the presence of intermittent and discontinuous surface drainage, and variations that may occur in the composition of waters caused by climatic changes. (Auth)

<230>

Hilsley, C.T., and R.L. Kinnaman; AEC, Grand Junction, CO

Mobile and Portable Units for Geochemical Exploration for Uranium. RME-131, 27 pp. (1959, July)

In geochemical uranium exploration mobile laboratories and portable geochemical kits are utilized. The specifications of the mobile laboratory and portable geochemical kit including supplies and equipment for both are discussed. Analytical procedures are given for the determination of uranium, bicarbonate and sulfate content in waters. (PAG)

<231>

Cameron, J.F.; Nuclear Enterprises Limited, Reading, England, United Kingdom

Relation Between Nuclear Techniques and Other Prospecting and Exploitation Techniques. In Proceedings of a Panel on Nuclear Techniques in Geochemistry and Geophysics, held in Vienna, Austria, November 25-29, 1974. International Atomic Energy Agency Publications.

Vienna, Austria, (pp. 225-232), 271 pp. (1976)

In mineral prospecting and exploitation, a great variety of techniques is employed covering practically every physical and chemical method of qualitatively and quantitatively evaluating mineral-bearing materials. The most appropriate technique, or techniques, for a particular measurement is often a combination of nuclear and non-nuclear techniques. The main methods and their combined applications are summarized in this report. (Auth)

<232>

Cameron, J.F.; Nuclear Enterprises Limited, Reading, England, United Kingdom

Review of Some Nuclear Techniques Used in Mineral Processing in the United Kingdom. In Proceedings of a Panel on Nuclear Techniques in Geochemistry and Geophysics, held in Vienna, Austria, November 25-29, 1974. International Atomic Energy Agency Publications, Vienna, Austria (pp. 175-179), 271 pp. (1976)

Instrumentation based on nuclear techniques is extensively used in the mineral processing industries. The major techniques are density and level gauging, and portable and laboratory x-ray fluorescence (XRF) analysis. The following methods are briefly discussed: continuous analysis XRF, in-stream XRF, on-stream particle size system, on-stream neutron activation analysis technique, on-stream neutron absorption analysis system, density and level gauges, portable and laboratory XRF analyzers, nucleonic belt weighers, and on-line neutron moisture gauges. (PAG)

<233>

Rhodes, J.R.; Columbia Scientific Industries, Austin, TX

Portable X-Ray and On-Line Nuclear Instrumentation-Recent Status of Applications in the Mining Industry in the United States of America. In Proceedings of a Panel on Nuclear Techniques in

Geochemistry and Geophysics, held in Vienna, Austria, November 25-29, 1974. International Atomic Energy Agency Publications, Vienna, Austria (pp. 167-173), 271 pp. (1976)

The present status of applications in exploration, development, mine control, and processing of hard minerals is reviewed. Portable x-ray analyzers and process analyzers are standard equipment but variations have been developed for specific uses. New instrument developments to mining which are commercially available or at the stage of extended plant trials are discussed. (PAG)

<234>

Caldwell, R.L., K.P. Desai, and W.R. Mills, Jr.; Mobil Research and Development Corporation, Field Research Laboratory, Dallas, TX

Geophysical Well Logging Using Nuclear Techniques. In Proceedings of a Panel on Nuclear Techniques in Geochemistry and Geophysics, held in Vienna, Austria, November 25-29, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 3-19), 271 pp. (1976)

Nuclear logging of boreholes is in world-wide use for locating and evaluating commercial deposits of hydrocarbons, coal, uranium and certain other useful minerals. Within the petroleum industry the principal uses of nuclear logs are for correlation between wells, for measuring the porosity of rocks, for identifying hydrocarbons and for determining rock type. Natural gamma-ray spectral measurements are used to solve correlation problems and to identify uranium-, thorium-, and potassium-rich minerals. In coal exploration natural gamma-ray and scattered gamma-ray density logs are used to locate the coal and, in favorable circumstances, to estimate ash content. For oil shale evaluation the density log has been used in small-diameter holes in Colorado oil shale to determine potential oil yield. A new method of uranium detection based on measurement of delayed fission neutrons produced by bombardment of the formations with 14-MeV neutrons from a pulsed accelerator source has recently been described. (Auth)

<235>

Overstreet, W.C., P.K. Thobald, Jr., J.W. Whitlow, and J. Stone: USGS, Washington, DC

Heavy-Mineral Prospecting. In USGS Professional Paper 388, (pp. 647-750), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 692-694), 825 pp. (1956)

A system of geologic prospecting based on studies of the distribution of detrital heavy minerals has been developed to show regional relations of monazite to other heavy minerals. It is especially suited to regions with intense weathering and deep residual soil, but it might be used wherever the stream pattern is dense and glacial deposits do not interfere. The system is potentially adaptable to rapid reconnaissance studies of the distribution of many economic minerals. Samples are obtained by panning riffle gravel from the beds of small streams. Various modifications of the technique, such as contouring weights rather than weight percents, and integrating heavy-mineral with appropriate geochemical and geophysical methods, readily suggest themselves to fill special exploratory needs. (MLB)

<236>

De Nault, K.: Stanford University, Stanford, CA

Origin of Sandstone Type Uranium Deposits in Wyoming: Suggestions for Exploration. In Ph.D. Dissertation, Origin of Sandstone Type Uranium Deposits in Wyoming, Chapter II, (pp. 274-277), 352 pp. (1974)

Several exploration activities are suggested by the model for formation of sandstone-type uranium deposits proposed. (See Chapter 10, "Formation of Sandstone-Type Uranium Deposits in Wyoming). If the post-Miocene faults provided channelways for the influx of uraniferous groundwaters from ash-rich sediments into underlying coarse-grained sands, these faults, particularly the normal faults,

should be mapped and examined for indications of the passage of uraniferous solutions. Ore-forming solutions may have also migrated into host sands when streams flowing on ash-rich sediments eroded down into underlying coarse-grained sands.

Reconstruction of Pleistocene drainages would indicate areas of possible influx of ore-forming solutions into potential host sands. Such information would delineate prospects warranting further examination. Groundwaters in tuffaceous sediments have distinct chemical characteristics that may be carried into host sands. Hundreds of groundwater analyses of potential host sands are available in the literature. If these analyses are punched onto data cards they can be rapidly evaluated by computer. Such a study would direct attention to areas of potential host sand which should be examined in the field. Ideally,

experimental studies should be undertaken to verify the model proposed for the formation of sandstone-type deposits. However, such studies require long periods of time. Computer models, though unsatisfactory in several aspects, do offer speed and flexibility over laboratory experiments. A computer model might (1) indicate how far ore-forming solutions need to migrate in a host sand before economic concentrations of uranium will occur, (2) provide limits on the composition of ore-forming solutions, and (3) provide limits on the mineralogic composition of host sands. Item (1) would be useful in determining drill hole sites for testing potential host sands located by fault and paleodrainage studies; item (2) would further assist groundwater inventories; and item (3) would provide quantitative mineralogic criteria for evaluating a potential host sand. In addition, other metals could be substituted for uranium and tested for possible concentration in sandstone-type deposits. (JMT)

<237>

Cannon, H.L.: USGS, Washington, DC

Description of Indicator Plants and Methods of Botanical Prospecting for Uranium Deposits on the Colorado Plateau. USGS Bulletin 1030-M, 399-516 pp. (1957)

Two methods of botanical prospecting for uraniferous deposits on the Colorado Plateau are useful in semiarid country in prospecting for ore-bearing beds at depths as much as 70 feet. By

one method, tips of tree branches are sampled and analyzed for uranium content. Generally more than 1 part per million of uranium in the ash indicates favorable ground for further geologic exploration. The second method, that of mapping indicator plants, is used in semiarid parts of the Plateau at low altitude. The distribution of indicator plants is controlled by the availability of chemical constituents of the ore, such as selenium, sulfur, and calcium. Plants of the genus *ASTRAGALUS* are most useful in prospecting for uranium deposits of high selenium content; plants of the genera *ALLIUM* and *ERIOGONIUM* are most useful as indicators of deposits with a high sulfur content. Fifty indicator plants commonly associated with carnotite deposits and plants tolerant of mineralized ground are described and illustrated. (Auth)

<238>

Derray, R.C., and K.E. Baker; AEC,
Denver, CO

**Result of Exploration at the Copper King
Mine, Larimer County, Colorado.**
RME-4018, 16 pp. (1953, April)

Uranium mineralization was encountered in shaft sinking through a vertical distance of 68 feet. The vein explored on the 140 sub-level of a 38-foot drift contained ore-grade material in a zone within 10 feet of the shaft and a small 5-foot pocket near the east end of the drift. An inclined raise on the 140 sub-level was driven to the 110 level and ore-grade pitchblende was encountered 3 feet below the 110 level. A 31-foot drift on the 110 level contained 22 feet of pitchblende ore. The wall rock is predominantly pre-Cambrian granite with some schist inclusions and pegmatites. An amphibole-pyroxene skarn occurs with the sulfide mineralization. The ore deposits consists of two distinct, superimposed types of mineralization, the pre-Cambrian contact metamorphic and the Tertiary mesothermal, with high-temperature oxides and sulfides of iron, lesser amounts of sulfides of copper and zinc, and pitchblende with quartz and siderite. Pitchblende occurs as sooty incrustations on fractures; botryoidal coatings; hard, semi-vitreous vein-filling material; in pyrite boxwork; and finely disseminated in altered wall rock. Alteration accompanying the uranium mineralization is rather weak and consists of sericitization and chloritization. The main

structural feature of the mine is a 1- to 4-foot steeply dipping fault which strikes northwesterly. Drilling established the extension of the main fault, explored secondary structures, and delineated the orebody. (Auth)(M.I.B)

<239>

Young, N.B., and R.G. Young; AEC,
Grand Junction, CO

**A Reconnaissance for Uranium in Part of
the Roan and Book Cliffs Area of East
Central Utah. TM-83, 8 pp. (1956)**

A reconnaissance search for uranium deposits was made in some Upper Cretaceous and Lower Tertiary strata for the Roan and Book Cliffs of Utah. Objectives of the reconnaissance were examination of prospects in a region of little prospecting; determination of the uranium potential of the Tuscher, North Horn, and Colton formations, of Upper Cretaceous, Paleocene, and Eocene age, respectively; and stimulation of private activity. Of the formations investigated, only the Colton gives evidence of being a potential uranium producer. All occurrences of carbonaceous material observed in the lower Colton were partially replaced by uranium compounds, indicating that uranium mineralization has been widely distributed throughout the lower Colton. Commercial deposits of uranium have been found only where trash is associated with conglomeratic sandstone filling paleostream scours. (M.I.B)

<240>

Rowntree, J.C., and D.V. Mosher;
Pancontinental Mining Limited, Sydney,
New South Wales, Australia

**Case History of the Discovery of the
Jabiluka Uranium Deposits, East
Alligator River Region, Northern
Territory of Australia. IAEA-SM-208:58,
(pp. 551-573), 807 pp.; In Proceedings of a
Symposium on Exploration for Uranium
Ore Deposits, held in Vienna, Austria,
March 29-April 2, 1976. International
Atomic Energy Agency Publications,
Vienna, Austria, (pp. 551-573), 807 pp.
(1976)**

The Jabiluka deposits are currently the largest of the four major uranium deposits in the East Alligator River Region. This region at present contains 24% of the western world's reasonably assured resources of uranium. The exploration techniques employed during primary and secondary exploration on the property between 1971 and 1975 and during the delineation of the Jabiluka deposits are discussed in detail. The case history illustrates the exploration philosophy which was successfully employed on the Jabiluka property. The philosophy encompasses the following points: The need for an assessment on the limits of airborne radiometric surveys; the necessity for detection and evaluation of point source anomalies; the necessity for exploration along extensions of favourable lithologies; and the desirability of modification of exploration techniques on different types of anomalies. Some aspects of this philosophy may be useful in exploration for similar stratabound uranium deposits in other areas. (Auth)(MLB)

This report includes tabular data.

<241>

Cameron, E.M., and E.H.W. Hornbroke;
Canada Geological Survey, Ottawa,
Ontario, Canada

Current Approaches to Geochemical Reconnaissance for Uranium in the Canadian Shield. IAEA-SM-208 31. (pp. 241-266), 807 pp., In Proceedings of a Symposium on Exploration for Uranium Ore Deposits, held in Vienna, Austria, March 29-April 2, 1976. International Atomic Energy Agency Publications, Vienna, Austria. (pp. 241-266), 807 pp. (1976)

The paper reviews the methodology employed for this reconnaissance to outline areas of enhanced potential for uranium and other mineral commodities. The generally low relief of the Shield virtually restricts wide-interval reconnaissance to the mobile elements that can travel some distance in solution. The high mobility of uranium, particularly in waters of neutral pH, makes it one of the most suitable types of mineralization for detection. For much of the Shield the most appropriate sampling media are lake sediments and lake waters. Centre-lake sediments are homogenous, and are readily and economically collected utilizing helicopter support. They provide

a good response for uranium and a variety of other indicator elements. Waters collected at the same sample sites are a useful supplement in the search for uranium mineralization particularly in carbonate terrain. However, because of the very low content of uranium in many Shield waters, they present as yet unresolved problems of analysis and storage. The influence of organic material, iron and manganese on the uranium content of lake sediments are examined. Their scavenging influence has been found to be significant only at their lower concentration levels, particularly for organic matter and iron. For the majority of centre-lake samples the effect is negligible. The choice of sample interval is related to total survey costs, to speed of coverage, and to ability to detect uranium and other types of mineralization. For current programs a sample density of one per five square mile appears optimal. The results are presented as 1:250,000 symbol maps that are prepared largely by computer, and as 1:1,000,000 contoured compilation maps. (Auth)(MLB)

<242>

Czubek, J.A., and J. Loskiewicz; Institute
of Nuclear Physics, Krakow, Poland

Optimum Conditions for Uranium Detection in Delayed Neutron Well Logging. IAEA-SM-208 37. (pp. 471-486), 807 pp., In Proceedings of a Symposium on Exploration for Uranium Ore Deposits held in Vienna, Austria, March 29-April 2, 1976. International Atomic Energy Agency Publications, Vienna, Austria. (pp. 471-486), 807 pp. (1976)

Some theoretical results of the determination of optimum measurement conditions are presented in the paper. They deal with the delayed neutron method of uranium logging. The optimum source-detector spacing and the logging velocities were found for both the pulsed and continuous types of logging techniques. The multigroup diffusion approximation was used to obtain the numerical results. An optimum source-detector spacing of around 20 cm was found for the pulsed delayed neutron log with the borehole neutron generator. This optimum distance depends very strongly upon the type of physical process being considered and the lithology of the formation. For the continuous type of log (with Cf 252 source) an optimum logging velocity of approximately 48

cm/s (for a source-detector spacing equal to 2 m) was found. Here the unique apparent decay constant 0.241 (E-1) gives the proper values of the optimum velocities: optimum velocity=0.241 x source-detector spacing (cm/s) required in the usual logging conditions. Theoretical results given in this paper also contribute to the development of the theory of the usual neutron activation logging when gamma radiation is measured. (Auth)

<243>

Garrett, R.G., and J.J. Lynch; Canada Geological Survey, Ottawa, Ontario, Canada

A Comparison of Neutron Activation Delayed Neutron Counting Versus Fluorimetric Analysis in Large-Scale Geochemical Exploration for Uranium. IAEA-SM-208/30, (pp. 321-334), 807 pp. In Proceedings of a Symposium on Exploration for Uranium Ore Deposits, held in Vienna, Austria, March 29-April 2, 1976. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 321-334), 807 pp. (1976)

The problems of iron and manganese quenching in the determination of uranium by fluorimetry have been demonstrated. For a large reconnaissance lake sediment survey in Saskatchewan samples originally analysed for uranium fluorimetrically were re-analysed by delayed neutron activation. The results are compared, the major features of the data do not change in serious fashion owing to the coincidence of the majority of high uranium samples with low manganese levels, i.e. less than 500 ppm. However, the data presented reveal the interval of 1000-10,000 ppm manganese as covering the decade where the effects of quenching increase most rapidly; after 10,000 ppm (1%) manganese, fluorimetric data should not be used. If geochemical surveys are to be undertaken in environments where manganese levels in excess of 1000 ppm are going to be frequently encountered the fluorimetric method of analysis described in this paper should not be used. Lastly, significant changes in the correlation matrix occur, even when much of the data lies below 1000 ppm manganese; therefore, sophisticated procedures based on correlation matrices should be used with care. (M.L.B)

<244>

Stuckless, J.S., and C. Pires Ferreira, USGS, Denver, CO; Comissão Nacional de Energia Nuclear, Rio de Janeiro, Brazil

Labile Uranium in Granitic Rocks. IAEA-SM-208/17, (pp. 717-730), 807 pp. In Proceedings of a Symposium on Exploration for Uranium Ore Deposits, held in Vienna, Austria, March 29-April 2, 1976. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 717-730), 807 pp. (1976)

Labile uranium in granitic rocks has been proposed as the source for many ore deposits. Tests of this hypothesis or development of commercial in-situ leaching of uranium from crystalline rocks will require analytical techniques that can be used to identify granites that contain labile uranium. U-Th-Pb isotopic systematics can be used to obtain quantitative or semi-quantitative data on the timing and extent of uranium mobilization, but the technique is limited to Precambrian rocks and is too expensive for general use as an exploration tool. Granite from the Granite Mountains, Wyoming, has been shown to contain labile uranium, and it is proposed that several characteristics of this granite may be typical of other granites that are possible uranium source rocks. Important characteristics for uranium source rocks are inferred to be (1) alkalic affinity and high (greater than 70%) silica content, (2) high Th content, and (3) disequilibrium between pairs of long-lived radiogenic daughter products within the U-238-decay chain. This last characteristic may possibly be identified by comparing R_{act} values (radium equivalent uranium obtained by gamma-ray spectrometry) with chemical uranium contents. (Auth)

Cited as a reference in NURE Contractor Reports.

<245>

Steinman, D.K., D.G. Costello, C.S. Pepper, R.N. Galloway, J. John, and P.H. Dodd; IRT Corporation, San Diego, CA; ERDA, Grand Junction, CO

Californium-252-Based Borehole Logging System for In-Situ Assaying of Uranium Ore. IAEA-SM-208/43, (pp. 487-498), 807

pp. In Proceedings of a Symposium on Exploration for Uranium Ore Deposits, held in Vienna, Austria, March 29-April 2, 1976. International Atomic Energy Agency Publications, Vienna, Austria. (pp. 487-498), 807 pp. (1976)

A Cf-252-based borehole logging system for in-situ assaying of uranium ore has been designed and constructed, and preliminary tests of system operation have been performed. The system employs a delayed neutron activation analysis (DNAA) technique. DNAA measures uranium directly, thereby circumventing the disequilibrium problem and low-grade ore identification problems which are inherent to natural gamma-ray logging. An improved DNAA technique has been implemented which utilizes a smaller Cf-252 source and is more sensitive. In particular, the size of the Cf-252 source has been reduced by more than a factor 10. Shielding for the Cf-252 source has been designed for ease of operation while meeting occupational radiological safety requirements. The present system is vehicle mounted and includes the downhole sonde, logging winch with 1000 m of 4H0 cable, data-handling electronics, data recording and display equipment, and source shielding. The design of the system includes the following features: logging speeds from stationary to 8 m/min with the capacity for determining 0.01% U₃₀₈ concentration at 1.5 m/min; uranium concentration readout independent of source intensity; auxiliary neutron measurement for accurate correlation of DNAA signal to actual U₃₀₈ present; natural gamma-ray detector for gauging disequilibrium; and short normal resistivity for lithology. The present system is a fully operational prototype. An extensive field calibration and evaluation programme will begin shortly to uncover design problems and to allow simplification of the system for production logging. Commercially available units will reflect the operational experience gained from the testing programme. (Auth)

<246>

Hafen, P.L., S.S. Adams, and G.B. Secor;
Anaconda Company, Salt Lake City, UT

Application of Magnetic Susceptibility Measurements to Uranium Exploration in Sandstones. IAEA-SM-208 36. (pp. 367-377), 807 pp.; In Proceedings of a

Symposium on Exploration for Uranium Ore Deposits, held in Vienna, Austria, March 29-April 2, 1976. International Atomic Energy Agency Publications, Vienna, Austria. (pp. 367-377), 807 pp. (1976)

The paucity of magnetic and ilmenite in proximity to certain uranium deposits in permeable sandstones has been noted. Studies indicate that these magnetic minerals were destroyed by the same processes which formed the uranium deposits. The antipathy between uranium deposits and magnetic and ilmenite suggests that magnetic susceptibility measurements may be useful in uranium exploration. To evaluate this possibility, a series of magnetic susceptibility measurements were made both on outcrops and samples collected from drill holes close to and remote from known uranium deposits. These data indicated that variations in the magnetic-ilmenite content of typical sandstones can be reliably measured. Down-hole magnetic susceptibility measurements have also been successfully correlated with magnetic-ilmenite concentrations in drill core and cuttings. A down-hole probe has been used in sandstone exploration programs and has provided a reliable, convenient method for collecting information on the distribution of detrital ilmenite and magnetic. This information, when compared with the cuttings, stratigraphic information, gamma-ray and resistivity logs, provides an additional guide in determining the favorability of certain sandstones for the occurrence of significant uranium deposits. (Auth)

<247>

Wormald, M.R., and C.G. Clayton;
Nuclear Physics Division, Harwell,
Didcot, Oxon, United Kingdom

Observations on the Accuracy of Gamma Spectrometry in Uranium Prospecting. IAEA-SM-208 36. (pp. 149-171), 807 pp.; In Proceedings of a Symposium on Exploration for Uranium Ore Deposits, held in Vienna, Austria, March 29-April 2, 1976. International Atomic Energy Agency Publications, Vienna, Austria. (pp. 149-171), 807 pp. (1976)

Accurate in-situ measurement of the natural radioactivity of rocks can be made using gamma

spectrometers provided that the proper calibration factors are used. In the paper accurate calibration factors for a wide range of conditions encountered in the field have been derived for scintillation spectrometers by using a semi-empirical computational approach. The results enable much more accurate measurements to be made than are possible by using a plane calibration pad. The present work provides sufficient information for the field geologist to acquire a fuller understanding and appreciation of the type of problem underlying the accurate use of in-situ gamma spectrometers (M.I.B.)

(248)

Hernandez, F.C. Philippine Atomic Energy Commission, Quezon City, Diliman, Philippines

Exploration for Uranium and Other Nuclear Materials- A Guide Applicable to the Philippines. PAEC(ID)-75002, 45 pp. (1975, July)

The paper is intended mainly to give an insight as to how prospecting and exploration for uranium and other nuclear raw materials are conducted. The paper is divided into four parts. Part 1 deals with radioactivity and uranium minerals, Part 2 with the geology and a brief discussion of some classical uranium deposits of the world, Part 3 with different exploration methods, and Part 4 touches on the country's possible areas for uranium mineralization. The different exploration techniques and their associated instrumentations are discussed, from a regional scale survey to a detailed survey. (M.I.B.)

(249)

Batley, G.C., and B.W. Hawkins; Australian Atomic Energy Commission, Conjee, New South Wales, Australia

Uranium Exploration in Australia. IAEA-CN-36 503, (pp. 1-10); In Proceedings of the International Conference on Nuclear Power and Its Fuel Cycle, held in Salzburg, Austria, May 2-13, 1977. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 1-10). (1977)

In the Alligator Rivers Uranium Province the "vein" type deposits at Jabiruka, Ranger, Koonagarra and Nabarlek contain 17% of the world's reserves. Most of these discoveries resulted from the investigation of airborne radiometric anomalies but cover over the prospective host rocks will necessitate the future use of costlier and more indirect exploration techniques. There was exploration for sandstone type uranium deposits in most of Australia's sedimentary basins. The greatest success was achieved in the Lake Frome Basin in South Australia. Other deposits were found in the Ngala and Amajcus Basins in Central Australia and in the Westmoreland area, N.W. Queensland. A major uranium deposit was found in an unusual environment at Yechirre, Western Australia, where carnotite occurs in a caliche and clay host which fill a shallow, ancient drainage channel. Although caliche occurrences are relatively widespread on the Precambrian shield no other economic deposit has been found. Discoveries in the Georgetown area of Queensland indicate the presence of another uranium province but it is too early to assess its potential. The ore occurs in clastic sediments at the base of a volcanic sequence overlying a Precambrian basement. (Auth)(M.I.B.)

(250)

Evans, F.I., F.Q. Barnes, D.S. Robertson, and D.R. Derry; Denson Mines Limited, Toronto, Ontario, Canada; David S. Robertson and Associates Limited, Toronto, Ontario, Canada; Derry, Michener and Booth, Toronto, Ontario, Canada

Evaluation of Modern Uranium Prospecting Techniques.

IAEA-CN-36 197, (pp. 1-6); In Proceedings of the International Conference on Nuclear Power and Its Fuel Cycle, held in Salzburg, Austria, May 2-13, 1977. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 1-6). (1977)

The most common methods of detecting uranium mineralization utilize the property of radioactivity, but the very nature of this property commonly requires that the source be very close to the surface. Consequently, most of the outcropping and the easily discovered deposits have been located and

now new methods are required for locating uranium ore at depth. Detecting the presence of uranium mineralization at depth is a costly operation and more often relies on indirect evidence requiring careful interpretation. As a regional guide to uranium, the geochemical methods of testing lake water and lake-bottom sediments are useful in signalling areas for more intensive prospecting but do not provide areas for drilling. It is generally accepted that the emanometric methods work in locations where uranium deposits are covered by a relatively thin layer of permeable overburden or cap rock. It must be determined whether the methods can be used where the deposits are overlain by a hundred or more meters of rock or overburden. (MLB)

<251>

Potts, M.J.: Texas Instruments Incorporated, Dallas, TX

Computer Methods for Geological Analysis of Radiometric Data.

IAEA-SM-206 46, (pp. 55-69), 807 pp.: In Proceedings of a Symposium on Exploration for Uranium Ore Deposits, held in Vienna, Austria, March 29-April 2, 1976. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 55-69), 807 pp. (1976)

Since anomalies are the targets for the detection of radionuclide dispersion haloes, the analysis of reconnaissance radiometric data should aid in eliminating, with a minimum of types I and II statistical errors (type I is the rejection of true anomalies and type II is the acceptance of false anomalies), as much land as possible from further consideration. Because of data-specific limitations, the best path for data analysis involves automated statistical testing of data significance. Provided the probability threshold type of analysis such as computerized geological analysis of radiometric data (CGARD) employs adequate geological information, the results of anomaly interpretation will be greatly improved. This technique allows the explorationist to obtain important spatial relationships from data collected in heterogeneous terranes. The subsequent application of regional smoothing techniques to the statistically transformed data and deconvolution of the components of radiometric data frequently distributions are two logical extensions of the

method. (MLB)

<252>

Clayton, C.G., H.A. Cole, W.C.L. Munnach, D. Ostle, and G.D. Symons: NUTMAQ Mining Instrumentation Unit, Harwell, Didcot, Oxon, United Kingdom; Institute of Geological Sciences, Geochemical Division, London, England, United Kingdom

New Instruments for Uranium Prospecting. IAEA-SM-206 62, (pp. 173-181), 807 pp.: In Proceedings of a Symposium on Exploration for Uranium Ore Deposits, held in Vienna, Austria, March 29-April 2, 1976. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 173-181), 807 pp. (1976)

While the development of new techniques must be a major objective in the increasingly urgent search for additional uranium resources, the measurement of natural surface gamma radiation and its spectral analysis must continue to be an important component of most uranium prospecting activities, especially those in as yet imperfectly surveyed regions. To meet the more rigorous performance specifications required to provide for greater precision of radioactive measurements, recent technological developments have been successfully incorporated in two portable survey instruments, a Gamma Survey Meter and a Portable Four-channel Spectrometer. Equipped with these, the uranium geologist has the self-contained capacity for the conduct of total-gamma reconnaissance on foot, by vehicle or by light aircraft, and of detailed investigations of anomalies at surface, in boreholes or in underground mine workings. The logical extension of radiometric surveys on land to underwater environments such as the Continental Shelf and lakes appear to have been largely ignored or achieved by the local construction of ad hoc equipment. The development of an integrated gamma spectrometric survey systems designed specifically for continuous operation on sea and lake bottoms, called Towed Sea-bed or Lake-bed Spectrometer, facilitates the underwater search for uranium indications and heavy mineral concentrations, as well as providing a powerful aid to underwater geological mapping. (MLB)

<253>

Bjorklund, A.J.; Finland Geological Survey, Espoo, Finland

Use of Till in Geochemical Uranium Exploration. IAEA-SM-208/25, (pp. 297-309), 807 pp.; In Proceedings of a Symposium on Exploration for Uranium Ore Deposits, held in Vienna, Austria, March 29-April 2, 1976. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 297-309), 807 pp. (1976)

The investigation demonstrated that a multi-stage approach to uranium exploration by means of drift geochemistry may be successfully used to follow up regional geochemical work. Sampling of glacial drift at 100-m intervals along lines 1 km apart across uranium anomalies in lake sediments gave several well-defined anomalies. Subsequent supplementary sampling over these anomalies from a 50-100 m grid indicated the directions and coherency of the anomalies. By sampling drift and underlying bedrock with heavy percussion drill equipment at a high density, mineralized bedrock was located in the two anomaly areas studied. Quick analysis of unprepared small samples was found to be a useful way of directing sampling with heavy equipment on a day-to-day basis. The lack of anomalous contents of uranium in the -0.06 mm fraction of drift over the boulder fan at Paukkajavaara and anomalous contents in stratified drift indicated that the anomaly is of hydromorphic nature. A good correlation between uranium contents of the -0.06 mm and 0.06-0.25 mm fractions of drift sampled in a semi-regional programme suggested, however, that the anomalies, at least in part, have a mechanical genesis. Samples from the surface part (less than 1 m) of drift failed on several occasions to indicate anomalies found at greater depths. Uranium is apparently leached out from the dry part of a drift profile. (M1.B)

<254>

Lovborg, L., P. Kirkegaard, and E. Mose Christiansen; Danish AEC Research Establishment Riso, Roskilde, Denmark

Design of NaI(Tl) Scintillation Detectors for Use in Gamma-Ray Surveys of Geological Sources. IAEA-SM-208/21,

(pp. 127-147), 807 pp.; In Proceedings of a Symposium on Exploration for Uranium Ore Deposits, held in Vienna, Austria, March 29-April 2, 1976. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 127-147), 807 pp. (1976)

The performance and the cost of a NaI(Tl) gamma-ray detector depend on three main factors: crystal volume, energy resolution, and photomultiplier gain stability. In gamma-ray surveys of prospective, unmineralized rock the most important performance characteristic is sensitivity, i.e., count-rate per concentration unit of equivalent uranium. It is adequate to compare the sensitivity and the cost of a detector unit with the ground-level sensitivity and the cost of a detector having crystal dimensions of 3 x 3 in. Computational studies indicate that the sensitivity of a typical portable scintillometer increases in direct proportion to the cost of the crystal-photomultiplier assembly installed in the instrument. For the users of portable spectrometers it is good economy and convenient to employ crystals as large as 4 x 4 in. In the design of airborne detector systems there is no reason to consider the rather weak dependence of the height attenuation coefficients and stripping ratios on the overall detector dimensions. A 6 x 4 in. crystal equipped with a 5-in. phototube seems to have a particularly high figure of merit as the basic component of a multi-crystal system. The energy resolution of a four-channel spectrometric survey instrument does not have strong influence on the time it takes to make a reliable determination of uranium, thorium, and potassium. Photomultiplier gain drift of more than about 2% will, however, result in unacceptable measurement errors, and therefore the temperature sensitivity of the phototube(s) has to be minimized or counterbalanced. (M1.B)

<255>

Sandefur, R.L., and D.C. Grant; Utah International Incorporated, San Francisco, CA

Preliminary Evaluation of Uranium A Geochemical Study of Drilling Density in Wyoming Solution Fronts. IAEA-SM-208/39, (pp. 695-713), 807 pp.; In Proceedings of a Symposium on

Exploration for Uranium Ore Deposits, held in Vienna, Austria, March 29-April 2, 1976. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 695-713), 807 pp. (1976)

Studies of a roll-front uranium deposit in Shirley Basin Wyoming indicate that preliminary evaluation of the reserve potential of an ore body is possible with less drilling than currently practiced in industry. Estimating ore reserves from sparse drilling is difficult because most reserve calculation techniques do not give the accuracy of the estimate. A study of several deposits with a variety of drilling densities shows that geostatistics consistently provides a method of assessing the accuracy of an ore reserve estimate. Geostatistics provides the geologist with an additional descriptive technique-one which is valuable in the economic assessment of a uranium deposit. Closely spaced drilling on past properties provides both geological and geometric insight into the occurrence of uranium in roll-front type deposits. Just as the geological insight assists in locating new ore bodies and setting preferential drill locations, the geometric insight can be applied mathematically to evaluate the accuracy of a new ore reserve estimate. By expressing the geometry in numerical terms, geostatistics extracts important geological characteristics and uses this information to aid in describing the unknown characteristics of a property. (Auth)

<256>

Gingrich, J.E., and J.C. Fisher; Terradex Corporation, Walnut Creek, CA

Uranium Exploration Using the Track-Etch Method. IAEA-S-4-208 19, (pp. 213-227), 807 pp.; In Proceedings of a Symposium on Exploration for Uranium Ore Deposits, held in Vienna, Austria, March 29-April 2, 1976. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 213-227), 807 pp. (1976)

The Track-Etch technique for uranium has proven to be a valuable tool for uranium exploration in areas where more conventional surface radiometric techniques are not effective. The method of sampling eliminates a major portion of the variability problem in radon measurement

encountered with other techniques and the simplicity makes it both highly reliable and easy to use in the field. It was found to be particularly attractive for preliminary surveys and for exploring in remote areas where there is usually a limited amount of field support available. Experience with the Track-Etch system has indicated that its use can result in significant savings in exploration drilling costs. Exploration drilling has been reduced by up to 90% by utilizing the Track-Etch radon contour maps to guide the initial drilling phases. In addition, valuable information about the sub-surface geology can be obtained which may be very useful not only in uranium exploration but also in exploration for other minerals. Experience has shown that the Track-Etch radon technique can operate effectively in most any terrain. The results from several exploration programmes that have successfully utilized the track-etch method are reviewed. (M.B.)

<257>

Vickers, R.S.; Stanford Research Institute, Menlo Park, CA

An Evaluation of High-Frequency Electromagnetic Sounding for Uranium Exploration and Mining. (JBN-27(77), 59 pp. (1976, October)

Underground sounding using radar techniques has been demonstrated in a number of mining situations. The use of such techniques in uranium mining and exploration was evaluated in a study of the Schwartzwalder mine and the Karnes County uranium district in south Texas. The evaluation was limited to experimental work with radar and resistivity at the two sites. The results of these experiments suggest that in the conditions encountered, the radar method fails to provide any useful diagnostic data to the industry. This failure is attributable to the presence of water in the hard rock mine in Colorado, and the presence of moist clay soils in the Karnes County uranium district. Resistivity data taken at both sites verify the radar findings. (Auth)

<258>

Not given; International Atomic Energy Agency, Vienna, Austria

Nuclear Techniques in Geochemistry and Geophysics. Proceedings of a Panel on Nuclear Techniques in Geochemistry and Geophysics, held in Vienna, Austria, November 25-29, 1974. International Atomic Energy Agency, Vienna, Austria, 271 pp. (1976)

Nineteen papers were presented on nuclear techniques utilized in the exploration of oil, gas and minerals and in process control. The advantages of nuclear and non-nuclear methods and standardization procedures were also discussed. (PAG)

<259>

von Backstrom, J.W.: Atomic Energy Board, Geology Division, Pretoria, Republic of South Africa

Report on Attendance at a Technical Committee Meeting on "Recognition and Evaluation of Uraniferous Areas" - Vienna, Austria, 17 - 21 November 1975. PER-2, 29 pp. (1976, April)

The energy situation has focussed attention on the potential role of uranium as a future source of increased and assured energy supplies. As a result, a large demand for uranium is forecast which cannot be satisfied merely by finding new ore bodies in known areas. New potentially favourable uranium areas must be discovered. How to select the most favourable regions for prospecting, how to evaluate the uranium potential of unexplored areas, and a review of current guidelines, are dealt with in 17 papers presented to the meeting, and by three Working Groups set up specially for this purpose. (Auth)

<260>

Hawkins, W.K., and M. Gearhart: Gearhart-Owen Industries, Inc., Fort Worth, TX

Use of Logging in Uranium Prospecting. In Wulf, G.R. (Ed.), Wyoming Geological Association Guidebook, Twentieth Field Conference, 1968, (pp. 131-139), 243 pp. (1968)

Wide range gross count gamma probes are now available for recording the count rate of wide grades of uranium ore with other logs being used for specialized study. Properly calibrated systems are being used for gross count quantitative evaluation of the ore bodies. Experimental data available in field spectral logging has helped define the limitations of existing equipment. The use of coaxial type transmission logging cables and field use of new solid state detectors are expected to advance spectral well logging in the future. New and different probe designs are being developed that will help to establish areas that will be more favorable for deposits of uranium ore. (JMT)

<261>

Mahn, R.C., and A.L. Nash: AEC, Denver, CO

Airborne Reconnaissance in Southwestern Arkansas. RME-1052, 14 pp. (1954, December 13)

Airborne and ground reconnaissance for uranium was carried out in southwestern Arkansas by geologists of the US Atomic Energy Commission and the US Geological Survey. Several areas near Magnet Cove, which contain abnormally radioactive rocks known prior to this survey, were examined and five anomalies, previously unknown, were discovered. The ground crew made isorad maps of two radiometric anomalies at Wilson's Potash Sulphur Springs. Slight radioactivity was detected in five bauxite pits near Bauxite and at Granite Mountain, both south of Little Rock. No abnormal radioactivity was found in the Sevier County lead and zinc district, the Pike County mercury mines, nor accompanying the asphalt pellets in Pike, Howard, and Sevier Counties. (Auth)

<262>

Marjanemi, D.K., and J.W. Robins: Lucius Pitkin, Incorporated, Grand Junction, CO

Uranium Favorability of Tertiary Sedimentary Rocks of the Lower Spokane River Valley and of Northern Spokane County, Washington. GJBX-1(76), 48 pp. (1975, August)

Tertiary sedimentary rocks in the lower Spokane River valley and in northern Spokane County, northeastern Washington, were investigated to determine the favorability for potential uranium resources. This project involved measurement and sampling of surface sections, collection of samples from isolated outcrops, chemical and mineralogical analyses of samples, and examination of available water well lithologic logs. An area of very high favorability is in the Spokane Indian Reservation along the lower Spokane River valley - an area which not only contains visible uranium minerals, but from which there has also been uranium production. Areas of medium favorability are the Harker Canyon area in the lower Spokane River valley and a portion of northern Spokane County. The Harker Canyon area is underlain by rocks which are stratigraphically and structurally similar to, and probably an extension of, the very highly favorable rocks in the Spokane Indian Reservation. The Latah Formation in northern Spokane County is judged to have medium favorability based on the occurrence of thick sandstones derived partially from a quartz monzonite provenance and which reportedly contain organic material and volcanic derivatives. (Auth)

<263>

Meyer, W.T.: Not given

Uranium in Lake Water from the Kaipokok Region, Labrador. Colorado School of Mines Quarterly, 64(1), 377-394. (1969)

Numerous uranium occurrences, including the Kitts deposit, have been found in the Kaipokok region of Labrador since the initial discovery of pitchblende in 1954. With the recent renewed interest in uranium exploration, the uranium content of lake water was examined in an orientation survey covering the area of known mineralization in September 1966. This sampling program established procedures which were used in the reconnaissance survey of a 500-square-mile region the following summer. Sixty to 70 small lakes were sampled each day, permitting completion of the regional survey within 4 days. The shallow lakes of the Kaipokok region are glacial in origin with the majority occurring in irregular depressions within ground moraine, and in ice-scour rock basins. Small seepage ponds were sampled in preference to lakes forming part of an established drainage

system. Seasonal variations in uranium concentration are apparent in a comparison of data from lakes sampled in both September and July, with a 3- to 4-fold increase in the lake water uranium content in the autumn. This factor contributed to a median uranium concentration of 0.4 ppb for the orientation survey, compared with the 0.1 ppb median value of the mid-summer regional sampling. The frequency distributions of uranium content in lake water were approximately lognormal in both cases. Rolling mean analysis applied to the regional survey data provided an outline of regional trends for uranium and related high samples to a local background. The biochemical cycle of uranium was found to be particularly important in interpreting results due to the accumulation of uranium in the organic material contributed by marginal swamps. Data from the lake water surveys compared favorably with the results of airborne geophysical surveys. (Auth)

<264>

King, J., M. Tauchid, D. Frey, M. Basset, I. Cetinturk, F. Aydonoz, and B. Kececi: International Atomic Energy Agency, Vienna, Austria; Mineral Research and Exploration Institute, Ankara, Turkey

Exploration for Uranium in Southwestern Anatolia. In Proceedings of a Symposium on Exploration for Uranium Ore Deposits, held in Vienna, Austria, March 29-April 2, 1976. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 501-529). 804 pp. (1976)

Exploration for uranium is being conducted in southwestern Turkey as a UNDP/IAEA technical assistance project with the Turkish Mineral Exploration and Research Institute. Previous airborne and ground radiation surveys, which have been considered adequate, resulted in discovery of several hundred tons of oxidized uranium ore in shallow deposits. The present project seeks unoxidized ore in the redox zone below the water table. It employs a multi-method attack that utilizes reconnaissance geological mapping, scintillometer surveys, stream sediment surveys, water sampling for uranium and radon, rotary non-core drilling, multielement geochemical laboratory analysis of field samples, radiometric determinations for secular equilibrium, and

computer treatment of the results. Ideally, the initial stages would include both radiometric surveys and reconnaissance geological mapping to establish a preliminary indication of favourability; the mapping also provides basic stratigraphic and structural control for drilling. More detailed follow-up surveys in anomalous areas provide secondary screening. These consist of a scintillometer survey, soil gas (Rn), and soil geochemistry on a predetermined grid, and a detailed hydrogeochemical survey where numerous wells exist. The geochemical investigations are supported by a laboratory in Ankara that can comfortably perform more than 1000 determinations a day with a five-man team. Non-core rotary drilling with 1-m samples of cuttings, together with gamma, spontaneous potential, and resistance logs provide adequate sub-surface information. About 25,000 m have been drilled by the equivalent of two rig years. Only four holes have been cored for mineralogical and equilibrium information. Drilling to a nominal 100-m depth is accomplished to determine the stratigraphy and to evaluate the area for uranium favourability. Particular attention is given to carbon and pyrite content and to the possibility of redox interfaces. Mineralized zones have been penetrated in two areas. At one, the lead was a possible redox interface. The favourability of the area was confirmed by later geochemical surveys. At the other area, drilling was stimulated and guided by hydrogeochemical anomalies. It is concluded that the multi-method attack on exploration is effective in identifying favourable areas for drilling and that the areas involved could not reasonably be investigated otherwise. (Auth)

<265>

Ostle, D., and T.K. Ball; Institute of Geological Sciences, Radioactive and Metalliferous Minerals Unit, London, England, United Kingdom

Some Aspects of Geochemical Surveys for Uranium. In Proceedings of a Panel on Uranium Exploration Methods, held in Vienna, Austria, April 10-14, 1972. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 171-187), 320 pp.; IAEA-PL-490/17, (pp. 171-187), 320 pp. (1973, November)

The distribution and concentration of uranium in

the weathering cycle is dependent on a large number of chemical and physiographic factors. Some of the more important factors influencing the transport and redeposition of uranium in the weathering cycle have to do with the presence of bicarbonate, sulfate and chloride complexes, organic matter, hydrous oxides of iron and manganese and phosphate precipitates. Carbonate is one of the most important constituents of water influencing the complexing of uranium in solution. The season, the relative proportions of exposed and soil-covered calcareous rock, the temperature and the proportion of surface water to groundwater will affect the bicarbonate content of water in an area. Statistical analysis indicates that a very strong degree of positive correlation exists between the alkalinity (mg CaCO_3 liter) and the uranium content of surface waters and borehole waters. Both the uranyl sulfate and chloride complexes are stable only under acid conditions of pH 3.5 or less. Waters of such acidity are rare but not unknown, as oxidizing sulfides may provide the necessary sulphate and acidity to enable uranium to be readily transported. In some conditions of water chemistry, uranium forms complexes with high dissociation constants which complicate the interpretation of hydrogeochemical data. In circumstances in which these complexes are not formed, or when changes occur in the chemical regime, the uranium in solution is available for sorption on organic materials or clays, or for scavenging by, or co-precipitation with, sesquioxide gels. Another condition in which anomalously high uranium concentration may occur without any relationship to the presence of discrete uranium minerals is in soils overlying calcareous structures in a dominantly acid lithology. This phenomenon is due to the formation of calcium phosphate in the soils derived from the carbonate and the ability of authigenic phosphate to concentrate uranium from water even when the latter contains appreciable amounts of carbonate. (JMT)

<266>

Adler, H.H.; ERDA, Washington, DC

Geochemical Factors Contributing to Uranium Concentration in Alkaline Igneous Rocks. In Proceedings of a Technical Committee Meeting on Recognition and Evaluation of Uraniferous Areas, held in Vienna, Austria, November 17-21, 1975.

International Atomic Energy Agency
Publications, Vienna, Austria, (pp. 35-45).
295 pp.; IAEA-TC-25 4, (pp. 35-45), 295
pp. (1977)

The uranium-ore-forming potential of felsic plutons is directly related to the emanation of uranium together with certain other elements in the presence of volatile components. The dispersive phases of uranium in the parent magma are developed to some extent early in the fractionation process and are followed by a sharp increase in concentration in late-forming solutions. If it is assumed that the amount of an element separating in the ore-forming solutions is reflected by the total amount of that element or associated elements dispersed or trapped in the crystallizing igneous rock, then residual element concentrations, as for example the Th/U ratio, may be useful guides to ore-forming potential in the igneous environment. It is suggested that the quantity of uranium in receptor minerals such as zircon, sphene and other accessory minerals may possibly aid in identifying quantitative elevations existing in the magma prior to uranium egression in hydrothermal solution. If this is so, the uranium concentrations in these minerals could reflect the ore-forming potential of igneous rocks. Zircon may be particularly useful in this respect because of its rather wide-ranging uranium content. Late-forming minerals, such as biotite, capable of incorporating uranium in their structures, may also be of considerable value. Their position in the massif might determine their uranium concentration levels, with uranium enrichment more likely to occur as haloes in and near the apical parts of intrusions at points of egress and post-magmatic solutions. In identifying specific plagiogranites, alkalic granites, and syenites as ore-bearing intrusions, particular attention might also be given to the use of element concentration ratios other than Th/U in both the whole rock and in specific minerals. Considerable research will have to be done to determine which elements are most useful for this purpose, as for example Li, Be, and others likely to migrate with the volatiles involved in uranium enrichment and, secondly, Ba, K, and others that show a tendency to accumulate in primary minerals in the pluton and have a weak relationship to volatiles. The observable ratios should distinguish between magmas with a high volatile content, which would likely be enriched in the volatile-associated elements, and magmas that are relatively barren, which would show greater concentration of the non-volatile-associated elements. The ratio of U to Ti, Nb, Ta and other

elements already mentioned may be of some value. Pathfinder element concentrations may prove particularly useful also in evaluating igneous bodies with extensive surface weathering and leaching. (JMT)

<267>

Beck, I.S., G.R. Parslow, and J. Hoeve;
Saskatchewan Department of Mineral
Resources, Regina, Saskatchewan, Canada

Evaluation of the Uranium Potential of Areas Covered by Lake Waters, Using Geophysical, Geochemical and Radiometric Techniques. In Proceedings of a Technical Committee Meeting on Recognition and Evaluation of Uraniferous Areas, held in Vienna, Austria, November 17-21, 1975. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 261-278). 295 pp.; IAEA-TC-25 14, (pp. 261-278), 295 pp. (1977)

To evaluate various techniques of exploring for uranium in areas underlain by lakes, the Alces Lake area was chosen for study. The lake is situated about 30 km northeast of Eldorado in northern Saskatchewan (59 degrees 40 minutes N, 108 degrees 0.3 minutes W). The Ace-Fay and Verna pitchblende deposits of Eldorado Nuclear Limited are associated with the St. Louis fault, which is believed to extend under Alces Lake. The lake was systematically sampled at 20 m intervals along grid-lines spaced 200 m apart. At each sample location, a lake-bottom sediment sample was taken, 2 litres of lake water from the basal meter of the lake were collected and depth soundings and VLF measurements were made. The lake-water samples were analysed in the field for radon and subsequently in the laboratory for uranium. Lake sediment samples were analysed for uranium. Several of the lines were traversed with an underwater scintillometer which was operated by towing the probe along the lake bottom from a boat and also by guiding the probe along the lake bottom by scuba divers. The paper describes and evaluates the various techniques and discusses the results. In view of the fact that as much as 30% of the uranium districts within the Canadian Shield are covered by lake water, these techniques will be of considerable interest for further evaluation of these uraniferous areas. (Auth)

<268>

Bowie, S.H.U., T.K. Ball, and D. Ostle;
Institute of Geological Sciences, London,
England, United Kingdom

Geochemical Methods in the Detection of Hidden Uranium Deposits. In Boyle, R.W. and McGerrigle, J.I. (Eds.), *Geochemical Exploration, Proceedings of the Third International Geochemical Exploration Symposium, held in Toronto, Canada, April 16-18, 1970, Special Volume II. The Canadian Institute of Mining and Metallurgy*, (pp. 103-111), 594 pp. (1971)

The establishment of additional uranium reserves will depend to an increasing extent on the discovery of ore bodies not detectable by gamma radiation at the surface. This will mean the introduction of geochemical as well as other search techniques on a larger scale than has been previously employed. Of the geochemical methods now available, the most successful has been found to be the analysis of surface waters for uranium, a technique which is equally valuable on the reconnaissance or detailed scale. Stream-sediment analysis has been found to be of limited applicability due to the very short dispersion train of uranium and to problems associated with the scavenging of uranium by manganese and iron oxide-hydroxide gels. However, under certain specialized circumstances, these properties may be of some considerable value. The highly accurate and precise method of determining uranium by neutron activation and measurement of the delayed neutrons greatly enhances the value of soil sampling, especially in areas of residual soils, and it has been found to give results in greater agreement with the known geology than radiometry. However, ground water movement can result in the redistribution of uranium and anomalies in soils remote from the original occurrence can be formed. Following an understanding of the behavior of radon at shallow depths, the use of equipment for the determination of radon in soil air overcomes much of the difficulty associated with downhill creep and inactive leached overburden which besets uranium-in-soil measurements, but here again, radon can also become redistributed by ground water. Indicator elements are of limited value when the quality of the determination of the primary element is high. Molybdenum and zinc have been found to portray accurately the trace of uranium-bearing structures in acid upland regions,

where, because of the effect of vadose circulation, uranium and radium have been removed from the vicinity of the structure and deposited elsewhere. (JMT)

<269>

Morse, R.H.; Watts, Griffiths, and McQuat Limited, Toronto, Ontario, Canada

Comparison of Geochemical Prospecting Methods Using Radium with Those Using Radon and Uranium. In Boyle, R.W. and McGerrigle, J.I. (Eds.), *Geochemical Exploration, Proceedings of the Third International Geochemical Exploration Symposium, held in Toronto, Canada, April 16-18, 1970, Special Volume II. The Canadian Institute of Mining and Metallurgy*, (pp. 215-230), 594 pp. (1971)

The application of radium-226 geochemistry to prospecting for uranium has been tested at Bancroft, Ontario, and compared with methods using radon-222 and uranium. Sediment, soil and weathered rock samples were analyzed for radium-226 and uranium, and water samples were analyzed for radon-222 and uranium. Radium and uranium in sediments are more useful in prospecting than are radon and uranium in water. Clastic and organic sediments are both useful, but clastic sediments are superior. In sediment surveys, radium and uranium are equally useful; in intermediate-scale prospecting using soils, radium and uranium in the A and B horizons are all useful; and in detailed prospecting, all except uranium in the A horizon are useful. Weathering leaches uranium from rocks more thoroughly than radium; therefore, radium analyses are highly preferable to uranium if weathered rocks are collected. (Auth)

<270>

Dyck, W., A.S. Dass, C.C. Durham, J.D. Hobbs, J.C. Pelchat, and J.H. Galbraith;
Canada Geological Survey, Ottawa,
Ontario, Canada

Comparison of Regional Geochemical Uranium Exploration Methods in the Beaverlodge Area, Saskatchewan. In Boyle, R.W. and McGerrigle, J.I. (Eds.),

Geochemical Exploration, Proceedings of the Third International Geochemical Exploration Symposium, held in Toronto, Canada, April 16-18, 1970, Special Volume II. The Canadian Institute of Mining and Metallurgy, (pp. 132-150), 594 pp. (1971)

The geochemical survey of the Beaverlodge area has shown that radon and uranium in surface waters and uranium in stream sediments outline uraniumiferous zones on a regional scale. The regional survey has reduced the uranium search area roughly by a factor of ten, and isolated mineralized zones in 3- to 10-square-mile zones. Radon or uranium in either lakes or streams may be used as an indicator for uranium mineralization.

Stream-water concentration levels are higher than lake-water levels, making analytical procedures simpler. However, stream sampling in the Beaverlodge area is much more difficult and expensive than lake sampling. It is estimated that the cost-benefit factor is about the same for uranium as it is for radon surveys. Uranium has the advantage of giving somewhat broader and more diffused anomalies, thus increasing the chance of detecting a uraniumiferous region; radon has the advantage of simpler, on-site analysis, giving immediate results. Organic sediments, bicarbonate and pH control the migration of uranium in the surface environment. The high organic content of sediments limits the migration of radium and uranium at significant concentration levels to about 2 or 3 miles from the source. The major factors influencing radon concentration levels at the surface of the lakes are: temperature, depth and distance of sample site from shore, and turbulence. (JMT)

<271>

Stevens, D.N., G.E. Rouse, and R.H. De Voto; Earth Sciences, Incorporated, Golden, CO; Colorado School of Mines, Golden, CO

Radon-222 in Soil Gas: Three Uranium Exploration Case Histories in the Western United States. In Boyle, R.W. and McGerrigle, J.I. (Eds.), *Geochemical Exploration, Proceedings of the Third International Geochemical Exploration Symposium, held in Toronto, Canada, April 16-18, 1970, Special Volume II. The*

Canadian Institute of Mining and Metallurgy. (pp. 258-264), 594 pp. (1971)

Radon, alone among the daughter products of uranium decay, is a gas and may be transported a significant distance from its immediate parent radium and therefore, from uranium. The half-life of Radon-222 is 3.8 days; the half-life of Radon-219, a daughter in the actinium series beginning with Uranium-235, is 4 seconds; and that of Radon-220, a daughter from the Thorium-232 series, is 54 seconds. The longer half-life of Radon-222 as compared to the other very short lived radon isotopes allows Radon-222 to travel much farther from close proximity of its immediate parent radium. However, the short half-life of Radon-222 means that, for practical purposes, its "detectable" migration distance will be the distance it travels in six half-lives, or 23 days, by which time only 1 per cent of the original radon still exists. The filled electronic shell structure of radon makes it chemically inert. As radon cannot be ionized under natural conditions, it does not combine with other elements to form precipitates or water soluble complexes, and it is not strongly adsorbed by colloidal material, such as clays or carbonaceous materials. Radon cannot be tied up chemically and is free to migrate under a pressure gradient and disperse. This property can be advantageous in exploration, because it can significantly enlarge a target, as the radon can migrate to the surface of the earth and thus indicate radium (and ultimately uranium) at depth. Radon is also fairly soluble in water and transportation of radon in ground water can greatly enlarge the target. These characteristics make the detection of radon a potentially powerful tool in the exploration of uranium deposits. Problems with this approach, however, can be encountered if a deposit is not in equilibrium. Radium is very soluble in waters of high chloride content, while uranium is relatively insoluble in such waters and, consequently, would remain near the site of the deposit. Uranium is very soluble and can travel in sulphate and carbonate-rich waters, whereas radium is relatively insoluble under these circumstances. In this case, also a radon-in-soil-gas anomaly could occur over a stationary radium accumulation and would be a false indication of uranium. In the uranium deposits of the Limon Valley area, the overlying "fractured shales and cementation of the Moss Back Sandstone are major factors in retarding and perhaps directing radon escape and migration. As a result, the presence and location of uranium mineralization at depth cannot be adequately predicted for radon-in-soil-gas

anomalies. The background radon content in soil gas from 4-foot holes in the Wind River Peaks of the Laramie Basin ranges from 3 to 8 counts per minute. Anomalous radon in soil gas (up to 32 counts per second) was discovered and found to be reproducible. Concentrations of clusters and "belts" of up to 39 counts per second (eight times background) were found to occur in the soil gas above broad areas of anomalous uranium content in ground water within stream channel sandstone sequences and independent of uranium content of the soil. A uranium-bearing sandstone bed was subsequently discovered 10 to 30 feet beneath the crest of the radon anomaly over a distance of a mile in an area of poor exposures. (JMT)

<272>

Smith, G.H., and T.R.D. Chandler;
Chemical Research Laboratory,
Teddington, Middlesex, England

A Field Method for the Determination of Uranium in Natural Waters. In Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Vol. 2, Survey of Raw Material Resources, held in Geneva, Switzerland, September 1-13, 1958. United Nations, New York, (pp. 148-152), 843 pp. (1958)

Hydrogeochemical methods have been shown to be of practical value in uranium prospecting. The practicability of this prospecting method depends on the availability of highly sensitive but inexpensive analytical techniques since very large numbers of analyses are required. A colorimetric method utilizing visual comparison with previously prepared standards was considered to be the most attractive procedure under field conditions. The most sensitive reagent available at this time is dibenzoylmethane and a method has been developed using this reagent. (Auth)(MLB)

<273>

Not given; AEC, Washington, DC

Geochemical Prospecting. In Nininger, R.D. (Ed.), *Exploration for Nuclear Raw Materials*. D. Van Nostrand, Inc., New York, (pp. 213-223), 293 pp. (1956)

The ready migration of uranium in solution upon weathering of primary ore suggests that geochemical techniques, involving quantitative chemical analysis for the metal in soils, alluvium, vegetation, and surface waters, may be of value in searching for new uranium ore bodies. But where such analytical examination is being made for other metals, tests for uranium might usefully be incorporated. A rapid method for such work, utilizing paper chromatography, has recently been developed. Chemicobotanical techniques involving the analysis of plant ash have also been studied, but seems likely to be useful only in the exploration for extensions of known ore bodies in subdesert regions where there is a thick overburden and plants are deep-rooted. No direct ecological aids to uranium prospecting are known, but locally geobotanical studies can be of indirect assistance. In Colorado bushes of *ASTRAGALUS* are dwarfed where rooted in soils rich in the selenium that commonly accompanies the uranium ore and in the Congo-Rhodesian copperbelt certain plants which are commonly found in soils overlying copper-cobalt ores direct attention to mineralization in which uranium may be present. (JMT)

<274>

Hilsley, C.T., C.W. Bills, and J.W. Pollock;
AEC, Washington, DC

Some Geochemical Methods of Uranium Exploration. In Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Vol. 2, Survey of Raw Material Resources, held in Geneva, Switzerland, September 1-13, 1958. United Nations, New York, (pp. 126-130), 843 pp. (1958)

The detection and interpretation of anomalous concentrations of uranium in soil, sediment, or water is directly related to the mobility of uranium during the weathering and sedimentation phases of the geochemical cycle. Few uranium minerals survive the effects of weathering, and in some cases, residual soils may contain fragments of primary uranium minerals, especially thin soils overlying near-surface, vein-type deposits. These soils are poor targets for geochemical prospecting because of the extreme heterogeneity of uranium concentrations within them. Most chemical reactions in the zone of weathering occur in nearly

neutral waters. The pH of surface films, however, is very different from the gross pH as measured in natural waters. The chemical reaction between water and granitic rocks may take place because the pH at the interface is relatively high (8 or 9); yet, upon dilution the gross pH is nearly neutral. If this film could be isolated in an undiluted state and the pH lowered, the dissolved solids would probably precipitate. In nature, this material remains in solution as a result of dilution and not because the measured pH indicates an effective solvent. Thus, conclusions drawn from natural-water pH values may be misleading without proper evaluation. Pure water in contact with granite dissolves as much as 30×10^{-6} grams of U_3O_8 per liter. These solutions are stable although the pH is only 6.5. A possible explanation for the stability of such solutions is the presence of colloidal silica and ferric hydroxide. Colloidal materials that absorb uranium contribute to its presence in water as long as the colloids remain dispersed. Waters from semi-arid regions commonly contain enough bicarbonate ion to stabilize uranium as a carbonate complex. Uranium present in waters containing abundant organic matter is kept in solution by the fulvic-acid fraction of the organic material. The soluble uranium complexes are readily absorbed on the hydroxide gels of iron, aluminum, and manganese, and possibly on silica gel since size and charge limitations are fulfilled by hexavalent uranium. This absorbed uranium is retained by these hydroxides during coagulation and precipitation and thus becomes enriched in sediments. These properties play an important role in applied geochemical methods of uranium exploration. (JMT)

<275>

Clarke, W.B., and G. Kugler; McMaster University, Department of Physics, Hamilton, Ontario, Canada; Atomic Energy of Canada Limited, Sheridan Park, Ontario, Canada

Dissolved Helium in Groundwater: A Possible Method for Uranium and Thorium Prospecting. *Economic Geology*, 68, 243-251. (1973)

Measurement of dissolved helium in groundwater should indicate the presence of uranium (or thorium) mineralization. Such measurements have

been made near two known deposits, near Elliot Lake, Ontario, and near Inla Lake, Labrador. Helium contents of up to 600 times normal-solubility were found, while neon contents were all within 20 percent of solubility equilibrium with the atmosphere. The ratio $He\ 4/He\ 3$ is correlated with $He\ 4$ content for the samples, although $He\ 3$ is enriched above solubility (up to a factor of 6) in some cases. Tritium contents were measured for the Labrador samples and indicate that the water residence time is less than 20 years. This rules out the possibility that the high helium values are due to rocks of "normal" uranium and thorium content. (Auth)

<276>

Not given; International Atomic Energy Agency, Vienna, Austria

Recommended Instrumentation for Uranium and Thorium Exploration. IAEA Technical Report Series No. 158, 93 pp. (1974)

Radiometric methods have proven to be the most universally applied, most effective and economical in the world-wide search for nuclear fuels during the past quarter-century. A great variety of instruments which measure natural alpha, beta or gamma radiation have been adapted or developed to support prospecting, exploration and exploitation of uranium resources. Specifications and minimum operating requirements for the various instruments are defined in the report. (Auth)(PAG)

<277>

Shtan', A.S.; USSR State Committee for the Utilization of Atomic Energy, Moscow, USSR

Prospects for the Use of Photoactivation and Radioisotope-Excited X-Ray Analysis in Mineral Exploration. In *Proceedings of a Panel on Nuclear Techniques in Geochemistry and Geophysics*, held in Vienna, Austria, November 25-29, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 129-138), 271 pp. (1976)

Photoactivation analysis using bremsstrahlung from linear accelerators, betatrons and microtrons is an effective method for determining the composition of ores and ore processing products. This method has now become even more attractive with the development of high-current accelerators. Neither of the two variants of radioisotope-excited X-ray analysis (the absorption or the fluorescent method) has the same sensitivity as conventional X-ray spectroscopic analysis. However, the particular advantages offered by this method make it eminently suitable for the following applications: rapid approximate analysis of bulk materials; in-situ analysis of deposits with portable instruments; and automatic on-line monitoring of technological processes. Some instruments made in the Soviet Union are described. (Auth)

<278>

Lovborg, L., H. Kunzendorf, and E.M. Christensen; Danish AEC Research Establishment Risø, Roskilde, Denmark

Practical Experiences of Various Nuclear Techniques Supporting Mineral Prospecting in Greenland. In Proceedings of a Panel on Nuclear Techniques in Geochemistry and Geophysics, held in Vienna, Austria, November 25-29, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 139-152), 271 pp. (1976)

In the prospecting for uranium and other metals, the techniques used in the field or in the laboratory or in both include gamma-ray spectrometry, delayed-neutron counting, radioisotope-excited X-ray fluorescence and gamma-activation analysis of beryllium. Field operations are based on airborne gamma-ray spectrometry, radiometric follow-up work, detailed geological mapping, and sampling of soils, stream sediments and river waters. The paper summarizes the practical applicability of the various nuclear techniques utilized in the field and in the laboratory in Greenland. (PAG)

<279>

Ohashi, S., K. Nozawa, and Y. Aoyama;
Not given

Geochemical Prospecting for Uranium Deposits in Sedimentary Rocks in Japan. In Proceedings of the Seminar on Geochemical Prospecting Methods and Techniques, Mineral Development Series No. 21, held in Bangkok, Thailand, August 5-14, 1963. United Nations, New York, (pp. 94-104), 202 pp. (1963)

In Japan, uranium deposits in sedimentary rocks were discovered in 1955 at Ningyo-toge. At present, the area consists of more than a dozen deposits and is estimated to have more than 2000 tons of U₃O₈. Prospecting in Japan today is underway in several areas which resemble the Ningyo-toge deposits. Effective prospecting systems are being established in Japan at present. Those systems are controlled to a large extent by the geological and geographical conditions, especially by various characteristics of the deposits in sedimentary rocks. Among the geographical conditions common to the favorable areas are a warm and humid climate, the existence of a number of stream valleys and a steep and complex topography. Geological conditions found in favorable localities are as follows: (1) The distribution of deposits is limited to regions consisting of granites and their roof pendants. (2) Sedimentary rocks such as conglomerate, sandstone and pyroclastic rocks in which uranium occurs are permeable layers of the Neogene in which the degree of cementation is low. They overlie unconformably impermeable granites and often are covered with impermeable layers such as younger volcanic rocks and shales. (3) The uranium mineralization is epigenetic. Uranium is believed to have been precipitated as the uranium minerals from stagnant ground water in the depressions on basement granites. Uranium ore bodies are often located at the basal points of sedimentary rocks on basement granites and are never separated from the unconformity plane by more than a few tens of meters. (4) The principal primary uranium minerals are ningyosite or coffinite. They are easily oxidized and dissolved by dilute acids. As a secondary mineral, autunite is more widely distributed. The principal associated metallic mineral is pyrite. Prospecting methods for the uranium deposits in sedimentary rocks are as follows: (1) prospecting methods such as ordinary airborne survey, U-scope survey, geological investigation and geochemical prospecting are used in combination in the preliminary reconnaissance. (2) Follow up work on the indications of mineralization or the extension of already-known ore bodies and discovery of new ore bodies in geologically promising zones, usually

utilizes such methods as geological survey accompanied by trenching or radiometric investigation, geochemical prospecting, and geophysical prospecting by electrical and seismic methods, and drilling. (3) Underground prospecting is the final stage. (JMT)

<280>

Gumbert, A., Not given

The Application of Geochemical Prospecting for Uranium in Forested Zones in the Tropics. In Proceedings of the Seminar on Geochemical Prospecting Methods and Techniques, Mineral Development Series No. 21, held in Bangkok, Thailand, August 5-14, 1963. United Nations, New York. (pp. 81-94). 202 pp. (1963)

The problems of deep soil and vegetation hiding outcrops, which normally beset prospecting for metalliferous deposits, are intensified in tropical regions. The warm wet climate greatly alters the surface of rocks, leaching out minerals, and favors the growth of very dense vegetation. Geochemical prospecting is sufficiently flexible for adaptation to the most varied cases, but like other techniques, it cannot by itself solve all problems in all situations. It is generally more suited than other methods to humid, tropical countries, where surface changes are considerable and movement difficult. Before it can be applied, however, a preliminary survey is essential as a basis for assessing the possibilities of the technique under local conditions, deciding on the methods of work to be adopted, and estimating the cost of the operation. Although strategic prospecting is slow when compared with aerial radiometry, it has certain advantages (i.e., (1) capital outlay is low, (2) quickly trained local labor can be used, (3) it permits simultaneous prospecting for several metals on the basis of samples collected, and (4) it offers the possibility of improving general knowledge of the area prospected through the preparation of geochemical maps based on the data collected). Information can also be obtained about regions which have not been prospected for uranium from geochemical samples collected according to the standards used in prospecting for other metals and by asking local inhabitants to take samples of spring and well, water, which are then sent in special containers to laboratories for analysis. (JMT)

<281>

Sato, G.; Atomic Fuel Corporation, Japan

The Combined Application of Apparent Resistivity and Geochemical Methods in Uranium Prospecting at Togo Mine, Japan. In Proceedings of the Seminar on Geochemical Prospecting Methods and Techniques, Mineral Development Series No. 21, held in Bangkok, Thailand, August 5-14, 1963. United Nations, New York. (pp. 169-174). 202 pp. (1963)

In prospecting for uranium in Japan, major effort is directed toward the discovery of "sedimentary-type" deposits. Such deposits have been discovered in many districts, of which the Nogyo-toge uranium district is the most representative. The Togo mine is located in the Nogyo-toge district. The surface prospecting carried out at the Togo mine is beyond the stage of a reconnaissance survey and may be classified as "detailed prospecting". It is focused on finding outcrops covered by surface soils. The procedure consists of first, inferring the location of the outcrop line of the unconformity plane by the resistivity method, then determining the uranium content of the soil in the vicinity of the outcrop line, and finally digging trenches where anomalous amounts of uranium are detected. In order to carry out detailed prospecting for uranium deposits, it is important to understand the geological characteristics of the deposits and to utilize this knowledge effectively. In addition to the general geology of the area, the following factors should be understood: (1) the spatial relationship between the uranium deposits and the bedrocks, (2) the mode of occurrence of uranium minerals in the uranium-bearing beds, (3) the spatial relationship of the uranium-bearing beds to other sedimentary rocks, (4) the presence or absence of impermeable beds as "cap rocks", (5) the kinds of uranium minerals and their behavior during such processes as leaching, migration, and deposition, (6) the physico-chemical properties of the bed rocks and of various sediments, and (7) the threshold value of the geochemical anomalies. With knowledge of the above mentioned factors, the maximum benefit can be derived from geophysical exploration. At the Togo mine, the uranium deposits occur nearly horizontally in the channels; prominent linear scours in the underlying bed rocks are filled with conglomerates, arkose sandstones, shales, and pyroclastics. Granite intrusive rocks probably of

late Mesozoic age constitute the Chugoku massif. The fact that all "sedimentary-type" uranium deposits in Japan occur in sedimentary rocks that overlie granite leads to the conclusion that granites play a very important role in the formation of uranium deposits. (JMT)

<282>

Kerr, P.F.; Columbia University, New York, NY

Rock Alteration Criteria in the Search for Uranium. In USGS Professional Paper 300, (pp. 633-639), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 679-684), 825 pp. (1956)

Rock alteration may serve as a guide in the search for uranium. Although the criteria are more obvious in igneous and metamorphic rocks, they are also observed in places in sediments. An outstanding example of rock alteration associated with uranium mineralization occurs at Marysvale, Utah, where solutions primarily responsible for the deposition of pitchblende seem to have reacted with the wall rock to form a halo of clay, chlorite, sericite, and quartz. At some uranium-bearing ore zones in northwestern Canada and in the Sunshine mine, Idaho, red hematitic coloration is associated with the ore. Alteration associated with uranium deposition in the Colorado Plateau sediments has recently been recognized. However, its extent and significance is only partly established. In several isolated sites at Temple Mountain, Utah, solutions have penetrated sediments, dissolved underlying sandy strata. This has been accompanied by local deformation, bleaching, upward chemical transfer and, in places, uranium deposition. (Auth)

<283>

Petrascheck, W.E., E. Erkan, and K. Neuwirth; Montanistische Hochschule Leoben, Leoben, Austria; Bergbau- und Mineralgesellschaft Vienna, Vienna, Austria

Permian-Triassic Uranium Ore in the

Acetian Alps - Paleogeographic Control as a Guide for Prospecting. In Proceedings of a Symposium on the Formation of Uranium Ore Deposits, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 291-298), 748 pp. (1974, November)

Prospecting by Bergbau- und Mineralgesellschaft, Vienna was concentrated on the areas of nonmetamorphic Gredener Sandstone of Permian age in Southern Austria, the nonmetamorphic Bunt Sandstone and Werfen Schists of Permian and lower Triassic age in the Northern Kalkalpen and on the epi-metamorphic sericite-chlorite quartzites of Permian and Triassic age in the Central Alps. The beds partly developed as red and gray sandstones, partly as semi-metamorphic quartzites and sericite-chlorite schists, are terrestrial and lagoonal in origin, while their upper parts are of shallow marine origin. After rearrangements of these deposits, which appear in their original position in the different overthrust nappes systems, distinct troughs and platforms can be delineated according to the variations of the thickness of the beds. These features interfere with the general E-W strike of the Alpine geosyncline, following predominantly a transversal direction, which was conditioned by the prealpine Hercynian structures. The comparatively larger uranium layers are situated in or near the areas of greater thickness, that is in the Permian troughs. A remobilization and reconcentration of uranium happened in those localities where younger hydrothermal solutions have penetrated into uraniferous sandstones. (Auth)(JMT)

<284>

Niminger, R.D. (Ed.); AEC, Washington, DC

Exploration for Nuclear Raw Materials. D. Van Nostrand Company, Inc., New York, 293 pp. (1956)

Part I of the book consists of a condensation of the summary paper on the natural occurrence of uranium and thorium prepared in behalf of the United Nations by Professor Paul F. Kerr, Columbia University, and four additional chapters comprising five United States papers which more adequately represent the important information

dealing with the theory of uranium occurrence, including the brief summary of uranium and thorium geology presented to the Conference by Dr. Lincoln R. Page, Assistant Chief Geologist, U.S. Geological Survey, based on all the United States papers submitted. Part II is divided into thirteen chapters comprising parts of twenty-five of the twenty-seven papers on prospecting techniques, arranged in order of the specific aspects of the subject covered. Papers from the United States, the United Kingdom, Canada, Brazil, the USSR, and France are represented. (JMT)

All 18 chapters of the publication have been abstracted separately.

<285>

Labrecque, R.A., AEC, Grand Junction, CO

Reconnaissance for Uranium in the Southern Carrizo Mountains, Apache County, Arizona. TM-103, 7 pp (1957, February)

A reconnaissance was conducted of an area about two miles square in the southern Carrizo Mountains where the Permian Cutler formation, including its De Chelly sandstone member, and the Triassic Shinarump member of the Chinle formation, are exposed. The purpose was to appraise the uranium potential of the area and to determine the cause of bleaching in the De Chelly. Extensive uranium mineralization in the Salt Wash Member of the Morrison formation around the Carrizo Mountains suggested that the Shinarump, a good producer in other areas on the Colorado Plateau, might be mineralized here as well. Bleaching, as shown in the De Chelly, has proven such a useful guide to uranium at other localities as to merit investigation here. (Auth)(M.B.)

<286>

Melancon, P.E., C.E. Farrow, Jr., and R.J. Garcia; AEC, Grand Junction, CO

Exploration Drilling in the Blanding District, San Juan County, Utah. RMO-827, 28 pp. (1951)

The exploration programs included two diamond drilling projects, a limited wagon drilling project,

and an airborne radioactivity survey. Radioactivity hole logging equipment was utilized on the second drilling project to aid in the evaluation of the airborne survey and later in the development of ore finding criteria. The ore found in the Blanding district is confined to the Salt Wash sandstone member of the Morrison formation. (M.B.)

<287>

Barrett, D.C., and D.N. Magleby; AEC, Salt Lake City, UT

Airborne Radiometric Survey, Kern and San Bernardino Counties, California, and Nye County, Nevada. RME-2015, 17 pp. (1954, August)

Approximately 180 square miles of mainly igneous rocks of the western Mojave Desert were covered by this airborne radiometric survey in 173 hours of flying time. Six anomalies were discovered, one of which appears to be of possible commercial value. Abnormally high radioactivity in the region appears to be associated with Cenozoic structures and, to a less extent, with particular rock types mainly Jurassic granites and Tertiary volcanics. Although ore-grade material has been found at only one anomaly, some sub-surface exploration may be warranted in other favorable areas to determine the possible presence of uranium ores. (Auth)

<288>

Simic, V., R. Pantic, and S. Konjevic; Institute of Geological and Mining Exploration and Investigation of Nuclear and Other Mineral Raw Materials, Belgrade, Yugoslavia

Methodology of Uranium Exploration in Yugoslavia. In Proceedings of a Panel on Uranium Exploration Methods, held in Vienna, Austria, April 10-14, 1972. International Atomic Energy Agency Publications, Vienna, Austria, (p. 21), 320 pp.; IAEA-PL-490:9, (p. 21), 320 pp. (1973, November)

A short description is given of uranium exploration procedures in Yugoslavia, from analysis of all available geological data to ore reserves

calculations and evaluation of ore deposits. The general area for regional prospecting is the result of preliminary research. After the regional prospecting phase, which is described in more detail, one can outline prospects or smaller areas for successive, complex, semidetained, and detailed prospecting. Short descriptions of applied methods in all phases and under different field conditions are given, as well as a possible model of uranium exploration, which is applicable to the exploration of other mineral raw materials. The most widely used and efficient methods in uranium prospecting are aeroradiometric and geochemical methods. (On the basis of Yugoslavian experience, the most efficient method for fast discovery of outcropping uranium deposits is the aeroradiometric method followed by a ground check of the radium-type anomalies obtained, and, in the case of non-outcropping uranium deposits, the most efficient methods are systematic and successive geological, geophysical, and especially geochemical exploration methods. (Auth)(M.I.B)

<289>

Moxham, R.M., G.W. Walker, and L.H. Baumgardner; USGS, Washington, DC

Geologic and Airborne Radioactivity Studies in the Rock Corral Area, San Bernardino County, California. USGS Bulletin 1021-C, 16 pp. (1955)

The investigation in the Rock Corral Area was undertaken to determine the relation between the anomalously high radioactivity recorded during an airborne survey and the distribution and mode of occurrence of radioactive material.

Thorium-bearing minerals occur in relatively small, highly radioactive biotite-rich inclusions in a porphyritic quartz monzonite. Radioactive accessory minerals are also disseminated in the porphyritic quartz monzonite and in detritus derived from the porphyritic quartz monzonite. The configuration and amplitude of the major radioactivity anomalies detected from the air indicate that they have resulted chiefly from the large masses of porphyritic quartz monzonite rather than the biotite-rich inclusions. An analysis of the recorded radioactivity anomalies in the Rock Corral area and the equivalent-uranium content of the source rocks indicates that the lower limit of sensitivity of the airborne equipment, with respect to gross geologic features, is probably 0.001

percent. (Auth)

<290>

Stead, F.W.; USGS, Washington, DC

Instruments and Techniques for Measuring Radioactivity in the Field. In USGS Professional Paper 300, (pp. 705-713), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 714-721), 825 pp. (1956)

The principal instruments used to prospect for radioactive raw materials are the Geiger counter and scintillation counter. The portable Geiger counter is used to detect, primarily, gamma radiation and, secondarily, beta radiation. The more efficient portable scintillation counter is not as rugged or reliable as the Geiger counter, is used almost exclusively for measuring gamma radiation. Techniques for measuring radioactivity in the field can be grouped roughly as surface, subsurface, and airborne. Surface methods include both detailed local surveys and broad regional surveys, using Geiger and scintillation counters specifically adapted to particular field conditions. Regional reconnaissance surveys usually are made with car-mounted scintillation instruments of the continuously recording type; such surveys locate radioactivity anomalies for more detailed surveys and also provide data on the surface distribution of radioactivity in large areas. Subsurface techniques include gamma-ray and neutron logging of exploratory drill holes and measurement of the radon content of gases issuing from soils, springs, and drill holes. The Geiger counter is almost universally used in logging small-diameter holes; scintillation counters and ionization chambers are widely used where the hole diameter is sufficiently large. Logging techniques have been applied semiquantitatively in exploration for uranium, thorium, uraniferous phosphates, and potash. Accurate measurement of radon content of gases requires a car-mounted complex ionization chamber apparatus; such measurements are restricted in application and difficult to interpret. Airborne-instrument techniques make use of highly sensitive radiation detectors in single- and multi-engine aircraft. Although portable Geiger

and scintillation counters can be used effectively in aircraft flying close to the ground, most airborne instruments are semipermanent installations of the continuously recording scintillation detector type. Airborne surveys cover large areas rapidly and economically, are widely and successfully used to locate points of anomalous radioactivity that may indicate radioactive ore deposits. (Auth)(MLB)

<291>

Briner, S., J.T. Lindow, and R.J. Kaldenbach; GeoMetrics Exploration, Sunnyvale, CA

Gamma-Ray Measurement and Data Reduction Considerations for Airborne Radiometric Surveys. IAEA-SM-208 34, (pp. 93-105), 807 pp.; In Proceedings of a Symposium on Exploration for Uranium Ore Deposits, held in Vienna, Austria, March 29-April 2, 1976. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 93-105), 807 pp. (1976)

Most airborne gamma-ray surveys utilize large crystal detectors, multichannel spectrometers and complex data reduction procedures. Many problems remain, however, for the successful application of these surveys to uranium exploration. Among these problems are poor gamma-ray count statistics, weak geological signals, excessive background and inadequate procedures for removing the effects due to the background. In the paper an attempt was made to demonstrate how the new prismatic exSquare crystal array, and improvements in computer-controlled multichannel spectrometers, might affect the quality of airborne radiometric data. (MLB)

<292>

Cameron, G.W., B.E. Elliot, and K.A. Richardson; Canada Geological Survey, Ottawa, Ontario, Canada

Effects of Line Spacing on Contoured Airborne Gamma-Ray Spectrometry Data. IAEA-SM-208 2, (pp. 81-92), 807 pp.; In Proceedings of a Symposium on Exploration for Uranium Ore Deposits,

held in Vienna, Austria, March 29-April 2, 1976. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 81-92), 807 pp. (1976)

A reconnaissance airborne gamma-ray spectrometer survey is usually designed to show the regional surface radioclement distribution pattern and locate broad areas of uranium enrichment. Perhaps the most important parameter to consider for this type of survey is the flight-line spacing which will give the desired information most economically. Airborne gamma-ray spectrometry data of equivalent uranium distribution have been computer contoured into maps to qualitatively illustrate the effect of varying the flight-line spacing between 400 m and 5 km. Data for two coincident surveys with perpendicular flight-line directions were also computer contoured. The results indicate, and the maps in the paper illustrate, that for a flight-line spacing of 5 km, a smoothing of 15 to 20 points with a grid spacing of 1.5 km to 2.0 km will produce contour maps from reconnaissance data that adequately show the regional radioclement distribution pattern. (Auth)(MLB)

<293>

Duval, J.S.; USGS, Denver, CO

Statistical Interpretation of Airborne Gamma-Ray Spectrometric Data Using Factor Analysis. IAEA-SM-208 12, (pp. 71-80), 807 pp.; In Proceedings of a Symposium on Exploration for Uranium Ore Deposits, held in Vienna, Austria, March 29-April 2, 1976. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 71-80), 807 pp. (1976)

The statistical technique of factor analysis provides a quantitative and non-subjective means of synthesizing and correlating data from gamma-ray spectrometry surveys. Factor analysis was applied to data from an aerial survey of the Freer-Three Rivers area in South Texas. Variables used were corrected count-rates for potassium, uranium, and thorium, total count, and the ratios Bi 214/K 40, Bi 214/Tl 208, and Tl 208/K 40. Analysis showed that three factors were sufficient to represent all seven variables. Statistical groupings correspond reasonably well to the mapped formations in the area, but some patterns suggest geological

complexities which do not appear on available maps. The analysis identifies unusual groupings that are unlike surrounding patterns; many of these occur over known oil and gas pools and appear to indicate geochemically abnormal ground. Factor analysis enables the geologist or geophysicist to rapidly produce a radiometric map with a minimum amount of subjectivity. The resulting map has the advantages that the ground intervals are correlated on the basis of all of the variables rather than on a subjective integration of individual contour maps or profiles. (Auth)(M.I.B.)

(294)

Charbonneau, B.W., P.G. Killean, J.M. Carson, G.W. Cameron, and K.A. Richardson; Canada Geological Survey, Ottawa, Ontario, Canada

Significance of Radioelement Concentration Measurements Made by Airborne Gamma-Ray Spectrometry Over the Canadian Shield. IAEA-SM-2083, (pp. 35-53), 807 pp.; In Proceedings of a Symposium on Exploration for Uranium Ore Deposits, held in Vienna, Austria, March 29-April 2, 1976. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 35-53), 807 pp. (1976)

Results of airborne gamma-ray spectrometer surveys conducted by the Geological Survey of Canada are presented as maps contoured in units of radioelement and concentrations. These contoured values represent the average surface concentrations of the radioelements over areas of the order of several square kilometres. The relationship between this "average surface concentration" and the radioelement concentration in bedrock underlying the area depends on: (1) the percentage of outcrop; (2) the relation between overburden and bedrock radioelement concentration; (3) percentage of marshland or surface water in the area; (4) soil moisture; and (5) density of vegetation. More than 2500 portable gamma-ray spectrometer analyses of outcrop and overburden have been made in the Bancroft, Elliot Lake and Fort Smith areas of the Canadian Precambrian Shield. In the areas examined, the radioelement concentrations in glacial drift reflect the concentrations in the underlying bedrock. Rocks with near-crustal average contents of

thorium, uranium and potassium are overlain by glacial drift having approximately the same concentrations. As the concentration in bedrock increases, the concentration in the local overburden also increases, but not to the same extent. In addition, in-situ gamma-ray spectrometry measurements were made at almost 1000 stations within the area of airborne surveys near Mont Laurier and Elliot Lake. These ground measurements were compared with the airborne measurements by averaging the values for all those ground stations located in the areas between each contour level on airborne maps. Radioelement concentrations in bedrock are considerably higher than corresponding airborne measurements, and this difference between bedrock and airborne values increases at higher radioelement concentrations. Radioelement concentrations in glacial drift are only slightly higher than airborne contour values for the same area. Airborne contour maps of the radioelement ratios give values that are similar to the ratios determined by ground measurements on overburden and outcrop. (Auth)

(295)

Dahlkamp, F.J.; Uranerz/berbau, Bonn, Federal Republic of Germany

Geochronological-Metallogenic Correlation of Uranium Mineralization. In Proceedings of a Technical Committee Meeting on Recognition and Evaluation of Uraniferous Areas, held in Vienna, Austria, November 17-21, 1975. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 131-148), 295 pp.; IAEA-TC-25.8, (pp. 131-148), 295 pp. (1977)

On the basis of a descriptive classification of uranium occurrences an attempt is made, using statistics, to establish a metallogenic-geochronological framework that encompasses the present economic uranium deposits. The studies reveal that certain types of uranium deposits and uranium source rocks prevail in certain geological times, especially in the Upper Archean-Lower Proterozoic and Hercynian, and that numerous uranium deposits in sediments and metasediments, irrespective of age, show a distinct affinity to these uranium-rich source rocks. From these results it is concluded that optimal conditions to find further uranium deposits of the traditional

types exist in areas where uranium-fertile source rocks and favorable host rocks occur in Upper Archean-Lower Proterozoic, Hercynian and, to a limited extent in Upper Proterozoic domains. (Auth)

<296>

Christell, R., K. Ljunggren, and O. Landstrom: Isotope Techniques Laboratory, Sto Åsholm, Sweden; AB Atomenergi, Studsvik, Sweden

Brief Review of Developments in Nuclear Geophysics in Sweden. In Proceedings of a Panel on Nuclear Techniques in Geochemistry and Geophysics, held in Vienna, Austria, November 25-29, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 21-45). 271 pp. (1976)

The variety of different kinds of ore deposits and ore elements in Sweden gave rise to the need for flexible, multipurpose logging techniques. A research and development program in nuclear geophysics was begun in 1967 by AB Atomenergi and the Isotope Techniques Laboratory. The following measurements were considered: continuous logging of boreholes for (1) natural radioactivity, (2) rock density (by gamma-gamma techniques), (3) heavy mineral zones (by selective gamma-gamma techniques), (4) elemental concentrations (by X-ray fluorescence, neutron capture, and activation analysis of short-lived nuclides); and stationary measurements at selected positions in boreholes for elemental concentrations (by natural gamma spectrometry, X-ray fluorescence, activation, and gamma-gamma methods). A brief description of the methods and equipment utilized is presented. (PAG)

<297>

De Nault, K.: Stanford University, Stanford, CA

Origin of Sandstone Type Uranium Deposits in Wyoming: Exploitation. In Ph.D. Dissertation, Origin of Sandstone Type Uranium Deposits in Wyoming, Chapter 4, (pp. 94-110). 352 pp. (1974)

There are three main groups prospecting for uranium in Wyoming: mining companies, oil companies, and small associations or individuals. Each of these has its own methods and philosophies. Porous permeable lower Eocene sands and anomalous uranium content are the main features looked for in a target selection program. One method of locating potential host sands is reconstruction of paleodrainage systems. In reconnaissance investigations anomalous uranium is ordinarily equated with anomalous radioactivity and the quickest and least expensive method of examining large areas is by airborne radiometric surveys. Such surveys have been very helpful in locating near-surface deposits in the Powder River Basin. In areas found anomalous by airborne radiometric surveys, ground traverses may be undertaken, mostly on foot or occasionally by vehicle, using portable scintillometers. Following an airborne radiometric survey, geochemical sampling may be undertaken. Geochemical prospecting is usually restricted to analyzing the uranium content of surface and ground waters. Geobotanical prospecting has been used in the Colorado Plateau and to a limited extent in Wyoming. Two methods are employed: analyzing plants for trace amounts of uranium and mapping the distribution of indicator plants. The first method has not been used in Wyoming, but the second method has been used with some success. Uranium deposits in Wyoming contain an appreciable amount of selenium, and *ASTRAGALUS PATTERSONI*, a member of the vetch group, requires large amounts of selenium in order to grow. Recent innovations in reconnaissance techniques for uranium prospecting are in the area of color photography. This type of photography can sometimes pick up color contrasts indicative of altered ground. Photographic surveys should become even more helpful as equipment becomes available at reasonable cost for photography at various wavelengths. The main reason large companies acquire property in a particular area, however, is not because of geologic or geophysical evaluation, but because there is exploration activity nearby. In the past, particularly because of the pressure of highly competitive and aggressive land acquisition, only a limited amount of scientific target selection has been employed. Economic concentrations of uranium are usually removed by open pit mining. The advantages of open pit mining over underground mining for Wyoming uranium deposits are cheaper costs and greater recovery. The maximum depth for open pit mining is

presently about 400 feet. In situ extraction of uranium was undertaken in the Shirley Basin district, by pumping sulfuric acid into ore-bearing sandstone and pumping the uranium-bearing solutions out. The operation has been abandoned in favor of open pit mining. (JMT)

CHEMICAL ANALYSIS AND GEOCHEMISTRY

<298>

Korkisch, J., and H. Hubner, University of Vienna, Institute for Analytical Chemistry, Analysis of Nuclear Raw Materials Division, Vienna, Austria

Determination of Uranium in Minerals and Rocks. *Talanta*, 23, 283-288. (1976, April)

A method is described for the determination of uranium in minerals and rocks by spectrophotometry and fluorimetry. After treatment of the sample with hydrochloric acid, uranium is separated from matrix elements by adsorption on a column of the strongly basic anion-exchange resin Dowex 1 X 8 from an organic solvent system consisting of IBMK, tetrahydrofuran and 12M hydrochloric acid (1:8:1 v v). Following removal of iron, molybdenum and co-adsorbed elements by washing first with the organic solvent system and then with 6M hydrochloric acid, the uranium is eluted with 1M hydrochloric acid. In the eluate, uranium is determined by means of the spectrophotometric arsenazo III method or fluorimetrically. The suitability of the method for the determination of both trace and larger amounts of uranium was tested by analysing numerous geochemical reference samples with uranium contents in the range 10(E-1) to 10(E+4) ppm. (Auth)

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Clarke, W.B., Z. Top, A.P. Beavan, and S.S. Gandhi; McMaster University, Department of Physics, Hamilton, Ontario, Canada; British Newfoundland Exploration Limited, Montreal, Quebec, Canada

Dissolved Helium in Lakes: Uranium

Prospecting in the Precambrian Terrain of Central Labrador. *Economic Geology*, 72, 233-242. (1977)

Measurements of dissolved helium, ^3He ^4He , and neon have been made in 60 water samples collected from 56 lakes and ponds in the Kaipokok region in Labrador. Tritium was measured in 8 water samples. The aim of the survey was to search for excess ^4He from decay of uranium and its daughter products. Excess ^4He varied from approximately 0% to 65% relative to the equilibrium solubility concentration at the temperature of the sample. $\Delta(^3\text{He})$, the helium isotope ratio anomaly relative to atmospheric helium, varied from +11% to -25%. Although the effect of tritium decay in the water prior to sampling must be considered, there is a good correlation between the lakes which have $\Delta(^3\text{He})$ -2% and lakes with excess radiogenic ^4He greater than or equal to 4%. The helium results when plotted on a map of the area show a remarkable fit with the locations of known uranium mineralization. (Auth)

<300>

Schrader, E.; Duke University, Department of Geology, Durham, NC

Relationships Between Uranium and Trace Metal Concentrations in Volcanic Rocks from Nevada. *Economic Geology*, 72(1), 104-107. (1977)

Cobalt, copper, and molybdenum were chosen because these elements are generally known to show proportional relationships to uranium in sedimentary environments and in uranium ore deposits localized within sedimentary strata. Lithium and lead were chosen since these elements, which are not major components in the rock-forming minerals, may be concentrated in residual fluids along with uranium. Chemical analyses for cobalt, copper, lithium, and lead were determined by atomic absorption spectrophotometry, and molybdenum and uranium content was obtained by standard colorimetric techniques. Triplicate analyses on all samples showed no more than five percent deviation in the values obtained. Mineralogic determinations were accomplished by X-ray diffraction and microscopic examination of the samples. All of the metals except lithium showed enrichment above their average concentrations in acid igneous rocks. The

molybdenum concentrations vary among all samples, but those samples rich in uranium have a tendency to have higher molybdenum concentrations. The data presented show that trace metals that commonly accompany sandstone-type uranium deposits are also seen to occur significantly with uranium in possible source rocks for such an ore. Anomalous concentrations of copper and cobalt in rhyolites altered by hydrothermal action could be used as a practical geochemical prospecting tool for uranium in a volcanic environment. (M.I.B)

<301>

Wollenberg, H.A., A.R. Smith, and E.H. Bailey; Lawrence Radiation Laboratory, University of California, Berkeley, CA; USGS, Menlo Park, CA

Radioactivity of Upper Mesozoic Graywackes in the Northern Coast Ranges, California. *Journal of Geophysical Research*, 72(16), 4139-4150. (1967, August)

Traverses across the Coast Ranges north of San Francisco were made to measure the field gamma radioactivity and to sample graywackes of the Franciscan formation, its coastal belt unit and the great valley sequence. In the laboratory, specimens were analyzed for U, Th, and K by gamma spectrometry; K feldspar contents were determined by point-counting stained slabs. The K feldspar content has little effect on radioactivity or heat production of the rock units. Low K feldspar content does not indicate low heat generation; therefore, low-temperature high-pressure metamorphism is not related to K feldspar content. Radioactivity tends to decrease with increasing metamorphic grade. Thorium uranium ratios fall within the range described as typical of eugeosynclinal sediments and are like Th/U ratios in granitic rocks of the Sierra Nevada, the suggested source area. Uranium, thorium, potassium concentrations of the graywackes are compatible with those of a cratonal source. (Auth)

<302>

Wollenberg, H.A., and A.R. Smith; Lawrence Radiation Laboratory, University of California, Berkeley, CA

Radioactivity and Radiogenic Heat in Sierra Nevada Plutons. *Journal of Geophysical Research*, 69(16), 3471-3478. (1964, August)

A radiometric traverse was made across granitic rocks in the Huntington Lake area of the Sierra Nevada, California. Field gamma-ray counting rates were recorded, and samples were taken and subsequently evaluated in the laboratory for U, Th, and K content by gamma-ray spectrographic analyses. These concentrations were converted to heat-generation values, using the factors: 1 ppm U = 0.73 microcal g yr, 1 ppm Th = 0.20 microcal g yr, 1 per cent K = 0.27 microcal g yr. Three principal plutons were sampled: a stock of pyroxene quartz diorite on the western border of the Sierra, hornblende-biotite granodiorite of the 'Dinkey Creek type' on the western slope of the range, and the Mount Givens granodiorite occupying the higher elevations east of Huntington Lake. Laboratory results indicate that the Mount Givens granodiorite averages nearly twice the U and Th content and, therefore, nearly twice the radiogenic heat production of Dinkey Creek granodiorite; the pyroxene quartz diorite is quite low in radioisotope content, and consequently in heat production, compared with the Mount Givens and Dinkey Creek plutons. The ratio of Th to U does not vary appreciably between the Mount Givens and Dinkey Creek plutons, averaging 3.24 in the Dinkey Creek and 3.06 in the Mount Givens. If the radioactivity of the Mount Givens granodiorite can be considered to be typical of the younger granitic rocks of the Sierra Nevada, and that of the Dinkey Creek granodiorite typical of the older plutonic rocks, a large central part of the batholith may have considerably higher radioactivity and radiogenic heat production than the older rocks on the western flank of the Sierra. (Auth)(M.I.B)

<303>

Sorensen, H.; University of Copenhagen, Copenhagen, Denmark

Features of the Distribution of Uranium in Igneous Rocks - Uranium Deposits Associated with Igneous Rocks. In *Proceedings of a Technical Committee Meeting on Recognition and Evaluation of Uraniferous Areas*, held in Vienna, Austria, November 17-21, 1975. International Atomic Energy Agency

Publications, Vienna, Austria, (pp. 47-52).
295 pp.; IAEA-TC-25 10, (pp. 47-52), 295
pp. (1977)

The generally accepted main features of the distribution of uranium and thorium in igneous rocks are briefly reviewed in this report. It was pointed out that uranium in most cases is strongly partitioned into the melt during consolidation of magmas and that uranium is concentrated in the most volatile-rich parts of the magma. In co-magmatic series of igneous rocks, the highest content of U and Th is usually found in the youngest, most felsic, and most silicic members. Often times, in such rocks, Th and sometimes U show a positive correlation with potassium and a negative correlation with Ca and Mg. Alkaline series of rocks are commonly richer in U and Th than equivalent sub-alkaline rocks, and volcanic rocks are often richer in U and Th than their plutonic equivalents. In viscous magmas, U and Th may be strongly concentrated in the most water-rich parts of the magma, and in some volcanic provinces, U and Th show the highest concentrations in the earliest eruptions, probably due to the tapping of successively deeper levels in the layered magma chambers which have the highest contents of U and Th in their uppermost parts. Peralkaline magmas, especially undersaturated magmas of agpaitic type, strongly retain their volatile components, first of all fluorine, a very effective complexing agent for U. As a result of this behavior, agpaitic rocks are characterized by high contents of U and Th. The behavior of uranium during crystallization of magmas indicates that the formation of high concentrations of uranium are realized most easily in the most evolved parts of intrusions of rock series. High concentrations may be formed within the igneous rocks if the volatile phase is retained during crystallization of water-saturated highly differentiated magmas. Because of this wide range of behavior exhibited by uranium in different types of magmas, it is difficult to establish universally valid exploration criteria. Detailed petrological and geochemical studies, however, may be useful in outlining exploration targets. (JMT)

<304>

Beers, R.F.; Massachusetts Institute of Technology, Department of Geology, Cambridge, MA

Radioactivity and Organic Content of Some Paleozoic Shales. Bulletin of the American Association of Petroleum Geologists, 29(1), 1-22, (1945, January)

By measurement of the total beta activity, the total alpha activity and the radium content, a new method has been developed for the routine determination of radioactive substances in sedimentary rocks. The important radioactive elements in these rocks are uranium, thorium, and potassium. Earlier work has shown that these radioactive elements may be found largely in three principal loci (1) association with the heavy minerals of sands and sandstones, (2) in K 40 the active isotope of potassium which is found in evaporites, oil-field brines, clastic fragments of micas and other potassium-bearing minerals and in clays and shales which may contain up to 6.5 per cent potassium, and (3) in the uranium and thorium content of shales and clays, impure limestones and marls, shaly sandstones, and organic sediments. Pure limestones and pure quartz sands are found to exhibit practically no measurable radioactivity. Black shales containing up to 16 per cent organic matter have been found to contain high concentrations of the three principal radioactive elements. Excellent correlations are shown to exist between the uranium content, the thorium-uranium ratio and carbon content in individual shale formations. These studies throw new light on three important problems: (1) the sedimentation environment of Paleozoic black shales, (2) the evolution of petroleum source beds, (3) the relationship of radioactive and organic matter in these beds. (Auth)

<305>

Scott, R.C., and F.B. Barker; USGS, Denver, CO

Radium and Uranium in Ground Water of the United States. In Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Vol. 2, Survey of Raw Material Resources, held in Geneva, Switzerland, September 1-13, 1958, United Nations, New York, (pp. 153-157), 843 pp. (1958)

Samples of ground water were collected from most major and some minor aquifers throughout the

United States from 1953 to 1957. Each sample was analyzed for uranium, radium, and the more common nonradioactive constituents. To facilitate statistical interpretation of the data, the United States was divided into ten geotectonic regions. The boundaries of these regions were based upon considerations of tectonics, geology, physiography, and ground-water provinces. The ratios of the radioelements to the dissolved solids content of the water, called "concentration factors" in this paper, may be especially useful in humid regions where hydrogeochemical interpretations are sometimes difficult because of dilution. In each geotectonic region, "anomalous concentration factors" are those greater than the largest concentration factor of the samples previously designated as anomalous because of the actual uranium or radium content. Therefore, samples having anomalous concentration factors of uranium or radium warrant further investigation. (Auth)(MLB)

<306>

Adler, H.H.; AEC, Washington, DC

Some Possible Geologic Relationships in the Formation of Uranium 235 from Curium 247. *Economic Geology*, 56(4), 689-694. (1961, June)

A mechanism for the derivation of U 235 from Cm 247 is considered as a possible source of U 235 enrichment in radioactive rare earth minerals. The presence of Cm 247 in early earth materials is predictable on the basis of synthesis through nuclear reactions and from extrapolations of abundances of lighter nuclides. The chemistry of curium reflects a geochemical similarity to rare-earth elements and possible incorporation in rare-earth minerals. The amount of enrichment of U 235 that might be expected from Cm 247 decay is calculated for monazite for several ages. Within the limits of the parameters considered, Cm 247 would not provide sufficient U 235 enrichment to be of economic consequence, but its possible existence in early geologic time may be of interest in geochronology studies. Underestimation of Cm 247 abundance may affect significantly the probability for finding interesting variations in U 235:U 238 ratios. (Auth)

<307>

Adams, J.A.S., and K.A. Richardson;
Rice University, Houston, TX

Thorium, Uranium and Zirconium Concentrations in Bauxite. *Economic Geology*, 55(8), 1653-1675. (1960, December)

Twenty-nine samples of bauxites from different locations were analyzed for thorium and uranium by gamma-ray spectrometric, alpha counting, and wet chemical method. The thorium concentrations range from 5.0 to 131 ppm and average 48.9 ppm. The uranium concentrations range from 2.7 to 26.7 ppm and average 11.4 ppm. The thorium-to-uranium ratios range from 1.5 to 20.9 with an average value of 5.1. Zirconium determinations on some of the bauxites gave values ranging from 0.02 to 0.65 percent Zr and averaging 0.09 percent Zr. The thorium, uranium and zirconium contents of the bauxites are related to the type of source rock. Bauxites derived from nepheline syenites contain more thorium and uranium than bauxites derived from other rock types; bauxites derived from basic igneous rocks have the lowest thorium and uranium concentrations, and bauxites derived from carbonate rocks, have the lowest thorium-to-uranium ratios. The greatest concentrations of Zr were found in bauxites derived from nepheline syenites, and bauxites derived from carbonates contained the lowest concentrations of Zr. A study of samples from alumina plants treating Surinam and Arkansas bauxites shows that during the process, over 70 percent of the thorium and uranium in these two bauxites is concentrated into the red mud, and the alumina contains very small amounts of these elements. (Auth)

<308>

Barker, F.B., and R.C. Scott; USGS,
Denver, CO

Uranium and Radium in the Ground Water of the Llano Estacado, Texas and New Mexico. *Transactions of the American Geophysical Union*, 39(3), 459-468. (1958, June)

Water samples were collected from 47 wells and springs in the Ogallala formation in the Llano Estacado section of the High Plains, Texas and

New Mexico. The Ogallala, a fluvatile geologic terrance, is hydrologically and geologically isolated in this region, therefore, the observed radiochemical concentrations are considered as inherent characteristics of the formation in this area. The uranium concentrations ranged from 0.9 to 12 ppb (median 6.2 ppb), and the radium concentrations ranged from less than 0.1 to 0.8 micromicrocuries per liter (median 0.1 uuc l). The uranium concentrations show a tendency to correlate with the gross chemical character of the waters in accordance with the expected chemical behavior of uranium. The departure of the radium-uranium ratios in all samples from radioactive equilibrium value is explained on the basis of carbonate-complexing of uranium and selective adsorption of uranium ions having a capacity for base exchange.

Cited as a reference in NUREG Reports.

<309>

Star., I.E., Y.V. Kurnetsov, S.M. Grashchenko, and M.S. Frenklkh; V.G. Khlopin Radium Institute, Leningrad, USSR

The Ionium Method of Determination of Marine Sediments. Geochemistry, 1, 1-5. (1958)

Results of an investigation of the vertical distribution of uranium, radium, ionium and thorium as well as iron, manganese and calcium in 7 cores of marine sediments raised from the bottom of the Indian and the Pacific oceans are given in the article. The results obtained allow the following conclusions to be drawn: (1) In deep sea sediments radium and ionium are in all experimental points in radioactive equilibrium. (2) Ionium and thorium occur in marine sediments in various forms. (3) The thorium and uranium content in all studied sediments does not change by the length of the core, remaining constant in the ranges of the error of measurement. (4) Three types of marine sediments may be distinguished according to the character of distribution of the ionium and radium to them: Littoral sediments, sediments of an intermediate type and typical deep sea sediments. (5) A connection between the vertical distribution of ionium and radium on the one hand and the vertical distribution of calcium on the other hand has been detected in a number of cores. (Auth)

<310>

Hyden, H.J.; USGS, Washington, DC; AEC, Washington, DC

Uranium and Other Trace Metals in Crude Oils of the Western United States. In USGS Professional Paper 300, (pp. 511-519), 739 pp. (1956)

A total of 107 samples of crude oil and 16 samples of oil-refinery residues was collected in the Western United States for uranium and other trace-metal determinations. The crude oils and refinery residues were converted by ignition to ash. The uranium content was determined fluorimetrically, and the content of vanadium, nickel, and copper was determined spectrographically. Results of the study show that uranium is not preferentially distributed with respect to age, lithologic character, or geographic location of the reservoir rocks, nor does it show any preferential distribution with respect to oil types as established from U.S. Bureau of Mines crude-petroleum analyses. The uranium content of crude oil is insufficient for commercial production but may serve as a prospecting guide to uranium deposits. Vanadium and nickel are known to exist in crude oils as metallo-organic porphyrin complexes. A comparison of vanadium-nickel and vanadium-uranium ratios in the present investigation shows that most of the uranium is not present as a porphyrin complex in crude oil. (Auth)

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Bates, T.F., and E.O. Strahl; Pennsylvania State University, University Park, PA

Mineralogy and Chemistry of Uranium-Bearing Black Shales. In Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Vol. 2, Survey of Raw Material Resources, held in Geneva, Switzerland, September 1-13, 1958. United Nations, New York. (pp. 407-411), 843 pp. (1958)

A study was conducted in which 1185 samples representing eleven black shale formations from various parts of the United States and Europe have been analyzed by mineralogical, chemical and radiometric techniques. From a mineralogical standpoint, all the shale samples are quantitatively

similar, except those from the St. Hippolyte district of France which contains siderite instead of calcite as one of the major constituents. The French shales also contain abundant meta-autunite but most of the uranium in these samples and all of the uranium in other shales is loosely held in the fine-grained organic-inorganic matrix in the rock. Except for the meta-autunite, there is no evidence of any uranium mineral. The 787 bituminous shale samples from the Chattanooga, Ohio, Woodford and Alum shales show a carbon-log uranium correlation of +0.89. The carbonaceous Kansas, Allegheny and St. Hippolyte shales deviate markedly from this largely as a result of the greater degree of oxidation which is reflected primarily in the amount of free iron and carbonate present. When this and the other compositional factors are taken into account by multiple regression analysis, the association of the composition with log uranium for all shales except those of St. Hippolyte improves 7.5%. (JMT)

<312>

Adams, J.A.S., J.K. Osmond, and J.J.W. Rogers. Not given

The Geochemistry of Thorium and Uranium. In *Physics and Chemistry of the Earth*, (pp. 298-348). (1956)

Studies have shown that the average Th/U ratio in igneous rocks is about 3.5. This ratio is fairly constant in rocks of greatly differing thorium and uranium contents, and it is the characteristic ratio of the low concentrations present in the major rock-forming minerals like quartz and the feldspars. Rocks that exhibit greatly differing ratios, such as granites, have been observed, but such wide deviations from 3.5 should probably be assigned to some special process of rock formation. This widespread occurrence of ratios of about 3.5 indicates that this is very close to the overall crustal average. Though the Th/U ratio in major rocks and minerals is commonly about 3.5, this ratio is not found in most of the accessory minerals in which thorium and uranium tend to be concentrated. The early-forming accessory minerals (i.e. zircon, apatite, and possibly sphene) commonly exhibit a Th/U ratio of about 1 or less. Later-crystallizing accessories, however, have Th/U ratios ranging from 100 (monazite) to 0.01 (xenotime). This pronounced fractionation of thorium and uranium in the late-stage minerals

may be explained by the oxidation of tetravalent uranium to uranyl ion, which is markedly different chemically from tetravalent thorium. The ratio of 1 found in the early-crystallizing minerals, however, is not readily explained by simple oxidation of the uranium. Presumably, if oxidation of the uranium occurred during the early stages of magmatic crystallization, the thorium tetravalent uranium ratio would be reduced, and minerals which incorporated these tetravalent ions would have a ratio greater than 3.5. The possibility that zircon and apatite can fractionate such chemically similar ions as tetravalent thorium and tetravalent uranium cannot be completely excluded, but the mechanism for such a fractionation is obscure. Rather than simple oxidation or crystal fractionation, complexes such as tetravalent uranium-phosphate complex may play an important role in determining the ratio of thorium and uranium available to enter a receptive accessory mineral at any magmatic stage. It is also possible that most magmas have a Th/U ratio of about 1 at the start of the crystallization and that the final ratio of 3.5 is caused by the hydrothermal escape of uranium; however, it seems unlikely that a uniform ratio would be obtained by such a process and the evidence from basic rocks and lavas, where accessory minerals have had an opportunity to crystallize with the thorium and uranium, indicates that normal, unassimilated magmas begin with a ratio of about 3.5. The importance of hydrothermal fluids in redistributing uranium, and even thorium to a certain extent, should not be minimized, and many of the great differences in the total uranium contents of comagmatic igneous rocks may be related to the movements of hydrothermal fluids. (JMT)

<313>

Sheldon, R.P.; USGS, Washington, DC

Geochemistry of Uranium in Phosphorites and Black Shales of the Phosphoria Formation. USGS Bulletin 1084-D. (pp. 83-115). (1959)

Uranium in the Phosphoria formation of Permian age in the western phosphate field occurs mostly in phosphorite and partly in black shale, but some of the phosphorites and most of the black shales of the formation are practically nonuraniferous. These anomalies in uranium content can be related to the petrography and the composition of the rocks. A

basic premise to this study is that the immediate source of the uranium in the Phosphoria formation was the ocean. The facts that the quantity of uranium in the formation is large and widely distributed and that comparable Recent marine phosphorites are uraniferous support this premise. The chemistry of uranium in the ocean has been little studied, but several deductions can be made from the known thermodynamic data and the chemical data of uranium in aqueous solutions. It has been shown that the pH and Eh control the oxidation state of uranium in natural water, and a survey of the literature reveals that the increasing pH favors the formation of complex ions made up of a uranyl ion and anions present in the sea, such as PO_4^{3-} , CO_3^{2-} , OH^- , and SO_4^{2-} . The formation of uranyl sulfate complexes is favored by high Eh. The phosphatic rocks of the formation are classified according to Eh and pH of their depositional environment, and their uranium contents are compared by means of a distribution-free statistical test. This analysis shows that the phosphatic sediments that were deposited in an environment of low Eh are relatively rich in uranium, whereas phosphatic sediments deposited in an environment of high Eh are relatively poor in uranium. The pH of the environment where apatite is stable apparently has no effect on the concentration of uranium. Two hypotheses for the occurrence of uranium in apatite are reviewed: (a) the substitution of U^{+4} for calcium in the apatite lattice, and (b) the adsorption of the uranyl ion on the surfaces of apatite crystallites. No clear-cut choice between these two modes of occurrence can be made with the present data, as both U^{+4} and U^{+6} are known to occur in the Phosphoria formation. Multiple regression analyses show that uranium is positively correlated with both Ph 205 and fluorine present in the apatite in quantities exceeding that of lattice requirements. This correlation seems to be best explained by adsorption of both excess fluorine and uranium on the surfaces of apatite crystallites. The size of apatite crystallites was investigated by X-ray diffraction techniques; the results suggest, but do not prove, that apatite rich in excess fluorine and uranium is made up of the smallest crystals. These data suggest that uranium is probably deposited in apatite in one or both of two ways: (1) low Eh of the depositional environment causes the highest concentration of the U^{+4} ion and thereby more U^{+4} is substituted for calcium in the apatite lattice; or (2) a low Eh of the depositional environment allows the accumulation of organic matter, which inhibits growth of apatite crystallites,

allowing more uranyl ion to be adsorbed on crystallite surfaces. Few data are available on the mode of occurrence of uranium in black shale, but from chemical and stratigraphic considerations, it seems possible that the uranium is deposited as disseminated UO_2 in a reducing acid depositional environment. (Auth)(JMT)

(314)

Landis, E.R.; USGS, Washington, DC

Uranium Content of Ground and Surface Waters in a Part of the Central Great Plains. USGS Bulletin 1087-G, (pp. 223-258). (1960)

The uranium content of water from various rock units and geologic terranes has been determined in an attempt to locate areas in which large amounts of uranium in the water might indicate the presence of nearby accumulations of uranium in the rocks of the central Great Plains. Water samples were collected from three geologic terranes in the report area: the tuffaceous-rocks terrane, of Tertiary and Quaternary age; the shale terrane, of Cretaceous age; and the sandstone terrane, of late Permian through Early Cretaceous age. The average uranium content of 179 water samples from tuffaceous fluvial rocks ranging in age from Pliocene to Pleistocene is 6.7 parts per billion. A total of 48 samples from Cretaceous shale and limestone of marine origin contain an average of 20.4 ppb uranium. Sandstone, siltstone, and claystone of terrestrial and near-shore from or related to these rock units, or groups of rock units, are listed according to the source from which the samples are collected, and for some samples by geographic parts of the report area. They are believed to be of more potential use in any future hydrogeochemical exploration in the area than are the data on average uranium content derived from the three geologic terranes. The average uranium content of ground water samples from 12 individual rock units or groups of rock units ranges from less than 1.0 to 38 ppb. Several rock units were sampled over areas large enough to indicate that waters from the same rock unit in different parts of the report area may range widely in average uranium content. Most of the water samples from the rock units of Permian and Triassic age contain large amounts of uranium. Also, relatively large amounts of uranium are present in water samples from some parts of the

report area, such as the Cimarron River area of westernmost Oklahoma and northeastern New Mexico, and the Rule Creek area of Bent and Las Animas Counties, Colorado. (Auth)(JMT)

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Rozhkova, E.V., E.G. Razumaya, M.B. Serebryakova, and O.V. Scherbak

The Role of Sorption in the Process of Uranium Concentration in Sedimentary Rocks. In Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Vol. 2, Survey of Raw Material Resources, held in Geneva, Switzerland, September 1-13, 1958. United Nations, New York. (pp. 420-431), 834 pp. (1958)

A study of the modes of occurrence of uranium in sedimentary rocks pointed out that processes of sorption may play a role in uranium accumulations in sedimentary deposits. An experimental study of the basic laws governing the sorption process on sedimentary rock constituents (uranium carriers) showed that the principal factors affecting the accumulation of uranium are: uranium concentration in solution, pH, and salt composition of the medium of sorption. Uranium may occur in solution in the form of a uranyl ion or of hydrolysis products of its salts depending on the pH of the medium. In the presence of a complexing agent anion, it occurs in the form of a complex compound in the cation or anion form. The pH of the medium essentially affects the magnitude of the electrokinetic potential of the sorbent, and in certain cases the sign of its charge. Both may influence the absorbing capacity of the sorbent. The conditions of uranium accumulation in organic material was also investigated. Ground waters feeding peat bogs and carrying uranium deposit it on humus substances and on vegetative material, both of which possess a high sorptive capacity with respect to uranium in a slightly acid medium (pH=5.5-6.0). The process of peat transformation into lignites is not yet clear, but the majority of the investigators believe that this transition takes place in a reducing medium. In this state, uranium loses the sorption bond and is thrown off the sorbent. If uranium remains sorbed to the coal, the throwing-off will occur later during the further metamorphism of the coal. This will be promoted by an alteration in the true surface dimensions of

the coal and smaller amount of uranium. Sorption of uranium on organic matter under conditions of a marine basin cannot take place to the extent it attains under conditions of a peat bog, since marine water and pore waters possess a considerably higher pH, and since a part of the uranium contained will be represented by the carbonate complex ions which do not sorb on the organic matter due to the fact that their sign coincides with that of the sorbent. In the course of migration of uranium-bearing solutions within coal beds or sedimentary deposits containing organic matter, favorable conditions are created for uranium sorption, especially if the solutions show a slightly acid reaction. (JMT)

<316>

Douley, J.R., Jr., H.C. Granger, and J.N. Rosholt; USGS, Denver, CO

Uranium-234 Fractionation in the Sandstone-Type Deposits of the Ambrosia Lake District, New Mexico. Economic Geology, 61(8), 1362-1382. (1966)

Isotopic analyses for U-234 were made on 30 samples from 5 vertical suites of ore-grade uranium bearing sandstone from the Ambrosia Lake District, McKinley County, New Mexico. U-238, U-235, and U-234 were measured by mass spectrometry, and U-234/U-238 ratios were verified by alpha spectrometry. No U-238/U-235 isotopic variations were found above the 1.2 percent level of accuracy of these measurements. Uranium-234 variations were as great as 58 percent deficient and as much as 36 percent enriched as compared to the radioactive equilibrium value attained in a reference sample of Republic of Congo pitchblende. The pattern of U-234 fractionation found in both primary ore and redistributed ore samples generally shows an enrichment just above the ore and a large relative deficiency near the richest uranium ore. Samples taken above the water table show another enrichment in U-234 at the bottom boundary of the ore but samples taken below the water table do not. The pattern of U-234 fractionation can be explained by assuming that the uranium was redistributed and U-234 was gradually enriched at the boundaries of mineralization except where the lower boundary is below the water table. Samples from two vertical suites believed to be redistributed ore show the greatest deficiency in U

234 with respect to the reference standard. Radiochemical analyses of Th 230 and Pa 231 indicate a complicated history of uranium migration in the deposit, significant redistribution of uranium having occurred during the last 200,000 years. The distribution of Th 230 and Pa 231 indicates that interphase isotopic exchange of uranium was the predominant mechanism producing U 234 enrichment, although deposition of U 234 enriched uranium from solution can be a contributing factor. Leaching of uranium apparently prevails more commonly where U 234 is relatively deficient, but uranium deposition is indicated in a few samples that have a deficiency of U 234. (Auth)(JMT)

<317>

Cowan, G.A., and H.H. Adler, Los Alamos Scientific Laboratory, University of California, Los Alamos, NM; ERDA, Washington, DC

The Variability of the Natural Abundance of U 235. *Geochimica et Cosmochimica Acta*, 40, 1487-1490. (1976)

The possibility that the atomic ratio U 235/U 238 may be slightly variable due to natural nuclear chain reactions such as have been identified in Gabon, West Africa, has prompted a re-examination of very precise gas mass spectrometric isotopic ratio data from a number of laboratories. Two modal values of the isotopic ratio exist in the data. Their relative difference, 0.03%, is statistically significant. The lower mode is principally in ores from the Colorado Plateau. This difference was recognized in 1963 by the US Atomic Energy Commission, but substantiating data have not been openly published. Insufficient data presently exist to attribute this difference to chemical differentiation of the uranium isotopes, presumably in the "sandstone" type deposits of the Colorado Plateau, or to dilution with Precambrian ore deposits, depleted in U 235 by nuclear reactions. (Auth)

<318>

Nekrasova, Z.A.: Not given

The Form of the Occurrences of Uranium in Some Coals. In *Proceedings of the*

Second International Conference on the Peaceful Uses of Atomic Energy, Vol. 2, Survey of Raw Material Resources, held in Geneva, Switzerland, September 1-13, 1958. United Nations, New York. (pp. 412-419), 843 pp. (1958)

Studies of the mineral composition of coals, the established specific features of uranium distribution in coals, and the other data obtained indicate that the bulk of uranium, both in coals and in sandstones, occurs in the form of oxides. In ore-bearing sandstones, the oxide form of uranium ore is certain for the pitchblende and uranium-black in them are easily identified by standard mineralogical methods. The proof of the occurrence of uranium in coals in the form of oxides is as follows: (1) The presence of uranium in both coals and sandstones in the form of oxides is established microscopically. (2) The separation of uranium oxides from coals with an indefinite form of uranium mineralization by means of fine grinding and separation in heavy liquor in a supercentrifuge. (3) The identification of uranium in such coals by means of X-ray analysis. (4) The association of uranium with the sections enriched with pyrite. (5) The identical nature of uranium distribution in the coals in which the bulk of uranium is represented by oxides and in the coals with an undetermined form of mineralization in these coals there is a direct relation between uranium concentration and ash content. (6) The identical recovery of uranium by various reagents from the coals enriched with uranium oxides and from the coals in which the presence of uranium cannot be detected by mineralogical methods. (7) The easy extraction of uranium from coals by weak acid solutions. High solubility in acids is also characteristic of the pitchblende present in coals. This specific feature of the pitchblende found here (in contrast to the pitchblende of hydrothermal deposits) is due to the high degree of its oxidation and dispersion, as well as to the presence of oxidizers in coals (the salts of trivalent iron which substantially effects the solubility of uranium oxides in acids). (8) The higher degree of the oxidation of uranium containing organic matter warrants the assumption that the process of mineralization was the result of oxidation-reduction reactions. The reduction of uranium was apparently accompanied by the oxidation of organic matter. The compounds most likely to form as a result of the reduction of uranium from solutions are oxides. Apparently uranium was precipitated out of subterranean

waters circulating in coals and reduced by organic matter or hydrogen sulfide. Adsorption processes also played an important part in uranium fixation. The results of these studies prove the oxide form of uranium occurs in coals, but questions the presence of uranyl humates in the investigated coals in the zone of primary ores. (JMT)

<319>

Cathcart, J.B.; USGS, Washington, DC

Distribution and Occurrence of Uranium in the Calcium Phosphate Zone of the Land-Pebble Phosphate District of Florida. In USGS Professional Paper 300. (pp. 409-494), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955, United Nations, New York. (pp. 514-519), 825 pp. (1956)

The land-pebble phosphate district, in west-central peninsula Florida, comprises more than 1,000 square miles, mostly in Polk and Hillsborough Counties. The matrix, or calcium phosphate zone, constituting the lower phosphorite part of the Bone Valley formation, and the upper residual part of the Hawthorn formation, consists essentially of equal parts of quartz sand, phosphate particles, and slime. The central area of the Bone Valley formation contains predominately coarse phosphate. The analysis of many thousands of samples has shown that the coarser phosphate particles are higher in uranium and lower in P2O5 content than the finer material. Uranium content of the coarser material (pebble) averages between 0.010 and 0.020 percent, and the P2O5 content averages about 31.5 percent. The uranium content of the finer materials (concentrates) is commonly between 0.005 and 0.015 percent, and the P2O5 content averages about 34 percent. A direct relation between P2O5 content and U content is present, however, within a size fraction; in pebble samples of the same size, the U content tends to increase as the P2O5 increases. (Auth)(MLB)

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Rosholt, J.N., Jr.; USGS, Marine Laboratory, Miami, FL; University of

Miami, Marine Laboratory, Miami, FL.

Late Pleistocene and Recent Accumulation of Uranium in Ground Water Saturated Sandstone Deposits. Economic Geology, 56(2), 423-430. (1961, March)

Protactinium 231 and thorium 230 relations in several ground water saturated sandstones containing uranium ore indicate that much of the uranium has been accumulating in very recent times. Samples from the Hauber mine, Crook County, Wyoming, were selected to illustrate the concept of recent accumulation and the methods of calculations of the estimated minimum and maximum dates of the start of the uranium accumulation. The radiochemical results of eight samples from this mine show extremely consistent radioactive daughter product distribution, and a close correlation between the estimated dates of the start of uranium accumulation and the uranium content of the ore. The results for mill pulp samples, representing large tonnages of ore, indicate that the major part of uranium deposition started between 40,000 and 130,000 years ago and the rate of deposition has increased approaching the present time. (Auth)

<321>

Masursky, H.; USGS, Washington, DC

Trace Elements in Coal in the Red Desert, Wyoming. In USGS Professional Paper 300. (pp. 439-444), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955, United Nations, New York. (pp. 450-463), 825 pp. (1956)

Uranium-bearing coal underlies approximately 300 square miles of the Red Desert, near the central part of the Great Divide basin, a large topographic basin of interior drainage along the Continental Divide in south-central Wyoming. The coal-bearing rocks were cyclically deposited in swamps marginal to the lakes formed in Green River time and are interbedded with coarse-grained fluvial arkose of the Wasatch formation to the northeast and organic lacustrine shale of the Green River formation to the southwest. The highest uranium

concentrations are in coal overlain by gravels of Miocene age, as at Creston Ridge, where the uppermost coal bed contains as much as 0.051 percent uranium near its top and 0.001 percent 40 feet lower. Acreally the uranium content of the coal beds increases toward the northeast as the lithofacies change and become coarser-grained and more permeable. (Auth:M.B.)

<322>

Breger, I.A.; USGS, Washington, DC

The Role of Organic Matter in the Accumulation of Uranium. In *Proceedings of a Symposium on the Formation of Uranium Ore Deposits*, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 99-124), 748 pp. (1974, November)

Geochemical studies were carried out on 64 specimens of coalified logs containing from 0.0005 to 16.5 uranium. The sediments from which the specimens were collected are more or less arkosic, fluvial sandstones in various degrees of lithification. In Colorado, Utah, and New Mexico the sediments are of Triassic or Jurassic age; in Wyoming, they are of Eocene age except for one specimen of Paleocene age. It was found that uranium, not being a significant constituent of plants, becomes associated with individual coalified logs or massive coal deposits through secondary processes. The uranium was probably carried in solution as complex alkali uranyl carbonates, which with contact with coal, are readily absorbed, at least in part by penetration of the solution into fracture and/or shrinkage zones in the coal. Initial retention may be in the form of complex or insoluble uranyl compounds; depending on the environment, these compounds can be reduced to form uraninite or coffinite. Where a coalified log is protected from the mineralizing fluid, it will remain free of uranium. Studies of the coalified logs from the Colorado Plateau have not only advanced a generalization of the principles underlying the coal-uranium association, but have provided detailed information on secondary processes in which the nuclear radiation from the uranium and its daughter products effects radiochemical transformations in the coal structure. In concert with known effects of nuclear radiation on organic compounds, it has been found that the coal is

radiochemically dehydrogenated and condensed, that it becomes more highly oxygenated by differential loss of both carbon and hydrogen, and that in the process of such changes it loses part of its calorific value. Uraniferous coalified logs collected in Triassic sediments of the San Rafael Swell of Utah differ from those of the rest of the Colorado Plateau in having organic sulfur contents that increase with increasing uranium content. Evidence indicates that the association between the organic sulfur and uranium contents is fortuitous rather than genetic, that the high organic sulfur contents of the coalified logs may have resulted from an interaction between the coal and hydrogen sulfide derived from underlying sediments, that both hydrogen sulfide and, later, uranium came into contact with the coalified logs by following zones of maximum permeability in the sediments, and that the sediments in which the logs were buried and coalified were essentially free of hydrogen sulfide at the time that the solutions of complex alkali uranyl carbonates were introduced. The coalified logs of Eocene age were of special interest in this study because of their particularly high uranium values (1.6 to 10.5%). Analysis of the data illustrates that they have undergone radiochemical dehydrogenation as have the Triassic and Jurassic logs. The radiochemical degradation of coal does not lead to the formation of anthracite, but is accompanied by demethanation and dehydrogenation as the dominant processes. The Triassic coals show that 1.7 moles of methane are evolved per mole of hydrogen and the Jurassic coals have a 1.1 to 1.0 methane to hydrogen ratio. (JMI)

<323>

Harshman, E.N.; USGS, Denver, CO

Distribution of Elements in Some Roll-Type Uranium Deposits. In *Proceedings of a Symposium on the Formation of Uranium Ore Deposits*, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 169-183), 748 pp. (1974, November)

Roll-type uranium deposits in the Shirley Basin and Gas Hills areas of Wyoming, the Black Hills area of South Dakota, and Karnes and Live Oak Counties of Texas were sampled on close-spaced centers (15 cm to 2 m). The samples were analyzed

chemically for uranium, ferric and ferrous iron, sulfate and sulfide sulfur, organic and mineral carbon, selenium, arsenic and phosphate, and radiometrically for equivalent uranium. The amounts of 54 elements in the samples were determined spectrographically. The sample sites extended from altered (oxidized) sandstone, through ore, and into unaltered (reduced) sandstone. The analytical data show that certain elements were added to parts of the host sandstone during the ore-forming process and that other elements were taken from it. Addition and depletion of elements took place in zones that show a consistent pattern in the deposits studied, a fact suggesting the geographically widely separated deposits were formed by similar geochemical processes. From the data, it appears that the solutions were oxidizing, and that the passage of these solutions resulted in increasing the amount of ferric iron at the expense of ferrous iron, decreasing the amount of mineral and organic carbon, and converting pyrite to goethite and/or hematite. Significantly, the principal elements in the ore generally form soluble compounds that either must or can be readily transported in neutral to somewhat alkaline solutions; elements that require acid solutions for mobility, such as copper, are lacking in the ore. This evidence together with the fact that the host rocks and tuffaceous material in them or associated with them are an alkaline environment, suggests that the ore-bearing solutions had a pH in the range of 7 to 8.12. Deposition of the ore minerals required a reductant, the character of which is difficult to ascertain. Deposits containing jordisite (MoS_2), may require an additional reductant because the sequence of mineral deposition is in the order of decreasing Eh. Jordisite, the most difficult (requiring the lowest Eh) mineral to precipitate, is found the greatest distance from the tongue's edge. The concept that sour gas, H_2S of biogenic origin, or H_2 has been an important factor in the genesis of some roll-type uranium deposits has merit, particularly in those areas such as Texas and the Gas Hills of Wyoming, where uranium deposits are underlain by accumulations of oil and gas. (JMT)

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Granger, H.C., and C.G. Warren; USGS, Denver, CO; Colorado State University, Fort Collins, CO

Zoning in the Altered Tongue Associated

with Roll-Type Uranium Deposits. In *Proceedings of a Symposium on the Formation of Uranium Ore Deposits*, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 185-200), 748 pp. (1974, November)

The altered tongues associated with roll-type uranium deposits commonly include a border zone that separates the hematitic core of the tongue from enclosing reduced pyrite rocks. This border zone—herein called the alteration envelope—can have characteristics that range from limonitic orange to bleached in appearance. It is speculated that a metastable mineral assemblage developed in this zone during genesis of the roll deposits. A tentative model of roll formation is proposed, in which oxygenated ground waters percolating through the hematitic core zone react abruptly with authigenic siderite and elemental sulfur in the alteration envelope. This results in the creation of soluble ferric thiosulfate complexes, which can flow past the siderite and sulfur without significant change. When the ferric thiosulfate ion contact pyrite, however, they react to release ferrous iron, elemental sulfur, and thiosulfate. Some of the ferrous iron precipitates as siderite and the remainder is transported ahead in solution with the thiosulfate to be reprecipitated as iron sulfides. Upon termination of roll formation, the zone containing siderite and elemental sulfur can be leached or can alter slowly to limonite or pyrite. The various characteristics of the alteration envelopes are therefore believed to be attributable to mild post-ore processes. (Auth)

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Dall'Aglio, M., R. Gragnani, and E. Locardi; Laboratorio Geominerario, Rome, Italy

Geochemical Factors Controlling the Formation of the Secondary Minerals of Uranium. In *Proceedings of a Symposium on the Formation of Uranium Ore Deposits*, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 33-48), 748 pp. (1974, November)

Geochemical processes capable of precipitating secondary uranium minerals directly from

circulating waters, even where there are no primary uranium mineralizations, are discussed. The first case refers to the autunite mineralization from the Sila plateau in the Calabria region of Italy, and the second to a carnotite deposit in the Yeelirrie calcrete of Western Australia. It was found that in the supergene ore genesis, the problem of uranium supply is mostly considered in terms of space and time. Peculiar environmental conditions are able to cause, in a short time and/or space range, an intense uranium mobilization and circulation. There are, however, certain widespread geochemical processes, which are a consequence of the environmental evolution, are of fundamental importance in the uranium accumulation, and they behave just like traps, even if of unusual type. There are series of geochemical processes capable of bringing about a very effective separation and concentration of uranium, with a yield extremely high for a natural system. Such processes may occur under humid temperate climatic conditions, as in the case of the Sila Plateau, as well as under arid climatic conditions in zones where the morphology is very flat. The most important geochemical process is the reaching of high CO_2 activity in circulating waters because of the low concentration of depletion of the carbonate ion which is the most effective uranyl chelating compound. Different environmental conditions may control the uranium concentration either as carnotite or as autunite mineralizations. The factors controlling the circulation and distribution of the compounds precipitating uranium may be important in determining the eventual fate of the uranium. (JMT)

<326>

Brinck, J.W.: International Resources Consultants B.V., Alkmaar, Netherlands

The Geochemical Distribution of Uranium as a Primary Criterion for the Formation of Ore Deposits. In *Proceedings of a Symposium on the Formation of Uranium Ore Deposits*, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 21-32). 748 pp. (1974, November)

The use of a log-binomial model of element distribution in the geological environment has been useful in the better evaluation of the long-term

supply problem for uranium. Some of the implications of this model for making an inventory of regional mineral potential and the selection of favorable exploration areas by multi-element geochemical surveys are discussed in the report. (Auth)(JMT)

Cited as a reference in NURE Contractor Reports.

<327>

Calvo, M.M.: Junta de Energia Nuclear, Direccion de Geologia y Mineria, Madrid, Spain

Consideraciones Sobre el Papel que Desempeñan las Sustancias Orgánicas Naturales de Caracter Humico en la Concentracion del Uranio. In *Proceedings of a Symposium on the Formation of Uranium Ore Deposits*, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 125-137). 748 pp. (1974, November)

The paper reports a short experiment on the metallogenetic aspect of the uranium-organic matter association in nature. Several experiments on uranium fixation by organic matter with different degrees of maturity were carried out. Although further studies are considered necessary, the results already obtained lead to the following conclusion: when uraniferous solutions come into contact with humic organic matter, the efficiency and nature of the uranium-organic matter association thus established depends on the degree of carbonization attained by the humic material. At the beginning of the development process, the organic matter has high chemical activity and the uranium tends to occur in stable organic phases. As the process continues, a stage is reached from which uranium tends to form its own minerals independently of organic matter. From the coalification stage onwards the tendency towards uranium-organic matter association becomes increasingly less in any form. Petrographically, the humic constituents to which uranium is closely and positively related belong to the huminite maceral group. Lastly, it is considered that when the organic matter is present as an accessory constituent in other sedimentary rocks and with quite low maturity indices, there is greater favorability for the formation of uranium deposits.

(Auth)

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Hockstra, H.R., and J.J. Katz; Argonne National Laboratory, Argonne, IL.

Isotope Geology of Some Uranium Minerals. In U.S.G.S Professional Paper 300, (pp. 543-547), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 547-550), 825 pp. (1956)

This paper is concerned with variation of oxygen 18 oxygen 16 ratio in uraninite and pitchblende from which might be deduced the temperature of formation of these minerals. Efforts have been concentrated on determining isotope ratios in a number of ores and in correlating results with the nature of the ore. Decomposition of the samples is effected by bromine trifluoride. Oxygen is separated from the remaining products as pure molecular oxygen. Isotopic ratios are determined directly on this material. Results show variation of isotope ratios amounting to 1.6 percent. Seemingly oxygen isotope ratios are not affected by treatment with water at or near room temperature. Experiments in synthetic uranium oxides indicate that temperatures approaching 300 degrees C are required to obtain a measurable rate of exchange of oxygen isotopes. Impurities in the samples often result in a measurable variation in isotope ratio. Weathered samples show higher oxygen 18 contents than unweathered samples from the same location. Uranium oxides from pegmatites show a somewhat lower oxygen 18 content than those from hydrothermal or sedimentary deposits, but no reasonable estimates of temperature of formation of the ores is as yet possible. The only correlation obtainable with the samples is with the isotopic content of the ground waters associated with the ores. Impurities in the ores and weathering cause some variations from the oxygen 18 content of the ground water. Exchange experiments with the same minerals and with synthetic oxides indicate that exchange rates are dependent upon temperature of formation of the mineral. (Auth)

<329>

Chow, T.J., and J.L. Earl; University of California, Scripps Institution of Oceanography, La Jolla, CA

Lead and Uranium in Pennsylvanian Anthracite. Chemical Geology, 6, 43-49. (1970)

The origin of lead and uranium in Pennsylvanian anthracite can be traced by examining the isotopic relationship of these elements. Lead concentration, its isotopic composition, and the uranium content of the anthracite have been determined. From the isotopic analysis, it is interpreted that common lead was incorporated into the ancient, bedded plant material in Carboniferous times prior to coalification, while the uranium was introduced into the anthracite after coalification. Washed samples were taken systematically, pulverized to 100-200 mesh, weighed, and ashed at 425 degrees C to constant weight. The lead was extracted by treating the ash with concentrated HNO₃ and HClO₄, isolated by ion exchange, purified, and then converted to the sulfide form. The lead and uranium concentrations were determined by isotope dilution. The uranium concentrations of three Pennsylvanian anthracite samples was 1.55, 2.10 and 2.65 ppm respectively. (M.B)(PAG)

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Rose, A.W., and M.L. Keith; Pennsylvania State University, Department of Geosciences, Mineral Conservation Section, University Park, PA

Reconnaissance Geochemical Techniques for Detecting Uranium Deposits in Sandstones of Northeastern Pennsylvania. Journal of Geochemical Exploration, 6, 119-137. (1976)

A variety of sampling and analytical techniques have been tested on stream water and stream sediment samples near known sandstone-type uranium prospects in the Catskill Formation of northeastern Pennsylvania and red-bed Cu-U occurrences in north-central Pennsylvania. Uranium in stream water varied with time by a factor of up to 70. The highest values were obtained during a period of low rainfall, but uranium contents were below the detection limit of 0.2 ppb at most other times so that interpretation

of uranium in water appears to be very difficult. Uranium extracted from stream sediment by an acetic acid H₂O₂ leach gives greater contrast than total uranium or treatment with nitric acid. Anomalies in sediment show relatively small changes with time, except perhaps during periods of high runoff, but a significant effect of organic matter is found. After correction for organic matter, sediment from small drainages near the known prospects is anomalous, but some of the larger second-order streams near occurrences are not anomalous. In general, anomalies are relatively weak, and careful planning, analysis, and interpretation are required to detect the known prospects of the region. (Auth)

<331>

Breger, I.A., and M. Deul; USGS, Washington, DC

The Organic Geochemistry of Uranium.

In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York. (pp. 418-421). 825 pp.; In USGS Professional Paper 300, (pp. 505-510). 739 pp. (1956)

The common association of uranium with naturally occurring carbonaceous materials is well established. Recent investigations have been conducted to determine the manner in which the uranium and naturally occurring carbonaceous substances are related. Uranium can become associated with carbonaceous materials by at least three mechanisms. The first mechanism suggests that the organic material serves as a reducing agent which converts the soluble uranyl ion to an insoluble uranous form. A second mechanism involves the sulfide ion, which is normally associated with carbonaceous substances, as a reducing agent to convert the uranyl ion to the uranous form. The third mechanism involves the use of the carbonaceous material as a chemical precipitant for the uranyl ion. This last mechanism has been found to be operative where coals absorb uranium from circulating ground water, with the formation of insoluble uranyl humates.

Carbonaceous materials, taken as a group, are but one of many possible precipitants, both chemical and physical, which influence the deposition of

uranium. They can be effective only when the element comes into contact with them under the proper chemical conditions. (Auth)

<332>

Brown, A.; USGS, Washington, DC

Uranium in the Chattanooga Shale of Eastern Tennessee. In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York. (pp. 439-444). 825 pp.; In USGS Professional Paper 300, (pp. 457-462). 739 pp. (1956)

The Chattanooga shale contains in places sufficient uranium to make it a potential low-grade ore. The most promising areas are the Eastern Highland Rim and the Walden Ridge area in Tennessee. The Chattanooga shale in this area is of late Devonian age and is divided into the Dowelltown and Gassaway members. The Dowelltown, or lower, member is of no present interest as a source of uranium, only the Gassaway member is being considered a potential source. The Gassaway member includes three units: a lower black shale 3.5 to 10.5 feet thick and averaging 7 feet; a middle unit composed predominantly of black shale, with minor thin beds of gray shale, averaging about 2.5 feet thick and thinning eastward; and an upper black shale from 2 to 8 feet thick and averaging 6 feet. In the Eastern Highland Rim the total thickness of the Gassaway ranges from 13.5 to 18.5 feet; the average is 16 feet in the Eastern Highland Rim. In Walden Ridge the range is 10 to 17 feet; the average is 14 feet. The black shale units of the Chattanooga are nearly massive in appearance and the rock breaks with a conchoidal fracture, but weathered outcrops show a marked fissility and a thin coating of iron oxide. Data from many outcrops and drill holes show that the Gassaway as a whole contains from 0.005 to 0.008 percent uranium. The highest average uranium content is in the upper unit; the lowest content is in the middle unit. The lower unit is of intermediate grade. The lateral distribution of uranium in each unit of the Gassaway in eastern Tennessee is remarkably uniform, though it is somewhat higher than average in an area southeast of Smithville, and in Walden Ridge. No uranium minerals have been identified in the shale, and the form in which the element occurs

is not now known. It is considered to be of syngenetic origin. (Auth)

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Thompson, P., D.C. Ford, and H.P. Schwartz; McMaster University, Department of Geology, Hamilton, Ontario, Canada

U 234/U 238 Ratios in Limestone Cave Seepage Waters and Speleothem from West Virginia. *Geochimica et Cosmochimica Acta*, 39, 661-669. (1975)

Speleothem from West Virginia, ranging in age from 2000 to 200,000 yr B.P. contains uranium with U 234/U 238 ratios significantly greater than unity. This ratio varies from one speleothem to another, as does average U content. Initial ratios, corrected for age, are remarkably constant for a given speleothem. By contrast, U 234/U 238 ratios in seepage waters vary significantly from month to month at a given drip site, and their average values differ from that of the speleothem which they are depositing. This discrepancy is attributed either to long-term averaging-out of fluctuations, or fractional precipitation on the speleothem of a chemical species of uranium with a more constant ratio. Constancy of initial U 234/U 238 ratios from Th 230/U 234 datable portions of speleothems should permit U 234/U 238 dating of older portions of the same speleothem, back to about $10(E+6)$ yr B.P., with estimated precision of plus or minus 5 per cent. (Auth)

<334>

Grimaldi, F.S.; USGS, Washington, DC

The Analytical Chemistry of Uranium and Thorium. In USGS Professional Paper 300. (pp. 605-617), 739 pp. (1956)

Uranium is usually separated by organic solvent extraction of uranyl nitrate from solution salted with nitrates, by chromatographic methods, or by precipitation and extraction methods involving the use of cupferron. Uranium is determined by fluorimetric, colorimetric, volumetric, polarographic, coulometric, radioactivation, X-ray spectrometric, and nuclear photographic plate techniques. Separations of thorium are based on

the precipitation of thorium with phosphate, ammonia at controlled acidity, potassium iodate, potassium iodate-oxalic acid, organic acids, hexamine, oxalic acid, and hydrofluoric acid. Thorium may also be separated by chromatographic techniques and by solvent extraction such as with mesityl oxide. It may be determined spectrophotometrically with thoron as well as by polarographic, titrimetric, mass spectrometric, and fluorescent X-ray spectrometric methods. (Auth)(PAG)

<335>

Moore, G.W.; USGS, Denver, CO

Extraction of Uranium from Aqueous Solution by Coal and Some Other Materials. *Economic Geology*, 49, 652-658. (1954)

Uranium in nature is commonly associated with carbonaceous material. Laboratory studies were therefore conducted to determine the relative ability of various types of carbonaceous material and some other substances to remove uranium from solution. The results of these experiments indicate that the low-rank coals are more effective in extracting uranium than any of the other materials used. A chemical determination shows that nearly 100 percent of the available uranium in solution is removed by sub-bituminous coal. The uranium is apparently retained in the coal by an irreversible process. The notable affinity of uranium for coalified plant remains suggests that some uranium deposits may have been formed over a long period of time by the extraction of uranium from dilute groundwater solutions. A possible application of the results of this work may be the extraction of uranium by coal from natural water or from waste solutions from uranium-processing industrial plants. (Auth)

<336>

Brown, H., and L.T. Silver; USGS, Washington, DC; California Institute of Technology, Pasadena, CA

The Possibilities of Obtaining Long-Range Supplies of Uranium, Thorium, and Other Substances from Igneous Rocks. In USGS Professional

Paper 300. (pp. 91-95). 739 pp. (1956)

An average granite contains about 4 ppm uranium and 12 ppm thorium. If all the uranium and thorium in 1 ton of average granite could be extracted and utilized by means of nuclear breeding, the energy output would be equivalent to that obtained by burning 50 tons of coal. Results also indicate that a variety of both major and minor substances of industrial importance can be obtained as byproducts of uranium and thorium production from igneous rocks. The techniques required for extracting uranium and thorium from igneous rocks are well within the realm of present mineral-dressing and industrial-chemical experience. (Auth)

<337>

Connor, J.J., and H.T. Shacklette, USGS, Washington, DC

Background Geochemistry of Some Rocks, Soils, Plants, and Vegetables in the Conterminous United States. USGS Professional Paper 574-F. 168 pp. (1975)

Geochemical summary statistics for 48 elements in natural materials from 147 landscape units have been compiled based on field and laboratory studies since 1958. Each landscape unit is briefly identified as to kind and location, and the expected concentration for one or more elements is given together with factors indicating the degree of observed variation in the study and the degree of laboratory or "analytical" variation. Also listed are the observed range and the total number of element analyses made in each study. The data on which these summaries are based have three attributes in common: they represent "large-scale" or regional geochemical studies; they represent background or "ordinary" natural geochemical variation; and they were collected according to objective sampling designs. The summaries clearly demonstrate the wide diversity to be expected in elemental properties of landscape units and suggest that published element abundances for broad categories like "soil" or "carbonate rock" may be misleading. (Auth)

Extensive tabular data is contained in this report.

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Newman, W.L.; USGS, Washington, DC

Distribution of Elements in Sedimentary Rocks of the Colorado Plateau - A Preliminary Report. USGS Bulletin 110-F. (pp. 337-445). (1962)

The average chemical compositions of sandstone from the principal host rocks of the Colorado Plateau - the Shinarump and Moss Back members of the Chinle formation and the Salt Wash member of the Morrison formation - differ only moderately from the average chemical compositions of sandstones from formations of Paleozoic and Mesozoic age on the Colorado Plateau. Sandstones of the Shinarump and Moss Back members contain more aluminum, iron, titanium, zirconium, vanadium, chromium, and copper than average sandstone of the Colorado Plateau, and less magnesium and calcium. Sandstones of the Salt Wash member contain more calcium and copper than the average sandstone of the Colorado Plateau, and less boron, nickel, and cobalt. Sandstones of the Shinarump contain more titanium, zirconium, copper, chromium, cobalt, nickel, vanadium, than sandstones of the Salt Wash, and more than two times as much aluminum and iron. The distribution of copper and vanadium in unmineralized sandstone of the Salt Wash member corresponds favorably to the area comprising the Urvan mineral belt. There is a good possibility of defining similar large areas of potential uranium-bearing rock on the basis of variations in concentration of these two elements in unmineralized sandstone. The distribution of elements commonly associated with igneous or crystalline rocks indicate three possible crystalline rock source areas for detrital minerals in sandstone of the Salt Wash member. These areas are the Meeker-Craig area of Colorado, just south of the so-called Four Corners in Arizona and New Mexico, and the San Rafael Swell area in east-central Utah. The distribution of chromium, titanium, zirconium, boron, ytterbium, vanadium, uranium, and copper in unmineralized sandstones of the Shinarump and Moss Back members shows two areas that contain abnormally high concentrations of these elements and may reflect possible source areas that contain abnormally high concentrations of these elements and may reflect possible source areas for detritus in these members. One area is located in east-central Utah. The second area is located in southeastern Utah and forms an indistinct belt of ground extending northwestward from the Four Corners area.

Studies of variations in chemical composition of sandstone from many formations of the Colorado Plateau with regard to the occurrence of uranium deposits show sandstones containing more than half a percent of potassium. Favorable host rocks, as judged by potassium content, include (1) sandstones of the Dakota sandstones, the Cedar Mountain formation including the Buckhorn conglomerate member; (2) the Burro Canyon formation, all of Cretaceous age; (3) the Salt Wash, Westwater Canyon, and Brushy Basin members of the Morrison formation of Jurassic age; (4) the Shinarump and Moss Back members of the Chinle formation of Triassic age; and (5) the Coconino sandstone of Permian age. (JMT)

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Brookins, D.G.; University of New Mexico, Albuquerque, NM

Trace Element Geochemistry. In AT(05-1)-1636-1, (pp. 88-118), 153 pp.; In (JJBX-16476), (pp. 88-118), 153 pp. (1975)

Approximately one hundred samples of whole-rock sandstones, mudstones, and clay-sized fractions from them have been analyzed for their trace element contents. The analyses were done at Los Alamos Scientific Laboratory by Instrumental Neutron Activation Analysis. The objective of the study was to obtain trace element data for ore versus barren samples and to interpret the data such that some elements may, if transported into an ore-bearing site, not only have been concentrated in the ore zone, but left behind lesser amounts that could be used as true pathfinder elements. The sample suites were divided into three different groups: outcrop, bleached barren zone, and ore zone. The clay fraction was preferentially enriched in most of the elements investigated except for Hf and Rb. The enrichment of various elements in the fine fraction of the ore zone samples points out that adsorption, fixation or cation exchange of colloidal particles were mainly responsible. It is postulated that humic acid-and/or fulvic acid-clay complexes were significantly responsible for the precipitation of uranium. (JMT)

<340>

Rich, R.A., H.D. Holland, and U. Petersen; Harvard University, Cambridge.

MA

The Chemistry of Hydrothermal Uranium Ore Deposits. In AT(05-1)-1640, (pp. 49-74), 383 pp.; In GJO-1640, (pp. 49-74), 383 pp. (1975)

Uraninite is the only important hypogene uranium mineral present in vein-type uranium deposits. Uraninite particle size is usually less than $10(E-2)$ mm and may be smaller than $10(E-6)$ mm. The varietal name pitchblende is normally used for such fine-grained uranium. The composition of hydrothermal pitchblende is rather variable and may not approach $UO_2.6$. With increasing $U(E+6)$ content the unit cell size of UO_2 decreases and density increases. This fact suggests that charge balance is maintained in the structure by the presence of additional O-2 ions rather than by a reduction in the number of uranium ions.

Hydrothermal uraninite contains only small quantities of rare earths and thorium. Natural uraninite spans nearly the entire compositions: range between UO_2 and U_3O_8 . Unfortunately the phase relations in the U-O system at temperatures below 400 degrees C are not well known, and this complicates the interpretation of solubility data. Solubility measurements of hydrated UO_3 at 25 degrees C have shown that in acid solutions hexavalent uranium is present largely as $UO_2(OH)^+$ and $UO_2(E+2)$ sulfate and fluoride complexes of uranium may be of importance in uranium transport, but their effect is probably less pronounced than that of the O-2, OH-, and $CO_3(E-2)$ complexes. With increasing temperature the solubility of UO_2 in equilibrium with UO_3 probably passes through a maximum near 260 degrees C. There is a rapid decrease in the solubility of UO_2 below 200 degrees C. (JMT)

<341>

Saukoff, A.A.; Not given

Radiohydrogeological Method in Prospecting for Uranium Deposits. In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 756-759), 825 pp. (1955)

The radiohydrogeological method of prospecting for uranium deposits is based upon the solubility of uranium and its daughter products, radium and radon, in natural waters. Uranium enters natural waters from the rocks through which the waters migrate, as well as from deposits in which uranium occurs as an independent mineral. Because of the high concentrations of uranium in its deposits, compared to rocks, and taking into account the relatively high solubility of its ore deposits, compared to rocks, and the relatively high solubility of its ore minerals, solutions washing uranium deposits should be enriched in uranium. Waters that circulate under conditions strongly promoting reductions are an exception due to the fact that most uranium ore minerals are insoluble under reducing conditions. These waters will usually contain high concentrations of Ra and Rn, but very little uranium. When sampling natural waters, attention is directed mainly to determining the uranium content. At sections where reducing conditions develop in the waters, for instance, in waters circulating in highly bituminous rocks, determination of radium and radon in all samples is necessary. When establishing the background uranium content in the underground waters of any given rocks, the hydrochemical conditions under those rocks occur are always taken into consideration - whether these conditions promote oxidation with free oxygen occurring in underground waters, whether they are bituminous and promote reduction, or whether they otherwise promote the solution of the ores and the migration of the uranium in the waters, or interlace with them. (IM1)

<342>

Patterson, E.D.: USGS, Washington, DC

Radioactivity of Some Coals and Shales in Southern Illinois. EE-466, 23 pp. (1954, August)

Channel samples of the commercially important coal beds in the Caseyville, Tradewater, Carbondale, and McLeansboro formations of Pennsylvanian age, and samples of the black, hard, sheety, roof shales of several coal beds were collected in southern and central Illinois. The content of the coal is generally less than 0.001 percent uranium, but at one locality a one foot thick layer of Herrin No. 6 coal contains 0.008 percent uranium, and ash of the coal contains 0.125

percent uranium. The radioactivity of some black shale beds overlying coals ranges from 0.003 to 0.018 percent equivalent uranium. The most widespread uranium-bearing rock found by this reconnaissance is the hard, black, sheety shale above the No. 5 coal in Saline, Gallatin, and Williamson Counties. Based on available sample data, the more radioactive parts of this shale range from one to three feet in thickness. (Auth)

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Maher, S.W., and J.M. Fagan: Tennessee Department of Conservation, Division of Geology, Knoxville, TN; Tennessee Valley Authority, Geologic Branch, Knoxville, TN

Trace Element Content of Some Ore Deposits in the Southeastern States.

Tennessee Information Circular 16, 1 sheet. (1970)

The results are presented by states and samples from a particular state are arranged in stratigraphic order, according to the age of the host rocks because the trace element distribution seems in some measure to reflect stratigraphic location. The absence of precious metals in most of the sphalerites is characteristic of Mississippi Valley type deposits. The presence of beryllium in nine samples of sphalerite is unusual. Beryllium in association with sulfide ores has been previously reported only from the Embreeville district, Unicoi and Washington Counties, Tennessee. Data in the present report show that this association is not rare in the Southeast, although generally metallic ores contain less beryllium than the crustal average. Hg and Zn were analyzed by wet chemical methods, and the values are reported in ppm and percent, respectively. Other elements sought in the present study, with detection limits indicated in parentheses, are as follows (in percent): Ag (.005), Al (.01), Au (.02), B (.01), Ba (.002), Be (.001), Bi (.01), Ca (.005), Cd (.04), Co (.005), Cr (.002), Cs (0.6), Cu (.005), Fe (.005), Ga (.01), Hf (.02), In (.02), K (.04), Li (.004), Mg (.01), Mn (.005), Mo (.002), Na (.01), Nb (.02), Ni (.01), P (1.0), Pb (.01), Pd (.002), Rb (.15), Sb (.04), Si (.01), Sn (.005), Ta (.15), Th (.04), Ti (.005), U (.3), V (.002), W (.08), Zr (.002). (Auth)(PAG)

<344>

Scott, M.R.; Yale University, Department of Geology, New Haven, CT

Thorium and Uranium Concentrations and Isotope Ratios in River Sediments. Earth and Planetary Science Letters, 4, 245-252. (1968)

Sediments from five rivers in the eastern and southern United States have been divided into several size fractions and analyzed for thorium and uranium isotope concentrations. The U-238 decay series exhibits disequilibrium as a result of weathering. The U-234/U-238 activity ratio is less than unity in sediment derived from well-leached soils and greater than unity in sediment containing relatively large amounts of organic material from organic-rich surface layers of soil profiles. Th-230 exists in excess of equilibrium amounts relative to its parent U-234 in the fine fraction of most of the sediments analyzed. The thorium concentration and Th-230 excess are significantly higher in the 2-0.2 microns and less than 0.2 micron size fractions than in the 2-20 microns fractions, indicating adsorption by clays, complexing with sesquioxides, or possible concentration in resitates. Unsupported Th-230 is being added to deep-sea sediments at a maximum rate of 0.5 dpm/cm (E+2) 1000 y; therefore, detrital material is not a significant source of excess Th-230 in deep-sea sediments. (Auth)

<345>

Miller, T.P., and C.M. Bunker, USGS, Anchorage, AK; USGS, Denver, CO

A Reconnaissance Study of the Uranium and Thorium Contents of Plutonic Rocks of the Southeastern Seward Peninsula, Alaska. Journal of Research of the USGS, 4(3), 367-377. (1976, May)

Large granitic Cretaceous plutons are exposed along and adjacent to an arcuate belt of igneous and high-grade metamorphic rocks in the southeastern Seward Peninsula of Alaska. Reconnaissance studies of these plutons have shown that the Darby pluton has well above average amounts of uranium and thorium (11.2 ppm and 58.7 ppm, respectively), the Kachauik pluton contains average to above average uranium and thorium (5.7 ppm and 22.5 ppm, respectively), and the Bendeleben pluton contains average

amounts of uranium and thorium (3.4 ppm and 16.7 ppm, respectively). The three plutons show compositional and textural differences indicative of different source materials that may have controlled the distribution of uranium and thorium. The high uranium and thorium contents of the Darby pluton, similar to those of the Conway Granite of New Hampshire which has been mentioned as a possible low-grade thorium resource, suggest that this pluton may be a favorable area for economic concentrations of uranium and thorium. (Auth)

<346>

Ward, F.N., H.W. Lakin, and F.C. Canney, USGS, Washington, DC

Analytical Methods Used in Geochemical Exploration by the US Geological Survey. USGS Bulletin 1152, 100 pp. (1963)

Chemical methods for 24 elements are described in sufficient detail to permit use by relatively nontechnical persons. These elements are as follows: antimony, arsenic, barium, bismuth, chromium, cobalt, copper, germanium, iron, lead, manganese, mercury, molybdenum, nickel, niobium, phosphorus, selenium, sulfur, tin, titanium, tungsten, uranium, vanadium, and zinc. Some of these methods are modifications of methods developed in laboratories abroad; others were developed originally in U.S. Geological Survey laboratories. A few are modifications of well-known analytical procedures. After sample dissolution by acid digestion or fusion with different fluxes, the methods are similar in that the element being determined is obtained as a colored compound whose intensity or shade of color is proportional to the amount of the element present. The methods differ in the operations employed to separate the element from interferences and to concentrate enough of the element to form the colored compound. Solvent extraction, confined spot tests, and paper chromatography comprise the major chemical operations to achieve the necessary separations and optimum concentrations. A field-applicable semiquantitative spectrographic procedure permits the determination of elements in addition to those given above as follows: beryllium, boron, cadmium, gallium, indium, lanthanum, magnesium, scandium, silicon, silver, strontium, tantalum, thallium, yttrium, and zirconium. (Auth)

<347>

Hyden, H.J.; USGS, Washington, DC

Distribution of Uranium and Other Metals in Crude Oils. USGS Bulletin 1100-B, 17-97 pp. (1961)

A total of 120 samples of crude oil and 16 samples of refinery residue were collected from oil fields and refineries located in the western half of the United States. The oil and residue samples were reduced to ash; the uranium content of the ash was determined by fluorometric analysis, and the content of other metals by emission spectrography. The uranium content in the ash of a majority of the samples is included in the range of 0.0002 to 0.001 percent. The reported average uranium content in the crust of the earth is within this percentage range. In contrast, vanadium and nickel contents in the ash of most of the samples are included in the range of 10 to 50 percent, which is several orders of magnitude greater than the reported vanadium and nickel contents in the crust of the earth. The amounts of other metals in the ash of oil are similar to those in the crust of the earth; among these latter metals, molybdenum shows the greatest relative enrichment in the ash of crude oil. The vanadium, nickel, gallium, and molybdenum contents of the ash of the several crude-oil classes are significantly different and tend to increase in the heavier, more naphthenic or aromatic crude oils. Among the metals the uranium content varied least from oil class to oil class. In further comparisons the vanadium and nickel contents are found to be associated with nitrogen content, residual carbon content, and other items measured in crude-oil analysis. Gallium and cobalt contents show a lesser association; titanium, chromium, and molybdenum seem to be slightly associated; and uranium and copper seem to be unassociated. The ratios of vanadium to nickel of the oil samples are restricted to a small range of values, but tend to increase with increasing age of reservoir rock. Vanadium and nickel are thought to be present in crude oil mainly as porphyrins, which are organo-metallic complexes. Gallium, cobalt, and molybdenum also are inferred to be present as organo-metallic complexes. Tests indicate that crude oil can leach uranium from sandstone containing uranium minerals such as uraninite and carnotite, although the chemical process is unknown. The uranium content of crude oils, therefore, can be indicative of the uranium content in sandstone oil reservoirs. (Auth)(JMT)

<348>

Landis, E.R.; USGS, Washington, DC

Uranium and Other Trace Elements in Devonian and Mississippian Black Shales in the Central Midcontinent Area. USGS Bulletin 1107-E, 289-336 pp. (1962)

The Woodford Shale, the Chattanooga shale, and the Arkansas novaculite are marine black and dark-grey shales of Late Devonian and Early Mississippian age. These rock units have been recognized over large parts of Kansas, Oklahoma, Arkansas, and Missouri, and are partial or total equivalents of each other. The Woodford shale was examined at 10 localities in Oklahoma. Uranium content of the samples ranges from less than 0.001 to 0.014 percent, but the modal, median, and arithmetic mean values of the Woodford samples as a whole and the samples of the shale only are 0.001, 0.002, and 0.003 percent uranium, respectively. These values are probably representative of most of the Woodford except the phosphatic nodules that are present in some parts of the formation. The samples of phosphatic nodules and laminae have an average uranium content of 0.006 percent. The Chattanooga shale was examined and sampled at 7 outcrop localities in Oklahoma, 10 in Arkansas, and 1 in Missouri, and samples of cores from 2 drill holes in Kansas were also collected. A total of 95 samples, of which 83 were shale samples, was collected, and the uranium content ranged from less than 0.001 to 0.55 percent. Only one sample contained more than 0.013 percent uranium; that was a selected sample of highly radioactive organic-rich material. No samples of shale contained more than 0.012 percent uranium, and the modal and median values of the Chattanooga samples as a whole are 0.002 percent uranium. The Arkansas novaculite was sampled at 15 localities in Arkansas and Oklahoma. Only one sample contained more than 0.004 percent uranium, and it was from a locality in Garland County, Arkansas, where the Arkansas novaculite has been contact metamorphosed. The average uranium value of all samples from the formation is 0.001 percent; this is believed to be representative of the uranium content of the formation in the report area. Despite the low uranium contents of these formations as a whole, at one locality the Chattanooga shale contains as much as 0.005 percent uranium in an interval 10.1 feet thick, and the Woodford contains as much as 0.005 percent uranium in intervals up to 20 feet thick. (Auth)(JMT)

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Hyden, H.J., and W. Danilchik; USGS, Washington, DC

Uranium in Some Rocks of Pennsylvanian Age in Oklahoma, Kansas, and Missouri. USGS Bulletin 1147-B, 82 pp. (1962)

The distribution of uranium and other trace elements in sedimentary rocks of Middle Pennsylvanian (Des Moines) age in Oklahoma, Kansas, and Missouri was studied during 1955 and 1956. This investigation was directed principally toward radioactive black-shale beds, some of which contain uranium-bearing phosphatic nodules.

Samples of coal, oil well water, and naturally occurring hydrocarbons also were collected for chemical analysis for uranium and semiquantitative spectrographic analysis for other trace elements. Very dark gray to black shale examined in this investigation is designated as either carbonaceous shale or phosphatic shale. The carbonaceous shale is soft and coaly in appearance, yields little or no oil on destructive distillation, and is less

radioactive; the phosphatic shale is more resistant to weathering, yields oil on destructive distillation, contains phosphatic nodules or laminae, and is more radioactive. Phosphatic shale contains more uranium than carbonaceous shale. The average uranium content in each of eight phosphatic shale units ranges from 0.002 to 0.005 percent. The average uranium content of each of six carbonaceous shale units ranges from 0.001 to 0.002 percent. Uranium is concentrated in the phosphatic nodules found in the black shale. The average uranium content in the phosphatic nodules is 0.016 percent, and the uranium content of individual samples ranges from 0.002 to 0.060 percent. As much as 0.085 percent uranium is present in ash of coal from the uppermost few inches of a coal bed immediately underlying a phosphatic shale unit; the lower part of the coal bed contains much less uranium, but contains as much as 0.07 percent germanium in the ash. No unusual amounts of other trace elements were found in any of the other rocks, or in the black shale, but the phosphatic nodules contain rare earths, including dysprosium, erbium, and neodymium, in concentrations that correlate directly with P₂O₅ contents. The rare-earth contents are generally higher than in phosphatic rocks from other areas. Recycled water in areas of secondary production in the Nowata oil field,

Oklahoma, was collected at injection and at production wells; gains of sulfate, uranium, and radioactive daughter products of uranium were obtained in some of the samples of produced water. Uranium contents of the oil from this field range from 0.007 to 0.052 percent of the ash and from 0.0010 to 0.035 parts per million in the oil. The highest percentages of uranium are in samples from the Lowery waterflood area in the Nowata oil field. Coaly material, asphaltlike material, and extracted oil from cores taken from the oil-producing horizon in this area are not highly uraniferous. (Auth)

<350>

Hagmaier, J.L.; University of North Dakota, Grand Forks, ND

Uranium Distribution and Groundwater. In Ph.D. Dissertation, Groundwater Flow, Hydrochemistry, and Uranium Deposition in the Powder River Basin, Wyoming. Chapter 6. (pp. 90-105). 166 pp. (1971)

Most of the shallow ore deposits in the Powder River Basin are located in the Wasatch Formation. The uranium is generally disseminated but local concentrations occur around organic material and as concretionary masses. The shallow deposits are above the water table and in an oxidizing environment. Most of the uranium minerals are tyuyamunite, carnotite, and uranophane. The shallow ore deposits are believed to be weathered primary uranium minerals which were deposited in a deep reducing environment and later exposed to weathering and oxidation by erosion. The deep, unoxidized uranium deposits of the area consist mostly of uraninite and coffinite. The uranium ore characteristically has organic material, calcite cement, and iron minerals associated with it. Generally, these deep, unoxidized ore bodies occur in the lower Wasatch Formation and in the Fort Union Formation. Most of the unoxidized deposits are located in the southern Powder River Basin between Box Creek and Monument Hill mining districts. The average background for the groundwater in the Wasatch and Fort Union Formations in the Powder River Basin is 2 ppb uranium. Sixteen samples were found to be anomalously high (5 ppb or greater with the highest being 125 ppb). All but two of the anomalies found were in water from the Wasatch Formation and all but four of the anomalies are from depths ranging

between 150 to 250 feet. Fewer uranium anomalies were found in groundwater than expected, and too few were found to draw valid conclusions regarding the type of groundwater in which maximum concentrations of uranium should be expected. The fact that all the uranium anomalies were from the $\text{HCO}_3^- + \text{SO}_4^{2-}$ and $\text{SO}_4^{2-} + \text{HCO}_3^-$ groundwater facies and none were found in the deeper HCO_3^- groundwater facies indicates that the uranium in solution is being precipitated somewhere in the transition zone between the $\text{SO}_4^{2-} + \text{HCO}_3^-$ and the HCO_3^- groundwater facies. The location of major unoxidized uranium deposits of the Powder River Basin coincides with a major change in groundwater chemistry. The groundwater loses sulfate and calcium from solution where the change occurs and the concentration of bicarbonate is increased. The change in the chemical facies of groundwater generally occurs near the contact between the Wasatch and Fort Union Formations. The associated uranium deposits are probably the result of reduction by hydrogen sulfide, a product of sulfate reduction. In similar areas, studies have shown that the associated pyrite contains sulfur of biogenic origin indicating the presence of sulfate reducing bacteria. In addition, calcite cement commonly associated with uranium deposits may also be the result of precipitation by sulfate reduction. The uranium in the Powder River Basin was probably transported and deposited during the Miocene and Pliocene Epochs. At this time uranium host rocks were buried under an estimated 1000 to 2000 feet of clastic and tuffaceous rocks. The groundwater chemical facies present during the time of uranium emplacement were probably not significantly different from present day groundwater facies. Uranium was leached from some disseminated source such as the tuffaceous rocks of the White River Formation or the arkose of the Wasatch Formation. It was transported in carbonate complexes by slightly alkaline water. When the water entered the flow system it was probably rich in dissolved oxygen then became depleted with increasing length of flow path, resulting in mild reducing conditions. When the water transporting the uranium entered a zone where abundant organic material was present strong reducing conditions, probably generated by sulfate-reducing bacteria, caused precipitation of the uranium and associated minerals. Major accumulations of uranium were associated with the regional groundwater-flow path in recharge areas and were concentrated where the flow path intersected abundant organic material. To utilize the groundwater-flow theory in uranium

exploration, a reconnaissance of the general geology should be done so that the past geomorphology can be reconstructed. The chemistry of present-day groundwater from various depths and from both recharge and discharge areas should then be evaluated. Any significant change in groundwater chemistry, particularly an abrupt decrease in sulfate concentration should be investigated thoroughly in that it is the most likely place to find uranium deposits. (JMT)

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Hagmaier, J.L.; University of North Dakota, Grand Forks, ND

Theoretical Groundwater-Uranium Model. In Ph.D. Dissertation, Groundwater Flow, Hydrochemistry, and Uranium Deposition in the Powder River Basin, Wyoming. Chapter 4, (pp. 36-41). 166 pp. (1971)

Uranium has five valence states, but only the +4 reduced state and the +6 oxidized state are of geologic interest. Transitions from the +4 to the +6 state may occur in nature because uranium in these states has a redox potential within the normal range for geologic environments (+0.33 volts). The uranous ion (+4) reacts with bases to form an insoluble hydroxide $\text{U}(\text{OH})_4$ whose low ionization potential, which is about $10(\text{E}-46)$ at 25 degrees Centigrade, is such that the concentration of uranium in the +4 state is negligibly small in neutral or even acid (pH 4) solutions. For this reason, pitchblende and uraninite are extremely stable in reducing environments. Under oxidizing conditions, however, such as in near-surface environments, these minerals are easily oxidized to the +6 uranyl ion, which is somewhat mobile in acid solutions and in neutral to slightly alkaline solutions if carbonate ions are present. The uranyl ion UO_2^{+2} may be transported in a simple soluble hydroxide form (UO_2OH^+) also. In a solution at pH 7 the concentration of uranyl hydroxide is $10(\text{E}-5.1)$ while the concentration of uranyl ion is $10(\text{E}-8)$ moles. As acidity is increased to pH 4, the concentration of each ion rises to about $10(\text{E}-2)$ moles. Decaying humus in soil commonly lowers the pH of natural waters to about 4.5 or 5, but any solution in contact with silicate minerals cannot long remain appreciably acidic. As a result, acid solutions are probably important in the near-surface leaching of uranium.

Acid conditions can persist to significant depths through the weathering of pyrite or a symbiotic relationship between the oxygen-acid producing bacteria, *THIOBACILLUS*, and a sulfate reducing genus, *DESULFOVIBRIO*. In such cases, it is possible that acid solutions could transport and deposit significant amounts of uranium at depth. In solutions containing carbonate ions, the solubility of hexavalent uranium is greatly increased by the formation of carbonate complexes. A solution at pH 7 and 0.01 mole total carbonate, for example, contains approximately 10 times the amount of total dissolved uranium as a carbonate-free solution under the same condition. Carbonates from bicarbonate-rich groundwater can form uranium-carbonate complex and carry the uranium into the transition zone between the bicarbonate and sulfate groundwater facies. In this zone the carbonate in solution is precipitated, usually in the form of calcite. Precipitation is caused by a number of interrelated factors such as pH, increased temperature, and sulfate reduction. The precipitation of the carbonate releases the uranium ion of uranium, and readies it for precipitation. In the Powder River Basin, the most likely source for the uranium now found in the Eocene arkosic sediment was the tuffaceous Oligocene sediment. The area is a present-day groundwater recharge area and was probably one throughout the Tertiary Period, whereas most of the northern part of the basin is a regional discharge area and was probably one throughout the Tertiary Period. For this reason uranium ore deposits occur in the southern part of the basin rather than the northern part. (JMT)

<352>

De Nault, K.; Stanford University.
Stanford, CA

Origin of Sandstone Type Uranium Deposits in Wyoming: Groundwater. In Ph.D. Dissertation, Origin of Sandstone Type Uranium Deposits in Wyoming. Chapter 8. (pp. 182-196). 352 pp. (1974)

Analyses of groundwater in the Battle Spring Formation are sparse, only three wells and springs, but numerous analyses of ground water in the Wind River, Wasatch, and younger tuffaceous formations have been published. These analyses were evaluated to determine a representative set of characteristics for groundwater in lower Eocene

host formations and younger tuffaceous formations. The first examination consisted of determining the maximum and minimum reported values and the mean and standard deviation for each component - temperature, pH, SiO₂, etc. These data were refined by determining the mode for each component. The mean is the average value and the mode is the most probable value based upon the data at hand, but it may not be representative of the component in the groundwater at the time of uranium deposition. For instance, in many cases the sulfate concentration in shallow wells in the Wind River Basin is very high because of the addition of fertilizers to pasture and farm land. Lower Eocene host formations were buried from Oligocene until late Pliocene or Pleistocene time and water therein at the time of uranium roll formation may have been quite different from average water today. It is impossible to date the water in any analysis, but generally, the deeper a well the older or longer the residence time of the water being removed. The mean concentration of SiO₂ in groundwater in lower Eocene host formations is 13.0 ppm and in younger tuffaceous sediments it is 46.7 ppm. The mode in host formations is around 11 and in tuffaceous formations around 57. The maximum value for SiO₂ in a host formation is 32 ppm. An examination of the data, however, shows a bimodal distribution with a secondary mode around 27 ppm. It may be possible that the waters of the secondary mode represent groundwater in areas of host sands that contain some ash beds. Another explanation is that they represent groundwaters that have influxed from younger tuffaceous sediments. If the latter explanation is correct, groundwaters high in SiO₂ would be a good geochemical exploration tool because they could delineate areas where potential uraniferous groundwaters have influxed into potential host units. The mean and modes of pH in both host and tuffaceous sediments are quite similar, but a plot of pH versus depth shows a marked contrast. In tuffaceous units pH at depth is the same as the mean and the mode. However, in host formations pH shows a marked increase over both mean and mode with increasing depth. A representative value of 8.4 was therefore chosen as characteristic of groundwater in host sands at the time of uranium deposition. Both units have a similar calcium and bicarbonate concentration in their groundwaters. Permeability measurements showed the Wind River Formation to be 45 gpd/sq ft, whereas the permeability of the White River Formation is typically 10(E-3) gpd/sq ft, virtually impermeable.

Within the White River Formation and other younger tuffaceous formations are numerous channels filled with porous permeable sands which are good aquifers. These channels provide a means for lateral migration of groundwater within these units whereas vertical motion is practically eliminated. Normal faults are open and permeable and would provide channelways for influx of groundwaters from tuffaceous formations down into underlying lower Eocene host sands. (JMT)

<353>

Hagmaier, J.L.: University of North Dakota, Grand Forks, ND

Groundwater Flow, Hydrochemistry, and Uranium Deposition in the Powder River Basin, Wyoming. Ph.D. Dissertation, University of North Dakota, Geology Department, 166 pp. (1971)

The Powder River is the discharge area for the regional groundwater-flow systems in the Powder River Basin. The Dry Fork Cheyenne River is a discharge area for the intermediate groundwater-flow systems. Regional groundwater recharge occurs around the east, south, and west margins of the basin. The northern Powder River Basin is an area of groundwater discharge and the groundwater flow is in a direction opposite to that of the structural dip in the area. Regional groundwater flow, which is recharged in the southern Powder River Basin, moves northward under the smaller flow systems associated with the Dry Fork Cheyenne River. Groundwater-flow systems of the late Tertiary Period had recharge and discharge areas in similar locations to those of present-day flow systems. The sequence of the groundwater anion facies from the recharge to discharge area is $\text{HCO}_3^- + \text{SO}_4(2) \dots \text{SO}_4(2) + \text{HCO}_3^- \dots \text{HCO}_3^-$. Uranium anomalies in groundwater are restricted to the $\text{HCO}_3^- + \text{SO}_4(2)$ and $\text{SO}_4(2) + \text{HCO}_3^-$ groundwater facies and were found only in groundwater recharge areas. Known unoxidized uranium deposits are located in both the regional groundwater recharge areas of the past and those of the groundwater-flow systems of today. The major uranium deposits occur at the stratigraphic position where the groundwater facies changes from the $\text{SO}_4(2) + \text{HCO}_3^-$ to the HCO_3^- facies. The uranium was probably precipitated from solution by hydrogen sulfide. Hydrogen sulfide is a product of sulfate reduction, which is

interpreted to be the reaction responsible for the abrupt change in groundwater chemistry at the $\text{SO}_4(2) + \text{HCO}_3^- \dots \text{HCO}_3^-$ facies interface. The uranium was deposited during the late Tertiary period when recharging groundwater leached uranium from a disseminated source and transported it into the zone of transition between the $\text{SO}_4(2) + \text{HCO}_3^-$ and HCO_3^- groundwater facies where sulfate-reducing bacteria caused the uranium to precipitate. The calcite found in association with uranium deposits was also precipitated from solution by sulfate reduction. (JMT)

Select chapters of this thesis have been input separately.

<354>

Hagmaier, J.L.: University of North Dakota, Grand Forks, ND

Groundwater Flow, Hydrochemistry, and Uranium Deposition in the Powder River Basin, Wyoming: Present-Day Hydrogeology. In Ph.D. Dissertation, Groundwater Flow, Hydrochemistry, and Uranium Deposition in the Powder River Basin, Wyoming, Chapter 5, (pp. 42-89), 166 pp. (1971)

The predominant ions in solution in the Powder River Basin groundwater flow path are: HCO_3^- and $\text{SO}_4(2)$. Generally the groundwater with the highest values of sulfate and total dissolved solids in the Powder River Basin is from the areas of the shortest groundwater-flow path. Both constituents decrease in concentration with increasing flow-path length. This is contrary to what would be expected, but may be generally explained by sulfate reduction. The bicarbonate and fluoride increase with increasing flow-path length. The increased bicarbonate is probably the result of secondary reactions related to sulfate reduction. Fluoride minerals have a relatively low solubility and consequently go into solution slowly. Higher concentrations of fluoride would therefore be expected in water that has been in contact with sediments for the greatest period of time. The high values of fluoride in water from wells in the valley of the Powder River when compared to the low values from wells in recharge areas, support earlier conclusions that the Powder River valley is a regional groundwater discharge area. The very low values of chloride in the water samples from all

stratigraphic horizons probably reflect a general absence of soluble chlorides in most of the sediments. Calcium and magnesium concentrations decrease with increased flow-path length, and sodium increases. The calcium and magnesium ions are removed from solution by cation exchange and by the precipitation of carbonates. The cation exchange process results in an increase in sodium concentration. The pH values increase with increasing flow-path length. The sediments are predominantly composed of silicates, which cause a rise in the pH of groundwater with time because of the process of silicate hydrolysis. The groundwater chemistry during the Tertiary Period is interpreted to have been similar to the present-day groundwater chemistry because the same sediments were present then and the groundwater-flow directions were similar. There is no physical or chemical evidence that indicates groundwater flushing as a result of glaciation has occurred in the Powder River Basin area. (JMT)

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Hagmaier, J.L.; University of North Dakota, Grand Forks, ND

Groundwater Flow, Hydrochemistry, and Uranium Deposition in the Powder River Basin, Wyoming: Groundwater Theory. In Ph.D. Dissertation, Groundwater Flow, Hydrochemistry, and Uranium Deposition in the Powder River Basin, Wyoming. Chapter 2, (pp. 22-36), 166 pp. (1971)

A general discussion of hydrological theory, terminology and concepts, and groundwater flow models is put forth in this chapter. Particular attention is paid to Meyboom's Prairie Profile of groundwater flow. (Meyboom, P., 1963, Patterns of groundwater flow in the Prairie Profile: Proc. Hydrol. Symp. No. 3, Natl. Res. Council Canada, pp. 5-33). This model shows how a largescale flow system bounded by topographically significant lows may occur. Meyboom's Prairie Profile model was specifically designed for application in the western Canadian prairie regions, for which it was named. (JMT)

<356>

Morgan, J.W., and K.S. Heier; Australian National University, Department of

Geophysics and Geochemistry, Institute of Advanced Studies, Canberra, Australia

Uranium, Thorium and Potassium in Six USGS Standard Rocks. *Earth and Planetary Science Letters*, 1, 158-160. (1966)

The USGS has distributed a set of six standard rocks, andesite AGV-1, basalt BCR-1, dunite DTS-1, granite G2, granodiorite GSP-1, and peridotite PCC-1. These rocks have been analysed for uranium, thorium, and potassium using the techniques of gamma-ray spectrometry, flame photometry, and neutron activation analysis. Results of the gamma-ray spectrometry method showed the levels of uranium, thorium, and potassium in the dunite DTS-1 and peridotite PCC-1 were below the limits of detection for routine operation. Agreement between uranium and thorium results obtained by gamma-ray spectrometry and by neutron activation analysis in most cases is good, indicating that the accuracy of the determinations is probably of the same order as the precision. The results obtained by gamma-ray spectrometric measurements and by flame photometry for potassium abundances were in excellent agreement. Some discrepancies arose using neutron activation analysis due to sampling problems. (MLB)

<357>

Megumi, K., and T. Mamuro; Radiation Center of Osaka Prefecture, Sakai, Osaka, Japan

Concentration of Uranium Series Nuclides in Soil Particles in Relation to Their Size. *Journal of Geophysical Research*, 82(2), 353-356. (1977, January)

Soil was separated according to particle size, and the concentrations of the uranium series nuclides U 238, Th 230, Ra 226, and Pb 210 in each size-separated fraction were determined by gamma ray spectrometry with Ge(Li) detectors. The activity ratios of Th 230, Ra 226, and Pb 210 to U 238 were larger than unity in all fractions. The activity ratio of Th 230 to U 238 was unexpectedly high, reaching 3-5. In the particle size range below 0.15 mm the concentrations of these uranium series nuclides were found to increase with decrease in particle size. Such a trend was also found for the

elements Fe, Mn, Zn, and Cu. The elements K and Ca, however, were found to have a direct correlation with particle size. (Auth)

<358>

Krumbein, W.C., and H.A. Slack;
Northwestern University, Evanston, IL.

**Statistical Analysis of Low-Level
Radioactivity of Pennsylvanian Black
Fissile Shale in Illinois.** Bulletin of the
Geological Society of America, 67,
739-762. (1956, June)

Black fissile shale in Pennsylvanian cyclothems in the western part of the Illinois Basin shows low-level radioactivity as measured by alpha-particle emission. Preliminary analysis showed a ten-fold variability in radioactivity among closely spaced samples, with no apparent concentration in particular zones of the thin shale units. These relations favored design of a sampling experiment for evaluation of average radioactivity of the shale and for detection of regional radioactivity gradients. Interlocked regional and local sampling designs were set up and provided 176 samples for a regional study and 32 samples for a local study, including evaluation of the experimental error. The interlocked designs furnished data for estimating stratigraphic variability of samples spaced from about 1 foot to 18 miles apart. Strip mines, mine dumps, and some well cores provided regional samples of the 3-foot black fissile shale bed overlying Coal No. 6 in an area about 200 miles long and 20 miles wide. The local samples were collected from four localities within a single mine. In both sampling designs the maximum variability occurred at the lowest sampling level, indicative of a "spotty" distribution of radioactivity in the black shale. Neither the geological evidence nor the statistical analysis suggested any strong regional gradient in radioactivity over the area studied. Both the geological and statistical data support the inference that the radioactive material was associated with the depositional environment, rather than introduced by wholly diagenetic processes. (Auth)

<359>

Lindsey, D.A.; USGS, Denver, CO

**A Reconnaissance Survey of Mineralogy
and Trace Element Content of Some
Upper Tertiary and Quaternary
Water-Laid Tuffs and Tuffaceous
Sediments in the Basin and Range
Province, Western United States.** PB-236
067, 33 pp. (1974)

Important mineral resources are known in tuffaceous rocks of Late Tertiary age in the Basin-and-Range province of the western United States. This report summarizes the results of mineralogical and trace element studies of tuffaceous rocks at thirteen localities, with emphasis on mineralized tuff. These tuffaceous rocks show potential for uranium and other metals (Miocene Siebert tuff at Tonopah, Nevada), lithium in the Pliocene Muddy Creek Formation of southern Nevada, and the Opale mercury district of Oregon, and beryllium (Hamblin Valley, Utah). In addition, tuffaceous rocks of the Mojave Desert region possess potential for a wide variety of mineral deposits. The existence of extensive trace element anomalies in tuff adjacent to the Spor Mountain beryllium-fluorspar district suggests that geochemical studies should be a good method for evaluating other tuffaceous rocks for mineral potential. (Auth)

<360>

Gottfried, D., R. Moore, and E. Campbell;
USGS, Washington, DC

**Thorium and Uranium in Some Volcanic
Rocks from the Circum-Pacific Province.**
USGS Professional Paper 450-E, (pp.
85-89). (1963)

Forty-seven samples of volcanic rocks from the Mariana Islands, Mount Garibaldi Area of Southwestern British Columbia, and Strawberry Mountain in Eastern Oregon, were analyzed for thorium and uranium concentrations. Most of the andesites and dacitic rocks had Th/U ratios of 1.5 to 2.5. The data presented indicate strong regional variations of thorium and uranium in igneous rocks can be closely correlated with the chemical characteristics of the rock series and their tectonic setting. (PAG)

<361>

Aylmer, J.A., P.L. Eisler, P.J. Mathew, and A.W. Wylie; Commonwealth Scientific and Industrial Research Organization, Port Melbourne, Victoria, Australia

The Use of Natural Gamma Radiation for Estimating the Iron Content of Sedimentary Iron Formations Containing Shale Bands. In Proceedings of a Panel on Nuclear Techniques in Geochemistry and Geophysics, held in Vienna, Austria, November 25-29, 1974. International Atomic Energy Agency Publications, Vienna, Austria. (pp. 53-74), 271 pp. (1976)

In Australia natural gamma radiation has been logged to estimate the mean grade of iron ore in dry boreholes traversing layered mixtures of hematite and shale. The shale contains uranium and thorium of approximately 10-20 ppm. Potassium may or may not be present. The field data were subjected to regression analysis to determine the mean grade of hematite in single drill holes. The pooled, transformed, data from all holes were then utilized to derive the final expression for prediction of mean ore grade from the mean count-rate of a given hole, and the 95 percent confidence limits of $\pm$ or $\pm$ 0.8 percent Fe for this mean grade. The method is applicable to both exploration holes and blast holes. (Auth)(PAG)

<362>

Watt, J.S.; Australian Atomic Energy Commission, Research Establishment, Sutherland, New South Wales, Australia

Nuclear Techniques of Analysis in the Mining and Milling of Basic Metal Ores in Australia. In Proceedings of a Panel on Nuclear Techniques in Geochemistry and Geophysics, held in Vienna, Austria, November 25-29, 1974. International Atomic Energy Agency Publications, Vienna, Austria. (pp. 153-165), 271 pp. (1976)

Quantitative analysis for basic metal elements in ores is required at various stages of mineral exploitation including exploitation, evaluation of mineral deposits, mine operations and mineral processing. The paper outlines typical requirements

for field and on-line analysis for the basic metal content of ores at the various stages of mineral exploitation. The main potential for their use is in grade control at the mine face and for blending, and in continuous on-stream analysis of mineral process streams. Examples of nuclear techniques being developed or in use in Australia for grade control at the mine face or for blending are gamma-ray resonance scatter, radioisotope X-ray techniques, and neutron and selective gamma-gamma techniques. (Auth)(PAG)

<363>

Rhodes, J.R.; Columbia Scientific Industries, Austin, TX

EDXES for Multielement Trace Analysis: Calibration Standards and Interlaboratory Comparisons. In Proceedings of a Panel on Nuclear Techniques in Geochemistry and Geophysics, held in Vienna, Austria, November 25-29, 1974. International Atomic Energy Agency Publications, Vienna, Austria. (pp. 235-244), 271 pp. (1976)

Calibration standards of a previously unavailable type are demanded by the rapid application of energy dispersive X-ray emission spectrometry (EDXES) to multielement trace analysis. Also, interlaboratory comparison studies are necessary to test new instrumentation, new analytical procedures, and laboratories new to chemical analysis. The paper describes calibration standards recently made available, and two laboratory intercomparisons. A widespread application of this technique is expected in natural resource investigations such as geochemical, geobotanical and hydrogeological exploration, since the analytical requirements are similar. (Auth)(PAG)

<364>

Puchelt, H., and U. Kramar; Universität Karlsruhe, Institut für Petrographie und Geochemie, Karlsruhe, Federal Republic of Germany

Standardization in Neutron Activation Analysis of Geochemical Material. In Proceedings of a Panel on Nuclear

Techniques in Geochemistry and Geophysics, held in Vienna, Austria, November 25-29, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 245-252). 271 pp. (1976)

Single-flux monitor, monitor-comparator, single-element standards and geochemical reference materials are methods of standardization in neutron activation analysis. The applicability of these methods for geochemical analysis is discussed. The possibility of errors due to flux variations is shown for the flux-monitor method. The source and availability of five new geochemical reference materials (granite, latite, andesite, phonolite, and hornblende) are given. (Auth)

<365>

Brits, R.J.N., and M.C.B. Smit; South Africa Atomic Energy Board, Chemistry Division, Pretoria, South Africa

Determination of Uranium in Natural Water by Preconcentration on Anion-Exchange Resin and Delayed-Neutron Counting. Analytical Chemistry, 49(1), 67-69. (1977, January)

A method is proposed for the determination of uranium in water. The uranium is extracted by sorption of the uranyl thiocyanide complex on an anion-exchange resin. The preconcentration step is largely independent of water quality and insensitive to experimental parameters. Uranium on the resin is directly determined by delayed-neutron counting, which is a specific and sensitive analytical method for uranium. The accuracy is 4 percent and the detection limit for a 1 liter sample is 0.04 micrograms liter. (Auth)

<366>

Not given; Not given

Geochemical Prospecting Methods and Techniques. Proceedings of the Seminar on Geochemical Prospecting Methods and Techniques, Mineral Development Series No. 21, held in Bangkok, Thailand, August 5-14, 1963. United Nations, New York, 202 pp. (1963)

The publication contains the report and principal documents of the Seminar on Geochemical Prospecting Methods and Techniques, which was held at Bangkok, Thailand from 5 to 14 August 1963 under the sponsorship of the United Nations Economic Commission for Asia and the Far East (ECAFE) and the United Nations Bureau of Technical Assistance Operations (BATO). The publication consists of two parts: Part I, Report of the Seminar and Part II, Documentation. Part II is further divided into (A.) National reviews of geochemical prospecting; (B.) Analytical techniques; (C.) Heavy mineral reconnaissance; (D.) Geochemical prospecting for metals; (E.) Integration of geochemical prospecting with other methods of mineral exploration; and (F.) Geochemical prospecting for oil and natural gas. (JMT)

Six papers from the seminar have been abstracted separately.

<367>

Ruxton, B.P.; Not given

Some Aspects of Detailed Geochemical Testing at Rum Jungle, Northern Territory, Australia. In Proceedings of the Seminar on Geochemical Prospecting Methods and Techniques, Mineral Development Series No. 21, held in Bangkok, Thailand, August 5-14, 1963. United Nations, New York, (pp. 104-111). 202 pp. (1963)

The discovery, in 1949, of uranium minerals at an old copper prospect near Rum Jungle, sixty miles south of Darwin, was followed by airborne radiometric surveys by the Bureau of Mineral Resources (BMR) in 1950. Geologic mapping by the BMR in 1960 showed two domes of granitic rocks surrounded by annular rings of Lower Proterozoic sedimentary rock. A general synclinal structure occurs between the two domes. In the center of this a topographic ridge is capped by hematite quartz breccia, which is interpreted as the basal bed of the Upper Proterozoic. A basal arkose resting unconformably on the igneous complex, is followed by a thick dolomitic sequence which contains a bed of quartz pebble conglomerate and then by a pyritic carbonaceous or chloritic shale. The rocks are weathered to depths of 60 to 80 feet, but the base of the weathering is very irregular. The landforms around Rum Jungle are of the typical

"hill and dale" type of humid-temperate regions. There is no development of the pediment landform common in other savannah areas of the tropics. Background radioactivity in the Rum Jungle district is generally taken as 0.015 milli-roentgens per hour. Examples of the concentration of uranium in ferruginous soils are very common in the Rum Jungle Area. In two places around Castlemaine Hill, highly ferruginised weathered carbonate rocks have surface values of 0.30 and 0.10 mR/hr. Along the western flank of Castlemaine Hill, where solifluction is an important feature, there is little surface expression of the underlying uranium mineralization. The soil near the land surface appears to be leached free of uranium, which is distributed lower in the profile, frequently concentrating at the soil weathered rock boundary. The strong surface anomalies are explained by their association with concentrations of iron oxides and phosphate rock, both well known for their ability to collect and retain uranium from sources such as circulating uraniferous groundwater. (JMT)

<368>

Von Gaertner, H.R.; Germany Geological Survey, Federal Republic of Germany

Geochemical Prospecting for Uranium in a Region of the Bavarian Forest, Germany Covered by Thick Old Tropical Soil. In Proceedings of the Seminar on Geochemical Prospecting Methods and Techniques, Mineral Development Series No. 21, held in Bangkok, Thailand, August 5-14, 1963. United Nations, New York. (p. 94), 202 pp. (1963)

Granite rock in the Bavarian Forest area is known to contain 50-100 ppm uranium in the fresh rock. There are numerous zones of enrichment partly connected with quartz veins, partly with pegmatites or normal joints. Normally autunite and other secondary uranium minerals are found. The enrichment goes up locally to 1-2 kg/t. The investigation of the age of the uranium showed an age between 1 to 2.5 million years; but the surrounding granite is 350 million years old. The granite is strongly weathered down to a depth of 150 m. Soil investigations showed that the weathering corresponds to the base of a tropical lateritic soil. One large geochemical anomaly, 1.5 km long in clayish peat of Holocene age, with

values of 200-250 ppm uranium showed up in the area. At the surface, the scintillometric survey did not show any anomaly. The peat is estimated to contain a total of about 12 tons of uranium, which would not have been found without wet chemical prospecting methods. In other tropical regions there may be similar conditions which require the use of geochemical prospecting methods instead of scintillometric ones. (JMT)

<369>

Sakanoue, M.; Not given

The Sensitive Paper-Chromatographic Determination of Uranium. In Proceedings of the Seminar on Geochemical Prospecting Methods and Techniques, Mineral Development Series No. 21, held in Bangkok, Thailand August 5-14, 1963. United Nations, New York. (pp. 46-48), 202 pp. (1963)

Prospecting methods for uranium based on surveying the activities of its daughter nuclides are widely used, but since uranium cannot be distinguished easily from the other radioactive elements, a definite conclusion on the presence of uranium is not obtained. It, therefore, becomes important to establish a simple chemical method for sensitive determination of uranium. Several reports concerning paper-chromatographic determination of uranium have been published. Testing these methods, the author found that many experimental conditions should be carefully controlled to obtain the narrow and reproducible color band of uranium on the one-dimensional ascending chromatograms. The sensitivity of this method is reported to have a lower detectable limit of 0.1 micro-gram uranium on the paper strip even under the best experimental conditions. This limit is considered not to be sufficiently low for the purpose of sensitive geochemical prospecting. In addition, another unfavorable factor for the simple determination of uranium is that the standard series of uranium needed for comparison with the amount of this element in samples should be newly prepared at each experiment, because the color bands obtained by spraying potassium ferrocyanide reagent are unable to be preserved on the paper strip at the time of washing out the excess reagent from the paper. In order to improve these points which are unfavorable for the purpose of simple geochemical prospecting, the author studied the

front line reaction of uranium ascending from the original and reaching the reagent at a definite position on the paper strip, which has been previously impregnated with the reagent. A sharp colored line of uranyl ferrocyanide was obtained. And even with simple operational conditions, these lines were reproducible and can be preserved for a long time without changing the original conditions by washing out the excess reagent from the paper. This newly devised method is explained in detail. (JMT)

<370>

De Nault, R.: Stanford University,
Stanford, CA

Mineral Stability in Groundwater. In
Ph.D. Dissertation, Origin of Sandstone
Type Uranium Deposits in Wyoming.
(Chapter 9, (pp. 197-265). 352 pp. (1974)

Transportation of uranium and solution of zircon and hornblende are facilitated by bicarbonate rich solutions. Groundwaters in tuffaceous sediments are bicarbonate rich. Mineral zonation in uranium rocks going from altered to fresh ground is selenium-pyrite-uraninite-calcite. The pyrite and uraninite zones overlap and may be reversed but selenium occurs in a narrow and sharply defined band. This zonation would be produced in an area of rapidly decreasing Eh such as would be expected if oxygenated groundwaters from tuffaceous sediments migrated into lower Eocene host sands with strongly reducing characteristics. Pyrite-uraninite overlap and reversal would be a function of the uranium bicarbonate concentration in influxing solutions. The narrow selenium zone would be caused by solution of selenium in the reduced environment of fresh ground. (JMT)

<371>

Pipiringos, G.N.: USGS, Washington, DC

**Origin of Elements Associated with
Uranium in the Cave Hills Area Harding
County, South Dakota.** USGS
Professional Paper 476-B, 75 pp. (1966)

Chemical, radiometric, and semiquantitative
analysis of 354 samples of coal, carbonaceous
siltstone, and phosphatic claystone collected during

geological investigations of the uranium deposits in the Cave Hills area, Harding County, South Dakota, are presented in the report. Eight stratigraphic units of the Paleocene Fort Union Formation were chosen for study of the distribution of uranium and 32 other trace elements and for study of radioactivity equilibrium reactions. The stratigraphic units include six coal zones, a carbonaceous siltstone facies of one of the coal beds locally called the Carbonate ore zone, and a phosphatic silty claystone bed locally called the Lanesome Pete ore zone. These units contain all known uranium occurrences in the area. In general, the uranium content decreases from the stratigraphically highest unit downward. All the higher grade uranium occurrences are adjacent to or nearly adjacent to aquifers. The lower coal beds, which are the farthest removed from the aquifers, contain the least uranium. The amount of radioactivity disequilibrium in the stratigraphic units is also greatest near the aquifers. These field relations suggest strongly that the initial deposition of uranium, as well as the subsequent leaching and redeposition of uranium, was accomplished by circulating groundwater. The syngenetic and epigenetic origin and subsequent history of the trace elements other than uranium in the host rocks of this area were studied by use of three semi-independent methods of investigation. All three methods were based on the assumption that trace elements in these rocks were employed in one or more of the following ways: (1) as plant constituents, (2) as constituents of the original inorganic fraction of the rock, and (3) as constituents added to the rock by circulating groundwater. Probable origin and history of the elements were determined by (1) comparison of the range, average, and maximum abundance of elements in coal with those in the non-coals; (2) comparison of the average abundance of elements in coal and non-coals low in uranium content with the abundance of elements in the earth's crust; and (3) determination of the inherent composition of the organic fraction of coal. During Paleocene time the elements Ca(?), Mn, B, and Co apparently were concentrated in coal by plant action. After coalification, during post-Paleocene to late Pleistocene time, the elements Fe, P, As, Ba(?), Be, Cu(?), Ge, La, Mo, Nd, Ni(?), Pb(?), Sc(?), Sn, Sr(?), V, Y, Yb, and Ar were absorbed by the coal from circulating groundwater which at the same time leached much of the syngenetic Ca(?) K(?), and B from the coal. The other elements detected in the coal samples, (Si, Al, Mg(?), Na, R, Ti, Ag, Cr, and Ga) seem principally to have been original

constituents of the inorganic rock. The elements Ca, P, La, Mo, V, Y, and Yb were added with uranium to the non-coal Carbonate and Lonesome Pete ore zones, after lithification, by circulating groundwater. Radioactivity data suggest that the effect of groundwater on coal during about the last 500,000 years was much greater than during post-Paleocene through early Pleistocene time. (Auth)(JMT)

<372>

Kolodny, Y.; University of California, Los Angeles, CA

Studies in Geochemistry of Uranium and Phosphorites. Ph.D. Dissertation, University of California, Geology Department, 220 pp. (1969)

The dissertation is composed of three parts: 1) Uranium Isotopes in Sea Floor Phosphorites; 2) Uranium in an Anoxic Fjord; and 3) Carbon and Oxygen Isotopes in Apatite CO₂. Analyses of uranium concentration and U 234/U 238 activity ratios were performed on 40 samples of marine phosphorites, almost all of them dredged from the sea floor. Analytical techniques were developed enabling isotopic analysis of uranium in phosphates by alpha-spectroscopy. Uranium concentrations in analyzed nodules vary between 6 and 524 ppm, tetravalent uranium constituting 38-84% of the total. The mean activity ratio for total uranium is 0.97; the ratio in U(IV) uranium is 0.71 and the calculated activity ratio for U(VI) uranium is 1.57. The interpretation of these results has two consequences: a) all the analyzed nodules are old (probably older than $8 \times 10^{(E+5)}$ years), and are at the present, being eroded rather than deposited. The deposition of phosphorite in the present day ocean is rather doubtful. b) The difference in isotopic ratios between the two oxidation states of uranium generally confirms previously proposed mechanisms of uranium isotope fractionation. Differential oxidation of U 234 is largely responsible for the measured U 234/U 238 disequilibrium ratios. Uranium is also effectively removed from sea water into anoxic sediments. This process is extremely fast compared to the rate of removal into deep sea sediments. Authigenic uranium is most strongly correlated with organic carbon content of the sediments, probably because of the formation of organo-uranyl complexes. Analysis of stable carbon and oxygen isotopes has

been applied to a solution of a mineralogical problem: elucidation of the relation of the carbonate ion to the apatite structure. Calcite was separated from co-existing apatite in pelletal phosphorites, phosphatized limestones and synthetically prepared apatites by dissolved calcite in triammonium citrate. Both calcite and apatite CO₂ were then analyzed for carbon and oxygen isotopes. Carbon and oxygen in the CO₂ associated with apatite are enriched in their light isotopes as compared to the co-existing calcites. This indicates that carbonate ions are a structural part of apatite, a conclusion which is in accord with other mineralogical studies. (JMT)

<373>

Lee, M.J.; University of New Mexico, Albuquerque, NM

Trace Element Geochemistry. In Ph.D. Dissertation, Geochemistry of the Sedimentary Uranium Deposits in the Grants Mineral Belt, Southern San Juan Basin, New Mexico, (pp. 154-172), 241 pp. (1976)

Approximately 100 samples of whole-rock sandstones, mudstones, and their clay-sized fractions were analyzed for their trace element contents. Analyses were conducted on samples from ore zones, bleached zones, and from outcrops for the following elements: Sm, Ce, Lu, Th, Cr, Hf, Ba, Nd, Ga, As, Cs, Ni, Tb, Sc, Br, Rb, Fe, Ta, Co, Eu, La, Sb, and Mn. The enrichment chromium, scandium, cobalt, nickel, manganese, and various other elements in the fine fraction of the ore zone samples shows that absorption, fixation or cation exchange of colloidal particles were mainly responsible. It is postulated that humic acid- and/or fulvic acid-clay complexes were significantly responsible for the precipitation of uranium. Some important interpretations can be made from the results of the present study that may be used in the uranium exploration. First, since clay materials, especially montmorillonite, possesses high electrokinetic forces, there is a good chance that they have competed with the soluble uranyl complexes for the uranyl ion and preferentially enriched it. Particularly promising elements for use in exploration are the Rare Earth Elements, Ta, Sb, Br, As, V, and a few other transitional group metals. With drilling into the deeper part of the basin in the Grants Mineral Belt

and elsewhere, trace element analysis could cut exploration costs by 10 to 20 percent. (JMT)

<374>

MacDonald, J.A.; Eldorado Mining and Refining Limited, Ottawa, Ontario, Canada

An Orientation Study of the Uranium Distribution in Lake Waters, Beaverlodge District, Saskatchewan. Colorado School of Mines Quarterly, 64(1), 357-376. (1969)

An orientation survey was conducted in the Beaverlodge uranium district to evaluate surface water sampling as a method of delineating regions of epigenetic pitchblende mineralization. Deterioration studies revealed that the chemical parameters of pH, bicarbonate content, specific conductance, and uranium content were sufficiently stable to allow analytical work to be performed in a central laboratory. Detailed study of 13 control lakes indicate that, with the exception of the spring break-up period, there is no significant variation in the uranium content of lake water which can be attributed to seasonal temperature changes or precipitation. Although seasonal variations in the pH and bicarbonate content to occur, these changes do not affect the solubility of uranium. Correlation studies indicate an increase in the specific conductance of lake water in the vicinity of mineralized areas. This is a result of the increased bicarbonate content of the surface waters and reflects the carbonate-pitchblende association characteristic of deposits in the area. Lake water assays show that the Beaverlodge uranium district is delineated by an analytical plateau of 0.9 ppb U_3O_8 , approximately twice the regional background value of 0.4 ppb U_3O_8 . Numerous peaks occurring within this analytical plateau define zones of pitchblende mineralization. (Auth)

<375>

Wukasch, M.C., and L.M. Cook; Texas State Department of Health, Occupational Health and Radiation Control Division, Austin, TX

High Radioactivity in Drinking Water and Ground Water in South Texas. CONF-730907-P1, (pp. 272-278); In

Proceedings of the Third International Congress of the International Radiation Protection Association, held at the Washington Hilton Hotel, Washington, DC, September 9-14, 1973. (pp. 272-278). (1974)

High radium 226 concentrations in well waters in South Texas were discovered in 1971 and a considerable amount of data on the ground waters in the vicinity of the uranium deposits has been collected. In most wells, alpha and beta radioactivity is low; however, in 25 wells shallower than 300 feet, 15 had concentrations in excess of 3 pCi per liter. In two wells, used for drinking water for humans, high levels of radium 226 were found. These high concentrations, well above those allowable in industrial discharges, and very much in excess of recommended drinking water standards have resulted in individual exposures probably exceeding the Radiation Protection Guide (RPG) and raise concern for other uses of the ground water. Less than two percent of the samples have concentrations in excess of occupational limits of exposure. Attempts are being made to screen supplies in the area most likely to contain elevated radioactivity. Work in progress in the area includes sampling every source of public water supplies and selected private wells used principally for drinking water. Body burden estimates are presented for some individuals. (MLB)

<376>

Not given; Canada Geological Survey, Ottawa, Ontario, Canada

Determination of Radioactive Disequilibrium in Uranium Ores by Alpha-Spectrometry. Canadian Geological Survey Paper 75(38), 15 pp. (1976)

The present thick-source alpha particle spectrometric technique permits the detection of radioactive disequilibrium with a minimum of sample preparation time. The equilibrium study involves the following steps for a sample containing both thorium and uranium: a) Production of the experimental alpha particle spectrum from an infinitely thick source which is under investigation. b) Computation of a synthetic equilibrium alpha spectrum for the Thorium-232 decay series. c) Fitting the synthetic Thorium-232 equilibrium spectrum at the location of the highest energy peak

(to eliminate interference of the U-238 series for the fit). d) Subtraction of the synthetic Thorium-232 series spectrum. The residual is the alpha spectrum of the Uranium-238 series component. e) Computation of a synthetic equilibrium alpha spectrum for the U-238 series. f) Fitting the synthetic U-238 equilibrium spectrum to the uranium residual obtained above in (d). Again the fit is made at the highest energy peak. g) Subtraction of the synthetic U-238 equilibrium spectrum. The residual spectrum represents the statistical scatter present in all radioactivity counting results, and should fluctuate about a residual count value of zero. h) The departure of any residual spectrum from zero indicates a state of disequilibrium since the experimental and theoretical spectra differ. The location in the residual spectrum where the departure from zero exists indicates the location of the radioactive disequilibrium. Steps b, c, d can be eliminated if no thorium is present. The samples ranged from badly weathered surface exposure to fresh samples obtained from underground in active uranium mines. The main limitation of the technique seems to be the low emission rate of alpha particles from some samples, necessitating counting times beyond that permissible to retain good energy resolution without incurring instrumental variation. The limit is probably about 0.1 percent U3O8. The samples considered here illustrated a case of radioactive equilibrium, and one of definite disequilibrium. Disequilibrium was a result of losses of two or more nuclides in the U-238 decay series. (MLB)

<377>

Klassen, R.A., and W.W. Shiller: Canada Geological Survey, Terrain Sciences Division, Ottawa, Ontario, Canada

Uranium Exploration Using Till, District of Keewatin. Canadian Geological Survey Paper 77-1A, 471-477 pp. (1977)

Research on drift prospecting in the District of Keewatin has been directed towards developing reconnaissance and detailed sampling techniques that can indicate uranium mineralization as well as base metal mineralization. The purposes of the report are: (1) to discuss briefly the techniques of sampling and processing samples; (2) to update the uranium dispersal map of the Kaminak Lake area; (3) to show the results of detailed sampling around a site of known uranium mineralization, which also

was indicated by reconnaissance anomalies; and (4) to show the results of reconnaissance uranium drift sampling in the Baker Lake area. The techniques used were the mudboil sampling technique, the "wet clay" technique, and the "dry clay" technique. The results of the paper are shown by histograms and scatter plots, and on geologic maps showing the uranium in clay. (MLB)

<378>

Murphy, J.F.: USGS, Laramie, Wyoming

Uranium-Bearing Water in the Crow Creek and Muskrat Creek Areas, Fremont County, Wyoming. USGS Report of Investigations No. 5, 15 pp. (1956, March)

Thirty-eight water samples from various sources were collected from localities within Fremont County, Wyoming. High uranium content of many of the samples suggests possible uranium minerals in two areas. Water samples from the Crow Creek area, in the northwestern part of the Wind River Basin, contain as much as 150 parts per billion uranium, and water from the lower Muskrat Creek area, in the central part of the Wind River Basin, contains as much as 340 parts per billion uranium. The uranium content of these samples is comparable to and in many instances exceeds the uranium content of water samples taken from known mineralized localities in the Gas Hills and Crooks Gap areas, some 20 miles and 45 miles farther southeast. (Auth)

<379>

Bayeva, A.I., and E.A. Mugalinskaya: Not given

Lithium and Thorium Content in Yellow Podzolic Soils. PB-254 584, 6 pp. (1970)

The paper examines the lithium and thorium content of yellow podzolic soils as well as questions concerning the distribution of these elements through the soil profile. Yellow podzolic soils with different degrees of podzolization are used as the example. Colorimetry was used to determine the lithium and thorium content. The reagents used were, for lithium, "thoron" in sodium stearate, and for thorium, "arsenazo III" in an acid medium. A

calibration curve was used for the quantitative calculation. The magnitudes of element content were calculated in weight percents. (MLB)

<380>

Rogers, J.J.W., K.C. Condie, and S. Mahan; Rice University, Department of Geology, Houston, TX; Washington University, Department of Earth Sciences, St. Louis, MO

Significance of Thorium, Uranium, and Potassium in Some Early Precambrian Gneisses from Wyoming and Minnesota. *Chemical Geology*, 5, 207-213. (1969)

Thorium, uranium, and potassium concentrations have been measured by gamma-ray spectrometry in graywacke sequences from the Wind River Mountains of Wyoming and the Knife Lake area of Minnesota. Thorium concentrations are compatible with the clay, quartz, and lithic contents of the rocks, but the uranium contents are low, thus yielding Th/U ratios in the neighborhood of 5 or above. Assuming that all post-depositional elemental abundance variations in the graywackes have been caused solely by radioactive decay since the rocks were formed (about 3×10^9 years ago), the initial Th/U ratios would have been in the range of 3-4. If the graywackes are random samples of the continental crust at their time of formation, then these data support the data that the continental crust 3×10^9 years ago had a Th/U ratio significantly higher than that of the whole earth. (Auth)

<381>

Aamodt, P.L., G.R. Waterbury, and M.E. Bunker; Los Alamos Scientific Laboratory, University of California, Los Alamos, NM

Hydrogeochemical and Stream Sediment Reconnaissance of the National Uranium Resource Evaluation Program - Progress Report - January-March, 1977. LA-6831-PR, 15 pp.; GJBX-51(77), 15 pp. (1977, June)

During the quarter of January-March 1977, field

work was sharply reduced due to cold weather. Only a few pilot study samples were taken by personnel from the University of Colorado in a local area in northeastern Colorado. A majority of effort went into preparation of reports on areas previously surveyed. Five reports were open filed through the ERDA Grand Junction Office.

Preparations are well along for surveys to be conducted during FY 77, including preparation of bid specifications for three large areas in south-central Alaska. Fluorometric analyses of water samples continued at a rate of 800 to 1000 per week. Late in the quarter an evaporative concentration procedure was implemented for Alaskan waters due to their very low uranium content. This procedure increases the normal sensitivity a factor of ten (to 0.02 ppb instead of 0.20 ppb uranium) but reduces the throughput to about 675 samples per week when used.

Non-interference development of spectrochemical and X-ray fluorescent techniques for multielement analyses is continuing. Delayed-neutron counting of sediment and waters (those with > 10 ppb uranium) has continued at a rate of several hundred per day. The multielement capability by neutron activation analysis continues to be upgraded, particularly through automation techniques. Data management and statistical capabilities are also being improved and expanded as time permits. (Auth)

<382>

Aamodt, P.L., J.M. Hansel, Jr., M.M. Minor, and R.J. Beckman; Los Alamos Scientific Laboratory, University of California, Los Alamos, NM

Hydrogeochemical and Stream Sediment Reconnaissance of the National Uranium Resource Evaluation Program - Progress Report - October-December 1976. LA-6708-PR, 27 pp.; GJBX-20(77), 27 pp. (1977, February)

Field sampling in New Mexico was limited to the collection of water and/or sediment samples from 4000 locations in two 20,000-km² areas in the southeastern corner of the state. Approximately 1100 locations were sampled in Montana and Colorado as parts of pilot studies in those states, and 100 locations were sampled by a commercial contractor in south-central Wyoming. Several thousand samples were inventoried and sent to the

analytical laboratories for analysis. Uranium analysis of waters by fluorometry continued at an average rate of 850 analyses per week.

Multielement analysis capability using x-ray fluorescence and spectrochemical methods continued to be improved to increase both sample throughput and analytical precision. Modifications to the reactor transport system have lowered the effective uranium detection limit for 40-ml water samples to 0.25 ppb. The pneumatic transfer system has also been expanded to allow rapid multielement analyses of sediment samples. Not all of the detectors have been installed to complete this system, but they will be in the near future. Sediment samples have been analyzed for uranium at an average rate of 1000 per week. Several new computer programs have been developed to improve both the management and statistical treatment of NURE-HSSR data. (Auth)(MLB)

<383>

Illsley, C.T.; AEC, Grand Junction, CO

Hydrogeochemical Reconnaissance for Uranium in the Stanley Area, South-Central Idaho. RME-140, 21 pp. (1961, July)

Geochemical data obtained from the analyses of 73 water samples collected in the Stanley area, Idaho, demonstrate the applicability of hydrogeochemical techniques to uranium exploration. Uranium concentrations in surface waters of the area ranged from 0.2 to 22.0 ppb U₃₀₈. The geometric mean for 27 samples from the Basin Creek mining area was 3.9 ppb U₃₀₈, and the geometric mean for the remainder of the Stanley area was 1.1 ppb U₃₀₈ (39 samples). Samples from seven hot springs averaged 0.3 ppb U₃₀₈. The conductivity of the surface waters ranged from 45 to 350 micromhos, with the higher conductivities generally found in water from areas underlain by sedimentary rock. The pH of the surface waters varied only slightly from the average value of 7.4. Twelve of the most highly anomalous uranium concentrations in the Basin Creek district were found from 0.15 to 2 miles downstream from known uranium deposits. Outside Basin Creek district 2 of the 3 highest concentrations are from areas immediately adjacent to Basin Creek district; and of 4 other possible anomalies, one is along the strike of structural trends which may mark an extension of the mineralized area, and the other 3 are presumably

influenced by higher conductivity of water from areas of sedimentary rocks. Hot springs waters are geochemically distinct from the surface waters of the uranium district, and apparently are neither contributing unusual amounts of uranium nor dissolving significant amounts of uranium from the surrounding rock. (Auth)

<384>

Bowles, C.G.; USGS, Denver, CO

Theory of Uranium Deposition from Artesian Water in the Edgemont District, Southern Black Hills. In Wulf, G.R. (Ed.), *Wyoming Geological Association Guidebook, Twentieth Field Conference, 1968*, (pp. 125-130), 243 pp. (1968)

A discussion of uranium deposition from artesian waters in the Black Hills is presented in this paper. The discussion is based on the ground water analytical data from 32 water wells in the Edgemont district. Ground water in the Minnehaha, Lakota, and Fall River Formations were classified into three types: calcium sulfate, sodium sulfate, and sodium bicarbonate. Calcium sulfate ground water carries uranium, derived from anhydrite and other sources, up fault, fracture and breccia pipe structures to the Inyan Kara Group where, during basinward migration, the water is modified by base-exchange softening and sulfate reduction. Uranium is reduced and precipitated by a hydrogen sulfide environment, although, locally, organic acids may have affected deposition. Greatest precipitation occurs marginal to bicarbonate water having a large concentration of hydrogen sulfide. Ground water conditions in the past, and at somewhat higher elevations on the flanks of the Black Hills, were similar to present conditions and similarly affected uranium deposition. Uranium from the older deposits in the Inyan Kara Group may be leached at higher elevation and reprecipitated downdip in this favorable environment. Exploration for concealed uranium deposits in the southern Black Hills should be based on the coincidence of vertical conduits overlying the evaporites and the occurrence of favorable host rocks in which uranium deposits are present near the outcrop. Areas along the Long Mountain structural belt in the vicinity of terrace gravels of late Quaternary age, updip from the present hydrogen sulfide reducing environment, offer a favorable target for exploration above the

water table. Below the water table, water sampling during drilling exploration would supplement the usual stratigraphic, mineralogic lithologic, and radiometric studies conducted during exploration and would aid in the systemic search for uranium deposits. (JMT)

<385>

Mason, B.; U.S. National Museum,
Department of Mineral Sciences,
Washington, DC

Principles of Geochemistry. John Wiley
and Sons, Inc., New York, 329 pp (1966)

The book is a general geochemistry text covering the entire field of geochemistry, from high-temperature igneous geochemistry to low-temperature geochemistry and sedimentary processes. Uranium and thorium are discussed only in passing. (JMT)

<386>

Not given; Lawrence Livermore
Laboratory, University of California,
Livermore, CA

**Hydrogeochemical and Stream-Sediment
Survey of the National Uranium
Resource Evaluation (NURE) Program -
Western United States - Quarterly
Program Report - October through
December 1976.** UCID-16911-76-4, 15 pp.;
GJBX-34(77), 15 pp. (1977, March 1)

Field work was completed for two orientation study areas in the Northern Rocky Mountain Province (Washington and Idaho), and planning is underway for three orientation studies in the southern Basin and Range Province (Arizona). Work continued on new office and laboratory facilities. Completion is scheduled for early in the second quarter of FY 1977. Planning and site selection were completed for reconnaissance surveys in west-central Utah and southern Nevada scheduled for the third quarter of FY 1977. Installation of the delayed-neutron counter and instrumental neutron-activation analysis system is nearly complete and the system will be operational next quarter. (Auth)

<387>

Hurley, P.M.; AEC, Grand Junction, CO

**Direct Radiometric Measurement by
Gamma-Ray Scintillation Spectrometer.**
Bulletin of the Geological Society of
America, 67, 395-404, (1956, April)

Where uranium and thorium are in secular equilibrium with their decay products, these elements may be determined by this direct radiometric method if the materials show more than 0.01 per cent equivalent uranium. This method is based on the measurement in a scintillation spectrometer of the relative amplitude of the response from the 238 kev gamma ray from Pb 212. Tests on known samples containing different relative proportions of uranium and thorium have verified the predicted precision of better than 4 per cent standard deviation per single comparison with a standard when the element measured is a major contributor to the activity. (Auth)

<388>

Not given; Lawrence Livermore
Laboratory, University of California,
Livermore, CA

**Preliminary Report on the Cave Valley
Basin Pilot Study.** GJBX-43(76), 48 pp.;
UCID-16911-P-4, 48 pp. (1976, August 1)

This study in the Cave Valley Basin characterizes carbonate surface lithology containing known uranium occurrences. Cave Valley Basin drains an area of about 360 square miles (927 square kilometers) in an extensive area of Nevada devoid of known uranium mineralization. It is bounded on the east by the Schell Creek mountain range and on the west by the Egan mountain ranges. The units which make up these mountains were deposited in the same paleogeographic environment as those of the Goodsprings uranium-bearing area (UCID-16911-P-5), however, they are more dolomitic. Thus, the results of this study along with the Roach Lake study will help characterize the eastern portion of the Basin and Range Province. The report contains only the analytical data and sample locations. Details of the sampling methods and equipment, analytical sensitivity, errors, interferences, and geochemical interpretation will

be reported separately. (JMT)

<389>

Not given; Lawrence Livermore
Laboratory, University of California,
Livermore, CA

**Preliminary Report on the Roach Lake
Basin Pilot Study.** GJBX-44(76), 31 pp.;
UCID-16911-P-5, 31 pp. (1976, August 1)

Roach Lake is surrounded by several areas of carbonate terrain, the most important of which is the Spring Mountain Range to the north and west. These mountains contain the Goodsprings Mining district, noted for lead, zinc, and copper mines. Many of these mines contain uranium minerals within the oxidized sulfide zone. Mineralization is mainly confined within the Mississippian limestone. The basin drains an area of 250 square miles and is bounded on the east by McCullough Range. The study area is typical of the eastern portion of the Basin and Range province and should be relevant to southeastern Idaho, the western half of Utah, central and eastern Nevada, small portions of northwest Arizona, and a portion of southeast California. The report contains only the analytical data and sample locations. Details of the sampling methods and equipment, analytical sensitivity, errors, interferences, and geochemical interpretation will be reported separately. (JMT)

<390>

Not given; Lawrence Livermore
Laboratory, University of California,
Livermore, CA

**Preliminary Report on the Smoke Creek
Desert Basin Pilot Study.** GJBX-42(76), 48
pp.; UCID-16911-P-3, 48 pp. (1976,
August 1)

The Smoke Creek Desert Basin is the largest of the four playa basins and contains an area of about 2700 square kilometers (1003 square miles). The basin is bordered on the east by the Fox Hills and on the north and east by the Granite Ranges which are characterized by granite, pegmatites, and Tertiary rocks very similar to the lithology of the Winnemucca Basin boundary ranges (study UCID-16911-P-2). On the west, the Desert is

bordered by an area of extensive basalt flow. There is no known uranium occurrence in the area, and metallization of any kind is scarce. This study is applicable to the western igneous portion of the Basin and Range Province. The report contains only the analytical data and sample locations. Details of the sampling methods and equipment, analytical sensitivity, errors, interferences, and geochemical interpretation will be reported separately. (JMT)

<391>

Not given; Lawrence Livermore
Laboratory, University of California,
Livermore, CA

**Hydrogeochemical and Stream-Sediment
Survey of the National Uranium
Resource Evaluation (NURE) Program -
Western United States - Quarterly
Progress Report - July through September
1976.** GJBX-10(77), 44 pp.;
UCID-16911-76-3, 44 pp. (1976,
September)

The report summarizes activities of the Hydrogeochemical and Stream Sediment Survey being conducted by the Lawrence Livermore Laboratory in support of the National Uranium Resource Evaluation Program. The Lawrence Livermore Laboratory (LLL) study is part of a nationwide systematic investigation by ERDA to determine uranium distribution in surface and underground waters and in stream sediments as a possible indication of areas favorable for the discovery of uranium. Included in the LLL portion of this study are the seven western states of Arizona, California, Idaho, Nevada, Oregon, Utah, and Washington. The two current projects, as of the writing of this report were at the Humboldt River Basin in Nevada, and the Six Basins area also of Nevada. (JMT)

<392>

Not given; Lawrence Livermore
Laboratory, University of California,
Livermore, CA

**Preliminary Report on the Winnemucca
Dry Lake Basin Pilot Study.** GJBX-41(76),
46 pp.; UCID-16911-P-2, 46 pp. (1976,

August 1)

Winnemucca Lake is surrounded by the igneous environment of the mountains of the Lake Range on the west and the Nightingale-Selenite Range on the east. Fifteen known uranium occurrences exist over a large area on the east side of the basin. They are commonly vein deposits of secondary uranium minerals in metamorphic rocks near, or in granite, pegmatites, or Tertiary volcanic rocks. The basin includes drainage from an area of 356 square miles. Results of the study are applicable to the western Basin and Range igneous metallogenic province, which includes southeastern Oregon, western Nevada, and southeastern California. The report contains only the analytical data and sample locations. Details of sampling methods and equipment, analytical sensitivity, errors, interferences, and geochemical interpretation will be reported separately. (JMT)

<393>

Not given; Savannah River Laboratory, Aiken, SC

Savannah River Laboratory Quarterly Report, January-March 1975, Hydrogeochemical and Stream Sediment Reconnaissance - Eastern United States. DPST-75-138-1. 30 pp.; (JBRX-5(76). 30 pp. (1975)

The National Uranium Resource Evaluation (NURE) program was begun in the spring of 1973 to stimulate commercial uranium exploration in an attempt to meet the rapidly increasing national demand for uranium. This program was established to evaluate domestic uranium resources in the continental United States and to identify areas favorable for uranium exploration. In 1975, the Savannah River Laboratory accepted responsibility for hydrogeochemical and stream sediment reconnaissance of twenty-five states in the eastern United States. The distribution of uranium and associated trace elements in surface and underground waters and stream sediments will be systematically determined, and the data will be processed to locate favorable areas for the discovery of uranium districts with potential for commercial development. (Auth)

<394>

Byrd, J.S., and R.J. Sand; Savannah River Laboratory, Aiken, SC

Microcomputer-Based Pneumatic Controller for Neutron Activation Analysis. DP-1439. 139 pp. (1976, October)

A microcomputer-based pneumatic controller for neutron activation analysis was designed and built at the Savannah River Laboratory. In this system, commercially available microcomputer logic modules are used to transport sample capsules through a network of pressurized air lines. The logic modules are interfaced to pneumatic valves, solenoids, and photo-optical detectors. The system operates from programs stored in firmware (permanent software). It also commands a minicomputer and a hard-wired pulse height analyzer for data collection and bookkeeping tasks. The advantage of the system is that major system changes can be implemented in the firmware with no hardware changes. The report describes the hardware, firmware, and software for the electronics system. (Auth)

<395>

Immel, R., and J.K. Osmond; Florida State University, Department of Geology, Tallahassee, FL

Micromanganese Nodules in Deep-Sea Sediments: Uranium-Isotopic Evidence for Post-Depositional Origin. Chemical Geology, 18, 263-272. (1976)

Micromanganese nodules from three deep-sea cores are found to contain less uranium than average nodules dredged from the sea floor. The U 234/U 238 ratio in these micronodules is higher than any previously reported in deep-sea sediments. It is believed that at least some micronodules form well after deposition of the enclosing sediments, in particular where conditions are less oxidizing than average. (JMT)

MAPPING, SURVEYING, AND LOCATION OF DEPOSITS

<396>

Wahner, T.N.; AEC, Washington, DC

Uranium Occurrences of the Eastern United States. Mining Engineering, 7(6), 545-547. (1955)

Uranium occurrences in the eastern United States are in several different geologic environments, including sandstone, arkose, black shale, coal, and crystalline rocks. In the Jim Thorpe area, Carbon County, Pennsylvania, several small pods of uraniferous material have been found in fluvial sandstone and graywacke in the Catskill formation of Devonian age. Uranium occurrences have been found in the same area in siliceous conglomerate in the Pottsville formation of Pennsylvanian age. In Hunterdon County, New Jersey, and Bucks County, Pennsylvania, small amounts of uranium minerals have been found in arkosic redbeds of the Stockton formation of Triassic age. In southwest Virginia, abnormal radioactivity has been found in the Price sandstone of Mississippian age. (Auth)

<397>

Wyant, D.G.; USGS, Washington, DC

Lost Creek (Wannatter) Schrockingerite Deposits, Sweetwater County, Wyoming. TEM-10B, 3 pp. (1952)

Schrockingerite deposits occur at Lost Creek, Wyoming, in clays and sands of Eocene or younger age. The yellow, platy, micaceous mineral occurs as rounded aggregates in the clay beds, and as fine disseminations in the sand and sandy clay beds. The uraniferous beds are discontinuous and their areal distribution is erratic. The beds strike northwest and dip 14 degrees - 27 degrees NE. The area lies in the Continental Divide Basin. (Auth)

<398>

Not given; International Atomic Energy Agency, Vienna, Austria

Recognition and Evaluation of Uraniferous Areas. Proceedings of a Technical Committee Meeting on Recognition and Evaluation of Uraniferous Areas, held in Vienna, Austria, November 17-21, 1975. International Atomic Energy Agency Publications, Vienna, Austria, 295 pp. (1977)

The energy situation has focused attention on the present and future role of uranium as a source for ensuring that expanding energy requirements can be met. A heavy and continuing demand for uranium is forecast, which cannot be satisfied by merely finding new ore bodies in the known uraniferous areas or by raising the cut-off cost of reserves. Clearly, new uranium provinces must be discovered, and in this work uranium exploration must be guided by new geological concepts. In view of the importance of this matter, a Technical Committee Meeting on Recognition and Evaluation of Uraniferous Areas was convened in November of 1975, in Vienna, Austria, by the International Atomic Energy Agency. The subject of the meeting attracted the attention of uranium geologists, with 51 experts attending from 23 countries. Eighteen papers and discussions, along with two of the panel reports are presented in these Proceedings. (JMT)

Ten papers from this symposium are abstracted separately.

<399>

Darnley, A.G., B.W. Charbonneau, and K.A. Richardson; Canada Geological Survey, Ottawa, Ontario, Canada

Distribution of Uranium in Rocks as a Guide to the Recognition of Uraniferous Regions. In Proceedings of a Technical Committee Meeting on Recognition and Evaluation of Uraniferous Areas, held in Vienna, Austria, November 17-21, 1975. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 55-86), 295 pp.; IAEA-TC-25/9, (pp. 55-86), 295 pp. (1977)

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Regional distribution of uranium over parts of the Canadian Shield has been determined by reconnaissance airborne gamma-ray spectrometry surveys carried out by the Geological Survey of Canada during the past seven years. Most of the areas surveyed are near the southern edge of the Precambrian Shield, or along the northwestern edge of the Shield, where Canada's known uranium occurrences are concentrated. The regions surveyed show prominent areas of above-average uranium content, either enclosing the known uranium occurrences, or the prominent areas are older formations adjacent to the area of economic interest. It is also apparent that there are areas containing few occurrences where uranium concentrations are generally low. The observed association of uranium occurrences with areas of above-average regional concentrations of uranium is consistent with knowledge concerning the geochemical cycle of uranium, whereby uranium initially contained in rocks of igneous origin is subjected to weathering, and under favorable circumstances is concentrated in a variety of depositional situations. From an exploration viewpoint, each regional uranium "high" should be examined both for the possibility that it may contain some significant concentration within its boundaries, and that adjacent and geologically related to it there may be more important derived concentrations, which will usually be less extensive and thus less likely to be located during the preliminary reconnaissance phase of exploration. The prime object of preliminary reconnaissance surveys is to locate regional highs. Once these have been found then more detailed surveys must be undertaken in order to locate all the near surface concentrations which may present, either within or adjacent to each high. (JMT)

<400>

Brookins, D.G.; University of New Mexico, Department of Geology, Albuquerque, NM

Uranium Deposits of the Grants, New Mexico Mineral Belt. AT(05-1)-1636-1, 153 pp.; GJBX-16(76), 153 pp. (1975)

The uranium deposits of the Grants Mineral Belt in New Mexico are discussed in this report. The major topics include: (1) the geology of the Grants Mineral Belt, (2) geochronological studies, (3) clay mineralogy, (4) trace element analysis and (5) the

uranium content of various rocks from the Grants Mineral Belt and other selected areas. (JMT)

Each of the chapters have been abstracted.

<401>

Everhart, D.L.; AEC, Denver, CO

Uranium-Bearing Vein Deposits in the United States. In USGS Professional Paper 300, (pp. 97-103), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 257-264), 825 pp. (1956)

In the Western United States, the uranium-bearing vein deposits are distributed in an arcuate pattern surrounding the Colorado Plateau and Wyoming Basin. They occur from the Black Hills of South Dakota southward through the Rocky Mountains to southern New Mexico, westward throughout the Basin and Range province of Arizona, Nevada, and southern California, and northward through the Rocky Mountains of Idaho and Montana. The uranium-bearing vein deposits of the United States may be divided into at least 5 mineralogic types with varying complexity and geochemical character, which may occur in any 1 of 6 favorable host-rock types. In general, the veins occupy zones of structural tension, and except in the Michigan part of the Canadian Shield, the uranium minerals were emplaced in Tertiary time. The emplacement of uranium in vein deposits of the Western United States appears to be an important part of a complex series of related metallogenic processes which together have produced a uranium province containing many deposits of varying geologic character. (Auth)(MLB)

<402>

King, J.W., and H.B. Young; AEC, Grand Junction, CO

High-Grade Uraniferous Lignites in Harding County, South Dakota. In USGS Professional Paper 300, (pp. 419-431), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of

Atomic Energy, Vol. 6, *Geology of Uranium and Thorium*, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 473-483), 825 pp. (1956)

Lignite beds, the uranium content of which ranges between 0.10 and 10 percent, were discovered in Harding County, northwestern South Dakota during the summer of 1954, and economically significant reserves have since been found. The lignite field lies in the Missouri Plateau section, unglaciated, of the Great Plains province between the Black Hills uplift and the Williston basin. The uranium deposits are in thin lignitic beds of the Tongue River and Ludlow members of the Fort Union formation of Paleocene age. Uranium occurs principally in a urano-organic complex. Meta-autunite and other uranium minerals also occur as coatings on fracture surfaces in the richest deposits. (Auth)(MLB)

<403>

Morton, R.D.; University of Alberta, Department of Geology, Edmonton, Alberta, Canada

Sandstone-Type Uranium Deposits in the Proterozoic Strata of Northwestern Canada. In *Proceedings of a Symposium on the Formation of Uranium Ore Deposits*, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 255-273), 748 pp. (1974, November)

Epigenetic uranium deposits within a Proterozoic, marine to continental, volcanic-sedimentary sequence are described from the Great Slave Lake region of NW Canada. Mineralization occurs in faulted and folded, fluvial arenites and rudites, in part metamorphosed to a maximum of zeolite facies of regional metamorphism. The sediments carry interstitial, disseminated uranium minerals which clearly replace pre-existing sulfides and are associated with hematite or graphite. Genetic hypotheses are forwarded and it is suggested that these deposits, being possibly generated by metamorphic fluids, might be a type intermediate between those associated with younger sandstones at shallow levels and syn-metamorphic vein deposits. (Auth)

<404>

De Andrade Ramos, J.R., and M.O. Fraenkel; Comissao Nacional de Energia Nuclear, Rio de Janeiro, Brazil

Uranium Occurrences in Brazil. In *Proceedings of a Symposium on the Formation of Uranium Ore Deposits*, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 637-658), 748 pp. (1974, November)

The most important uranium occurrences in Brazil are discussed briefly and genetic speculations are put forth. The deposits are grouped according to the following host rocks: (1) alkalic igneous rocks, (2) sedimentary rocks, (3) metaconglomerates, and (4) granitic rocks. The alkalic igneous rock type of deposits include mainly the occurrences located in the alkalic pipe of Pocos de Caldas (southwest of the State of Minas Gerais) which is situated in a SSE-NNW striking volcanic belt. This nepheline syenite pipe appears topographically in the form of a circular plateau, having a diameter of 30 km and altitudes ranging between 1000 and 1700 m above sea level. After the volcanism and consequent intrusions of the alkalic magma, two or more tectonic events followed by hydrothermal activity occurred in the interior of the massif. These deposits on the Pocos de Caldas Plateau are estimated to contain a reserve of more than 5000 tons of U₃O₈. The authors believe that these deposits are the result of concentration of uranium leached from metamict zircon crystals during hydrothermal alteration and weathering. The large Paleozoic intracratonic sedimentary basins and small Mesozoic basins of the Brazilian northeast have been intensely prospected, and some good prospects have been found. At the present time, appreciable uranium reserves have been defined only in the Parana Basin in the south of Brazil. Various occurrences associated with the clay and phosphatic matrix of sandstones deposited in Devonian coastal environments were found in the Pirari-Maranhao and Jatoba Basins, both located in the northeast of Brazil. This syngentic origin mineralization is not of economic importance. In the Parana Basin a reserve of 2000 tons of U₃O₈ is estimated in the sandstones of the lower part of the Rio Bonito Formation (Middle Permian). It is believed that this deposit was formed in a lithostratigraphic unit protected from surface oxidation by two impermeable strata, a coal seam

below and a limestone bed at the top. Since Permian time, ground water flow within this confined hydrologic system has leached uranium and reprecipitated it in favorable locations. (JMT)

<405>

Smith, L.E., and K.E. Baker; AEC,
Denver, CO

**Uranium in Fall River Area, Clear Creek
County, Colorado.** RMO-913, 12 pp.
(1951, October 15)

The Fall River area is four miles northwest of Idaho Springs, between Quartz Hill and Lawson, in Clear Creek County, Colorado. Pitchblende occurs in No. 4 vein of the Gokonda mine and in the Blazing Star vein of the Almaden mine. Sampling of No. 4 vein indicates two pitchblende shoots respectively 45 feet and 65 feet long, averaging 10 inches in width and 0.183% in U₃O₈. A selected sample from a dump on the Blazing Star vein assayed 2.4% U₃O₈ and a sample from the same vein assayed 0.90% U₃O₈. No other significant occurrences were noted in the Fall River area. (Auth)

<406>

Stocking, H.F., and L.R. Page; AEC,
Grand Junction, CO; USGS, Washington,
DC

**Natural Occurrence of Uranium in the
United States - A Summary.** In USGS
Professional Paper 300, (pp. 5-12), 739
pp.; In Proceedings of the International
Conference on the Peaceful Uses of
Atomic Energy, Vol. 6, Geology of
Uranium and Thorium, held in Geneva,
Switzerland, August 8-20, 1955. United
Nations, New York, (pp. 211-216), 825 pp.
(1956)

Within the boundaries of the United States abnormal amounts of uranium have been found in rocks of nearly all geologic ages and lithologic types. Distribution of ore is more restricted. On the Colorado Plateau, the Morrison formation of Jurassic age yields 61.4 percent of the ore produced in the United States, and the Chinle conglomerate and Shinarump formation of Triassic age

contribute 26.0 and 5.8 percent, respectively. Clastic, carbonaceous, and carbonate sedimentary rocks of Tertiary, Mesozoic, and Paleozoic ages and veins of Tertiary age are the source of the remaining 6.8 percent. In most batholiths the uranium, dominantly in acid-soluble form at intergrain boundaries, systematically increases in abundance from the mafic to the alkalic end-products of differentiation; in the Boulder Creek batholith, Colorado, the contrary is true. Uraniferous pyroclastic rocks, most of Tertiary age, are widely distributed; associated ore-bearing clastic sedimentary rocks commonly contain appreciable quantities of volcanic debris. Minable syngenetic deposits of uranium are unknown in pegmatites and other igneous rocks.

Pitchblende-bearing veins of Tertiary age are mined at Marysvale, Utah; Rabston Buttes, Gunnison, and Central City, Colorado; and Boulder, Montana. In the Coeur d'Alene district, Idaho, uranium-bearing veins of Precambrian age are known. Numerous other uraniumiferous veins are found in crystalline rocks of the United States. The pitchblende may be associated with copper, lead, silver, zinc, and gold minerals; with sulfides and fluorite; or with carbonate and silica gangue minerals and only minor amounts of sulfides. In the Thomas Range, Utah, are uraniumiferous fluorite veins and pipes of ore grade. Secondary uranium minerals occur in the upper parts of many of the veins. Oxidized and unoxidized uranium and vanadium minerals occur over a wide geographic, stratigraphic, lithologic, and structural range in terrestrial sedimentary rocks. Carnotite, tyuyamunite, autunite, torbernite, and other vanadates, phosphates, carbonates, and arsenides are common in near-surface ores; unoxidized ores at depth contain pitchblende and coffinite, with or without copper and other sulfides. Most ore bodies occur in fluvial sedimentary rocks of Triassic and Jurassic age in the Colorado Plateau and of Tertiary and Cretaceous age in Wyoming and South Dakota; some ore has been found in eolian, lacustrine, paludal, and marine rocks. The lacustrine Todilto limestone of Jurassic age is the host rock in the Grants district, New Mexico lignites of Tertiary age bear uranium in South Dakota and Wyoming. Ore bodies in separate areas have different primary controls; however, tectonic and sedimentary structures, carbonaceous material, carbonate and other cements, and variations in permeability appear to affect localization. Coarse-grained marine clastic rocks are hosts for minor epigenetic ore deposits in the Colorado Plateau; marine black shales and phosphorites contain low-grade syngenetic

uranium. (Auth)

<407>

Marjanicmi, D.K., and J.W. Robins;
Lucius Pitkin Incorporated, Grand
Junction, CO

**Uranium Favorability of Tertiary
Sedimentary Rocks of the Pend Oreille
River Valley, Washington. GJBX-3(76). 62
pp. (1975)**

Tertiary sedimentary rocks in the Pend Oreille River Valley were investigated in a regional study to determine the favorability for potential uranium resources of northeastern Washington. The Box Canyon Dam area north of Lone is judged to have very high favorability. Thick-bedded conglomerates interbedded with sandstones and silty sandstones compose the Tiger Formation in this area, and high radioactivity levels are found near the base of the formation. Uranophane is found along fracture surfaces or in veins. Carbonaceous material is present throughout the Tiger Formation in the area. Part of the broad Pend Oreille valley surrounding Cusick, Washington, is an area of high favorability. Potential host rocks in the Tiger Formation, consisting of arkosic sandstones interbedded with radioactive shales, probably extend throughout the subsurface in this area. Carbonaceous material is present and some samples contain high concentrations of uranium. Several other possible chemical indicators are found. The Tiger-Lost Creek area is rated as having medium favorability. The Tiger Formation contains very hard, poorly sorted granite conglomerate with some beds of arkosic sandstone and silty sandstone. The granite conglomerate was apparently derived from source rocks having relatively high uranium content. The lower part of the formation is more favorable than the upper part because of the presence of carbonaceous material, anomalously high concentrations of uranium, and other possible chemical indicators. The area west of Lone is judged to have low favorability, because of the very low permeability of the rocks and the very low uranium content. (Auth)

<408>

Moore, F.B., and C.R. Butler; USGS,

Washington, DC

**Pitchblende Deposits at the Wood and
Calhoun Mines Central City Mining
District, Gilpin County, Colorado. USGS
Circular 186. 8 pp. (1952)**

Pitchblende has been mined in commercial quantities from four gold- and silver-bearing pyrite-sphalerite-galena veins that occur in an area about one-half mile square on the south side of Quartz Hill, Central City district, Gilpin County, Colorado. These veins are the Kirk, the German-Becker, the Wood, and the Calhoun. Two of these veins, the Wood and the Calhoun, were studied in an attempt to determine the geologic factors favorable for pitchblende deposition. All accessible workings at the Wood and East Calhoun mines were mapped by tape and compass, and the distribution of radioactivity was studied in the fill. Channel and chip samples were taken for chemical assay to compare radioactivity with uranium content. The pitchblende-bearing veins cut both Precambrian granite gneiss and quartz-biotite schist; however, the gneiss was the most favorable host rock. Two host-tonite porphyry dikes of Tertiary age were crosscut by the Wood and Calhoun veins. The pitchblende occurs in lenses erratically distributed along the veins and in stringers extending outward from the veins. In the lenses it forms hard masses, but elsewhere it is soft and powdery. The pitchblende is contemporaneous with the pyrite but earlier than the sphalerite and galena in the same vein. All the observed pitchblende was at depths of less than 400 ft. (Auth)

<409>

Bates, R.G., and H. Wedow, Jr.; USGS,
Washington, DC

**Preliminary Summary Review of
Thorium-Bearing Mineral Occurrences in
Alaska. USGS Circular 202. 13 pp. (1953)**

Thorium-bearing minerals are known at 47 localities in Alaska. At these localities the thorium occurs as a major constituent or in minor amounts as an impurity in one or more of the following 12 minerals: allanite, columbite, elsworthite, eschynite, gummite, monazite, orangite, parisite, thorianite, thorite, xenotime, and zircon. Other minerals, such as biotite and sphene, are

radioactive and may contain thorium. Several unidentified niobate minerals with uranium or uranium and thorium as major constituents have been recognized at some localities. The distribution, by type of deposit, of the 47 thorium occurrences is as follows: lode, 3; lode and placer, 1; granitic rock, 3; granitic rock and related placer, 14; and placer, 26. (Auth)(MBW)

<410>

Norman, H.W., Daybreak Uranium Incorporated, Mining and Exploration Division, Opportunity, WA

Uranium Deposits of Northeastern Washington. Mining Engineering, 9(6), 662-666. (1957, June)

Commercial bodies of uranium are known to occur in three distinct geologic environments in northeastern Washington: 1) in and near the contact of granitic and metamorphic rocks, 2) in Tertiary sediments, and 3) in sheared and faulted zones within granitic intrusives. The mineralized contact zones and the sedimentary deposits occur on the Spokane Indian Reservation, while the remaining type is found in the Mount Spokane district. The three types of uranium deposits described are only those of known commercial value in northeastern Washington. Numerous finds of minor or undetermined value have been made throughout this part of the state, the most common of these being the pegmatite dike deposits. (MLB)

<411>

McKeel, B.K.; AEC, Salt Lake City, UT

Uranium in the Great Divide Basin, Wyoming. In Schell, E.M. (Ed.), Wyoming Geological Association Guidebook. Twenty-Fifth Field Conference, 1973, (pp. 131-138), 246 pp. (1973)

Potential uranium deposits of the Great Divide Basin are expected to occur largely as rolls resulting from solution-front activity. The potential host rocks are arkosic sands of the Battle Spring Formation of early and middle Eocene age and possibly the uppermost Fort Union Formation of Paleocene age. The apparent lack of high-grade deposits may be due to the dispersal of uranium

mineralization in the immense, restricted sand bodies, highly mobile frontal systems, and the apparent scarcity of carbonaceous materials to aid in precipitation of uranium. Uranium deposits of higher grades may occur at greater, unexplored depths. (MLB)

<412>

Bateman, J.D.; Not given

Uranium-Bearing Auriferous Rocks at Jacobina, Brazil. Economic Geology, 53(4), 417-425. (1958, June)

Near Jacobina, Brazil, are uranium-bearing gold deposits in reef-type conglomerates of Proterozoic age. Uraninite and gold occur in association with pyrite in the matrix of closely packed quartz pebble conglomerates. A comparison of the geological and geochemical features is made with the Witwatersrand gold ores and the Blind River uranium deposits, leading to the conclusion that, in the three widely separated areas, the deposits are the product of a similar metallogenetic cycle of erosion, sedimentation, and mineral deposition restricted to a late Precambrian epoch. (Auth)

<413>

Boyer, R.E.; University of Texas, Department of Geology, Austin, TX

Occurrence of Radioactive Fluoritic Sandstone, Wet Mountains, Colorado. Economic Geology, 56, 780-783. (1961)

Dakota sandstone with a fluorite cement containing thorium, uranium, and zirconium occurs in the proximity of a Tertiary hypabyssal rhyolite stock at the southern end of the Wet Mountains, Colorado. Field relations and proximity to the stock suggest a hydrothermal origin for the mineralization. Regional mapping indicates the age of intrusive activity is mid-Tertiary, and possibly younger. (Auth)

<414>

McKeown, F.A.; USGS, Washington, DC

Reconnaissance of Radioactive Rocks of

Vermont, New Hampshire, Connecticut, Rhode Island and Southeastern New York. TEI-67. 46 pp. (1951, June)

In 1948, 7,662 miles of roadside rocks and soils in Vermont, New Hampshire, Connecticut, Rhode Island, and southeastern New York were traversed with a car-mounted Geiger-Mueller counter. The observed distribution of the abnormally radioactive rocks and soils is limited to certain areas, herein called "radioactive provinces," that are separated from each other by areas of essentially nonradioactive rock. These provinces, and their maximum percent equivalent uranium are: (1) The Hudson and Housatonic Highlands of southeastern New York and western Connecticut, 0.240 equivalent uranium; (2) Central New England, 0.006 equivalent uranium; and (3) the Milton area of northwestern Vermont, 0.029 equivalent uranium. The distribution, grade, form, and uranium-thorium ratio of the radioactive deposits differ in the three provinces. Most of the radioactivity outside of the Milton area is caused by thorium. (Auth)

Cited as a reference in NURE Contractor Reports.

<415>

Narten, P.F., and F.A. McKeown; USGS, Washington, DC

Reconnaissance of Radioactive Rock of the Hudson Valley and Adirondack Mountains, New York. TEI-70. 54 pp. (1952, May)

In August 1949 a carborne reconnaissance for radioactivity was made along 3,750 miles of road in the Paleozoic rocks of the Hudson Valley and the pre-Cambrian rock of the Adirondack Mountains in eastern and central New York state. In the Paleozoic rocks the average radioactivity of the most strongly radioactive rocks is 0.003 percent equivalent uranium. The area underlain by pre-Cambrian rocks in the northwestern and southeastern parts of the Adirondacks contain the greatest concentration of abnormally radioactive rocks and glacial materials. This radioactivity is most apparent near the contacts of the igneous and metamorphic rocks where the average range of equivalent uranium content is estimated to be 0.003-0.004 percent. Pegmatites contain as much as 0.043 percent uranium and 0.62 percent thorium.

Iron slag containing 0.030 percent equivalent uranium was found near Moriah Center, and uranium and thorium in iron minerals have contributed to the radioactivity at several other abnormally radioactive localities. (Auth)

<416>

Nelson, H.E., and R.L. Hillier; AEC, Salt Lake City, UT

Preliminary Report on the Uranium Occurrence of the Silver Lady Claim, Jaw Bone Mining District, Cross Mountain Quadrangle, Kern County, California. RME-2012. 19 pp. (1954, June)

An area of high anomalous radioactivity and visible uranium minerals is associated with a nearly vertical north 70 degrees west trending shear zone. The shear zone is 50 feet wide and over 2,000 feet long, cutting Jurassic granite and Pliocene volcanics. Fragments of meta-torbernite covered granite are associated with molybdenite, molybdite, pyrite, quartz, sericite, and manganese oxide. The area is highly altered with a colorful oxidized zone of various shades of red and brown. (Auth)

<417>

Nelson, H.E.; AEC, Salt Lake City, UT

Uranium Occurrences in Mojave Mining District, Kern County, California. RME-2058. 25 pp. (1957, February)

The Mojave mining district is located about 12 miles southwest of Mojave, California. Several areas of anomalous radioactivity were discovered here by the U.S. Atomic Energy Commission (AEC) and published on anomaly map in the spring of 1954. Two of these anomalies have been exposed by surface excavation. Anomaly No. 2, the Dono-Han prospect, was developed by an incline to a depth of 20 feet. Low-grade uraniferous material has been stockpiled. Anomaly No. 3, the Verdi Development prospect, was developed by open-pit mining. The ore minerals are autunite, meta-autunite, and uranophane. Gangue minerals, with the exception of iron oxide, are absent. The uranium minerals are associated with northwest-striking faults and slips that cut Jurassic quartz monzonite. A later andesite-porphyry dike

and several quartz-monzonite aplite zones are found in close proximity to the uranium minerals. Economic potential in the area appears to be limited, although further work may expose additional reserves. (Auth)

<418>

Hart, O.M.; AEC, Casper, WY

Uranium Deposits in the Pryor-Big Horn Mountains, Carbon County, Montana, and Big Horn County, Wyoming. In Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Vol. 2, Survey of Raw Material Resources, held in Geneva, Switzerland, September 1-13, 1958. United Nations, New York, (pp. 523-526), 843 pp. (1958)

Uranium deposits in the Pryor-Big Horn Mountains of Carbon County, Montana, and Big Horn County, Wyoming, were discovered in 1955. They occur in the Madison limestone of Early Mississippian age within a complex cavern system developed during two distinct periods of solution activity. The deposits are located on the northeastern margin of the Big Horn Basin, which is one of several structural basins in the central Rocky Mountains formed during of Laramide orogeny. The ore deposits are believed to be a result of ground water processes related to the geomorphic evolution of the Big Horn Basin and its drainage system during a cycle of degradation, from Pliocene to the present time. (M1.B)

<419>

Bachman, G.O., and C.B. Read; USGS, Washington, DC

Trace Elements Reconnaissance Investigations in New Mexico and Adjoining States in 1951. TEM-443A, 22 pp. (1952, October)

In 1951, a reconnaissance search was made in New Mexico and Arizona for uranium in coal and carbonaceous shale, chiefly of Mesozoic age, and black marine shale of Paleozoic age. Tertiary volcanic rocks, considered to be a possible source for uranium in the coal and associated rocks, were

examined where they were found near coal-bearing strata. Uranium, possibly in commercial amounts, was found at La Ventana Mesa, Sandoval County, New Mexico. Slightly uraniferous coal and carbonaceous shale were found near San Ysidro, Sandoval County, and on Beautiful Mountain, San Juan County, all in New Mexico, and at Keams Canyon, Navajo County, and near Tuba City, Coconino County, in Arizona. Except for the La Ventana deposit, none appeared to be of economic importance. Marine black shale of Devonian age was examined in Otero and Socorro Counties, New Mexico and in Gila County, Arizona. Mississippian black shale in Socorro County and Pennsylvanian black shale in Taos County, New Mexico also were tested. Equivalent uranium content of samples of these shales did not exceed 0.004 percent. Rhyolitic tuff from the Mount Taylor region is slightly radioactive as is the Bandelier tuff in the Nacimiento region and in the Jemez Plateau. Volcanic rocks in plugs and dikes in the northern Chuska Mountains in New Mexico, northeastern Arizona, and southeastern Utah are slightly radioactive. Coal and carbonaceous rocks in the vicinity of these and similar intrusions are being examined. (JMF)

GENESIS OF ORE DEPOSITS

<420>

Adler, H.H.; AEC, Washington, DC

Concepts of Genesis of Sandstone-Type Uranium Ore Deposits. *Economic Geology*, 58(6), 839-852. (1963, September)

Although the sources of uranium in sandstone-type ores are in most cases obscure, the formation of the ore deposits can be attributed on the basis of sulfur isotopic data to the precipitating action of hydrogen sulfide of bacteriological origin. In some areas deposition has been related heretofore to natural gas, but the isotopic evidence does not support this origin. Certain fracture-controlled and breccia-pipe deposits also show isotopic evidence of having been formed under conditions similar to those existing for the sandstone-type ores. Geochemical relations suggest that salt-dome structures as well as fractures transecting carbonaceous sediments may be favorable sites for uranium accumulation. Certain features provide a unique basis for appraising the uranium potential of salt domes. The sulfur isotopic data reflecting bacteriological involvement in uranium deposition in no way refute the possibility that the uranium was initially derived as an igneous emanation, but the tuff-leach mechanism may provide a more favorable model on which to base exploration in some areas of the US. (Auth)

<421>

Gahelman, J.W.; Utah International Incorporated, UT

Orogenic and Taphrogenic Uranium Concentration. In *Proceedings of a Technical Committee Meeting on Recognition and Evaluation of Uraniferous Areas*, held in Vienna, Austria, November 17-21, 1975. International Atomic Energy Agency

Publications, Vienna, Austria. (pp. 109-121), 295 pp.; IAEA-TC-25 6. (pp.109-121), 259 pp. (1977)

Crustal compression at consuming plate boundaries, continental margins, or craton block junctions produces orogenic mobile belts of folding, thrusting, intrusion, metamorphism, and anatexis according to an asymmetric deformation gradient across the belt. Compression stimulates orogenic mineralization by remobilizing crustal metals, responding to a similarly oriented temperature paragenetic gradient, in a coincident zoned mineralization belt along the orogenic grain. Types of mobile and mineralization belts vary according to maximum deformation intensity. Low-intensity belts such as the Rocky Mountains are weakly or possibly not mineralized orogenically. Deep crust or mantle-generated tensional or wrench taphrogeny generates mineralization in belts enclosing grabens or horsts, wrench or transform faults, lineaments or linears or volcanic feeders. These form along or across orogenic mobile belts, in continental interiors, or in ocean basins. Metals may be juvenile from the mantle or remobilized from the crust. Strong mineralization belts diagonally across low-intensity orogenic belts suggest taphrogenic mineralization superimposed on much weaker orogenic mineralization. The Colorado and other northeast mineralization belts, including the broad northeast uranium belt of the western United States are examples. To determine which deformation type exerted stronger control over uranium distribution in this region, an isopycnic map of uranium occurrence density was prepared. The regional northeast uranium belt is sharply defined as composed of smaller belts enclosing or parallel to prominent taphrogenic features of several distinctive orientations. The weaker orogenic gradient is portrayed within the broad belt by the increase of uranium quantity toward a maximum near the Cordilleran foreland boundary. (Auth)

<422>

Walker, G.W., and F.W. Osterwald;
USGS, Washington, DC

Concepts of Origin of Uranium-Bearing Veins in the Conterminous United States. *USGS Professional Paper 455-F*. (pp. 105-120). (1963)

Several different theories have been proposed to account for the formation of uranium-bearing veins. Most theories consider that vein deposits were derived directly through magmatic differentiation or, conversely, through concentration of uranium from a dispersed source in rocks of the crust as a result of the development of energy gradients through diastrophic activity. In many places, it can be assumed that these different modes of origin are not mutually exclusive. The wide distribution of uranium-bearing veins in the conterminous United States and the diverse geologic characteristics of these deposits and of their structural and petrologic environments seem more compatible either with several different modes of origin or with concentration of dispersed uranium as a result of tectonic, petrologic, or hydrologic processes. Both liquid and gaseous transport of uranium have been postulated and are described in several of the hypotheses of uraniferous vein formation. Postulated ore-transporting solutions have included magmatic, meteoric, and connate water, some unidentified liquid organic material, and liquid carbon dioxide. The uranium within these different phases may have been in true solution as ions or ion complexes, or it may have been in colloidal suspension. In some places it has been postulated that uranium has been transported in a gaseous phase, presumably as a halide. Deposition of uranium has been attributed to several different, but commonly interrelated, physical and chemical factors largely related to changes in pH and Eh within the vein system. In some places uranium seems to have been fixed solely by evaporation of solvent, by the formation of stable metallo-organic compounds, or by adsorption. An extremely wide range of temperature and pressure conditions of formation, essentially from near-surface deposition by cold ground water to high-temperature (about 500 degrees C or more) deposition at great depths and confining pressures, has been demonstrated for uranium-bearing veins as well as most of the larger veins can be assigned to epithermal or middle to upper mesothermal pressure-temperature classes. (Auth)(JMT)

<423>

Noble, E.A.; AEC, Grand Junction, CO

Genesis of Uranium Belts of the Colorado Plateau. In Proceedings of the International Geological Congress, Report

of the Twenty-first Session, Part 15, Genetic Problems of Uranium and Thorium Deposits, held in Copenhagen, Denmark, 1960, (pp. 26-39), 164 pp. (1960)

Concentrations of major Colorado Plateau uranium deposits in restricted belts, independent of apparent structural or lithologic limits, suggest that the uranium was transported in moving ground water and deposited where changes occurred in the transporting fluid. The ground water is believed to have derived the uranium from local rocks, perhaps following devitrification of volcanic debris. The enriched ground water was then forced from the source beds by anomalous fluid pressure built up by gravitational compaction and tectonic compression, or perhaps by magmatic pressures. Fluid pressure decreased as the migrating fluid passed laterally through aquifers, away from zones of maximum pressure. The decrease in pressure caused disequilibrium in the ore fluid, with consequent deposition of uranium. The equipotential surfaces enclosing a zone of optimum conditions for uranium deposition thus determined the outlines of a mineral belt. (JMT)

<424>

Brookins, D.G.; University of New Mexico, Department of Geology, Albuquerque, NM

Uranium Deposits of the Grants, New Mexico Mineral Belt: Geochronologic Studies. In AI(05-1)-1636-1, (pp. 35-49), 153 pp.; In GJBX-16(76), (pp. 35-49), 153 pp. (1975)

Efforts to date the source areas, allogenic and authigenic constituents of the ore-bearing strata of the Grants Mineral Belt are discussed. While some data on K-Ar and U-Pb are reported, this report focuses on efforts to use the Rb-Sr geochronological method. There are few U-Pb dates from the Grants Mineral Belt due to the loss of some of the intermediate daughters from U-235 and U-238 decay chains. From the Jackpile-Paguate area, U-235-Pb-207 dates for coffinite of 94 plus or minus 3 my and 90 plus or minus 3 my have been reported. A date of 107 plus or minus 6 my for ore from the Section 33 Mine, Ambrosia Lake District has also been reported. For all three samples, the U-238-Pb-206 dates are lower such that the Pb-207-Pb-206 dates are

anomalously high. Studies of three suites of samples were conducted in the Ambrosia Lake District: (1) the minus-two micron fraction of montmorillonite-rich samples from barren, reduced ground, (2) the minus-two micron fraction from chlorite-rich material from ore pods, and (3) the two to sixty-two micron fraction from reduced ground. The age of montmorillonite formation by the Rb-Sr method is calculated at 149 plus or minus 17 my. The chlorite-rich material formed at the expense of the montmorillonite, evidently forming penecontemporaneously with the uranium mineralization. The Rb-Sr date received from this fraction was 139 plus or minus 10 my, and this date may be taken as the age of mineralization. The two to sixty-two micron size fractions from oxidized, barren and reduced ground gave a wide spread in dates, and all that can be said with confidence is that this fraction is weighted by Precambrian material. In the Smith Lake District, minus-two micron, chlorite-rich clay mineral assemblages were tested and they yielded an age of 139 plus or minus 13 my. This age is indistinguishable from that for the same size fraction from Ambrosia Lake samples. In the Laguna District, minus-two micron fraction samples from barren, reduced ground from the Jackpile Mine were analyzed and yielded a Rb-Sr date of 146 plus or minus 5 my. This is almost exact agreement with the 149 plus or minus 17 my for the same material from the Ambrosia Lake District. For ore samples from the Jackpile Mine, both minus-two micron and minus-0.5 micron size fractions were tested. These dates received were 115 plus or minus 9 my and 110 plus or minus 10 my, respectively. These two ages are significantly younger than the suggested age of mineralization for minus-two micron material from ore-bearing material in the Ambrosia Lake and Smith Lake districts. Interpretations of this data may include: (1) a truly younger period of mineralization for the Jackpile-Paguete ore than for that in the Westwater Canyon Member in the Ambrosia Lake-Smith Lake districts or (2) some type of resetting off the isochrons at one, but not both, locations. The author prefers the former interpretation and notes that the sedimentological evidence suggests significantly younger paleochannel development (and in a different direction) in the Jackpile Sandstone relative to the Westwater Canyon Member. As an outgrowth of the isochron assessment, it is proposed that the ore in the Ambrosia Lake district may be the result of leaching of volcanogenic detritus from the overlying Brushy Basin Member. If this is so, then a different source would have to be proposed for

the stratigraphically higher Jackpile-Paguete ores (JMI)

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Magne, R., J.R. Berthelin, and Y. Dommergues, Centre de Recherches Radiogéologiques, Nancy, France, Centre de Pédologie Biologique du CNRS, Nancy, France

Solubilization et Immobilisation de L'Uranium des Granites par des Bactéries Hétérotrophes In Proceedings of a Symposium on the Formation of Uranium Ore Deposits, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 73-88), 748 pp. (1974, November)

Batch cultures and semi-continuous flow perfusions are used as experimental devices to study microbial solubilization and insolubilization of uranium from granites by heterotrophic bacteria. The nutrient media are synthetic (with dextrose or amino acids) or natural (with mine water containing organic compounds). Microbial activity increases 2 to 97 times the solubilization of uranium. The processes are biosyntheses of complexing or chelating compounds. The micro-organisms involved are soil microflora and bacteria of mine water and granites. Some species are identified. Microbial insolubilizations of uranium are described in batch cultures. These processes involve biodegradation of uranium binding organo-compounds. These biodegradations occur after long periods of incubation and promote some neoformations of uranium deposits. Black and yellow deposits are observed and described. These experimental results suggest the model described in the paper. This model seems to apply easily to superficial processes of solubilization and concentration of uranium and in reworking deposits. However, in the case of primary intragranite uranium deposits it is only an hypothesis correlated by the existence of favorable environmental conditions for bacterial growth and by some geological observations mentioned in the paper. (Auth)

<426>

Jayaram, K.M.V., K.K. Dwivedy, M.C. Bhurat, and S.G. Kushrestha; India

Department of Atomic Energy, Atomic Minerals Division, New Delhi, India

A Study of the Influence of Microflora on the Genesis of Uranium Occurrences at Udaipur, Udaipur District, Rajasthan In Proceedings of a Symposium on the Formation of Uranium Ore Deposits, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 89-98), 748 pp. (1974, November)

An area near Udaipur Lake in Rajasthan, India was found to have uranium ore samples that contained 2.3×10^{11} bacteria per gram, and a detailed investigation was carried out to evaluate the possible role of the sulfur and iron-oxidizing bacteria in the mobilization of the uranium in the carbonaceous phyllites and its redeposition in breccias and fault gouge. From the investigation of the area it was concluded that while the hydrothermal activity connected with the post-Aravalli granitic intrusions is responsible for introducing uranium into the country rock, the higher radioactivity in the black carbonaceous phyllites is due to the higher uranium content in the unaltered sediment. The higher concentration of uranium into a shallow, low-grade deposit is brought about by the microbial leaching of the contained uranium in the continuously eroding carbonaceous phyllites and its subsequent adsorption on the natural mineral exchangers in the fault gouge below the water table, by reduction, in the presence of active anaerobes. Since considerable reconcentration of uranium could be brought about through the agency of bacteria, areas containing sizeable thickness of suitable host rocks, autotrophic bacteria, transportation channels extending below the water table and structural and lithologic traps may yield similar deposits. (Auth)(JMT)

<427>

Rich, R.A., H.D. Holland, and U. Petersen; Harvard University, Cambridge, MA

Origin of Vein-Type Uranium Deposits. In AT(05-1)-1640, (pp. 90-109), 383 pp.; In GJO-1640, (pp. 90-109), 383 pp. (1975)

Three different generalized models for the

formation of vein-type U deposits are as follows (1) very shallow U leaching and deposition by oxidizing surface waters, (2) U leaching and deposition by deeply circulating oxidizing waters which originated at the surface, and (3) U leaching and deposition by deeply circulating oxidizing waters which are not of direct surface origin. The presence of red beds is required for the third model and would be extremely useful in the second. Many important vein-type U deposits occur in crystalline basement rocks associated with, or overlain by, either red bed or clean sandstone units. Pitchblende is deposited in vein-type U deposits from oxidizing solutions in response to the reduction of U^{VI} to U^{IV} . The ore solutions may either be descending or deeply circulating surface waters which have equilibrated with atmospheric oxygen or deep waters of non-surface origin which have equilibrated with a hematitic aquifer. The U deposited in the veins was probably scavenged from U-rich granitic rocks by the oxidizing fluids (JMT)

<428>

Not given, AEC, Washington, DC

The Genesis of Uranium Deposits. In Nüninger, R.D. (Ed.), Exploration for Nuclear Raw Materials, D. Van Nostrand, Inc., New York, (pp. 55-70), 293 pp. (1956)

In igneous rocks, the youngest member of a series, regardless of the particular liquid line of descent that the magma may have followed, generally contains the maximum concentration of thorium and uranium. Pegmatites contain a wide variety of uranium minerals, including uraninite, as well as many multiple oxides containing rare earths, niobium, tantalum, and titanium. Three important types of uraniferous veins may be recognized: (1) nickel-cobalt-native silver veins, (2) silica-iron-lead veins, and (3) iron-titanium veins. The nickel-cobalt-native silver veins are characterized by pitchblende, a complex assemblage of sulfides, carbonates and minor amounts of silica. The silica-iron-lead veins are also characterized by pitchblende, but the assemblage of associated minerals is generally a simple one, mainly pyrite, galena, and quartz or jasper. The iron-titanium veins are characterized by uranium titanites (such as davidite), ilmenite, rutile, and quartz. The uranium in hydrothermal veins is derived mainly from residual solutions arising from late-stage differentiates, generally those rich in silica and the

alkalis. Of chief concern are the composition and temperature of transporting solutions, depth and pressure relationships at the site of deposition, the chemistry of precipitation and structural control in the localization of the ore. Several sources have been postulated for the uranium in the sandstone ore: (1) detrital uranium minerals or chemical or biochemical precipitates of uranium deposited at the same time as the enclosing rocks, (2) dispersed concentrations in tuffs or ordinary rocks in the sedimentary column, (3) migrating petroleum or solutions derived from petroleum source beds, and (4) hypogene solutions. Because certain land plants concentrate enough uranium to be of value in prospecting for ore deposits, it might be supposed that uranium in coal is concentrated by living plants. It appears, however, that significant concentrations of uranium are found only in plants growing on mineralized ground. The irregular distribution of uranium in the individual beds, its regional relationship to unconformities, its vertical distribution within individual beds, and its local concentration along fractures and permeable beds indicate that it was introduced after deposition of the enclosing rocks, though its even distribution in individual specimens suggests that it was introduced prior to coalification. (JMT)

<429>

Bergiot, W., Columbia University, New York, NY

Absolute Age Relationships in Selected Colorado Plateau Uranium Ores, Ph.D.
Dissertation, Geology Department,
Columbia University, 149 pp. (1970)

New lead-uranium isotopic ages for primary minerals, together with geologic evidence, suggest several periods of ore deposition in uranium bearing strata of the Colorado Plateau. Concordant age sequences, where the apparent ages derived from the ratios Pb 206/U 238, Pb 207/U 235, and Pb 207/Pb 206 agree within the experimental error, have been obtained for uraninite from the Upper Jurassic Todilto Limestone, near Grants, New Mexico, and the Upper Triassic Chinle Formation, near Moab, Utah. These ages are about 150 m.y. and 200 m.y., respectively, and agree with the independently estimated absolute age of the host rocks, suggesting mineralization shortly after sedimentation, as geologic evidence apparently precludes strict

syngeneity. For Todilto deposits, evidence against syngeneity includes cross-cutting relationships, occasional fracture control of ore, and localization of ore bodies by intraformational folds which formed after sedimentation but before complete lithification. Ages for coillinite from the Jackpile mine area, near Laguna, New Mexico, together with geologic evidence, indicate mineralization of the Upper Jurassic Morrison Formation during the Lower Cretaceous. Primary deposits in the Morrison in the Ambrosia Lake District, near Grants, New Mexico, probably formed contemporaneously with the Jackpile deposits. Mineralization of the Todilto Limestone apparently preceded deposition of the ore-bearing Morrison Formation in the Grants-Laguna district. At Kane Creek, Utah, essentially concordant ages for bedded and fracture-controlled deposits are about 200 m.y. and 60 m.y., respectively, also suggesting two different periods of ore formation in the same mineralized area. Plateau samples usually yield discordant apparent age sequences, which are generally best explained by partial loss of radiogenic lead, with preferential loss of Pb 206. Loss of intermediate daughter products in the U 238 decay chain may have contributed to Pb 206 deficiencies. Geologic evidence for extensive redistribution of relatively unoxidized ore exists at Ambrosia Lake, New Mexico. Discordant age sequences with Pb 206/U 238 and Pb 207/U 235 ages much less than the absolute age of the enclosing sediments have been obtained for apparently primary minerals from many deposits. Concepts of origin of Plateau ores must be revised in light of the age data, but only the syngenetic hypothesis, among those previously proposed, seems to be ruled out of isotopic and geologic data. (Auth)(JMT)

<430>

De Nault, K., Stanford University,
Stanford, CA

Formation of Sandstone-Type Uranium Deposits in Wyoming, In Ph.D.
Dissertation, Origin of Sandstone Type Uranium Deposits in Wyoming, Chapter 10, (pp. 266-273), 352 pp. (1974)

After the deposition of the Fort Union Formation of Paleocene age, but prior to deposition of sediments of early Eocene age, the Fort Union Formation and older rocks were uplifted around

the margins of the basins and the exposed updip edges were eroded away. Sediments of early Eocene age, the principal host rocks for sandstone-type uranium deposits in Wyoming, were unconformably deposited upon the Fort Union and older formations around the basin margin.

Deposits were composed of sands, gravels, and silts that were laid down in alluvial fans, stream beds and flood plains. Lush vegetation abounded during the early Eocene and plant debris was dispersed throughout the sediments. Following deposition of clastic sediments of early Eocene age, volcanic activity commenced and mountain building ceased. Ash-rich sediments of middle and late Eocene age were deposited in some parts of the state, but much of these sediments were eroded away. From Oligocene until near the close of Pliocene time, ash-rich sediments are uraniferous and the tenor of uranium content becomes greater in younger ash falls. These ash-rich deposits, particularly the White River Formation of Oligocene, are very impermeable. They effectively capped underlying units and prohibited downward migration of oxygenated meteoric groundwater, retaining the uraniferous groundwaters in the White River and overlying formations, and providing an opportunity for strongly reducing conditions to develop in the underlying Eocene sands. Sometime during late Pliocene or Pleistocene time, normal faulting commenced on the North and South Granite Mountains. These faults broke the seal over lower Eocene sediments and provided channelways for the influx of uraniferous groundwaters. About the same time that normal faulting occurred, Wyoming underwent regional uplift. Basins and mountains were exhumed, and streams eroding the mountain flanks broke through volcanic-rich sediments, resulting in an influx of uraniferous groundwaters and surface waters into the Eocene sands. The influx, oxygen-rich, uraniferous groundwater percolated down-dip through the host sand. As it progressed through the sediments, a transition zone developed between Eh and pH conditions initially present in the host sediments and those of the influx, ore-carrying solutions. In this transition zone, calcite, pyrite, uraninite, and selenium would precipitate. The elements would concentrate because the rate of movement of the transition zone would be slower than the rate of movement of the ground water. The rate of movement of the transition zone would depend upon the amount of pyrite, H₂S, and other reduced species that were present prior to influx of ore-carrying solutions. In addition, sufficient calcite must have been present to neutralize hydrogen ions

released by oxidation of pyrite. Otherwise, the pH would become so low that uranium would be mobile even in the reduced uranous state (JMT)

(431)

Lee, M.J., University of New Mexico,
Albuquerque, NM

Isotope Geochemistry. In Ph.D.
Dissertation, Geochemistry of the
Sedimentary Uranium Deposits in the
Grants Mineral Belt, Southern San Juan
Basin, New Mexico, (pp. 121-153), 241 pp.
(1976)

Attempts to apply the Rb-Sr systematics to define, a) possible source materials, b) age of Morrison sedimentation, and c) age of primary uranium mineralization, by analyzing authigenic and allogenic constituents of the Morrison Formation are discussed. The Rb-Sr method of age determination, when applied to certain authigenic minerals in the sedimentary rocks, has certain advantages over U-Pb and K-Ar methods, since loss of the daughter product, Sr 87, is considered to be minimal. Although most workers refer to the Morrison as Late Jurassic, its absolute geologic age is not known. The only authigenic phase that may give an age close to the Morrison sedimentation is believed to be the montmorillonite in bleached but barren grounds. Two montmorillonite assemblages were analyzed: Ambrosia Lake samples and Jackpile samples. The Rb-Sr testing indicated an age of formation of 149 plus or minus 17 m.y. for the Ambrosia Lake samples. Samples of the Jackpile-Paguate area yielded an age of 149 plus or minus 5 m.y. When the two ages are averaged, an approximate age of sedimentation of 147 m.y. may be inferred for the upper Morrison in the GMB. Chlorite-rich samples of high-grade primary ore were also analyzed. Two sample groups from Ambrosia Lake and Smith Lake districts yield apparently identical ages of 139 plus or minus 10 m.y. and 139 plus or minus 13 m.y., respectively. The upper Morrison Formation in places contains abundant pebble-sized microcline and other potassium feldspars which are generally fresh. An isochron age of 1.33 plus or minus 0.02 b.y. with initial $Sr\ 87/Sr\ 86 = 0.7056$ plus or minus 0.0007 was obtained. This confirms the suspected Precambrian age of these detrital materials and can be compared directly to the Precambrian rocks of the Zuni uplift which yield a preliminary isochron

age of 1.39 ± 0.02 b.y.

Potassium-argon testing was also conducted on Morrison sediments. The K-Ar ages for the clay-sized fraction were consistently younger when compared to the Rb-Sr results. These younger K-Ar ages on clay minerals suggest that daughter Ar 40 loss is responsible. Several lines of geologic evidence associated with the primary deposits place certain limits to the age of the ore relative to the time of deposition of the Morrison Formation and Dakota Sandstone. The following observations are considered to be important: 1) The deposits are found within and parallel to the channel sandstones developed in the Morrison. 2) Within the channel, ore pods commonly have non-uniform distribution. They tend to be concentrated in one particular edge of an individual channel, frequently on the up-dip side, suggesting an epigenetic mode of formation. 3) Authigenic chlorite, which was formed after montmorillonite, is commonly surrounded by or intimately mixed with uranium-bearing organic carbonaceous material. 4) In the eastern part of the Ambrosia Lake district, collapse structures of probable Morrison age, as well as other fracture systems, displace high-grade primary ore bodies. 5) U-235 Pb-207 age determinations indicate minimum ages of mineralization around 90 to 100 m.y. These observations indicate that primary mineralization occurred shortly after the Morrison sedimentation, but certainly before the Dakota deposition. The Rb-Sr ages of ore-related clay minerals strongly support this premise. (JMT)

<432>

Snow, C.D.; Utah Construction and Mining, Riverton, WY

Sedimentary Tectonics of the Wind River Formation Gas Hills Uranium District, Wyoming. In Renfro, A.R. (Ed.), Wyoming Geological Association Guidebook, Twenty-Third Field Conference, 1971, (pp. 81-83), 187 pp. (1971)

The Gas Hills Uranium District is located along the southeastern margin of the Wind River Basin. The Wind River Basin is an east-west trending basin defined by the positive areas of the Wind River Mountains to the west, the Owl Creek Mountains on the north, the Granite Mountains on the south, and on the east by the Casper Arch. At the beginning of Wind River time tectonic components

present that were to influence the lithologic nature and geographical distribution of the sediments in the subject area include in part (1) The Granite Mountains which supplied much of the material for the massive arkosic sediments in the central portion of the district. (2) The enechelon folds along the mountain flank, including the Puddle Springs and Dutton Basin anticlines that had been eroded to maturing surfaces. (3) The depositional basin area to the north that periodically continued to subside during much of Eocene time. The orogenic events at the close of the Paleocene and early Eocene included major deformation of the basin area, continental uplift, and uplift of the Granite Mountains that induced erosion of the Fort Union Formation along with the "toothhills" of the Granite Mountains. These tectonic events and subsequent erosion opened the northern portion of the Wind River Formation allowing groundwater to flow from the relatively higher groundwater surface of the Beaver Run through the Wind River Formation into the eroding basin. The uraniferous

Precambrian granitic source rocks were transformed into extremely lean arkosic uranium protore that was permeable, carbonaceous, and pyritiferous. With ingress of oxygenated groundwater, geochemical cells developed in the protore. Water and oxygen reacted with disseminated diagenetic and epigenetic pyrite to form an acid wave that moved generally downdip to leach the uranium and other susceptible elements from the protore. These elements were deposited in solution or roll fronts where Eh and pH changes caused precipitation at the edges of geochemical cells. Movement of the cells continued until late Quaternary faulting partially interrupted the continuity of the formation and reduced groundwater flow. (JMT)

<433>

Koerberlin, F.R.; Not given

Sedimentary Copper, Vanadium-Uranium, and Silver in Southwestern United States. Economic Geology, 33(4), 458-461. (1938)

It is suggested that the metals may have been derived from pyroclastic material. Mineral-bearing fluids may be expelled from cooling magmas and collected in domes and cupolas near the roofs. If the magmatic extract enters fractures and permeable zones, veins are formed. However, if the

roof is not sufficiently strong to confine the magma, the material may be ejected into the atmosphere as volcanic ash. The metallic content of the ash beds would be easily available to surface or ground-water solutions because of the minute size of the metal-bearing particles. This mechanism may have furnished the metals to the deposits under discussion. (Auth)

<434>

Kelley, V.C.; University of New Mexico, Albuquerque, NM

Influence of Regional Structure and Tectonic History upon the Origin and Distribution of Uranium on the Colorado Plateau. In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 299-306), 825 pp. In USGS Professional Paper 300, (pp. 171-178), 739 pp. (1956)

Regional structures indirectly influence the distribution and perhaps the origin of uranium deposits on the Colorado Plateau. A description and analysis of the regional tectonics and a geologic and tectonic history, together with a discussion of the tectonic influence on origin and distribution of uranium, are presented. Tectonic events, probably as remote as Permian, have affected indirectly the provenances of sediments and the environments in which they were deposited, the paleohydrology, the igneous activity, and the erosional history of the Plateau. These factors are discussed in relation to their probable effect on the origin of uranium deposits. It is assumed that most of the ore was precipitated from ground water and, because of paleohydraulic conditions, concentrated in the central part of the Plateau. (Auth)

The conference paper is entitled "Influence of Regional Structure upon the Origin and Distribution of Uranium in the Colorado Plateau".

<435>

Not given; International Atomic Energy Agency, Vienna, Austria

Formation of Uranium Ore Deposits

Proceedings of a Symposium on the Formation of Uranium Ore Deposits, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria, 740 pp (1974, November)

The International Atomic Energy Agency, conscious of the importance of the study of uranium geology and exploration techniques, first sponsored a panel meeting in April 1970 to discuss uranium exploration geology and as a result of that meeting, a number of Working Groups were set up to study genetic concepts, the various principal types of uranium deposits and their formation. As a result, a symposium on the Formation of Uranium Ore Deposits was convened by the International Atomic Energy Agency and held May 6-10, 1974 in Athens, Greece. A total of 220 participants from 40 countries and two international organizations attended the Symposium, at which 43 papers were presented. The papers are in the following categories: Chemical and Physical Mechanisms in the Formation of Uranium Mineralization; Geochronology; Isotope Geology and Mineralogy; Sedimentary Basins and Sandstone-Type Deposits-North American Deposits; Sedimentary Basins and Sandstone-Type Deposits-Permian Deposits in Europe; Sedimentary Basins and Sandstone-Type Deposits-Sedimentary Deposits in Other Areas; Uranium in Quartz-Pebble Conglomerates; Vein- and Similar-Type Deposits; Other Uranium Deposits; Relation of Metallogenic, Tectonic and Zoning Factors to the Origin of Uranium Deposits. (JMT)

Twenty-six reports presented at the symposium have been abstracted separately; cited as a reference in NURE Contractor Reports.

<436>

Bossi, J.; Facultad de Quimica, Montevideo, Uruguay

Use of Fluid Inclusions in the Genetic

Study of Vein Deposits. In Proceedings of a Symposium on the Formation of Uranium Ore Deposits, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 583-592), 748 pp (1974, November)

The formation process of the "properly uraniferous" type of uranium vein deposits is still under discussion. In this paper the systematic application of the study of fluid inclusions is proposed in order to contribute to the interpretation of the genetic process. The behaviour of fluid inclusions of a vein deposit of lead-zinc in the south of the French Central Massif, which is believed to be per descensum (deposited by solutions moving downwards) is taken as a model and it is proposed that such a criterion be applied to uraniferous deposits. The aim of the paper is to interpret the genesis of these uranium vein deposits, in the belief that this will be of great importance in assessing guides for provisional prospecting, once the theoretical conditions that control the supergenic process are known. (Auth)

<437>

Bowers, H.E., and D.R. Shaw; USGS, Washington, DC

Heavy Minerals as Guides to Uranium-Vanadium Ore Deposition in the Slick Rock District, Colorado. USGS Bulletin 1107-B, (pp. 169-218). (1961)

The similarity of the actual weight percentage of heavy minerals other than black opaques in most of the suites from the Morrison formation indicate that, when deposited, most of the sandstone of the Morrison had a generally uniform heavy-mineral content, with similar amounts of various species. Geologic and petrologic evidence indicates that the variation in black opaque minerals resulted from alteration after deposition. The uniformity in heavy-mineral content of the original sediment suggests that all the rocks of the Morrison formation studied in this investigation had a common source. In places in the Morrison,

abundant carbonaceous material was deposited, notably in the ore-bearing sandstone. Presumably, these rocks almost from the time of deposition existed in a reducing environment. For this reason black opaque minerals probably never were oxidized as they were in the light reddish-brown sandstone found in other parts of the formation. Probably long after deposition of the sediments, after consolidation and faulting of the beds, the light reddish-brown sandstone was attacked by altering solutions that were localized there because of the channeling effect of the shattered and more permeable rocks along a fault zone. The chief effects of the alteration were almost total removal of black opaque detrital minerals, removal of all interstitial hematite dust and hematite in the form of filars coating other detrital grains, and redeposition of some of the iron as pyrite. A light gray rock resulted. The heavy minerals in altered sandstone close to faults and in light-gray sandstone adjacent to mineralized layers differ principally in the relatively greater abundance of anatase and pyrite, both authigenic minerals, close to the deposition. Possibly these minerals are abundant there because of conditions for precipitation which also induced deposition of ore minerals. Because of the implied relation of the deposits to epigenetic alteration in the fault zone, and the geologic evidence to suggest that the deposits were formed long after deposition of the sediments, alteration that was related to uranium-vanadium deposits is believed to be epigenetic. On the basis of the foregoing hypothesis, the conclusion is reached that at some time after deposition of the sediments of the Morrison formation in the Disappointment Valley area, after consolidation and after faulting of the beds, solutions flowed through the fault zones causing alteration of sandstone close to faults and joints. In the Salt Wash member below the ore-bearing sandstone the zone of alteration was generally about 2 or 3 miles wide, but in the laterally non-continuous, and initially more permeable, ore-bearing sandstone itself the zone of alteration was much wider. In the ore-bearing sandstone the contact of the altering fluid with pockets of stagnant water where strongly reducing conditions already existed close to the carbonaceous material, resulted in precipitation of minerals in the uranium-vanadium deposits. (JMT)

<438>

Miesch, A.T.; USGS, Washington, DC

**Distribution of Elements in Colorado
Plateau Uranium Deposits - A
Preliminary Report** USGS Bulletin
1147-F, 57 pp (1963)

Studies of the regional variation and geochemical coherence of extrinsic elements in uranium deposits in the Salt Wash member of the Morrison formation indicate that some of the elements (Fe, Co, Ni, Mo, As, Se, and Y) may have been derived mainly from sources external to the Salt Wash member in the salt anticline area of western Colorado and eastern Utah. Some of the lead, however, is of radiogenic origin, and is derived from the decay of uranium in place. Zinc appears to have been derived from both sources. Uranium and probably vanadium in the Frenchy Incline deposit were derived from sources outside the altered part of the sandstone lens in which the deposit occurs. The elements derived from tuffaceous materials could have come from the altered sandstone lens. Uranium deposits in the Salt Wash member could have formed entirely during a period when ground water solutions were migrating through the sandstone, most likely after regional deformation in the Late Cretaceous or Early Tertiary time. Alternatively, they could have formed partly during an early period of relatively stagnant hydrologic conditions and partly during later ground migration. Both hypotheses pose difficulties. According to the "one stage" hypothesis of origin, solutions bearing Cu, Ag, Pb, and Zn were brought to the Salt Wash member from external sources by way of fractures in the salt anticline area, during a period of ground-water migration. The solutions may also have carried uranium and vanadium, but these elements could also have been leached from rocks within the Salt Wash as the solutions migrated through it or they could have been transported separately. Other elements, including Fe, Co, Ni, Mo, As, Se, Y, and some Zn, were leached from tuffaceous materials in the sandstone. According to the "multiple stage" hypothesis of origin, Fe, Co, Ni, Mo, As, Se, Y, and some Zn (possibly also some Cu, Ag, Pb, U, and V) accumulated in the deposits during an early stage of relatively stagnant ground water conditions by process of solute diffusion. Roll structures, defined largely by concentrations of pyrite, originated in the ore bodies during this time. After structural deformation of the Salt Wash member and acceleration of ground water migration, solutions bearing Cu, Ag, Pb, and Zn entered the Salt Wash, and deposits of these elements were superimposed on the earlier

accumulations of elements. Uranium and vanadium may have been brought by the same solutions carrying Cu, Ag, Pb, and Zn but may also have been transported separately. Roll structures containing uranium and vanadium minerals may have formed the precipitation of these elements in the earlier pyrite rolls. (JMT)

<439>

Premoli, C., Not given

**Formation of, and Prospecting for
Uraniferous Calcretes.** Australian Mining,
68(4), 13-16, (1976)

In 1972, Western Mining Corporation announced the discovery in Western Australia of the Yeelrie uranium deposit. The figures released for the deposit are 46,000 metric tons of uranium oxide at an average grade of 0.15% (3.3 lb/t). The uranium mineral is carnotite in a porous carbonatic matrix. Some doubt still persists about the precise geochemical mechanism responsible for the accumulation of carnotite in calcretes. Several mechanisms have been proposed, but none are completely free of objections. The possibility that carnotite may move in colloidal form and the fact that bacteria can play an active role in changing the redox potential of the depositional environment further increase the complexity. From field work performed in Western Australia it appears that the most satisfactory concept in explaining the majority of occurrences is that of precipitation of carnotite in an aqueous medium and control by the redox potential. This involves the oxidation of vanadium from the tetravalent to the pentavalent state according to the reaction: $2\text{UO}_2(\text{OH}) + 2\text{K} + 2\text{H}_2\text{VO}_4 + \text{H}_2\text{O} \rightarrow \text{K}_2(\text{VO}_2)_2\text{V}_2\text{O}_8 \cdot 3\text{H}_2\text{O} + 2\text{H}^+$. Exploration methods being used in prospecting for uraniferous calcretes at the present time are: (1) ERTS imagery and air photo interpretation, (2) airborne reconnaissance, (3) airborne radiometry, (4) hydrogeochemistry and biogeochemistry, (5) detailed ground reconnaissance, and (6) systematic drilling and sampling. (JMT)

<440>

Knipping, H.D.; Gulf Minerals Canada,
Limited, Toronto, Ontario, Canada

The Concepts of Supergene Versus

Hypogene Emplacement of Uranium at Rabbit Lake, Saskatchewan, Canada. In *Proceedings of a Symposium on the Formation of Uranium Ore Deposits*, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 531-549), 748 pp. (1974, November)

The Rabbit Lake uranium deposit is located within rocks of the Wollaston Lake Fold Belt in the southwestern part of the Canadian Shield.

Archaean rocks, the source of the sediments in the Wollaston Lake Fold Belt, are mainly of granitic composition, which is reflected in the generally arkosic character of the strata. Meta-arkose, biotite paragneiss, and calc-silicate rocks with marble form the main rock units indicating miogeosynclinal conditions for sedimentation. The sedimentary assemblage was deformed and metamorphosed during the Hudsonian orogeny. The Middle and Upper Proterozoic Athabasca Formation is not metamorphosed and overlies the Lower Proterozoic unconformably. The formation

comprises quartz sandstone and conglomerate up to 5000 feet thick, and has been K-Ar dated between 1700 and 1100 million years ago. The Lower Proterozoic rocks south of Rabbit Lake are asymmetrically folded and the axial region of the synform was strongly sheared and brecciated. This brecciated axial region is the ore zone at Rabbit Lake. A young cross-cutting reverse fault, with east-northeast strike, limits the ore zone on the north end. The uranium solutions entered the porous rock and the uranium minerals were deposited on the walls of pores and fractures. The deposition appears to be a simple process of coating the open spaces. Primary uranium minerals at Rabbit Lake are colloform and massive pitchblende, sooty pitchblende, and rarely coffinite. Secondary uranium minerals are boltwoodite, uranophane, and sklodowskite. The pitchblende is often overlain by massive or euhedral quartz and calcite, with some euhedral dolomite occurring on the tips of the quartz crystals. The sooty pitchblende often coats the euhedral quartz and is thus, the youngest pitchblende observed in the deposit. The paragenetic succession is always identical in different parts of the orebody and is as follows: alteration of host rock-development of porosity and permeability-deposition of pitchblende on the walls of void space-deposition of sooty pitchblende. Within the orebody are a few blebs and specks of sulphides, such as pyrite, marcasite, chalcopyrite, and galena. Some of these

sulfide minerals are intimately associated with pitchblende, suggesting syngenetic deposition. At the present time, the bulk of the evidence favors the hypothesis of supergene uranium emplacement. The uranium was deposited by supergene solutions in a regolith acting as a trap, prepared during a long weathering interval after the erosion and peneplanation of the Hudsonian orogen. The uraniferous solutions originated east of the Wollaston Lake area and flowed westward during the deposition of the Athabasca formation, finally percolating through the porous and permeable regolith below the unconformity. The extraordinary sparse metal paragenesis of Rabbit Lake ore indicates that the uranium passed through a geological filtering process during which other metals normally associated with uranium in hydrothermal environment (i.e., Co, Ag, Bi, Sb) were completely filtered out. (JMI)

7-441-

Bell, K. G.; USGS, Washington, DC

Uranium in Precipitates and Evaporites.

In *Proceedings of the International Conference on the Peaceful Uses of Atomic Energy*, Vol. 6, *Geology of Uranium and Thorium*, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 520-524), 825 pp.; In USGS Professional Paper 300, (pp. 381-386), 739 pp. (1956)

Precipitates and evaporites, excluding some carbonaceous and phosphatic sediments, contain only trace amounts of syngenetically deposited uranium. Carbonaceous sediments composed predominantly of sapropelic derivatives and marine-deposited phosphatic sediments may contain up to a few tenths of a percent uranium. Epigenetic uranium deposits in all of these sediments may contain ore-grade material. The low amounts of syngenetic uranium in carbonate sediments from almost nil up to about 4 parts per million (ppm), can be attributed to deposition in oxidizing environments and to the inhibitory effects of high carbonate and bicarbonate ion concentrations on precipitation of uranium compounds. Uranium is deposited epigenetically in carbonate rocks from ground and surface water, hydrothermal solutions, and petroliferous residues. All phosphatic marine sediments contain uranium up to about 1,500 ppm. The uranium is believed to

be in isomorphous substitution for calcium in calcium phosphate minerals, and the amount of uranium is roughly proportional to organic content and inversely proportional to carbonate content. Evaporitic deposits appear to carry only traces of uranium even though the surrounding terranes may carry more than average. Uranium appears to be preferentially deposited in clay strata and particularly in black shale strata. Siliceous precipitates such as opal, flint, and chalcedony formed in or near uraniferous terranes may contain up to a few tens of parts per million of uranium. The silica may be a product of weathering and decomposition of volcanic ash and transportation and deposition by ground and surface waters. Smaller amounts of uraniferous siliceous precipitates were deposited from hydro-thermal solutions. The uraniferous siliceous precipitates generally are fluorescent. Leaching of uraniferous volcanic ash, lignites, and mineral bodies by ground and surface waters in semiarid to arid regions may extract uranium and deposit it in caliche-like deposits in soils and near-surface parts of rock formations. The uranium of such deposits generally does not constitute ore. (Auth)

<442>

Rich, R.A., H.D. Holland, and U. Petersen; Harvard University, Cambridge, MA

Review of Fluid Inclusion Studies of Vein-Type Uranium Deposits. In AT(85-1)-1640, (pp. 33-48), 383 pp. (1975)

With a few exceptions, filling temperatures for the pitchblende-depositing stage of all vein-type U deposits studied are low (less than or equal to 190 degrees C). Most (7 of 12) deposits studied have filling temperatures less than 150 degrees C. Although filling temperatures in general differ from formation temperatures, the epithermal nature of many vein-type U deposits and the low (less than 1 kb) formation pressures suggest that formation temperatures were not markedly higher than filling temperatures. Compositional data for fluid inclusions associated with pitchblende deposition are rare, but the absence of daughter crystals in most fluid inclusions of the pitchblende stage suggest that the fluids depositing pitchblende have low to moderate salinities. Liquid CO₂-bearing fluid inclusions have been reported in vein material from several vein-type deposits, and CO₂ hydrate

has been observed during freezing stage runs in fluid inclusions from additional deposits. (JMT)

<443>

Rich, R.A., H.D. Holland, and U. Petersen; Harvard University, Cambridge, MA

The Deposition of Pitchblende from Ore Fluids. In AT(85-1)-1640, (pp. 75-89), 383 pp.; In GJO-1640, (pp. 75-89), 383 pp. (1975)

The presence of hematite as a vein and wall rock mineral in most vein-type uranium deposits is consistent with uranium transport in the +6 valence state. The deposition of sulfides and arsenides with or shortly after uraninite is consistent with the reduction of U(E+6) to U(E+4) and the deposition of the very sparingly soluble UO₂ at low oxygen levels. The isotopic composition of sulfur in sulfides and carbon in carbonates observed in some vein-type uranium deposits is consistent with and probably best explained by the reduction deposition model. The presence of rather large CO₂ contents in fluid inclusions from vein-type uranium deposits probably suggests an increase of U solubility in the ore-forming fluids, but the role of CO₂ loss during boiling on UO₂ deposition is unclear. There are too few systematic data on the effect of pH on the solubility of pitchblende at elevated temperatures to evaluate its effect on the development of hydrothermal uranium deposits, but at present it seems likely that the pH effects are not as important as those of redox reactions. (JMT)

<444>

Waters, A.C., and H.C. Granger; USGS, Washington, DC

Volcanic Debris in Uraniferous Sandstones, and its Possible Bearing on the Origin and Precipitation of Uranium. USGS Circular 224, 26 pp. (1953)

Volcanic debris, now altered to clay minerals, is a major component of the Brushy Basin shale member of the Morrison formation of Jurassic age and the Chinle formation of Triassic age. These formations directly overlie, respectively, the uranium-bearing Salt Wash sandstone member of the Morrison formation and the uranium-bearing Shinarump conglomerate. On the devitrification of the volcanic debris, large quantities of silica and smaller quantities of alkalis and trace elements, including uranium, vanadium, and selenium, would be released in solution, leaving a residue consisting largely of montmorillonite. On this premise, a hypothesis for the origin of uranium deposits on the Colorado Plateau has been developed. The silica released from the ash beds by devitrification migrated into the underlying sandstone beds, resulting in widespread but irregular silicification of the sandstone. The alkalis and some of the trace elements remained in solution in the connate waters in the sandstone; this water was of a reducing character. The uranium and vanadium would be immediately taken out of solution by the montmorillonite in the devitrifying tuffs. In Tertiary time considerable structural deformation occurred which upset the formerly static ground water conditions; widespread igneous activity also prevailed on the Colorado Plateau. It is thought that uranium- and vanadium-bearing hypogene solutions derived from the Tertiary magmas entered and mixed with the ground water. Uranium-vanadium deposits formed where these solutions came into contact with organic material. (Auth)

<445>

Davidson, C.F.; University of St. Andrews, St. Andrews, Scotland, United Kingdom

On the Occurrence of Uranium in Ancient Conglomerates. *Economic Geology*, 52(6), 668-693. (1957, September)

In recent discussions on the origin of the mineralization of the Witwatersrand and of Blind River, various departures from actualistic principles have been postulated by geologists of the placentist school in necessary support of their views. None of these hypotheses stands up to critical examination; and from consideration of the mineralogy and geochemistry of the blanket reefs it is concluded that the mineralization is certainly not

of alluvial origin. Claims that detrital uraninite can be recognized in micrographic studies lack due objectivity. Because of reworking of the uranium and the probable presence of old radiogenic lead, it is not yet possible to place any reliance on the apparent ages recorded for these blanket ores. In speculation on the source of the pay-metals, it is suggested that the mineralization may be linked to periods of granitization late in the history of the Witwatersrand and Huronian geosynclines. (Auth)

<446>

Hockstra, H.R., and L.H. Fuchs; Argonne National Laboratory, Lemont, IL

The Origin of Thucholite. *Economic Geology*, 55(6), 1716-1738. (1960, December)

The origin of the organic material, and the mechanism of formation of the organo-uranium complex, in thucholite from the Deser Mine, Parry Sound District, Ontario was investigated. Results indicate that thucholite was formed by the action of aqueous solutions containing organic material, possibly as an oil-in-water emulsion. Uranium, lead, and other relatively soluble oxides were leached from uraninite, while aluminum, iron, magnesium, and silica were deposited in the thucholite. The separation of uranium from thorium and the rare earths is believed to have occurred by oxidation of tetravalent uranium to the more soluble hexavalent oxidation state. Oxidation of uranium and the organic fraction of thucholite in an otherwise reducing environment is assumed to be due to the action of radiation decomposition products of water, the hydroxyl radical and/or hydrogen peroxide. Oxidation of the organic material may also be due to subsequent reaction with hexavalent uranium. The liquid and solid hydrocarbons, by virtue of their optical activity, are shown to be of plant or animal origin, rather than polymerization products of methane and other low molecular weight gases. The hydrocarbons are probably not contemporaneous with organic fraction of thucholite. (Auth)

<447>

Rackley, R.L., P.N. Shockey, and M.P. Dahill; Tetron Exploration Drilling Company, Inc., Casper, WY

**Concepts and Methods of Uranium
Exploration.** In Wulf, G.R. (Ed.),
Wyoming Geological Association
Guidebook, Twentieth Field Conference,
1968, (pp. 115-123), 243 pp. (1968)

Uranium is concentrated into orebodies only under uncommon conditions. The first prerequisite in the formation of uranium orebody is a source rock. The authors propose granite as the source rock of the Wyoming deposits, pointing to analyses which show the Granite Mountains of central Wyoming to have an abnormally high concentration of uranium. Uplift and weathering of the granitic rocks resulted in the deposition of protore sediments. The exact transport mechanism of the "primary" uranium is not known, but it is probable that some was transported in solute and some as particles. A favorable depositional environment of the protore would include the incorporation of abundant vegetation into the sediments. Rapid erosion and deposition produces a poorly sorted, "dirty" sediment which is ideal for the preservation of associated organic material. Burial protected the sediments from erosion and provided a cover capable of containing the hydrodynamic system which developed in the "host" following subsequent tectonic adjustments. Events following burial of the sediments included the initial stages of carbonization and fermentation of plant materials. As a co-product, anaerobic bacteria produced hydrogen sulfide and hydrogen. These in turn precipitated available iron as pyrite and any uranium in solution. Tectonism subsequent to burial is required in the evolution and development of a uranium district. The event may be igneous, epirogenic, or orogenic folding which resulted in movement of groundwater through the aquifer. As these waters flowed through the "host" sands, a change was initiated in the sediments. A complex physical, chemical, and biochemical reaction caused this change. The zone of reaction is a solution front or roll. The changes which took place in the rock inside the solution front is alteration. The solution front and the alteration it produced is called a geochemical cell. Metals concentrated by the cell are those present in the source and subsequently in the host rock in sufficient quantities to enter the reactions of the cell. With the passage of time, the cell continues to grow. Erosion of the strata covering the host formation would tend to accelerate that growth by enlarging the surface area exposed to recharge by surface waters. A great many biochemical reactions take place in the geochemical cell, but only three

are considered important in playing a direct role in the cell. The first reaction to consider is the fermentation of the cellulose and other organic material by the anaerobic sporeformers,

CLOSTRIDIUM CELLULOSAE -

DOSSOLVENS, which produce a number of products required by other bacteria. The products of fermentation are then further oxidized by the mixed population in anaerobic respiration. The sulfate reducing genus, **DESULFOVIBRIO**, through anaerobic respiration, utilizes the inorganic sulfates, CO_2 , succinic acid, and sometimes gaseous hydrogen to produce CO_2 . These bacteria are extremely strict anaerobes and produce an environment of pH 7.8 to 8.4 and an Eh of approximately minus 200 mV. The **CLOSTRIDIUM** produces hydrogen as a by-product of the fermentation of the cellulose and hydrogen is a strong reducing agent. The environment produced by these two and other bacteria provides an environment which physically reduces and precipitates the uranium and other metallic ions in order of their solubility. The **DESULFOVIBRIO** and **CLOSTRIDIUM** both operate in the protore portion of the geochemical cell; the area in which the uranium is deposited. **THIOBACILLUS FERROOXIDANS** are the principal bacteria in the altered side of the cell. These bacteria are the principal cause of the extreme acidity of coal mine waters. Not only do they create an oxidizing environment, but they create pH values as low as 1.8 and can survive a pH of zero. The oxidation of ferrous iron by the **THIOBACILLUS** is approximately 200 times faster than by atmospheric oxygen, and along with the oxidation of pyrite, sulfuric acid is produced in greater quantities than is consumed by pyrite oxidation. The activity within the geochemical cell produces a metal zoning. In the zone between the **THIOBACILLUS** and the **DESULFOVIBRIO**, where the sharp contact called the roll front is located, selenium and lead are deposited. The more complex vanadium-uranium minerals form the next zone, and molybdenum is deposited outside that zone. In exploration, alteration can be used to detect deposits. Pyrite morphology is one of the more consistent guides in determining alteration. (JMT)

REMOTE SENSING

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Sakakura, A.Y.; USGS, Washington, DC

Air Scattering of Gamma-Rays from Thick Sources. In USGS Professional Paper 300, (pp. 715-719), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955, United Nations, New York, (pp. 748-751), 825 pp. (1956)

To develop means of interpreting gamma-ray intensities measured at considerable air distances between natural sources and a detector, a knowledge of radiation-intensity distribution from sources of various strengths and configurations is necessary. This distribution can best be determined by superposition of elementary sources over suitable geometrical configurations. In the past, this method entailed the integration of the point-source expression over a suitable source volume assuming either an inverse-square exponential attenuation or the former expression modified by a build-up factor deduced from experiments in homogeneous media and in back-scattering geometry. The first assumption not only neglects scattering, which predominates at any great distance from the source, but also attempts to represent the multitudinous lines of the average uranium series gamma-ray spectrum by a single absorption cross section. The second assumption does not take into account the variation of build-up factor with geometry. To eliminate these difficulties, the intensity from an infinitely thick elementary source was measured as a function of the air distance above and to the side of the source, and a semiempirical expression composed of the following three factors was fitted to the experimental data: The usual inverse-square exponential law corresponding to the hardest gamma ray; a build-up factor, a polynomial in air distance to account for scattering and the complexity of spectra; an obliquity factor, a function of the angle of view from source to detector. The above expression was integrated over various surface areas; that is, the integration in

depth has been incorporated into the original data. From the integrations, the area under the curve recorded on a counting ratemeter was calculated. Quantitative relationships between the two observables recorded by a counting ratemeter (the peak intensity and the area under the curve) and the source strength and size are established as functions of the velocity and distance of a detector from the source. Furthermore, dependent upon the nature of the source and the parameters of height and speed of an aircraft, more than one line of measurement may be required for interpretation of the source characteristics. (Auth)

<449>

Offield, T.W.; USGS, Denver, CO

Remote Sensing in Uranium Exploration. IAEA-SM-208-15, (pp. 731-744), 807 pp.; In Proceedings of a Symposium on Exploration for Uranium Ore Deposits, held in Vienna, Austria, March 29-April 2, 1976, International Atomic Energy Agency Publications, Vienna, Austria, (pp. 731-744), 807 pp. (1976)

Multispectral reflectance data offer a useful tool in mapping discoloured, possibly altered, ground very rapidly over broad areas. Image enhancement by computer techniques markedly improves the capability to discriminate such target areas as compared with black-and-white or, often, even colour photographs. Some studies show that the spectral bands available on Landsat are not optimum for some of the subtle discriminations needed in uranium exploration. Nevertheless, Landsat data have been computer enhanced to show distinctly the reddish altered ground used in the past to guide exploration in the Crooks Gap, Wyoming uranium area. Other enhanced images of the southern Powder River Basin area can be used to define red altered ground, but yellow unaltered ground also in the scene cannot be satisfactorily distinguished from the red areas. Lineaments seen on these images may mark structures which locally could have affected the deposition of the uranium-bearing Wasatch Formation. In the South Texas uranium area, study of enhanced Landsat images indicate that the area is probably too heavily vegetated to permit mapping of small altered areas of fairly subtle discoloration. Thermal-infrared images in the Texas area, however, are an excellent aid in detecting and

mapping conglomerate-filled channels in the clayey Cataboula Tuff; these are potential loci of uranium mineralization. (MLB)

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Blair, R.G., F.T. Seible, and R.A. Levich;
AEC, Grand Junction, CO

**Report on Airborne Radioactivity
Surveys and the Uranium Deposits in the
Red River Region of Texas and
Oklahoma. GJBX-13(76). 16 pp.; TM-190.
16 pp. (1973, November)**

The region described is located in the Osage Plains section of the Central Lowland province in northern Texas and southern Oklahoma, south of the Wichita Mountains. The Red River forms the boundary between the states of Oklahoma and Texas. The land surface varies from a gently rolling plain in Oklahoma to locally hilly regions in Texas. North of the Red River, small exposures of indurated rocks are found in gullies and along the channels of intermittent streams. The best exposed sections are found on bluffs which rise 200 feet above the floodplain of the Red River. To the south, resistant rocks cap low escarpments and buttes. The ubiquitous soil cover conceals much of the bedrock. Elevations range between 750 and 1,200 feet above sea level. Field examinations were conducted on anomalies discovered by airborne reconnaissance as well as those reported by private individuals. Forty localities were examined, the majority in sandstones, siltstones, or conglomerates. Uranium and copper minerals were identified at several localities. Ferruginous staining, bleaching of the sandstone color, calcium carbonate cement, and carbonized plant remains are common to the deposits. The uranium minerals were deposited by solutions, probably groundwater, which contained iron and copper in addition to uranium. The solutions moved laterally along the more porous sandstone beds. The uranium precipitated near carbonized plant material which had been deposited along with the coarser sand fraction in Permian stream channels. Particular attention was paid to those areas where exposures are found of red beds of the Permian Wichita Group. Little correlation can be made between background radioactivity and geology. There appears to be a general relationship between known radioactive occurrences and greater than average background. (MLB)

Cited as a reference in NURE Contractor Reports; This report is a compilation by Levich taken from manuscripts by Blair and Seible dated 1956 and 1957, and includes updated and expanded material.

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Foot, R.S., and N.B. Humphrey;
Geodata International, Incorporated,
Dallas, TX

**Airborne Radiometric: Technique and
Applications to Uranium Exploration. In
Proceedings of a Symposium on
Exploration for Uranium Ore Deposits,
held in Vienna, Austria, March 29-April 2,
1976. The International Atomic Energy
Agency Publications, Vienna, Austria, (pp.
17-34), 807 pp.; IAEA-SM-208/47, (pp.
17-34), 807 pp. (1976)**

The paper presents the technique used for obtaining maximum information with the greatest accuracy from a large-volume NaI(Tl) airborne gamma-radiation detection system for measuring gamma-ray energies from 4 pic solid angle where the detector volume is greater than 54,400 cubic centimeters. In this airborne system a 12 K core special purpose computer is used to record gamma-ray spectral energy and other data each second using two magnetic tape units with no dead time caused by data readout. A single large detector of 6000 cubic cm is placed over a shield which allows the radiation from the upper 2 pic solid angle to reach the detector. An array of six photomultiplier tubes for each detector uses a single resistor voltage divider with individual tube gain control to improve the long-term intertube gain stability for each detector. The system is teletype-controlled and is designed to read out 256 channels of dual spectral data, up to 30 different input signals and dual magnetometer data. The airborne software allows computation of the air density, and corrects all data to a surface height of 120m according to radiation attenuation calculations. Backgrounds are determined for the aircraft in the absence of surface water by a technique of gathering multi-altitude data along a given line. Data from the 2 pic measuring system have been compared with that from a filter paper and a charged wire system for determining the atmospheric eU counts/second, and the factor of improvement and the advantages and disadvantages of the shielded detector are given.

Limitations on the allowed time-of-day for gathering flight data and a procedure for determining temperature inversion-caused cU concentrations are discussed. Proper data reduction will produce a statistical zero for the surface radiation components over water-covered regions. Radiation energy standards of high quality for all variables are required if no modulation by a large change of one variable on the calculated amounts of the others is to be achieved. Examples of the effect of large variations in individual variables will be given. A summary of the problem areas encountered in gathering and evaluating airborne gamma-ray spectral data is discussed. Many data have been taken under the National Uranium Resources Evaluation Program (NURE) using the system described. Examples of the results of analysis of NURE data from many areas are shown and discussed. (Auth)(JMT)

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Gabelman, J.W.: Utah International Incorporated, San Francisco, CA

Remote Sensing in Uranium Exploration.
In Proceedings of a Technical Committee Meeting on Recognition and Evaluation of Uraniferous Areas, held in Vienna, Austria, November 17-21, 1975.
International Atomic Energy Agency Publications, Vienna, Austria. (pp. 251-260). 295 pp.: IAEA-TC-25 15. (pp. 251-260). 295 pp. (1977)

Geophysical sensing methods most used in uranium exploration are those measuring the natural radioactivity fields generated by concentrations of uranium, thorium, and potassium. Gamma surveys are most useful because of the significant distance range of radiation. A geochemical significance is added by gamma spectrometry to distinguish and approximately quantify the natural radioelements. The great disadvantage is that uranium daughters, rather than uranium itself are detected. Other forms of photon surveys involving electromagnetic radiations depend on radiation induced in, or reflected by, the substances being studied. These include radiation in the gamma, X-ray, optical and infra-red regions of the electromagnetic spectrum. Gamma and X-ray fluorescence spectrometry have been used widely in exploration for a large variety of elements including uranium, but mostly on a laboratory scale. The logistical problems of

transporting bulky equipment to remote locations and its sensitivity to rugged field conditions have retarded the field application. The measurement of electromagnetic radiations in the optical and infra-red regions of the spectrum has been employed in uranium exploration only as aerial photography, and this has proved useful indirectly. Larger-particle radiometric surveys, involving beta, neutron and alpha measurements are also well known, but less used because of the decreasing trajectory range through minerals and rock pores with increasing particle size. The use of large radiation particles to induce artificial radiation in non-radioactive elements is by far their greatest use. However, the same factors that prevent large atomic particles from being directly useful in natural radiometry, limited the use of such particles generated by induced radiation. Remote sensing concepts that may be potentially useful to uranium exploration include thermal radiation mapping and detection of non-radiogenic particle emanation. Geometric interpretations of orbital-height electromagnetically sensed images are now very useful and would be more so if more uranium geologists would accord a greater role to tectonics in uranium mineralization. Reflectance spectrometry should prove highly useful when the ground-resolution element size is matched better to the average size of those geological features which are useful in uranium exploration. This can be accomplished by reducing the observation level of existing spectral scanners, or designing new ones. (JMT)

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Darnley, A.G., and R.L. Crusty; Canada Geological Survey, Ottawa, Ontario, Canada

Mapping from the Air by Gamma-Ray Spectrometry. In Boyle, R.W. and McGerrigle, J.I. (Eds.), *Geochemical Exploration, Proceedings of the Third International Geochemical Exploration Symposium, held in Toronto, Canada, April 16-18, 1970, Special Volume II.* The Canadian Institute of Mining and Metallurgy. (pp. 485-500). 594 pp. (1971)

Since 1967, the Geological Survey of Canada, in conjunction with Atomic Energy of Canada Ltd., has been developing a high-sensitivity airborne gamma-ray spectrometer system for the purpose of

measuring surface concentrations of K, eU, and eTh. During the initial stages of the program, which have been described in earlier publications, problems of optimum spectrometer design, calibration and data correction were investigated. At the same time, ground investigations were undertaken to compare the K, eU and eTh content of various rock types and overburden. One of the most important findings of this research was that, in the Shield areas examined, there is a close similarity between the radiometric composition of rock and its associated overburden. In 1969, the first extended trials of the complete spectrometer system took place, with a detailed survey of approximately 400 square miles in the Bancroft area of Ontario. Flight lines flown at 400 ft above surface were spaced at 1/4-mile intervals and radiometric data were accumulated, with read-out onto magnetic tape at approximately 500-ft intervals along the flight line. In this way, approximately 75 per cent of the total surface of the area has been radiometrically sampled. The data on the magnetic tape have been corrected to allow for variable atmospheric radioactivity, variations in terrain clearance, and Compton scattering contributions in the spectrometer's lower energy channels. Corrected profiles have been computer-drawn along each flight line and a variety of computer-drawn geochemical maps have been made over the area covered, based on a contouring program devised by Holroyd and Bhattacharyya. These show good correlation with the known surface geology, and principal rock types in the area can be distinguished. Information is also provided about the northeast-trending zone of uranium and thorium enrichment which crosses the area, and a subdivision of granitic types can be made. The relative abundances of the various radioelements are shown to be a sensitive indicator of unusual concentrations, and these variables are particularly significant in using this type of data for mineral exploration purposes. (Auth)

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Bennett, R.; Geophoto Services, Incorporated, Denver, CO

Exploration for Hydrothermal Mineralization with Airborne Gamma-Ray Spectrometry. In Boyle, R.W. and McGerrigle, J.I. (Eds.), *Geochemical Exploration, Proceedings of the Third International Geochemical Exploration*

Symposium, held in Toronto, Canada, April 16-18, 1970, Special Volume II. The Canadian Institute of Mining and Metallurgy, (pp. 475-478), 594 pp. (1971)

In two recent Australian survey areas, copper mineralization was located along favorable structures within hydrothermal dispersion patterns delineated by airborne geochemical surveys. In metamorphic terrane where there has been potassium metasomatism, the hydrothermal dispersion patterns were indicated by high potassium uranium ratios. In a sedimentary environment that has been intruded by a large stock, the path of hydrothermal fluids was indicated by uranium, by thorium and by uranium:thorium ratios. In the Canadian survey area, molybdenum mineralization was associated with uranium:thorium anomalies and many of the ground-measured radioactivity sites lie within the uranium anomalies from the airborne survey. The cases discussed illustrate the application of airborne geochemical surveys to mineral exploration. Mineralized areas can be separated from barren ground, thereby enabling the geologist to direct ground exploration toward the more favorable areas. (JMT)

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Darnley, A.G.; Canada Geological Survey, Department of Energy, Mines, and Resources, Ottawa, Ontario, Canada

Airborne Gamma-Ray Survey Techniques—Present and Future. In *Proceedings of a Panel on Uranium Exploration Methods*, held in Vienna, Austria, April 10-14, 1972. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 67-108), 320 pp. (1973)

There are a variety of spectrometer systems available for commercial use. To use them in the most effective way it is necessary to consider the problems involved. Districts containing uranium mineralization generally fall within or on the margin of regions containing above-average abundances of all the radioelements. These radioactive regions can be readily found by airborne surveys which measure only total radioactivity. Sometimes the mineralization controls within an area may be so well known that

it is unnecessary to use spectrometer systems. In general it is advantageous to use the discriminating ability of a spectrometer to identify anomalies containing significant amounts of uranium. This selection of anomalies is not essential wherever the costs of ground work are high. The most sensitive spectrometers available are capable of measuring the mean ground level abundances of potassium, uranium and thorium, which can be expressed in conventional units of concentration. From an exploration viewpoint the most important parameters which can be measured are the relative concentrations of uranium to thorium and uranium to potassium. These are diagnostic for identification of zones of anomalous uranium concentration. Good counting statistics are essential to obtain meaningful ratio measurements. These are obtained by maximizing detector volume and minimizing ground speed of the aircraft. Minimizing flight elevation improves sensitivity for small area targets, but it entails closer line spacing for a given percentage coverage of an area. As a general principle, airborne gamma-ray surveys should be aimed primarily at finding target zones with linear dimensions of the order of hundreds or thousands of meters, where the mean enrichment of uranium at the surface may be only one or two parts per million higher than the surroundings. It can be shown that high-sensitivity equipment is most cost-effective for this purpose. The availability of fully corrected data, with a comprehensive display of all the parameters in profile and map form is essential to extract maximum value from a survey with such equipment. (Auth)

Cited as a reference in NURE Contractor Reports.

<456>

Not given; AEC, Washington, DC

The Natural Occurrence of Uranium in the United States. In Nininger, R.D. (Ed.), *Exploration for Nuclear Raw Materials*. D. Van Nostrand, Inc., New York, (pp. 52-54), 293 pp. (1956)

Uranium has been found in all major geologic environments in the United States except those typified by ultramafic and plateau basalt igneous rocks, and certain marine sediments. Concentrations of uranium occur in igneous rocks, veins, terrestrial clastic rocks; precipitates and

evaporites; lignites, coal, and asphaltic materials; marine black shales and phosphorites. Most of the uranium deposits of ore grade are in the orogenic belt between the 100th and 120th meridian of west longitude; a few occur elsewhere. Some igneous rocks contain much more uranium than do most granites. The uranium occurs as discrete uranium minerals, disposed in the structure of the rock-forming minerals, adsorbed on surfaces of grains, and dissolved in fluid inclusions and intergranular fluids. The uraniferous intergranular fluids are leachable in dilute acid and may offer a very low-grade, exploitable source of uranium for the future. Uraniferous vein deposits in the western United States are mainly Tertiary in age, and most of the exploitable deposits are in crystalline rocks of Precambrian, Mesozoic, and Tertiary age. Occurrences in the eastern United States, mostly undated, are mainly in rocks of Paleozoic or Precambrian age. Pitchblende or uraninite, associated with base metal sulfides or fluorine, are the principal uranium minerals in the vein deposits at depth. Supergene secondary uranium minerals occur in some deposits, but they are not abundant. The principal source of uranium, however, is terrestrial sandstones, mudstones, and limestones, in which the uranium minerals occur disseminated as pore fillings and impregnations. The largest and most numerous of these deposits are in rocks of Mesozoic age on the Colorado Plateau, but similar deposits also occur in Mesozoic and Tertiary rocks on the fringes of the Plateau, and in the Cordilleran Foreland east of the main folded and thrust belts of the Rocky Mountains. Uranium occurs in Paleozoic sandstones on the Colorado Plateau, and in Texas, New Mexico, Oklahoma, and Pennsylvania. In all, 37 sedimentary units have yielded uranium; 18 have furnished at least 1000 tons of ore averaging more than 0.1% U₃O₈. Widespread uraniferous marine sedimentary rocks include the phosphatic rocks of Permian age in Idaho, Montana, Wyoming, and Utah and of Tertiary age in Florida; the Chattanooga black shale of Devonian and Mississippian age; and some black shales of Pennsylvanian age in the Central States. (JMT)

<457>

Not given; AEC, Washington, DC

Aerial Radiometric Techniques. In Nininger, R.D. (Ed.), *Exploration for Nuclear Raw Materials*. D. Van Nostrand,

Inc., New York. (pp. 155-192), 293 pp. (1956)

Aerial radiometric techniques in the United States, the USSR, Brazil, and Canada are discussed, as well as the basic equipment and basic techniques involved in this type of prospecting. Instruments used in air-borne surveying must be sufficiently sensitive to measure unambiguously a small change in radioactivity at an air distance governed by aircraft safety. Large-volume thallium-activated sodium iodide crystals or plastic scintillators are almost universally used as the radiation detector. High-efficiency Geiger-Muller counter tubes having a multiple-plate cathode structure are occasionally used as the detector. Most instruments are counting-rate meters of the continuously recording type and are specifically designed for installation in aircraft. In addition to radiation detection instruments, equipment in multiengine aircraft usually includes instruments for accurately locating the position of the aircraft in respect to the ground. Helicopters, light single-engine aircraft, and long-range multiengine aircraft have been used for air-borne surveys, dependent on the objectives of the particular survey and on the location of the area in respect to the operating base. The spacing of flight lines for air-borne surveys is governed largely by the problem involved. The width of the zone from which anomalous radioactivity can be detected is approximately twice the distance of the aircraft above the ground. For detailed surveys, the flight level and spacing of flight lines are decreased, but for regional surveys the spacing may be increased to give only partial coverage. The absorption and scattering of gamma radiation at considerable air distances from a natural radioactive source place an effective upper limit on the flight level of air-borne surveys. The initial radiation intensity from a natural point source of radiation is decrease to about 1/1000 at an air distance of 500 feet. Few air-borne surveys are made at air distances greater than 500-600 feet and most surveys are made at air distances of less than 200 feet. Quantitative interpretation of air-borne survey data is not necessary for most applications. Anomalies simply indicate localities of more than average radioactivity where there is a greater probability of the occurrence of uranium and thorium deposits. (JMT)

<458>

Vohra, K.G.; India Atomic Energy

Establishment, Trombay, India

Remote Location of Uranium and Thorium Deposits. In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York. (pp. 760-765), 825 pp. (1956)

The technique of ion collection can be successfully used to estimate and analyze the decay products of radon and thoron in the air. Ion collection can give detailed information about the decay products which cannot be obtained by the methods of filtering or precipitation recently used for natural radioactivity studies. Nevertheless, the filtering and precipitation techniques can be used to supplement the analysis. The "age" determinations in the present theory can be fairly satisfactory in the case of thoron contamination. In the case of radon the decay curves are not sensitive to the "age" of the air but the relative concentrations of the decay products is "age" dependent. Therefore the theory is being further developed to give the activity ratios of radon and radon decay products. This ratio is sensitive to the "age" of the air. The radon can be freed from its daughters and measured independently by other methods. With the standardized apparatus the measurements could be carried out at fixed stations in a selected area, along with the relevant meteorological measurements. These measurements taken over a long period of time will tell the general nature of radioactive minerals in the surrounding areas. New stations could then be established in the areas found suitable for detailed prospecting. Within a distance of a few hundred miles, the location of the mineral deposits could be predicted from the "age" determinations. (MLB)

<459>

Baranov, V.I.; Not given

Aeroradiometric Prospecting for Uranium and Thorium Deposits and the Interpretation of Gamma Anomalies. In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United

Nations, New York, (pp. 740-743), 825 pp. (1956)

The purpose of aeroradiometric prospecting is to determine the radioactivity of mineral rock from the air, using geophysical instruments and subsequently to give geological and geophysical interpretations of the anomalies discovered.

Together with the development and improvement of the technique and methods of measuring radioactive geophysical parameters from the air, methods of choosing regions and air routes for survey, and of interpreting the results obtained, are also worked out. A characteristic feature of prospecting for deposits of radioactive ores by aviation is the closely linked correlation between geological and geophysical methods of investigation which makes it possible for the whole work—from the choosing of the route to the evaluation of the discoveries—to be done by a single air-prospecting party. In practice,

aeroradiometrical work has shown that a large part of the disclosed anomalies are not connected with deposits of industrial value. Therefore the checking of all aerogamma anomalies on the ground causes unproductive expense in labor and material. The primary problem in interpreting anomalies is the rejecting of anomalies without prospects, obvious from both the geophysical and geological data, and hence having no need of checking or of studying on the ground. (MLB)

<460>

Moxham, R.M.; USGS, Washington, DC

Airborne Radioactivity Surveys in the Mojave Desert Region, Kern, Riverside, and San Bernardino Counties, California.
TEM-360, 34 pp. (1952, July)

Airborne radioactivity surveys in the Mojave Desert region, Kern, Riverside, and San Bernardino Counties were made in five areas recommended as favorable for the occurrence of radioactive raw materials: (1) Rock Corral area, San Bernardino County, (2) Searles Station area, Kern County, (3) Soledad area, Kern County, (4) White Tank area, Riverside and San Bernardino Counties, (5) Harvard Hills area, San Bernardino County. Anomalous radiation was detected in all the Harvard Hills area. The radioactivity anomalies detected in the Rock Corral area are of the greatest amplitude yet recorded by the airborne equipment

over natural sources. The activity is apparently attributable to thorium-bearing minerals associated with roof pendants of crystalline metamorphic rocks in a granitic intrusive. In the Searles Station, Soledad, and White Tank areas, several radioactivity anomalies of medium amplitude were recorded, suggesting possible local concentrations of radioactive minerals. (Auth)

<461>

Winkler, E.M., and T. Voigt; University of Notre Dame, Notre Dame, IN

The Detection of Radioactive Minerals with Infrared Aerial Photography.
Economic Geology, 56(1), 211-212. (1961, January)

In order to achieve objective information a number of commercial films were exposed to radioactive sources of different intensities, both natural and fission products. Three pictures were taken for each experiment both in subdued light and in total darkness at about 24 inches from the object to the film. Photographs were taken in subdued daylight according to the indicated exposure settings. Those pictures taken in total darkness were exposed one and five minutes each. None of the films showed unusual shadows or discoloring upon critical examination. After the specimens failed to bring any results a much stronger radioactive source (5 mg of radium) was applied. Even this high powered source of radiation did not affect the film emulsions with the normal exposures. Although the distance from the camera to the source was just a few feet as compared with the altitudes common in aerial photographic flights no effect of any radioactive source material could be observed nor should be expected, as the intensity of radioactive emission depends upon the inverse square of the distance. This fact proves the apparent inability of radioactive sources to affect any one aerial film, neither directly by the bombardment of the film emulsion by radiation nor indirectly by the heat freed during radioactive decomposition.

(Auth)(MLB)

<462>

Nash, A.L.; AEC, Grand Junction, CO

Airborne Radiometric Surveying in

Grand, San Juan, Emery, and Wayne Counties, Utah and Montrose County, Colorado. RME-4854, 23 pp. (1953, October 3)

Airborne radiometric surveying in Grand, San Juan, Emery, and Wayne Counties, and Montrose County, Colorado was conducted by the Atomic Energy Commission between November 24, 1952 and June 12, 1953. Five general geographic areas were surveyed: Lisbon Valley area, Indian Creek area, Green River Desert-Cataract Canyon area, Inter-River area, and Skien Mesa area. Twenty-two areas of anomalous radioactivity were found. Probably the most significant result of the survey was the discovery of numerous anomalies in the Cutler Formation in the Indian Creek area. (Auth)

<463>

Nash, A.L., and L.J. Brown; AEC, Denver, CO

Results of an Airborne Radiometric Survey in the Canon City Embayment Area, Colorado. RME-1050(Rev.), 11 pp. (1954, June 16)

An airborne radiometric survey of the Dakota Sandstone and Morrison Formation in the Canon City embayment was conducted by the Atomic Energy Commission from November 1, 1953 to December 5, 1953. In addition, reconnaissance flights were made over the Dawson Arkose Formation between Denver and Colorado Springs. Three anomalies were discovered in the Dakota Formation; each representing an area of weak mineralization. No anomalies were found in the Morrison Formation or in the Dawson Arkose. (Auth)

<464>

Saunders, D.F., and M.J. Potts; Texas Instruments Incorporated, Dallas, TX

Interpretation and Application of High-Sensitivity Airborne Gamma-Ray Spectrometer Data. IAEA-SM-208/45, (pp. 107-125), 807 pp.; In Proceedings of a Symposium on Exploration for Uranium Ore Deposits, held in Vienna, Austria, March 29-April 2, 1976. International

Atomic Energy Agency Publications, Vienna, Austria, (pp. 107-125), 807 pp. (1976)

Interpretation of high-sensitivity gamma-ray spectrometer reconnaissance data has two major objectives: to define broad uranium provinces in which the rocks and soils are preferentially enriched in uranium; and to evaluate uranium anomalies along the flight lines in order to determine the geological types of deposits that may be found, and to eliminate any false or misleading anomalies. Spectrometer data showing U, Th, K, U/Th, U/K, and Th/K that have been statistically corrected for surface geology are examined in conjunction with the geology, topography, and flight logs to identify uranium anomalies which may have been caused by problem in statistical processing; meteorological effects in shielding and on the distribution of radon and its daughters; errors in geological mapping; downstream transport of gamma-ray emitters; and cultural effects. The more significant anomalies are classified according to types of deposits most likely to be found under the local geological conditions. Experience has shown that aeromagnetic data interpretation and geomorphic lineament studies using satellite imagery can be useful in the gamma-ray data interpretation by providing information on basement structure. (Auth)

<465>

Malkmus, W., and M. Griggs; Science Applications, Inc., La Jolla, CA

Remote Temperature Inversion Sensor. GJBX-1(77), 37 pp. (1977, January)

In conducting aircraft surveys for uranium, it is found that temperature inversions in the atmosphere can give misleading results because they promote the accumulation of radon gas. The gamma-rays of radon's daughter product, Bi-214, detected from the atmosphere-borne radon are difficult to separate from the Bi-214 gamma-rays originating from the ground, which provide strange evidence for uranium deposits. The purpose of this

study was to examine the feasibility of making remote temperature soundings of the atmosphere below a low-flying aircraft (100 meters or less above the ground) by the inversion of radiance measurements taken in the 15-micron carbon dioxide absorption band. Such measurements would identify those temperature inversion conditions possibly leading to an unacceptably large background of gamma-rays from atmospheric radon. It was concluded from this study that the uncertainties in the temperature profile resulting from expected realistic errors of measurement were too large to consider further study of this approach. Another alternative approach considered was spatial scanning. It too was determined to be unfeasible. (JMT)

RESOURCE UTILIZATION AND RESERVES

<466>

Nininger, R.D.; ERDA, Washington, DC

Recognition of Uranium Districts. In Proceedings of a Technical Committee Meeting on Recognition and Evaluation of Uraniferous Areas, held in Vienna, Austria, November 17-21, 1975. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 1-11), 295 pp.; IAEA-TC-25:1, (pp. 1-11), 295 pp. (1977)

The present known uranium resources are inadequate for projected requirements beyond 1985. These resources should be soon enlarged by greatly increasing exploration efforts, the success of which will determine if the projected uranium demand can be met. Much additional work needs to be done to improve exploration techniques in uranium geology. The main hope of expansion rate of reserves lies in identifying entirely new uranium provinces and new types of high and intermediate grade deposits containing 100 to 700 ppm uranium. Very low-grade deposits--granites, most black shales, phosphate rock and sea-water--can provide, at best, only a fraction of world needs. (Auth)

<467>

US Department of Commerce, Energy Resources Council, Washington, DC

Uranium Reserves, Resources, and Production. FEA/C-76/316, 14 pp.; PB-254 896, 14 pp. (1976, June 15)

The paper summarizes the uranium information available by drawing on the technical, economic, and environmental expertise of the Federal agencies who are ERC members and it provides a brief view of United States uranium reserves,

resources, and production. (MLB)

<468>

Not given; Western Interstate Nuclear Board, Lakewood, CO

Nuclear Power and Uranium Fuel Requirements in the Western United States. Western Interstate Nuclear Board Report, 32 pp. (1975, October)

The report describes the results of a survey of nuclear power and associated uranium fuel cycle requirements in the Western Region. The survey covers the period 1975-1990 for electric energy and nuclear power except for uranium and other fuel cycle requirements which is limited to the period 1975-1985. The shorter time span coverage for fuel cycle requirements was chosen due to many uncertainties in future federal policy in such areas as uranium enrichment, plutonium utilization in light water reactors, spent fuel reprocessing, and high-level radioactive waste management. Also contained in the report is information on projected national and western regional trends in electric energy demand and supply. The principal objective of the survey was to determine future development trends in nuclear-electric power generation and attendant fuel cycle requirements in the Western Region. (MLB)

<469>

Armstrong, F.C.; USGS, Spokane, WA

Uranium Resources of the Future--"Porphyry" Uranium Deposits. In Proceedings of a Symposium on the Formation of Uranium Ore Deposits, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 625-635), 748 pp. (1974, November)

The economics of the electrical utility industry indicate that nuclear fuels will largely replace fossil fuels in large generating plants of the future. This use will cause a large demand for uranium; it will also cause the price of U3O8 to increase perhaps as much as threefold, and will release fossil fuels for other more beneficial uses. In the next quarter century, the uranium mining industry will probably

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undergo changes similar to those experienced by the copper mining industry in the last half century. With increased price and large assured market, deposits containing as little as 0.04% U₃O₈ will become economically exploitable, and the large sums of capital necessary for their development will become available. Deposits containing 0.03-0.05% U₃O₈ occur in late magmatic differentiates.

Alaskite, leucocratic granite, biotite granite, and biotite quartz monzonite that are intruded by networks of aplite and pegmatite dikes of similar composition are the favorable host rocks for "porphyry" uranium deposits. Uraninite and radioactive black minerals are the principal ores. Uranium also occurs as ionic and molecular disseminations. Possible examples of "porphyry" uranium deposits are Rossing, South West Africa; Charlebois Lake, Canada; Crocker Well, Australia; and certain areas in central Idaho and northeastern Washington. The deposits will be easiest to find in arid climates, and unmetamorphosed rocks are perhaps the most likely hosts. (Auth)

<470>

Saenger, R.D.; AEC, Washington, DC

The World Uranium Supply Challenge - An Appraisal. In Proceedings of a Symposium on the Formation of Uranium Ore Deposits, held in Athens, Greece, May 6-10, 1974. International Atomic Energy Agency Publications, Vienna, Austria, (pp. 3-18), 748 pp. (1974, November)

The world demand for uranium during the remainder of the century is projected at around 4 million tons. It could be greater if the trend towards the use of electricity is accelerated and if other fuels continue to become more expensive. The increase in uranium production which will be required poses a major challenge to uranium geology and exploration. World reserves at a cost of up to \$15 lb U₃O₈ are estimated at little more than 2 million tons and additional resources at a 1 equivalent amount. However, the production levels needed towards the end of the century will require a resource base approaching three times the present resource estimates. A number of questions and problems are presented by the magnitude of the uranium supply challenge. Uranium deposits in sandstone and quartz-pebble conglomerates presently represent the preponderance of uranium resources. Yet there is a question whether

geological limitations on the occurrence of such deposits may preclude their discovery in numbers sufficient to meet the eventual resource needs. New types of deposits, low in grade, but larger in size, representing the equivalent of the porphyry copper deposits, may supply the bulk of future resource additions. Further investigation is needed on the characteristics of such deposits and the means of their identification. Similarly, additional investigation is needed to determine whether limits on the more conventional deposits do in fact exist and, if not, what advanced approaches to rapid identification of additional such deposits might be employed. The world probably cannot rely on the very low-grade deposits such as most uraniferous black shales for both economic and environmental reasons. There is probably a minimum grade between 100 and 500 ppm below which uranium deposits cannot be effectively exploited for nuclear power. (Auth)(JMT)

<471>

Scarl, M.F., and J. Platt; Electric Power Research Institute, Palo Alto, CA

Views on Uranium and Thorium Resources. *Annals of Nuclear Energy*, 2, 751-762. (1975)

Research has been conducted and estimates made of uranium resources present in conventional, and unconventional deposits or accumulations, such as phosphate rocks, certain igneous and granitic rocks, black shales, heavy sands and the like. Information compiled by various agencies to estimate the total reserves and costs is presented. Information on thorium resources is sparse. Thorium has principally been recovered as a by-product of rare-earth production so the estimates will increase with exploration. (PAG)

<472>

Cameron, J., and M.V. Hansen;
International Atomic Energy Agency,
Division of Nuclear Power and Reactors,
Vienna, Austria

Uranium Resources and Supply. *Aware*, 6-10. (1976, July)

While it appears that the known uranium resources

are adequate to support the planned and projected nuclear reactor programs for the next ten to fifteen years, severe supply problems may arise in the longer term. It is therefore necessary to monitor continuously the development in nuclear power growth forecasts and to set them into relation to the known uranium resources and the production they can support. The report attempts to present a most recent overall picture in this respect. Its emphasis lies on the uranium resources side, being in its larger part compiled by a working party of uranium resources experts but the rest of the nuclear fuel cycle and future uranium demand are presented. (Auth)

The report was also published in the February 1976 International Atomic Energy Agency Bulletin.

<473>

Manne, A.S., and O.S. Yu: Electric Power Research Institute, Palo Alto, CA

Breeder Benefits and Uranium Ore Availability. PB-239 513, 29 pp.; EPRI SR-3, 29 pp. (1974, October)

The relation between economic benefits of the breeder and the availability of uranium ore resources is discussed. The model has been constructed around a future role of the Fast Breeder Reactor (FBR) in a mix of nuclear, coal, and other possible advanced concept power systems. Only a small number of variations has been calculated, making assumptions on the cost of uranium, the discount rate for research and development investments, etc. (Auth)(MLB)

<474>

Not given: Not given

Uranium: Supply and Demand. Ambio, 5(3), 117-118. (1976)

The contents of a report produced jointly by the IAEA and the NEA of the OECD presented in **Uranium Resources, Production and Demand** are summarized. According to current projections, demand for low-cost uranium fuel will surpass uranium production capacity by about 1985. From the 1980s and onwards, steep increases in demand are expected, with doubling times of six or seven

years, creating the possibility of severe and fundamental supply problems over the long-term. The uranium production capacity in 1975 was about 26,000 tonnes, and there are plans to increase this capacity to 44,000 tonnes in 1978. Present uranium reserves are about one million tonnes of uranium. The estimated requirements for the year 2000 is ca 4 million tonnes, and for the year 2025, 10 million tonnes. Included in the report are estimates of future requirements of the following: uranium enrichment fuel reprocessing, fuel fabrication, and capital requirements for all nuclear fuel cycle provisions, except reactor construction up to 1995. (MLB)

<475>

Stoller, S.M., and J.F. Hogerton, S.M.
Stoller Corporation, New York, NY

Uranium Availability for Power Generation. Public Utilities Fortnightly, 99(2), 34-37. (1977, April)

The feasibility of expanded commercial nuclear power generation-even the continuance of such power generation at all-is in the minds of many dependent upon assured adequate supplies of uranium from which an essential fuel for nuclear reactors is derived. The article addresses the question of the volume existence of the element and the further question of the probable costs of discovery and production of the fuel. Particular advantages can accrue to electric utilities from active participation in uranium development through financial support programs. (MLB)

<476>

Sondermeyer, R.V.; US Bureau of Mines, Nonferrous Metals Division, Washington, DC

Mineral Facts and Problems: Thorium. In US Bureau of Mines Bulletin 667, (pp. 1115-1126), 1266 pp. (1975)

Thorium is widely distributed in the earth's crust. It is usually associated with uranium or rare-earth elements and is commercially obtained principally from monazite. Thorium nitrate is used for producing incandescent gas mantles, and the oxide is used as a refractory and in nuclear reactors as

fuel. Thorium metal is used as an alloying agent, particularly with magnesium. Thorium is transmuted under neutron bombardment into uranium 233. Thus, it is a fuel for the generation of nuclear energy. If successful, the light water breeder reactor (LWBR), which uses thorium as a fuel, would increase the demand for thorium. US and world thorium reserves are extensive and pose no near- or long-term supply problems. In addition, thorium exists in residues at monazite processing plants in the United States, in US Government stocks, and in tailing ponds at uranium mills in Canada. Existing facilities for monazite processing and thorium recovery are adequate to meet probable demand to 2000. (MLB)

<477>

Bement, T.R., and F.C. Genter; Los Alamos Scientific Laboratory, University of California, Los Alamos, NM

Geostatistics Project of the National Uranium Resource Evaluation Program, July-September 1977. LA-7050-PR, 9 pp.; GJBX-4478), 9 pp. (1977, November)

Statistical theory has been applied to the problem of characterizing the random and systematic errors associated with the use of airborne gamma-ray detection procedures. The statistical theory associated with least squares techniques has been applied to the problem of error analysis in aerial radiometric data. Most aerial radiometric surveys may not make direct use of least squares procedures in calibration. However, it appears that some of the procedures used are nearly equivalent to weighted least squares with some rather sophisticated weights. If these weights can be determined, then the methods which have been described can be used to help characterize the errors associated with various data processing procedures. By making use of least squares theory, one can simplify the problem of error propagation and possibly arrive at a more accurate estimate of error. It is recognized that a typical procedure for processing data involves many more steps than have been considered here. However, a number of these steps operate linearly on the data and can easily be incorporated into a least squares model. In order to get a reasonable approximation of the errors associated with any set of data, however, a combination of analytical and Monte Carlo techniques will probably have to be used. Some

preliminary results were obtained and are presented in the report. (MLB)

This report includes extensive tabular data.

<478>

Drew, M.W.; United Kingdom Atomic Energy Authority, London, England

US Uranium Deposits: A Geostatistical Model. Resources Policy, 3(1), 60-70. (1977, March)

Using data on presently viable deposits and a simplified function which links production cost to deposit grade and size, a bivariate log normal deposit grade size distribution may be calibrated for a given geologic environment. Exploration is introduced by assuming that the proportion discovered of the potential uranium reserve available at or below a given production cost can be represented by a function of the average deposit size and the unit exploration expenditure. As output the model derives estimates of total reserves linked to maximum production costs and to exploration expenditure where the latter may be expressed either as expenditure per pound of mineral discovered or as a given percentage of operating profit. The input requirements for the deposit distribution model for US data are tabulated. The model as described is static. It cannot yet be used to describe a dynamic process in which prices and mineral flows are constantly interacting. Rather, it offers a picture of the limits to what is actually available at any long-term price. What it does show is that a uranium shortage based on a real lack of deposits discoverable and exploitable at prices below \$35 per pound is extreme unlikely given the forecasts of uranium demand up to the year 2000. Thus it is in the political rather than the geological environment that shortages will arise. (MLB)

<479>

Buturlo, F.J., and M.E. Schwenk; Rocky Mountain Energy Company, Bear Creek Project, Casper, WY

The Bear Creek Uranium Project. In Laudon, R.B. (Ed.), Wyoming Geological Association, Twenty-Eighth Field

Conference, 1976, (pp. 231-234), 328 pp.
(1976)

The Bear Creek Project represents one of the first new uranium operations resulting from the rapidly rising prices of uranium. Over 8 years of exploration drilling and engineering design have been invested in the project which because of its low grade nature, required the higher price presently found in the market to become a mine. The first ore from the Bear Creek Project may be the first of many efforts to bring resources into reserves. (JMT)

URANIUM INDUSTRY

<400>

Kentro, D.M.: Not given

Processing Uranium Ores. Mining
Congress Journal, 40(12), 58-60. (1954)

Methods of processing uranium ores from the Colorado Plateau are discussed. The two basic methods are the acid leach and the carbonate leach; variations of these hydrometallurgical processes are used as necessary for different types of ore. In the acid circuit, the crushed ore may first be roasted to destroy carbonaceous material, thus reducing acid consumption. If vanadium is to be recovered also, salt is added to the roaster feed to convert the vanadium to a water-soluble compound, and the vanadium is then removed by a water leach. The residue goes to the acid tanks. A sulfuric acid leach for one to twenty-four hours at temperatures of 30 degrees to 40 degrees C is normally sufficient to dissolve the uranium. Separation of the leach solution from the solids is difficult, but baking the ores prior to leaching and adding certain chemicals usually improve filtering and settling rates sufficiently. The uranium may be separated from the leach solution by a number of methods. The carbonate leach process is particularly useful on ores that have a high lime content. A solution containing 5 to 20 percent sodium carbonate and 1 to 5 percent sodium bicarbonate is used. Leaching times of 4 to 24 hours at temperatures of 70 degrees to 115 degrees C are normally sufficient for good recoveries. The addition of an oxidizing agent is usually necessary. If sufficient vanadium is present in the ore, the metals can be precipitated from the leach solution by lowering the pH, and if not, caustic soda is added to precipitate the uranium. The uranium-bearing product from both processes may be shipped as yellow cake, or it may be fused and shipped as black oxide of uranium. (Auth)

<401>

Kimball, G.; Mining Engineer, Ouray, CO

Discovery of Carnotite. Engineering
Mining Journal, 77(24), 956. (1904)

In May, 1898, 10 tons of ore containing 21 1/2 percent U3O8 and over 15 percent V2O5 were shipped from claims on Red Creek, Montrose County, Colorado, to Denver, Colorado where it was sold for \$2,600. The yellow ore occurs in white sandstone as disseminated grains, bedded vein seams, occasional pockets, and vug fillings. (Auth)

<402>

Kuerr, A. (Ed.), and G. (Ed.) Lutjen, Not given

U3O8-Formula for Profit. Engineering
Mining Journal, 155(9), 87-118. (1954)

The economic aspects of the uranium industry on the Colorado Plateau are discussed in this collection of several papers by several authors. Exploration and development, mining, and milling of ore are also covered. Diagrams illustrating various ore controls and ore guides are included in a generalized discussion of the geology of the ore deposits. (Auth)

<403>

Duggan, E.J.; Climax Uranium Company,
Grand Junction, CO

Leaching of Uranium and Vanadium Ores
on the Colorado Plateau. Mines
Magazine, 44, 50, 84, 86, 88. (1954, June)

A classification of the uranium-vanadium ores of the Colorado Plateau is presented in this paper. The ores are grouped into the following categories: (1) the roscoelite ores which are essentially vanadium ores with a small uranium content; (2) the low lime carnotite ores from the Morrison Sandstone; (3) the high lime carnotite ores; (4) the asphaltic ores mostly from the Temple Mountain district in Utah; (5) the Shinarump or deeper ores from eastern Utah; (6) the copper uranium ores of southeastern Utah; and (7) the Todilite limestone ores near Grants, New Mexico. Several methods are discussed for the treatment of the different types of ores. (JMT)

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Johnson, J.C.; AEC, Washington, DC

Nuclear Fuel for the World Power Program. In USGS Professional Paper 380, (pp. 13-15), 739 pp.; In Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 6, Geology of Uranium and Thorium, held in Geneva, Switzerland, August 8-20, 1955. United Nations, New York, (pp. 60-62), 825 pp. (1956)

Uranium production already developed is adequate for a major nuclear power program of world-wide extent. Resources of western nations total between 1 and 2 million tons of uranium which can be produced at an average cost of \$10 per pound from high-grade concentrates. A considerable reserve in low-grade shales and phosphates can be exploited at costs as high as \$50 per pound. Milling costs, a factor in production, may vary from \$5 to \$15 per ton. Ion exchange has had its first commercial application to recovery of metals in uranium mills, and it and solvent extraction by either acid or alkaline solutions constitute the main processes of extraction. (Auth)

<485>

Woodmansee, W.C.; US Bureau of Mines, Washington, DC

Uranium. In US Bureau of Mines Bulletin 667, Mineral Facts and Problems, 1975 Edition, 24 pp. (1975)

Uranium demand for nuclear fuel use has gathered momentum in recent years and is expected to rise steeply in the future. The anticipated growth is worldwide in scope. The industrialized nations and many of the developing nations are planning nuclear power programs. Future nuclear power growth and corresponding uranium demand are influenced by a number of variables, resulting in wide forecast ranges. Projected U.S. demand for uranium in 2000 is expected to be between 39,700 and 89,300 tons of uranium, with a probable demand for 69,500 tons compared with an estimated demand 6,900 tons U in 1973. The annual average growth rate for probable demand to 2000 is nearly 9 percent. U.S. and world low-cost uranium resources are expected to be sufficient in

the short-term, but their adequacy in the long term is uncertain. Discovery of new resources and development of low-grade resources would improve the resource position. Steeply rising uranium prices during 1974 and 1975 have spurred interest in low-grade resources. Imports of foreign uranium are expected to partly fulfill future domestic needs starting in 1977, when plans call for relaxation of an existing embargo on enrichment of foreign uranium for use in domestic reactors. The breeder reactor may also be a partial solution to a potential long-term uranium supply problem. Major capital investments in additional mining and milling capacity will be needed to provide uranium supplies to sustain a developing nuclear fuel industry, which encompasses uranium enrichment, the manufacture of nuclear fuels and consumption in the power reactor, spent fuel reprocessing, and management of radioactive wastes. (JMT)

<486>

Hitch, H.H.; First National Bank, Casper, WY

Economic Impact of Uranium Industry in Wyoming. In Barlow, J.A., Jr. (Ed.), Wyoming Geological Association Guidebook, Twenty-First Field Conference, 1969, (p. 173), 233 pp. (1969)

Wyoming has 40% of the nation's uranium reserves, and it ranks second in the production of uranium concentrates. Many major companies have made Wyoming their prime area of exploration for new uranium reserves. As of 1968, Wyoming had 5 uranium mills operating at capacity, and expanded uranium processing operations are planned by several mining firms. The author predicts that uranium will contribute significantly to Wyoming's economic growth in the future. (JMT)

<487>

Crew, M.E.; AEC, Casper, NY

Wyoming Uranium Review. In Barlow, J.A., Jr. (Ed.), Wyoming Geological Association Guidebook, Twenty-First Field Conference, 1969, (pp. 169-172), 233 pp. (1969)

Since the first announced discovery of commercial uranium deposits in Wyoming in 1951, the industry showed a tremendous growth, attaining peak production in 1968. As of January 1, 1969, nearly 7 million acres of Wyoming had had been leased for uranium exploration, ranking Wyoming first among all other states in this category. Wyoming also ranks first in number of exploration feet drilled, and in tons of reserve ores. In terms of tons of U3O8 in reserve, Wyoming ranks second as of January 1, 1969, behind New Mexico. (JMT)

<488>

Flanagan, P.E.; Philip E. Flanagan Associates, Riverton, WY; General Nuclear, Riverton, WY

The Nuclear Industry in Wyoming - 1968. In Wolf, G.R. (Ed.), Wyoming Geological Association Guidebook, Twentieth Field Conference, 1968. (pp. 109-113). 243 pp. (1968)

Uranium ore was first discovered in Wyoming in 1918, but it was not until 1951 that mineable quantities of the ore were located in the Pumpkin Buttes area of Campbell County. Actual mining operations were started in 1953. Further discoveries were made in other areas of the state such as the Gas Hills, Shirley Basin, and Crooks Gap between the years 1952 and 1955. By 1961, Wyoming was the second largest producer of uranium ore in the United States next to New Mexico. The first substantial order from private enterprise for Wyoming uranium oxide concentrate came in early 1966. The sale was made by Utah Construction to a Swiss utility company. As of 1968, exploration for uranium in Wyoming was moving at an increasingly rapid pace. Most of the exploration has been in the Wind River Basin, Shirley Basin, and the southern part of the Powder River Basin. Virtually every major energy company in the United States is involved in the search for uranium, and Wyoming is expected to provide between 40 and 50 percent of the nation's uranium in the future. (JMT)

<489>

Rautman, C.; New Mexico Bureau of Mines and Mineral Resources, Socorro, NM

The Uranium Industry in New Mexico. New Mexico Bureau of Mines and Mineral Resources Report, 24 pp. (1977, March)

The uranium industry of New Mexico originated in the mid-1940's with the birth of the Atomic Age. The industry has grown rapidly to the present day, and New Mexico has now produced more uranium than any other state. By far the greatest production, and all of the current production has come from a belt of land known as the Grants Mineral Belt. The larger and historically more productive uranium deposits in New Mexico have been those which occur in sedimentary rocks and which are essentially parallel to the bedding. The most productive deposits of this type have been found in thick fluvial sandstones. The host rocks of these sandstone-type uranium deposits are typically arkosic, coarse, poorly sorted, and contain locally abundant organic detritus, such as twigs and logs. The uranium mineralization itself appears to be largely controlled by the presence of very finely disseminated organic matter. Lesser production has come from uranium deposits in limestone, and deposits are known to occur in lignite, coal and carbonaceous shale as well. Peneconcordant uranium deposits occur in rocks which range from Paleozoic to Tertiary in age. By far the most important units in terms of quantity of ore produced are the Upper Jurassic Morrison Formation sandstones, and to a lesser extent the Upper Jurassic Todilto Limestone of the southern San Juan Basin. Mines in the Grants Mineral Belt range from open pit surface operations to underground mines with shafts up to 3500 feet deep. During 1976, twelve companies operated or were developing 32 major uranium mines in New Mexico; four mills capable of processing 15,160 tons of ore per day were in operation. At least ten additional companies have active drilling programs in progress, and several other groups are conducting preliminary exploration activities. By the year 2000, New Mexico will need to produce between 574,000 and 646,000 tons of U3O8. Present reserves in cost categories up to and including \$30 per pound are inadequate to meet even half of this projected demand. Intensive exploration efforts by industry are needed to convert potential resources into known reserves. (JMT)

<490>

White, L.; McGraw-Hill, New York, NY

**In-Situ Leaching Opens New Uranium
Reserves in Texas. Engineering and
Mining Journal, 176(7), 73-81. (1975, July)**

A commercial in-situ uranium leaching operation that is quite probably the largest ever built started up in April 1975, 10 miles southwest of George West, Texas. Producing from a pattern of 66 injection wells and 46 extraction wells occupying an area of less than 3 acres, the Clay West mine and plant are expected to reach design capacity of 250,000 lb per year of yellowcake by the end of the summer. By late May, results were sufficiently favorable to make the owners think seriously about an early expansion. Built at a cost of \$7 million by joint venturers, the Clay West mine may be only the first of several mines to extract U_3O_8 from a uranium province that stretches from North of Houston to Brownsville, Texas. (MLB)

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