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TEI-620

GEOLOGY AND MINERALOGY

U. S. DEPARTMENT OF THE INTERIOR

GEOLOGIC INVESTIGATIONS OF RADIOACTIVE DEPOSITS

Semiannual Progress Report for December 1, 1955 to May 31, 1956

This report is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards and nomenclature.

June 1956

United States Geological Survey
Washington, D. C.

Prepared by the Geological Survey for the
UNITED STATES ATOMIC ENERGY COMMISSION
Technical Information Service Extension, Oak Ridge, Tennessee

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Printed in USA, Price $1.75. Available from the Office of Technical Services, Department of Commerce, Washington 25, D. C.

AEC, Oak Ridge, Tenn.

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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGIC INVESTIGATIONS OF RADIOACTIVE DEPOSITS

SEMIANNUAL PROGRESS REPORT

December 1, 1955 to May 31, 1956

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Trace Elements Investigations Report-620*

*This report concerns work done on behalf of the Divisions of Raw Materials and Research of the U. S. Atomic Energy Commission.

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INTRODUCTION

This report is a statement of progress during the six-months period from December 1, 1955 to May 31, 1956 on investigations of radioactive materials in the United States and Alaska, undertaken by the U. S. Geological Survey under the sponsorship of the U. S. Atomic Energy Commission.

The shift in emphasis of the Geological Survey's program from the search for minable deposits as such toward the understanding of geologic conditions favorable for uranium concentration, which was discussed in the preceding Semiannual report (TEI-590), was continued during the period. The exploration drilling program, which has been in progress since 1947, was concluded, and the effort is now directed toward a comprehensive understanding of the many factors involved in uranium geology and the publication of reports that will make available to the public information obtained in the various studies. Many investigations have progressed to the point where final reports have been completed or are in preparation for future publication with the permission of the Atomic Energy Commission; for other investigations, especially those of a continuing nature, it will be several years before final reports can be prepared.

Between December 1, 1955 and May 31, 1956, formal publications included one Geological Survey Professional Paper; nine Geological Survey Bulletin chapters; one Geological Survey Circular; 62 Geological Survey maps; and 29 papers in scientific journals. In addition, three Trace Elements reports were placed on open file, and five Trace Elements reports were sent to the Technical Information Extension of the Atomic Energy Commission for wider distribution and sale to the public. The 61 papers prepared during a former period for the United Nations International Conference on Peaceful Uses of Atomic Energy were published in the Proceedings of the Conference, Volume 6, Geology of uranium and thorium, in June 1956. These and additional related papers, some of them in enlarged and revised form, were published also in Geological Survey Professional Paper 300, which was issued during the early summer of 1956. Also, a total of 22 papers were given before scientific organizations by geologists on the program.

Publications issued on various phases of the geologic investigations of radioactive deposits during the period are listed in this report under the descriptions of the various projects.

HIGHLIGHTS, GEOLOGIC INVESTIGATIONS OF RADIOACTIVE DEPOSITS DECEMBER 1, 1955 - MAY 31, 1956

Uranium in sandstone-type deposits on the Colorado Plateau

Geologic mapping

During the period geologic mapping and related studies were carried on in the following areas: Bull Canyon district, Colorado; Slick Rock district, Colorado; Uravan district, Colorado; Western San Juan Mountains, Colorado; Ute Mountains, Colorado; Gateway district, Colorado and Utah; Sage Plain, Utah and Colorado; La Sal Creek area, Colorado and Utah; Lisbon Valley, Utah and Colorado; Moab-Inter-river area, Utah; Orange Cliffs area, Utah; San Rafael Swell, Utah; Circle Cliffs area, Utah; Elk Ridge, Utah; Abajo Mountains, Utah; East Vermillion Cliffs area, Arizona; Grants area, New Mexico; Laguna area, New Mexico; and Hopi Buttes, Arizona.

Results of drilling on Wild Steer Mesa in the Bull Canyon district, Colorado, indicate that the uranium-vanadium mineral deposits occur in east-trending groups, bordered on the north and south by unfavorable ground. The Navajo sandstone and Kayenta and Wingate formations were not cut by a hole drilled from the Morrison formation into the Cutler formation in the Jo Dandy area. Drilling in Dry Creek Basin indicates the presence of a synclinal structure bordering the northeast flank of Gypsum Valley. Within this synclinal structure the lithology of the Salt Wash member varies greatly.

Exploration drilling has been completed in the Slick Rock district, Colorado. Stratigraphic data show that most of the sedimentary formations exposed in the district are thicker along the Disappointment syncline than along the adjacent Dolores anticline. Fossils from the Burro Canyon formation in the Slick Rock district corroborate the formation's Early Cretaceous age and its correlation with the Cedar Mountain formation. Fossils from the lower 855 feet of the Mancos shale identify the rocks successively as of Greenhorn, Carlile, and Niobrara ages. Heavy-mineral studies suggest that two types of diagenetic changes took place after deposition of the sediments, one under oxidizing conditions and one under reducing conditions in the presence of carbonaceous material. A third type of alteration took place later and was associated with deposition of the uranium-vanadium ore deposits.

Preliminary results of studies of drill holes show that on Club Mesa in the Uravan district, Colorado, nearly all the known ore deposits occur where the host Salt Wash sandstone member is 30 feet or more thick and is in contact with 6 inches or more of gray or green mudstone or siltstone. Based on these criteria, about 10 percent of the explored area on Club Mesa is believed to be geologically favorable for the occurrence of ore.

Igneous rocks of the Placerville, Little Cone, and Dolores Peaks quadrangles in the Western San Juan Mountains, Colorado, are apparently associated with three major centers of igneous activity. Microgabbro and basaltic andesite dikes and sills are related to laccolithic intrusives that lie partly in the Gray Head quadrangle. Microgranogabbro dikes and sills in the Little Cone quadrangle are related to a zoned granogabbro-adamellite-granite stock in the Dolores Peaks and Mt. Wilson quadrangles. Quartz latite dikes and sills are not as definitely related to a center of igneous activity, but may be derived from a center in the northwestern part of the Dolores Peaks quadrangle. Lamprophyric dikes and sills and a basalt flow do not appear to be related to these three centers.

Most of the rocks of the Ute Mountains, Colorado, igneous complex are diorite and andesite porphyries. Dacites, quartz monzonites and a lamprophyre, possibly spessaritite, are present. The groundmass of many of the porphyries is too fine for the mineralogic composition to be determined microscopically, but is probably more acidic than the phenocrysts.

Most of the known uranium-vanadium deposits containing minable tonnages of ore in the western part of the Gateway district, Colorado and Utah, are in sandstone lenses in the upper half of the Salt Wash member of the Morrison formation of Jurassic age. Light gray and light brown sandstone that contains green mudstone splits and carbonaceous material is the most favorable host rock. The major uranium-vanadium producing area on Beaver Mesa in the district is in a structural low that trends northeast and is 1 to 1.5 miles wide. Principle uranium-vanadium ore minerals are uraninite, montroseite, coffinite, and corvusite.

Compilation of data on the uranium-vanadium mines in the Sage Plain area, Utah and Colorado, shows that about 65 percent of all the ore has been produced from within 50 feet of the Salt Wash outcrop. A qualitative study of the bleaching of red sandstone and mudstone of the Salt Wash member of the Morrison formation indicates that solutions of peat and water at room temperature are capable of bleaching reddish sand in a relatively short time by the reduction and solution of ferric iron.

Structure contours drawn at intervals of 10 feet at the base of the ore-bearing sandstone unit in the La Sal Creek area, Utah and Colorado, indicate that the larger deposits are found in depressions or scours and on the flanks of noses or ridges within and along the margins of major Salt Wash stream courses. In conjunction with lithologic guides these features may narrow the area to be searched for concealed ore deposits.

Geologic mapping and study in the Lisbon Valley area, Utah and Colorado, indicates that a distinctive chert which occurs near the base of the Chinle formation may be genetically related to the uranium deposits and thus may be a useful guide in prospecting for new deposits. Mapping of the surficial deposits has established the presence of rubble deposits which are cemented in part by pink caliche which may mark an erosion surface of Tertiary age. Samples of recent stream sediments from areas known to contain copper minerals have been divided by means of heavy liquids and the Frantz magnetic separator into several fractions including one fraction rich in copper minerals. Where copper minerals are associated with uranium ore deposits, the detection of abnormal amounts of copper in recent sediments by this method may be a useful guide to the uranium deposits.

The uranium deposits in the Moab part of the Moab-Inter-river area, Utah, can be divided into two groups on the basis of structure and ratio of vanadium to uranium. The first group are bedded deposits in the Cutler and Chinle formations, most of which appear to be related to small sedimentary structures. The V:U ratio in this group is about 1:4 and both low and high valent minerals are present. Microscopic examination indicates that the uraninite is younger than the sulfides and most of the calcite. The second group consists of deposits in the Rico, Cutler, and Chinle formations along faults on the Cane Creek anticline. The V:U ratio is about 2:1 and several rare minerals are present. One possible explanation for the higher V:U ratio in this group is accumulation from crude oil that migrated up the faults.

Available data indicate a geographic association of uranium occurrences in the Happy and Hatch Canyon area in the Orange Cliffs area with northwest-trending faults and fault zones, pinchout zones of the Monitor Butte and Moss Back members of the Chinle formation, and minor structural terraces and contiguous monoclines. Polished section studies of mineralized chert indicate the following paragenetic sequence: chert, pyrite, sphalerite, digenite, covellite, tetrahedrite or tennantite, calcite.

Isopach maps of the upper part of the Moenkopi formation in the San Rafael Swell, Utah, using mapped marked beds in the Moenkopi as datum surfaces, indicate that a Permian anticlinal fold, oriented northwest-southeast across the center of the Swell, may have been rejuvenated at the end of Moenkopi time. This slight uplift may have had some influence on sediment deposition during Chinle time which resulted in some areas being more favorable for uranium deposition than others.

Geologic mapping has delineated two areas in the Elk Ridge area, Utah, which contain Chinle sandstone beds favorable for uranium ore deposits. The positions of the ore deposits appear to be controlled by the proximity of Chinle sandstone to the Moenkopi-Chinle contact. It is suggested that the ore solutions may have moved through the Moenkopi rather than through the generally less permeable Chinle.

The Abajo Mountains, Utah, consist of an igneous core that intruded and arched the sedimentary strata. The mountains are rimmed by small domes formed of sedimentary rocks and underlain by igneous material; these are tentatively interpreted as laccoliths. Wherever exposed, the igneous rocks are similar in composition and texture and are classified as porphyritic hornblende latites. The rocks consist of subhedral to euhedral phenocrysts of andesine and hornblende in a very fine-grained groundmass. Chemical analyses of the igneous rocks indicate a potassium range from 1.22 to 3.96 percent. Most of this potassium is contained in the groundmass. Uranium-vanadium ore deposits are in the Salt Wash member of the Morrison formation of Jurassic age. The uranium-vanadium content is about 1:10 and the carbonate content is high.

Almost all of the known uranium mineralization in the East Vermillion Cliffs area, Arizona, occurs in the Shinarump member of the Chinle formation and in the Moenkopi formation at or near their contact in channel scours. Uranium minerals identified are metatorbernite and betazippeite. In the majority of samples the content of equivalent uranium (radioactivity) is less than the content of uranium (chemical analysis). This suggests a possible age of less than one million years for the minerals.

Correlation of measured sections in the Grants area, New Mexico, shows that members of the upper part of the Morrison formation are highly lenticular. Structural and analytic data indicate that large uranium ore bodies may be confined to shallow northeasterly trending synclines and that the original metallic composition of the ore may have been slightly changed by subsequent downdip migration of some of the metals.

The most prominent fracture pattern in the Laguna area, New Mexico, comprises two nearly vertical joint sets, striking N. 37° E. and N. 13° W. High angle faults approximately bisect the acute angle between the joint sets. The formation of this fracture pattern was essentially contemporaneous with the intrusion of the igneous rocks, which in the area include flows and volcanic plugs of olivine basalt and olivine andesite and dikes and sills of diabasic gabbro and diorite. Sills in the Sandy mine area include younger aplitic to pegmatitic rocks of granitic to syenitic composition. These sills have metamorphosed the enclosing sedimentary rocks in zones as much as 10 feet thick.

Uraniferous limestones from diatremes in the Hopi Buttes, Arizona, are interpreted as dolomitic travertines contaminated with varying amounts of quartz silt of probable eolian origin and subordinate amounts of volcanic detritus. In addition to uranium the travertines contain more than normal concentrations of sodium, phosphorus, strontium, molybdenum, vanadium, copper, nickel, cobalt, arsenic, and selenium. This assemblage of elements suggests a genetic relation between the solutions from which the travertines were precipitated and the associated volcanic rocks.

Photogeologic quadrangle mapping was confined principally to southwestern Utah and northern Arizona. Isopachous mapping of the Moenkopi-Hoskinnini interval in part of the White Canyon area, Utah was completed. During the period the 32 maps of quadrangles in the Colorado Plateau were completed at a scale of 1:24,000, and maps of 50 quadrangles were published.

Subsurface geologic investigations by drilling

Diamond drilling to test geologic concepts has been completed in the Disappointment Valley area, San Miguel County, Colorado; the Kirk's Basin-Taylor Creek area, Grand County, Utah; the Deer Flat and Clay Gulch areas, San Juan County, Utah; and the El Capitan Flat area (Oljeto Wash), Navajo County, Arizona. Diamond drilling undertaken to test geophysical data obtained in the El Capitan Flat area (Oljeto Wash) has led to the discovery of three uranium deposits.

General stratigraphic studies

A summary of stratigraphic features associated with uranium deposits of the Colorado Plateau shows that groups of ore deposits are associated with a number of regional stratigraphic features and that individual ore deposits are related to small-scale stratigraphic features. The association of uranium deposits with continental sediments, particularly with fluvial sandstones, focuses attention on the field interpretation of depositional environments and emphasizes the need for additional observations of deposition in modern continental environments.

The members of the Morrison formation were correlated in subsurface from the western edge to the southern and eastern margins of the San Juan Basin. A reference map showing oil and gas tests on the Colorado Plateau was prepared and a series of base maps of the formations of the Plateau was started for the recording and accumulation of thickness data.

Preliminary study suggests that the pinchout of the Lukachukai member of the Wingate sandstone of Triassic age in the northern part of the Defiance uplift and the southward thinning of the Rock Point member of the same formation beyond the limit of the Lukachukai is caused by erosion prior to the deposition of the overlying Entrada sandstone.

Lithofacies studies of the Moenkopi formation of Triassic age suggest an irregular gradation from a unit composed dominantly of horizontally laminated and structureless mudstone in southwestern Utah and northwestern Arizona to a unit composed dominantly of cross-stratified sandstone near the eastern margins of the formation in east-central Arizona and west-central Colorado. The upper part of the Chinle formation is predominantly horizontally laminated and structureless mudstone in the Circle Cliffs, Capitol Reef, and southern San Rafael Swell areas in south-central and central Utah and contains a large amount of cross-stratified sandstone in the eastern San Rafael Swell, Moab, and Big Indian Wash areas.

The Shinarump member of the Chinle formation shows a westerly direction of sediment transport in the Hurricane Cliffs area of southwestern Utah and southeastern Nevada, and a northeastern trend along the Mogollon Rim in east-central Arizona. In the Defiance uplift, the Shinarump member shows a variable direction of transport ranging from northeast through northwest to southwest.

The pebbles in the Shinarump member are dominantly sedimentary orthoquartzite and chert along the southwest portion of the outcrop of the member and dominantly quartz in the northeast portion of the outcrop of the member. Igneous pebbles are present in the Shinarump member and in the Sonsela sandstone bed of the Petrified Forest member of the Chinle formation in parts of northern Arizona and west-central New Mexico.

Petrographic study of the sedimentary formations on the Colorado Plateau was extended to rocks older than those of Triassic age to look for characteristics similar to those of the known Triassic ore-bearing rocks. A suite of samples from the Grand Canyon of the Colorado River was studied and compared with a suite from Capitol Reef, Utah. The older formations represented range in age from the Bass limestone of Precambrian age to the Kaibab limestone of Permian age. Comparisons were made of grain size, potash feldspar content, kaolin clay content and proportions of chemical components. The Shinumo quartzite of Precambrian age was found to resemble most closely the ore-bearing Monitor Butte and Shinarump members of the Chinle formation of Triassic age.

Regional synthesis

Study of the geology of uranium deposits in the Thompson district, Utah, indicates that ground thought to be relatively favorable for significant uranium deposits in the Salt Wash member of the Morrison formation in this district is essentially confined to an ancient stream channel system which trends northeasterly through the Yellow Cat area towards the town of Cisco, Utah.

About 600 gamma-ray logs taken from about 500 drill holes in the Todilto limestone, near Grants, New Mexico, were evaluated to study the relations of radon concentrations in the holes to the uranium deposits, the degree of radon concentration, and the behavior of the radon when flushed from the hole by compressed air or water. About 20 percent of the holes logged were found to have abnormally large radon concentrations, or contamination. The contamination showed a close spatial relation to the uranium deposits and a direct relationship to the uranium content of the mineralized material. The contamination also is related directly to the time that elapsed between drilling and logging.

In the Green River and Henry Mountains districts, Utah, primary sedimentary features, especially channels and the relative discontinuity of beds near regional pinchouts, are thought to be the principal ore controls. Belts of relatively favorable ground from 10 to 25 miles wide are inferred adjacent to and paralleling regional pinchouts of the Shinarump, Monitor Butte, and Moss Back members of the Chinle formation. Another favorable area is inferred on the southwest flank of the Moab anticline where concentrations of sandy stream deposits may provide host rocks favorable to the occurrence of uranium deposits.

Botanical studies

A chromatographic field test for uranium in plant ash which should be fast, easy, and useful to the prospector is under development. Analyses of plants from the Penasco Hot Springs, Sandoval County, New Mexico show a high radium content.

Recent study indicates that cutoffs in parts per million uranium between background and anomalously large uranium contents of trees differ in various tree species. Because the cutoffs appear to differ only slightly from 1.0 ppm uranium in the ash of all branch-tip samples of evergreens studied, a

1.0 ppm cutoff still can serve to define botanical anomalies. For aspen, however, a 1.0 ppm cutoff appears to be too large, and 0.5 ppm is tentatively recommended.

Mineralogic studies

Uraninite and coffinite are the major uranium minerals of unoxidized ore deposits in the Salt Wash member of the Morrison formation, and are best developed where they replace coalified wood. Montroseite and vanadium clays are the major vanadium minerals of these deposits. Sulfides are minor in most deposits; pyrite and marcasite are the most common. Coalified wood is associated with these deposits and varies in character from black, hard, opaque material associated with uranium and vanadium minerals to brown, soft, semitranslucent material that is not radioactive and contains no uranium or vanadium minerals.

Studies of clay minerals in Triassic formations show that in southwestern Colorado chlorite is present instead of kaolinite in the Moenkopi and the lower part of the Chinle formations. Studies of clays from stratigraphically equivalent mineralized and unmineralized rocks in White Canyon and Lisbon Valley, Utah, show no difference in the type of clay.

Studies of the clay minerals of the Morrison formation indicate the clays of the Salt Wash member are illitic, and those of the Brushy Basin member are montmorillonitic. The montmorillonite in the Brushy Basin member is probably of volcanic origin as evidenced by the shards found in samples of silicified shale.

Mineralogic study of sandstone-type uranium deposits in the Colorado Plateau, Wyoming, South Dakota, and Texas has given a general picture of the types of uranium ores, the nature of the primary ores, the sequence of oxidation, and the leaching and migration of uranium. Investigation of the sulfide minerals in several samples of primary ore (unoxidized) has given evidence that the temperature of formation of the uranium deposits in the Colorado Plateau was probably less than 138° C. It was found that the selenium content of the sulfides in ore is related to the selenium content of the enclosing sedimentary rocks in the Colorado Plateau but not in the Wind River basin of Wyoming.

Preliminary results of geochemical prospecting studies in the Henry Mountains district, Utah, suggest that abnormal amounts of vanadium in either the total rock or the soluble fraction; of copper, lead, and zinc in the soluble fraction; or of uranium in the total rock can serve to delineate broad areas in the district favorable for more detailed prospecting. Vanadium in soluble fractions of samples taken more than 100 feet from known ore varies from less than 15 to 840 ppm and the vanadium content is, in general, inversely related to the distance from ore.

Geophysical investigations

Characteristic magnetic patterns appear to be associated with some of the major uplifts of the Colorado Plateau, indicating that they may be underlain by basement rocks of different composition from those in the intervening basins.

Compilation and interpretation of geophysical data obtained in the Monument Valley, Arizona, show that the interpretation of seismic refraction measurements can be successfully used to delineate buried Shinarump channels where the Monitor Butte member of the Chinle formation is thin, absent, or badly weathered.

Electrical resistivity horizontal profiles made over a known Shinarump channel covered by 40 to 80 feet of Monitor Butte sediments were successful in indicating the presence of the channel. Experimental electrical measurements employing a modified version of the potential drop-ratio method were also made over the Shinarump channel. The results were sufficiently encouraging to warrant further testing of this method.

Original-state core studies

Analyses of physical properties of cores from the Lisbon Valley, Utah, experimental drill holes in uraninite terrane show that desaturated sandstone with pore water of higher salinity is continuous with underlying sandstone containing ore. A few feet above the ore the water content of the sandstone increases and the salinity decreases. In the ore zone streaks of higher and lower residual water saturation alternate. Downdip within 50 feet the average permeability of the ore sandstone increases from 99 to 3,115 millidarcies, the sandstone becomes completely barren, and the water saturation rises to such a high value that the presence of circulating ground water can be assumed. Nearly all the presently determined relations have been previously found for carnotite terrane in Long Park and for blue-black terrane in Bitter Creek, and none of the presently determined relations disagrees with those previously found in Long Park and Bitter Creek.

Uranium in sandstone-type deposits outside the Colorado Plateau

Black Hills uplift, South Dakota and Wyoming

To determine whether a significant amount of uranium is present along the outer margins of thermoluminescent calcium carbonate cemented bodies in the southern Black Hills, a limited core-drilling program was carried out using a channel sandstone as the target. The sandstone is almost completely impregnated with calcium carbonate at one exposure but at another exposure, about 3½ miles away, the amount of calcium carbonate is negligible. Drill holes were spaced about half a mile apart between the exposures, the objectives being to locate the margin of the cement and to determine whether uranium minerals are associated with it. This drilling, which was guided entirely by geologic information on conditions favorable for ore occurrence, penetrated a large mineralized body containing uraninite in the uncemented part of the channel.

Mechanical analyses of material previously mapped as dune sand in the southern Black Hills corroborate field evidence indicating that the deposits are probably terrace alluvium surficially modified by wind.

Some reworked uraniferous Inyan Kara sandstone boulders have been found in gravel of Chadron(?) (Oligocene) age. This suggests that the uranium mineralization in the Black Hills occurred during pre-White River and post-Fall River time.

Powder River Basin, Wyoming

Analyses of samples from the Southern Powder River Basin show that montmorillonite is the predominant clay in white sandstone lenses. The alteration of volcanic material to clay has altered the original red or drab color of the sandstone. Vanadium-uranium ratios in deposits are approximately 1:1.

Wind River Basin, Wyoming

The uranium ore in the Gas Hills area is restricted to the upper coarse-grained facies of the early Eocene Wind River formation, where uranium occurs mainly as autunite in the oxidized zone, and as uraninite in the unoxidized zone. Recent company drilling in the area indicates the presence of large ore bodies, the tops of some of which coincide with the nearly horizontal present day ground water table. At some localities the ore appears to transect beds in the Wind River formation which dip about 2 degrees to the south. Selenium has been found in association with uranium ores at several new localities.

Washakie Basin, Colorado and Wyoming

The Baggs area, in southern Wyoming and northern Colorado, includes outliers of the Browns Park formation of Miocene age which have an areal extent of about 80 square miles. Petrographic studies show that most of the uranium deposits in the Browns Park formation occur in or below the transition zone between the nontuffaceous and the overlying tuffaceous facies. Uranium in secondary minerals is scattered throughout the yellowish-brown oxidized zone, but uranium, selenium, arsenic, and molybdenum are concentrated, locally, in the lowermost part of the oxidized zone. The oxidized zone is related to an ancient water table and is underlain by a bluish-gray unoxidized zone at depths ranging from 20 to 70 feet.

In the Maybell-Lay area, Moffat County, Colorado, chemical analyses as high as 0.80 percent uranium have been obtained from samples of sandstone of the Browns Park formation of Miocene age. Heavy mineral studies show that three zones containing distinctive mineral assemblages are present in the tuffaceous facies which thickens to the west: a basal zone 500 to 700 feet thick containing abundant augite; a middle zone about 300 feet thick containing abundant hornblende; and an upper zone 500 feet or more in thickness containing abundant hypersthene. All samples of mineralized sandstone in the area contain a high amount of barium and some contain appreciable amounts of copper and rare earths.

Arizona

Stratigraphic studies of the Dripping Spring quartzite in Gila County, Arizona, indicate that the source area for the clastics may be to the south, in contradiction to earlier hypotheses. The original basin of deposition (Apache basin) may have been larger than earlier supposed.

Study of the diabases spatially related to the uranium deposits indicates that the rock-forming elements have differentiated in a normal manner and that the diabase bodies now contain less uranium (copper and cobalt) than the original magma. The behavior of cobalt, copper, and vanadium is more erratic. Metamorphism of siltstone adjacent to diabase is accompanied by very little, if any, compositional change although the rock is completely recrystallized to hornfels. Lead isotope determinations on two galenas from one of the deposits give conflicting Pb^{207}/Pb^{206} ratios. One would indicate a Tertiary age, the other an age of 1,125 million years. An age of about 730 million years was determined on uraninite by the controversial unit-cell dimension method.

Uranium in veins, igneous rocks, and related deposits

Studies of the Tertiary intrusive rocks in the central part of the Front Range mineral belt, Colorado, show that these rocks probably consolidated from two magma series and that both uranium and thorium were concentrated during differentiation of each series. The maximum enrichment in the radioactive elements took place in the youngest members of the series. Uranium, which was deposited in faults as pitchblende, was given off by late-stage, aqueous fluids of quartz bostonite and possibly also biotite-quartz latite magmas.

Studies of the two major types of quartz monzonite found near the Midnight mine in Stevens County, Washington, show that the porphyritic variety is more radioactive than the non-porphyritic variety. Tertiary sediments south of the Midnight mine contain torbernite-group minerals disseminated in tuffaceous sandstones and carbonaceous seams; locally the uranium content appears great enought to constitute ore.

Laboratory studies of the volcanic rocks of the Thomas and Dugway Ranges, Utah, have shown that these rocks are more salic and poorer in ferromagnesian minerals than either the average rhyolite, or rocks of similar sequences at Paricutin, Mexico, and Crater Lake, Oregon. In the Thomas Range rocks of the younger volcanic group, all of which are quite similar in composition, show no systematic variation in composition with time. The uranium content of the younger volcanic group is at least three times that of the average rhyolite in the western United States.

The epigenetic uranium deposits in the Kern River area, California, are small and are principally associated with regional fractures; the largest and richest deposits are in shear zones associated with one of the regional fracture sets. Most of the deposits are rich in autunite, but black ore, characterized by sooty pitchblende, conspicuous secondary molybdenum minerals, and minor fluorite forms the core of some autunite-rich deposits.

Analyses of 442 igneous rocks essentially complete the first phase of an investigation of the use of acid leaches in studies of the uranium geochemistry of igneous rocks. The results of this study will be used to find a leaching technique that will discriminate more clearly between uranium in rock mineral structures and that present in other situations in a rock fabric. Some results of the experiments now being completed appear to be negative, due generally to the fact that point-to-point variations in the uranium content and leachability of rocks are considerably greater than changes possibly due to geologic process or position. In general, data indicate that concurrent leaching of rock substance during weathering tends to mask any changes in uranium content due to weathering.

Studies of the reliability of using small 4-5 gram single fragments as samples of an igneous rock, in place of mechanical splits of larger samples, establish the surprising conclusion that these small samples yield more reliable data than splits of larger samples.

In a study of the disposition of uranium along the differentiates of the Apache diabase, Dripping Spring uranium district, systematic variations of uranium content and leachability were found among the differentiates. The experiment was repeated with copper, cobalt, and vanadium. From these data, it appears that copper and cobalt were probably lost in part from the diabase and that they and vanadium have been sporadically redistributed within the diabase since its crystallization.

Uranium in carbonaceous rocks

Most of the ore-grade lignite deposits of eastern Montana and the Dakotas are in shallow post-Oligocene synclines and a close relationship exists between degree of mineralization, permeability of the enclosing rocks, and proximity of the receptor beds to the pre-Oligocene erosion surface. Geochemical studies of lignite ash indicate that uranium, vanadium, arsenic, and molybdenum are among the elements present in uraniferous lignites. Analyses show similarly greater amounts of these elements in water residues from late Tertiary tuffaceous rocks than in those from Cretaceous sandstones and shales.

Core drilling in the E lignite bed of the Riley Pass area of the North Cave Hills indicates that the highest amounts of uranium generally occur in structural troughs even though the structural relief is less than 10 feet. Statistical studies indicate that an increase in uranium is associated with increases in molybdenum, arsenic, phosphorus, sulfur, scandium, vanadium, and zirconium, and with decreases in selenium and iron.

A bed of phosphatic mudstone, 0.3 to 1.0 foot thick, at the Lonesome Pete mine contains as much as 0.6 percent uranium and 17 percent P_2O_5. Dolomite and phosphate in this mudstone, together with marine shark remains in the associated rocks, suggest a marine origin.

Uranium in phosphate

Twelve drill holes in the Hardrock phosphate field, Florida, provide good sections through the Hawthorn formation and younger sediments. The stratigraphic sequence in most holes is: loose sand (top); clayey sand; clayey sand with coarse or fine phosphate; sandy phosphatic dolomite resting unconformably on Ocala limestone. This sequence is lithologically similar to that of the Bone Valley and Hawthorn formations in the land-pebble phosphate district. In nine of the twelve drill holes, radioactivity anomalies are at the top of the phosphatic beds or at the base of the overlying clayey sands. The position of the radioactive zone corresponds to that of the aluminum phosphate zone in the land-pebble district. Radioactivity anomalies occur also in unweathered phosphatic clayey sands and dolomite beds below this zone.

Uranium in natural waters

Progress was made in developing criteria for discriminating by hydrogeochemical techniques between mineralized ground and uranium ore deposits, especially in tuffaceous formations, and for discriminating between natural secondary uranium hydrodispersion haloes and the artifical effects of beneficiation by test drilling or mining. Beneficiation of ground water in a dry region (Karnes County, Texas) by test drilling resulted within the first year in an average increase of 3 times in the uranium content of surface streams nearby. A decreasing content of vanadium in ground water with depth suggests a zoning of vanadium with the greatest concentration in the upper part of the uraniferous section.

Correlation of airborne radioactivity data and areal geology

Airborne radioactivity surveys over part of the Texas Coastal Plain and in the vicinity of Galax, Virginia, indicate that lithologic units are distinguishable by the background radioactivity intensity measured above them. Airborne radioactivity surveys in Marquette and Dickinson Counties, Michigan, show that local variations in rock type are not distinguishable by airborne radioactivity measurements. Areal extent of outcrop controls the amplitude of the radioactivity anomaly. Surveys in East Pine Ridge Escarpment and Pine Mountain, Wyoming, show that elevation above the ground introduces difficulties in correlating radiometric measurements with geologic units in these areas.

Studies of the drift characteristics of radioactivity detection equipment tend to preclude contouring of airborne measurements as a significant drift may be inherent in the equipment.

Reconnaissance for uranium in Alaska

Radioactivity anomalies were found on southern Prince of Wales Island, Gravina Island, and near Skagway. Laboratory work has indicated that the mineralization at the Ross-Adams Lode on southern Prince of Wales Island is not closely related to the nearby pegmatite deposits. It is of hydrothermal origin but no structural control has been recognized.

Analytical service and research

Studies on samples of Conway granite show that the mean of the calculated thorium values (i.e., subtracting the uranium and the potassium counting equivalents from the radioactivity and multiplying the remainder by the U/Th counting rate ratio) may be used as an estimate of the mean of the determined thorium.

Results of all complete radiochemical analyses of disequilibrium samples performed to April 1956 were tabulated and classified according to type of equilibrium. Design and fabrication of a gas-scintillation counter is progressing satisfactorily, and measurements concerned with the half-life of Th^{232} are continuing.

During the period, a study of a method for determining the hafnium-zirconium ratio in zircon was completed.

In studies of the distribution of 27 minor elements in low-rank coal ashes from four states a possible correlation between uranium and molybdenum was indicated for the Dakota coals. High concentrations of tin, copper, and zirconium were found in the coals from Milam County, Texas.

Infrared spectroscopy was applied to the analysis of a variety of organic and inorganic samples, contributory to the work of other projects. Research projects involved analyses of tectosilicates and synthetic vanadates, and investigation of methods of solid-state sampling.

Generally applicable rapid methods for the determination of 0.001 percent or more of thorium dioxide in rocks and 0.01 percent or more of thorium dioxide in ores were developed. Work continues on the final objective--the development of a method for the determination of 0.0001 percent (and possibly less) of thorium dioxide in rocks.

Preliminary work was completed on the cooperative investigation of the lead content of standard granite sample G-1. Determinations on samples from five randomly selected bottles of G-1 averaged 48 ppm lead.

An automatic titration apparatus was constructed and tested for use in the ethylenediaminetetraacetic acid complexometric titration of calcium and magnesium.

Thenoyltrifluoracetone (TTA), was found to give a color reaction with uranium which is about six times more sensitive than thiocyanate. The reagent is being evaluated for the spectrophotometric determination of uranium. Optimum conditions were established for the reaction with pure uranium solutions.

A flame photometric method was developed during the period for calcium in rocks and a similar method is being studied for magnesium. A method was developed for reducing the interference of chromium in colorimetric phosphorus determinations, and a semi-micro carbon and hydrogen train was set up. A rapid method for the determination of uranium was designed for use at the Atomic Energy Commission sub-office at Spokane, Washington.

Thirteen chemists from various organizations within and without the United States were trained in methods for the determination of uranium.

Geologic and petrologic research

In the Amarillo-Wichita Uplift, east flank of the Big Horn Basin and the Delaware Basin, the extensive association of uraniferous asphaltite nodules with Permian carbonate-evaporite facies suggests that uranium is frequently mobilized and redistributed along with petroleum and natural gas during diagenesis of these kinds of rocks.

A preliminary comparison, on the basis of uranium analyses of "Silver Plume" granite from Colorado, suggests that although the upward variation in uranium content increases markedly with the size of the body being sampled, the lower limit remains fairly constant for all at about 3 ppm. The uranium contents of four "Silver Plume" dikes cutting the earlier Boulder Creek batholith conform to the geographical pattern of uranium distribution in that batholith. Results of uranium analyses on eighty 25 lb. samples of rocks from the Boulder Creek batholith itself fall into a geographic pattern whereby the average uranium content for each of the four major rock types increases approximately as follows: southern half interior $>$ northern half interior $>$ northern border $\geqq$ western border. Within any one of the geographic areas so recognized the average uranium contents fall in the expected order, quartz diorite $<$ granodiorite $<$ quartz monzonite $<$ granite.

Results of alpha activity determinations upon samples of zircon separated from 24 rocks of the Boulder Creek batholith show that the average alpha activity increases roughly systematically with the stage of magmatic differentiation. Approximate age determinations by the alpha/lead method on 24 samples of zircon from Boulder Creek batholith show that strongly crushed rocks of all types give substantially younger ages than their uncrushed correlatives and that the same crushed rocks have lower lead contents than the uncrushed rocks.

Oxidation potential measurements on some vanadium-clays indicate that the ore-forming fluids in the Morrison formation may have contained vanadium in the quadrivalent form. There is reason to believe that in some ore-forming fluids the vanadium may have been transported as vanadite ion, while the uranium was carried as uranyl carbonate complex.

Preliminary lead/alpha ages on zircon concentrates from igneous rocks of Baja, California, are in good agreement with the average age of 105 $\pm$ 10 million years obtained on 25 zircons from the Southern California batholith. Limited isotopic data on Blind River uranium ores in the Mississagi conglomerate (Lower Huronian) suggest the presence of at least two generations of radiogenic lead and an age for the present uranium ore of not older than Paleozoic. Preliminary tests indicate that the sample requirements for mass spectrometric analysis of lead using a modified electron bombardment source may be further reduced from 1 mg to approximately 50 μg of Pb.

The deuterium content of water in glassy rhyolitic rocks indicates that the water in high water content glasses is secondary. The primary water in obsidians is reasonably uniform as to deuterium content and differs from ocean waters.

Sea ice is enriched in deuterium by approximately 1.8 percent in relation to the water from which it is forming.

Studies of the variation of isotopic composition of lead in lead minerals developed new evidence bearing on the origin of metallic ore deposits, particularly from work in progress on a suite of samples from the Coeur d'Alene district of Idaho. The lead ores of this district are found to contain lead of characteristic isotopic composition, similar to other occurrences in correlative Precambrian sedimentary rocks in Montana and British Columbia, but strikingly different from occurrences in younger rocks throughout the region. The nature of this evidence suggests a number of alternatives to the orthodox hypothesis that Coeur d'Alene ores are related to the Idaho batholith in time and origin.

New studies of the relationship between plant debris and uranium on the Colorado Plateau indicate that mineralization is accompanied by an increase in organic sulfur, and by decreases in volatile content, organic hydrogen, and Btu value. Further investigation of organic isolates from impregnated sandstones shows them to be related to humic substances. Pile irradiation does not appreciably change the ultimate composition of coal.

Mineralogic and petrographic service and research

X-ray diffraction services programs show a 30 percent increase in the volume of service work over the previous six months. A two-dimensional Fourier Computer was constructed for crystal structure calculations and a high temperature diffractometer mount was constructed for clay samples.

Crystal structure studies continued on vanadium oxide minerals. Two new compounds were characterized by structure determination in a specimen from Carlile, Wyoming: $V_2O_3 \cdot V_2O_3 \cdot 3H_2O$ and $V_2O_3 \cdot 2V_2O_4 \cdot 5H_2O$. The crystal structure of doloresite also was solved. Structure studies on liebigite and johannite resulted in the refinement of the former and the solution of the latter crystal structures. These structures have led to clearer understanding of the transport of uranium in ground waters.

Geophysical service and research

The design, fabrication and testing of several new electronic devices are in progress. An experimental model of a new alpha probe was built and tested. Directional response data was compiled from tests made on several new models of scintillation probes. A "Time Interval Differentiator" was designed and fabricated for use in isotope identification. Data were compiled on the characteristics of various phototube-crystal scintillation detectors to determine counting rate as a function of temperature and source energy.

Additional work was done on the thermoluminescense equipment and an Oak Ridge Model DD-2 amplifier was built and put in operation. A continuously recording monitor for the Florida phosphate plants was assembled and tested.

Specifications for a new, stable ratemeter designed for use with scintillation loggers were written following extensive tests of available commercial models.

Calibration of gamma-ray logging equipment used in the Florida phosphate district has been completed.

Experiments with a simulated ore layer dipping 60° show that overestimations of grade and thickness will occur when gamma-ray logs from inclined ore bodies are interpreted as originating from horizontal layers.

A scintillation-type core scanner employing four crystals placed at 90° intervals around the scanning area has been completed.

Research and resource studies

Study of the association of uranium with petroleum, natural petroleum derivatives, and other natural bitumens shows: (1) a large portion of uranium in petroleum is associated with asphaltenes; (2) uranium content of crude oils bears no relationship to the geologic ages of the oils; (3) no evidence exists that petroleum acts as an ore-forming fluid for uranium; and (4) resources of uranium in crude oils are negligible.

Study of the relation of uranium deposits to tectonic elements in the Cordilleran Foreland suggests: (1) clusters of deposits appear to be preferentially located on large-scale regional structures; and (2) deposits associated with large-scale structures are further localized by smaller scale structures. Areas on margins of large-scale structures where smaller scale structures have an en echelon pattern are particularly favorable for deposits.

Study of the relationship between uranium and 30 other elements in 111 samples of lignite and lignitic shales from South Dakota shows a positive correlation exceeding the 5 percent level of significance between the relative amounts of uranium and the four elements, As, Mo, Sc, and Zr.

Study of the relationship between uranium-bearing veins and their host rocks shows that veins are in all varieties of rocks but are most abundant in holocrystalline igneous and metamorphic rocks characterized by moderate to high silica contents; these host rocks have widely variable chemical composition but have similar physical characteristics in that they tend to rupture under stress rather than undergo plastic deformation.

URANIUM IN SANDSTONE-TYPE DEPOSITS ON THE COLORADO PLATEAU

Geologic mapping

Geologic mapping as part of the uranium investigations on the Colorado Plateau was started in southwestern Colorado early in 1947. Since that time the original program has been extended and prior to this report period field work has been completed in the following areas: Southwestern Colorado; Monument Valley, Arizona; Mounument Valley, Utah; Carrizo Mountains, New Mexico; Capitol Reef, Utah; White Canyon, Utah; Red House Cliffs, Utah; and Deer Flat, Utah. During the report period field and office work continued in the following areas: Bull Canyon district, Colorado; Slick Rock district, Colorado; Uravan district, Colorado; Western San Juan Mountains, Colorado; Ute Mountains, Colorado; Gateway district, Colorado and Utah; Sage Plain, Utah and Colorado; La Sal Creek area, Colorado and Utah; Lisbon Valley, Utah and Colorado; Moab-Inter-river area, Utah; Orange Cliffs area, Utah; San Rafael Swell, Utah; Circle Cliffs area, Utah; Elk Ridge area, Utah; Abajo Mountains, Utah; East Vermillion Cliffs area, Arizona; Grants area, New Mexico; Laguna area, New Mexico; and Hopi Buttes, Arizona.

During the report period the following papers were published on geologic work previously completed on the Colorado Plateau:

Cater, F. W., Jr., 1956, Geology of the Davis Mesa quadrangle, Montrose County, Colorado, with a section on the mines by Leonid Bryner: U. S. Geol. Survey Geologic Quadrangle Map GQ-71.

Cater, F. W., Jr., 1956, Geology of the Anderson Mesa quadrangle, Colorado: U. S. Geol. Survey Geologic Quadrangle Map GQ-77.

Cater, F. W., Jr., and McKay, E. J., 1956, Geology of the Uravan quadrangle, Colorado: U. S. Geol. Survey Quadrangle Map GQ-78.

Jobin, D. A., 1956, Regional transmissivity of the exposed sediments of the Colorado Plateau as related to distribution of uranium deposits, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 317-320: New York, United Nations.

Phoenix, D. A., Relation of carnotite deposits to permeable rocks in the Morrison formation, Mesa County, Colorado, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 321-325: New York, United Nations.

Sears, J. D., 1956, Geology of Comb Ridge and vicinity north of San Juan River, San Juan County, Utah: U. S. Geol. Survey Bull. 1021-E.

Shoemaker, E. M., 1956, Geology of the Juanita Arch quadrangle, Colorado: U. S. Geol. Survey Geologic Quadrangle Map GQ-81.

Trites, A. F., Jr., 1955, Mineralogy and geochemistry of the uranium deposits in the White Canyon area, San Juan County, Utah (abs.): Econ. Geology, v. 50, no. 7, p. 795.

__________, 1956, Uranium deposits in the White Canyon area, San Juan County, Utah, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 379-382: New York, United Nations.

Withington, C. F., 1956, Geology of the Paradox quadrangle, Montrose County, Colorado: U. S. Geol. Survey Geologic Quadrangle Map GQ-72.

Bull Canyon district, Montrose and San Miguel Counties, Colorado
By R. M. Wallace and E. S. Santos

Three areas in the Bull Canyon district were investigated by diamond drilling during the report period: Wild Steer Mesa and Jo Dandy, within the Uravan mineral belt, and Dry Creek Basin, outside the belt (figs. 1 and 2).

Drilling on Wild Steer Mesa indicates that nearly all known uranium-vanadium ore deposits in the upper sandstone beds of the Salt Wash member of the Morrison formation are clustered in east-trending groups. These groups are bordered on the north and south by ground characterized by thin sandstone beds between thick red mudstone layers, which is considered

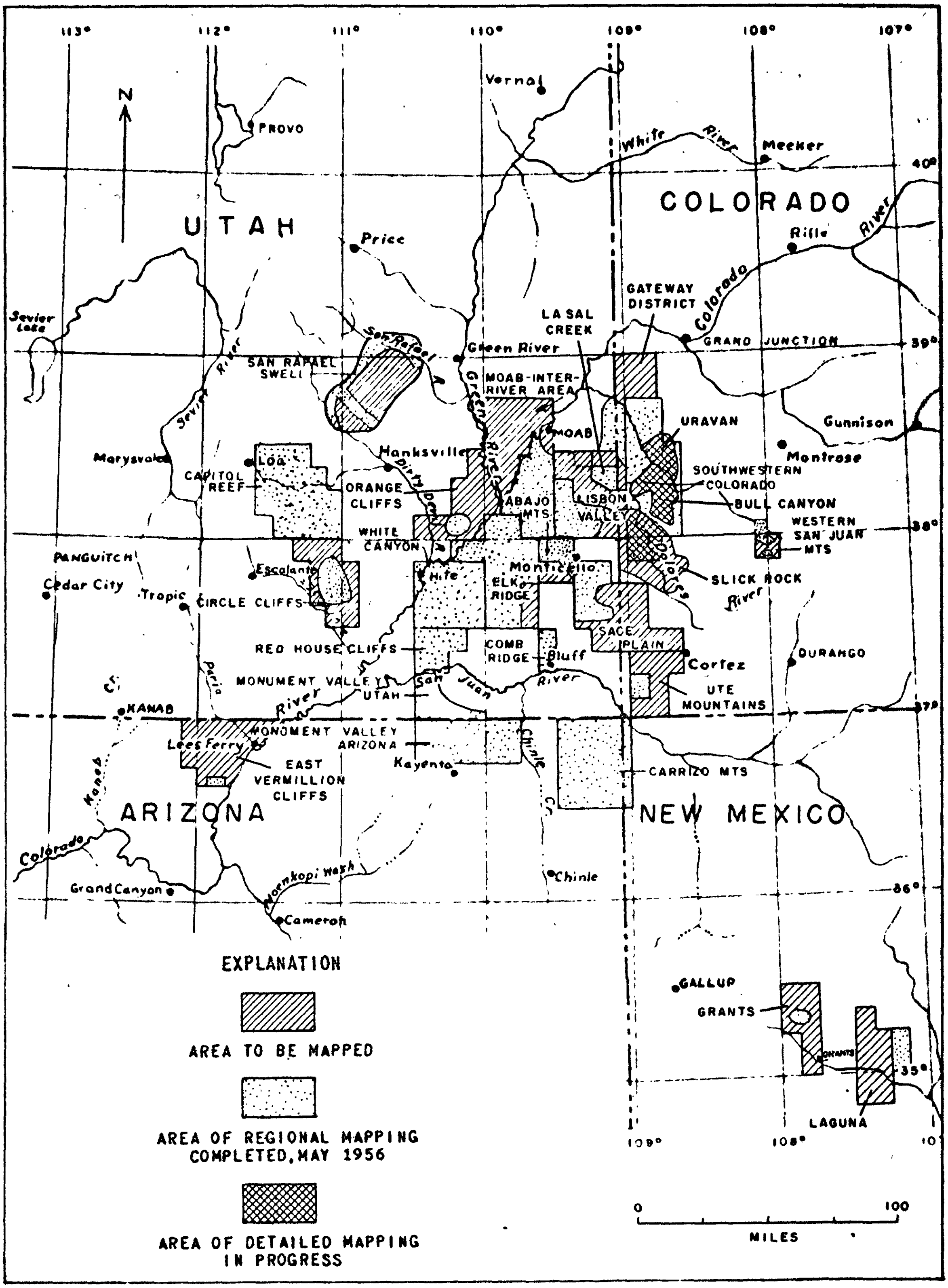


FIG. 1--INDEX MAP OF PART OF THE COLORADO PLATEAU SHOWING LOCATION OF MAPPING PROJECTS.

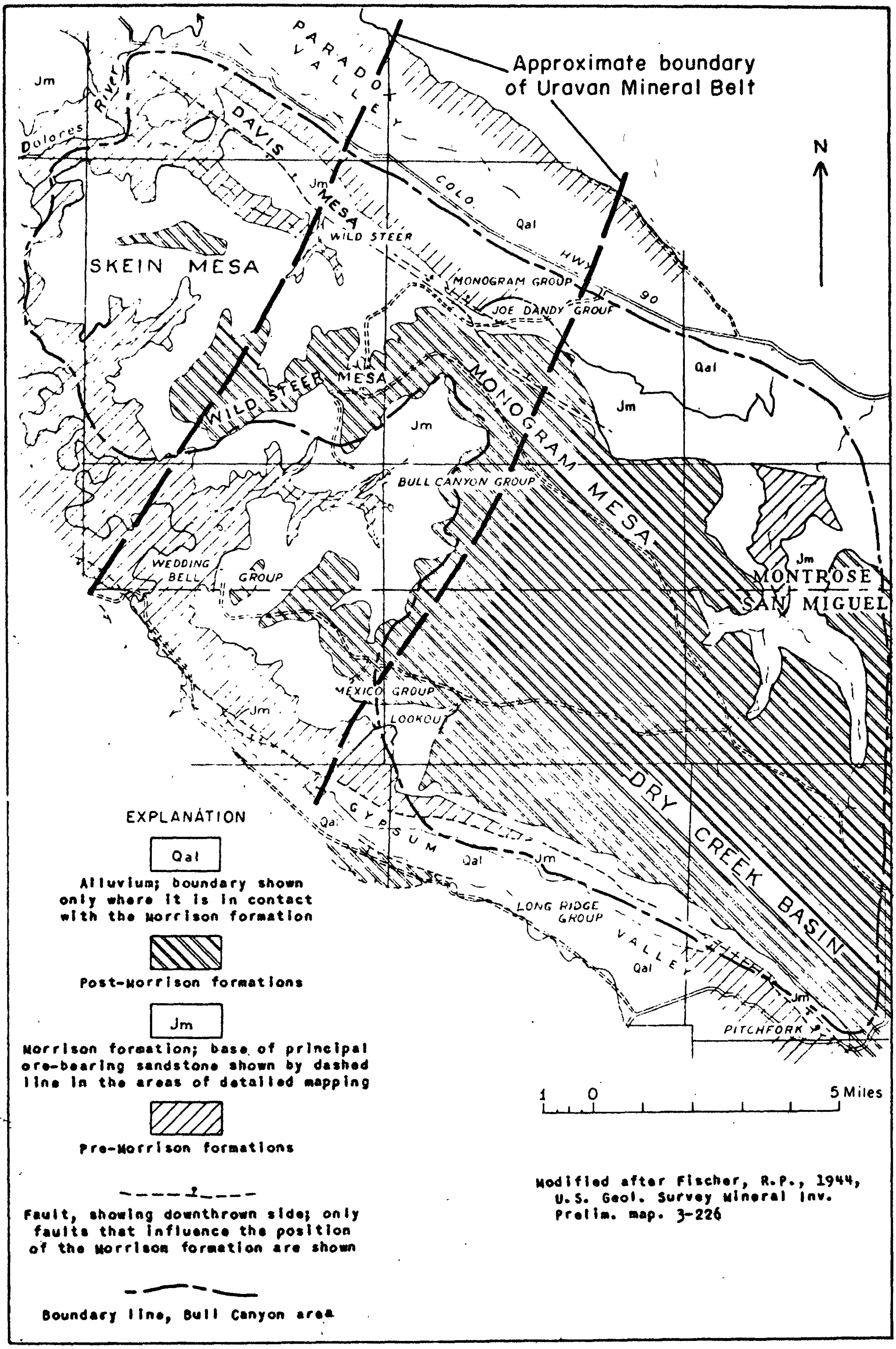


FIG. 2 --GENERALIZED GEOLOGIC MAP, BULL CANYON AREA, MONTROSE AND SAN MIGUEL COUNTIES, COLORADO.

unfavorable for the occurrence of uranium-vanadium deposits. The ore deposits occur where the upper sandstone beds of the Salt Wash aggregate more than 25 feet in thickness, are overlain and underlain by as much as several feet of green mudstone, and contain relatively abundant carbonaceous material.

A diamond-drill hole in the Jo Dandy area, collared in the Brushy Basin member of the Morrison formation of Jurassic age and bottomed in the Rico-Cutler formation of Permian age at a depth of 1,087 feet penetrated no Navajo sandstone, Kayenta formation, or Wingate formation. The absence of these units may be accounted for by pre-Entrada erosion or nondeposition inasmuch as there is no evidence in the cores of faulting.

Dry Creek Basin was drilled to test the nature of the Salt Wash member of the Morrison formation in that area. It was found that: (1) there is no positive correlation of the lithologic units in the Salt Wash member with those previously mapped at the outcrop on the northeast flank of Gypsum Valley and those cut by drill holes 3,500 to 5,000 feet northeast of the outcrop, down the dip; (2) the Morrison formation thickens abruptly directly down dip from the Gypsum Valley anticline, as do other formations peripheral to salt intrusions (Shoemaker, E. M., written communication), thins near the center of Dry Creek Basin, and thickens again near the Paradox Valley salt anticline; and (3) the calcite content of the Morrison formation, the number of green mudstone units in the Salt Wash member, and the amount of corrosion and bleaching of the constituent minerals and loss of siliceous cement in the Salt Wash sandstone units, increase from the northwest part of Dry Creek Basin to the southeast part.

Detailed outcrop mapping of the Morrison formation is in progress in the Davis Mesa and Skein Mesa areas to determine if synclinal structures similar to those in Dry Creek Basin are present northwest of the Uravan mineral belt.

Slick Rock district, San Miguel and Dolores Counties, Colorado
By D. R. Shawe, G. S. Simmons, and W. B. Rogers

Stratigraphic studies

Compilation of stratigraphic sections in a part of the Slick Rock district shows that most of the sedimentary formations exposed are appreciably thicker in the northwestern end of Disappointment Valley along the Disappointment syncline, than along the adjacent Dolores anticline. Exceptions are the marine or marginal marine Summerville and Carmel formations of Jurassic age.

The Early Cretaceous age designation of the Burro Canyon formation was corroborated by identification of fossils in suites collected at two localities in Disappointment Valley. Both localities are in NE$\frac{1}{4}$ NW$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 11, T. 43 N., R. 18 W., San Miguel County, Colorado. Concerning these fossils from the upper part of the Burro Canyon formation John B. Reeside, Jr. of the Geological Survey (written communication, 1956) states, "The record of invertebrates and plants closely associated in the Burro Canyon is particularly welcome. The invertebrates are the first that I know of and help to assure the accepted correlation between the Burro Canyon and the Cedar Mountain and between these units and others in the western interior." Fossils from a greenish brown silty sandstone about 18 feet below the top of the Burro Canyon formation, identified by Reeside, include Protelliptio douglassi Stanton, "Unio" farri Stanton, Nippononaia n. sp., a viviparid gastropod, an ostracode, and a ganoid fish scale. Fossils from a black fissile shale about 25 feet below the top of the Burro Canyon formation, identified by R. W. Brown (Reeside, written communication, 1956), include Frenelopsis varians Fontaine, Pinus susquaensis Dawson, fern pinnules, a ganoid fish scale, and ostracodes.

In a second report, on fossils taken from core of the lower 855 feet of the Mancos shale in SE$\frac{1}{4}$ NE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 20, T. 43 N., R. 16 W., Reeside (written communication, 1956) states:

> "The Mancos shale can perhaps best be classified by equivalence to subdivisions recognized in the Great Plains. I would assign the highest fossils in the cores to a later Niobrara equivalent and would extend this to about 225 feet depth. In this interval Inoceramus stantoni Sokolow, Baculites codyensis Reeside, B. asper Morton, Phlycticrioceras oregonense Reeside are more distinctive species, and Ostrea congesta Conrad ranges throughout. The next 150 feet, to about 375 feet depth, must represent the earlier Niobrara, but there are few distinctive fossils in the cores. I would assign the next 170 feet, to about 540 feet depth, to the later Carlile, in which interval Inoceramus dimidius White, I. fragilis Hall and Meek, Scaphites whitfieldi Cobban, S. ferronensis Cobban, Prionocyclus macombi Meek, and P. wyomingensis Meek are distinctive. The next 240 feet, to about 780 feet depth, must represent the earlier Carlile, but Collignoniceras hyatti Stanton in the upper part and C. woollgari Mantell in the lower part are the only distinctive fossils. One would expect a late Greenhorn fauna in the next 45 feet, to 825 feet depth, but nothing distinctive is available. The remaining cores, to 855 feet depth, contain chiefly Gryphaea newberryi Stanton, which is associated with the early Greenhorn, in Gilbert's original sense of the name, or with the next-to-the-top of four units, in the broader sence of Greenhorn now prevalent. G. newberryi is widespread in Utah, western Colorado, and Arizona at or near the base of the marine Upper Cretaceous beds."

Heavy mineral studies

Studies continued of heavy minerals in sandstone strata, largely in the Morrison formation of the Slick Rock district. Tentative conclusions are that two types of diagenetic changes took place in the sediments after they were laid down, and a third type of alteration took place still later.

One type of diagenetic change took place where no carbonaceous material was deposited with the sediments. Magnetite and ilmenite that constituted about half of the original heavy minerals were altered largely to hematite and leucoxene respectively, retaining however their original detrital form. Iron from both magnetite and ilmenite moved locally and formed hematite films coating quartz and other grains. The alteration of original magnetite and ilmenite and formation of hematite undoubtedly occurred under oxidizing conditions. Minerals such as hornblende and augite were probably present in the original volcanic material that constitutes a considerable proportion of many of the sedimentary formations. These minerals were almost completely dissolved into the intrastratal solutions which have more or less permeated the sediments since burial and may have supplied more iron. The reddish color of rock that was originally a noncarbonaceous sediment is notable.

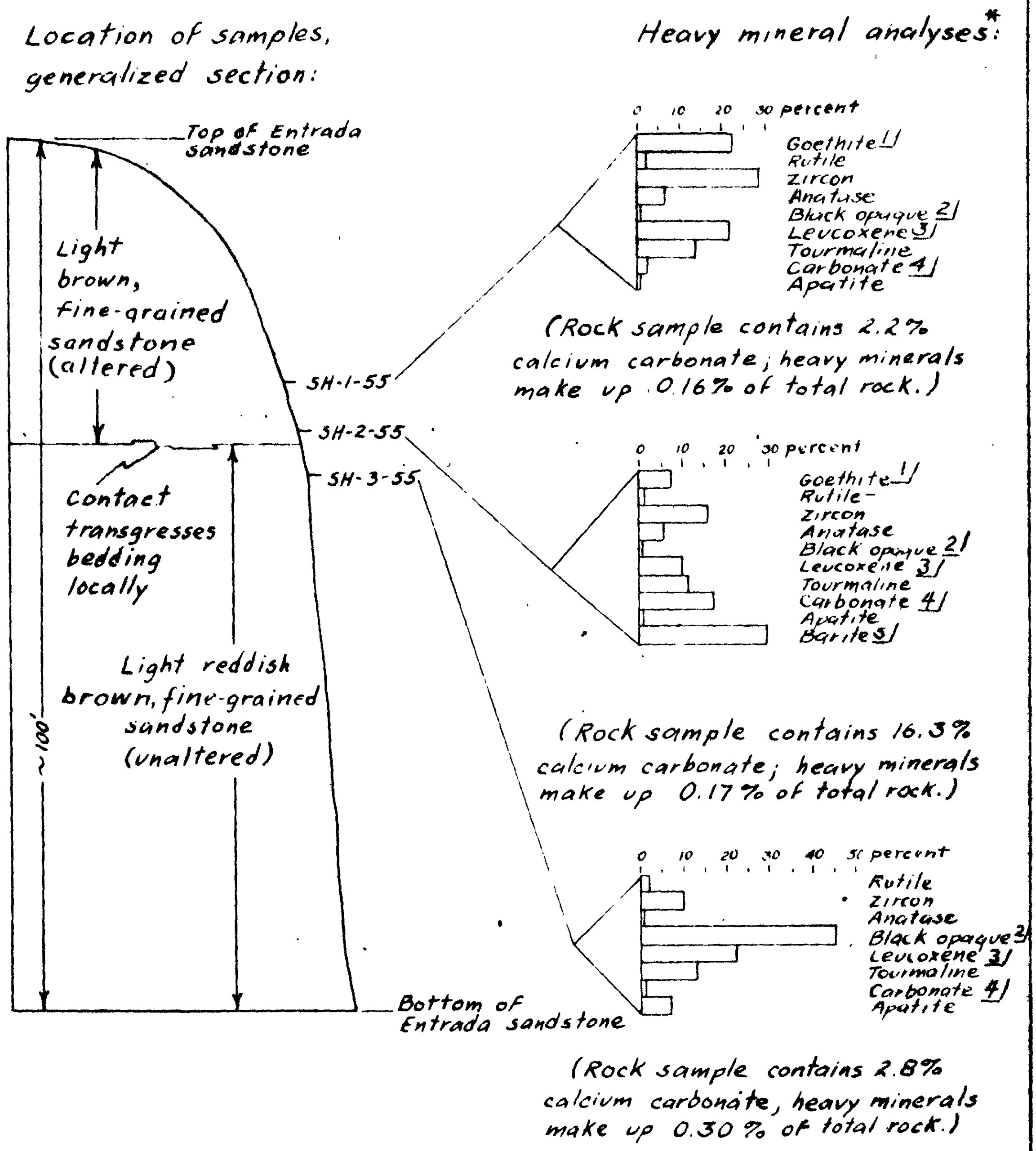
Where carbonaceous material was deposited with the original sediments, a different type of diagenetic change took place. In rocks formed from these sediments, magnetite and ilmenite were not altered as extensively, nor did iron migrate locally to form hematite films on quartz grains. Instead, pyrite was formed, and this alteration probably took place under reducing conditions. Original hornblende and augite largely disappeared. Rocks formed from these sediments are characteristically light gray to greenish gray in color.

These two types of diagenetic changes, one forming reddish and the other light gray colors in the sedimentary rocks, took place independently of one another, and at the same time. One type did not develop from the other type.

Through uplift and erosion, these oxidized and reduced types of sedimentary rocks were exposed to air above the water table or to oxygenated water, the reduced rock components were oxidized, and the color changed.

Pyrite oxidized to limonite, and the rock color changed from light gray to light yellowish brown. No apparent change is believed to have taken place in the reddish sediments in the near-surface oxidizing environment.

In addition to the two types of diagenetic changes discussed, a third type of alteration took place; its recognition has been hindered by the fact that it is characterized by the light gray to greenish gray color associated with one type of earlier diagenetic alteration. That this third type of alteration took place after the others is in part indicated by features such as bleaching of reddish sediments along fractures in many of the formations. Other effects have been found by studying heavy minerals; chief among them is the almost complete absence of magnetite, ilmenite, and hematite in any form, as well as of originally sparse garnet. In some of the rocks where the third type of alteration has taken place, barite--which in rocks affected by diagenetic changes only is largely interstitial cement--has been recrystallized into clear euhedral crystals. In addition, some leucoxene has recrystallized into authigenic anatase. Sparse galena and sulfides other than pyrite are found as much as 50 feet vertically and several hundred feet laterally from ore deposits in sandstone, and pyrite is concentrated in places near ore. The apparent redistribution of pyrite is analogous to that of calcium carbonate reported in the previous semiannual report (TEI-590, p. 29). These changes are evident in two principal locales: (1) light gray sedimentary rocks (light brown where oxidized) where no carbonaceous material is found--for an example in the Entrada sandstone, see figure 3; and (2) in carbonaceous light gray or light brown rocks, but in these only close to ore deposits--for an example in the Salt Wash sandstone, see figure 4.



1/ Goethite probably altered from pyrite

2/ Black opague is dominantly hematite, subordinately magnetite and ilmenite

3/ Leucoxene probably altered from ilmenite

4/ Carbonate is probably dolomite (sp. gr. > 2.8)

5/ Barite is partly recrystallized

* Heavy minerals separated in bromoform, sp. gr. > 2.8; percentages based on counts of 200 grains in -150+200 mesh fraction.

Fig. 3 – Diagram showing heavy mineral content of samples from the Entrada sandstone, Slick Rock district, Colorado.

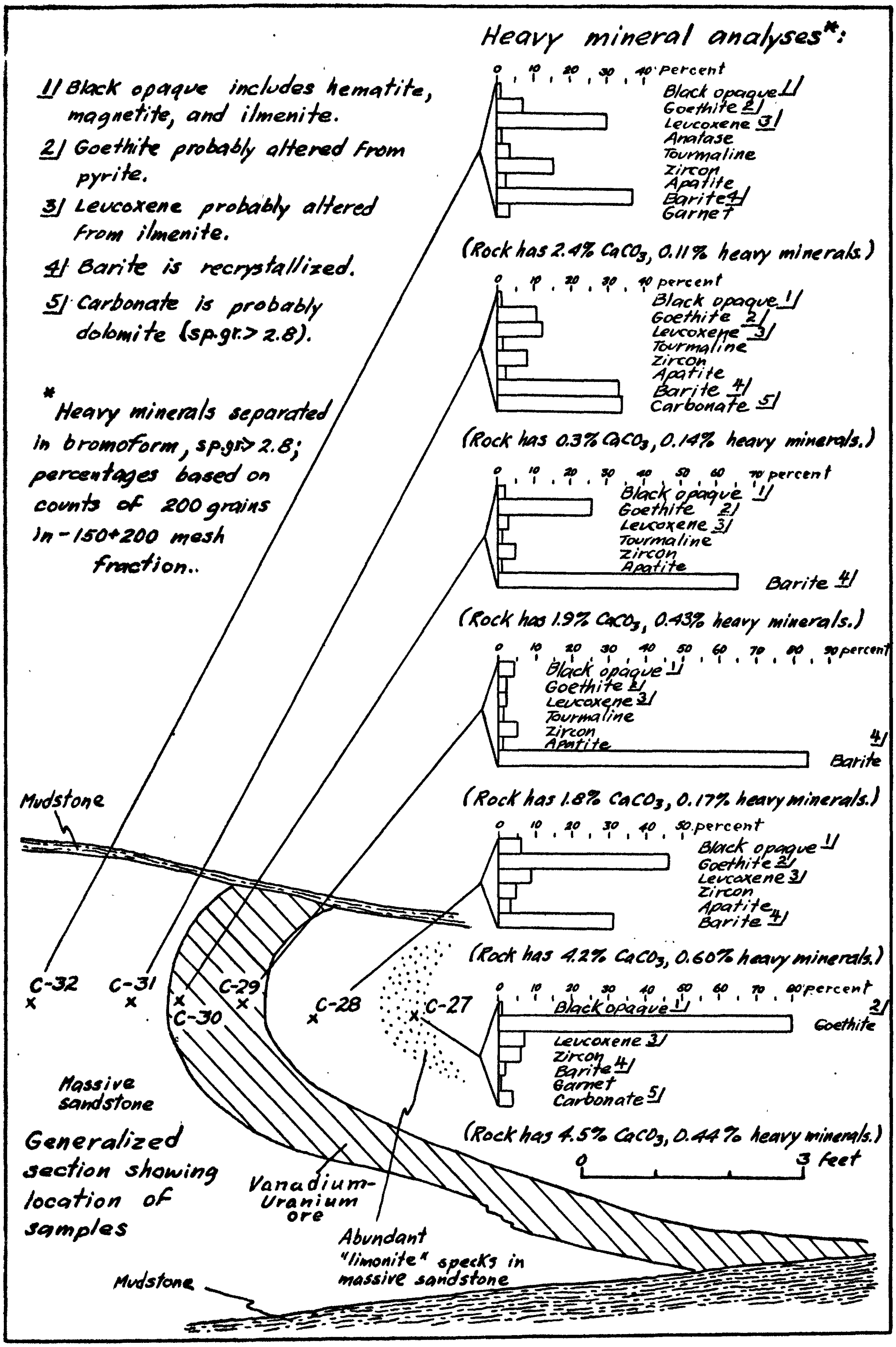


Fig. 4 - Diagram showing heavy mineral content of samples in and near an ore roll in the Salt Wash sandstone, Cougar mine, Slick Rock district, Colorado.

It is concluded that carbonaceous material, deposited locally in the sedimentary rocks of the Colorado Plateau, enabled a diagenetic change to take place under reducing conditions while oxidation prevailed elsewhere. Later, ore-forming solutions with strong solvent powers moved laterally through the sedimentary rocks, leaching and recrystallizing some rock constituents untouched by the earlier changes. It is suggested that where these solutions traversed carbon-bearing strata, uranium-vanadium ore deposits were formed in the strongly reducing environment.

The following reports covering work in the Slick Rock district were published during the period:

Archbold, N. L., 1955, Relations of calcium carbonate to lithology and vanadium-uranium deposits in the Salt Wash sandstone member of the Morrison formation (abs.): Geol. Soc. America Bull., v. 66, no. 12, pt. 2, p. 1526: Econ. Geology, v. 50, no. 1, p. 766.

Shawe, D. R., 1956, Significance of roll ore bodies in genesis of uranium-vanadium deposits on the Colorado Plateau, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 335-337: New York, United Nations.

Uravan district, Montrose County, Colorado
by R. L. Boardman, H. E. Bowers, L. R. Litsey, and C. T. Sumsion

During the winter of 1955-56, compilation was begun of geologic data from 660 Survey diamond-drill holes in the Club Mesa area and from 1,400 Survey diamond-drill holes in the Long Park and adjacent areas in the southern part of the Uravan district, Montrose County, Colorado. Base maps of these areas, showing pertinent subsurface geologic data and accompanying texts, are being prepared to show and describe the complex relationships of the principal ore-bearing sandstone units in the upper part of the Salt Wash member of the Morrison formation of Jurassic age.

Study of geologic logs of core and cuttings from Survey drill holes in the Club Mesa area shows the relative thickness of the ore-bearing Salt Wash sandstone units, and the amount of gray or green mudstone and siltstone in contact with these units, to be the most consistent recognizable geologic criteria associated with mineralized rock and ore deposits. Approximately 86 percent of the 181 holes in mineralized Salt Wash sandstone beds (rock containing 0.02 percent or more U_3O_8 or 0.1 percent or more V_2O_5) and 93 percent of the 74 holes in ore (rock 1 foot or more thick containing at least 0.1 percent U_3O_8 or 1.0 percent V_2O_5) penetrated host sandstone units 30 feet or more thick that are in contact with at least 6 inches of gray or green mudstone and siltstone. These mudstone and siltstone beds may be at the top, base, or included in the host sandstone unit. If these minimum thickness cutoffs are used, about 10 percent of the area of approximately 4 square miles explored on Club Mesa can be considered favorable for the occurrence of ore deposits and would contain nearly all of the ore reserves discovered by Survey drilling.

All of the large uranium-vanadium deposits found by Survey drilling in the Club Mesa area are in or near the thickest parts, locally, of the host sandstone units, and generally are within a few hundred feet of places where these units thin abruptly. Where ore was found by Survey drilling, the host sandstone unit ranges in thickness from 25 to 96 feet, and averages about 50 feet thick. About 77 percent of the holes in ore, accounting for nearly 90 percent of the predicted ore reserves, penetrated host sandstone units ranging in thickness from 30 to 60 feet.

All but one of the ore deposits discovered by Survey drilling on Club Mesa are in the uppermost recognizable Salt Wash sandstone unit. In the northeastern part of the mesa the ore deposits commonly are near places where the uppermost sandstone unit has channeled into the next lower sandstone unit.

The ore deposits are in the bottom half of the host sandstone unit in about 90 percent of all the holes penetrating ore in the Club Mesa area; the ore deposits are in the bottom quarter of the unit in more than 60 percent of the total ore holes.

During the period the following paper on geologic investigations in the Uravan district was published:

Boardman, R. L., Ekren, E. B., and Bowers, H. E., 1956, Sedimentary features of upper sandstone lenses of the Salt Wash member and their relations to uranium-vanadium deposits in the Uravan district, Montrose County, Colorado, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 331-334: New York, United Nations.

Western San Juan Mountains, Colorado
By A. L. Bush, R. B. Taylor, O. T. Marsh, and C. S. Bromfield

The relationship between the vanadium-uranium deposits of the Placerville district, Colorado, and the base and precious metal deposits and intrusive and extrusive igneous rocks of the San Juan volcanic province is being studied over an area of about 300 square miles comprising the Placerville, Little Cone, Gray Head, Dolores Peaks, and Mt. Wilson 7-1/2 minute quadrangles (fig. 5).

Numerous sills, dikes, larger discordant plutons, and a few flows are present in the area. During the report period, preliminary petrographic examinations of thin sections from these rocks in the Placerville, Little Cone, and Dolores Peaks quadrangles have shown a variety of rock types, apparently associated with three major centers of igneous activity.

The sills and dikes in the southeastern part of the Placerville quadrangle and the northern part of the Little Cone quadrangle appear to be

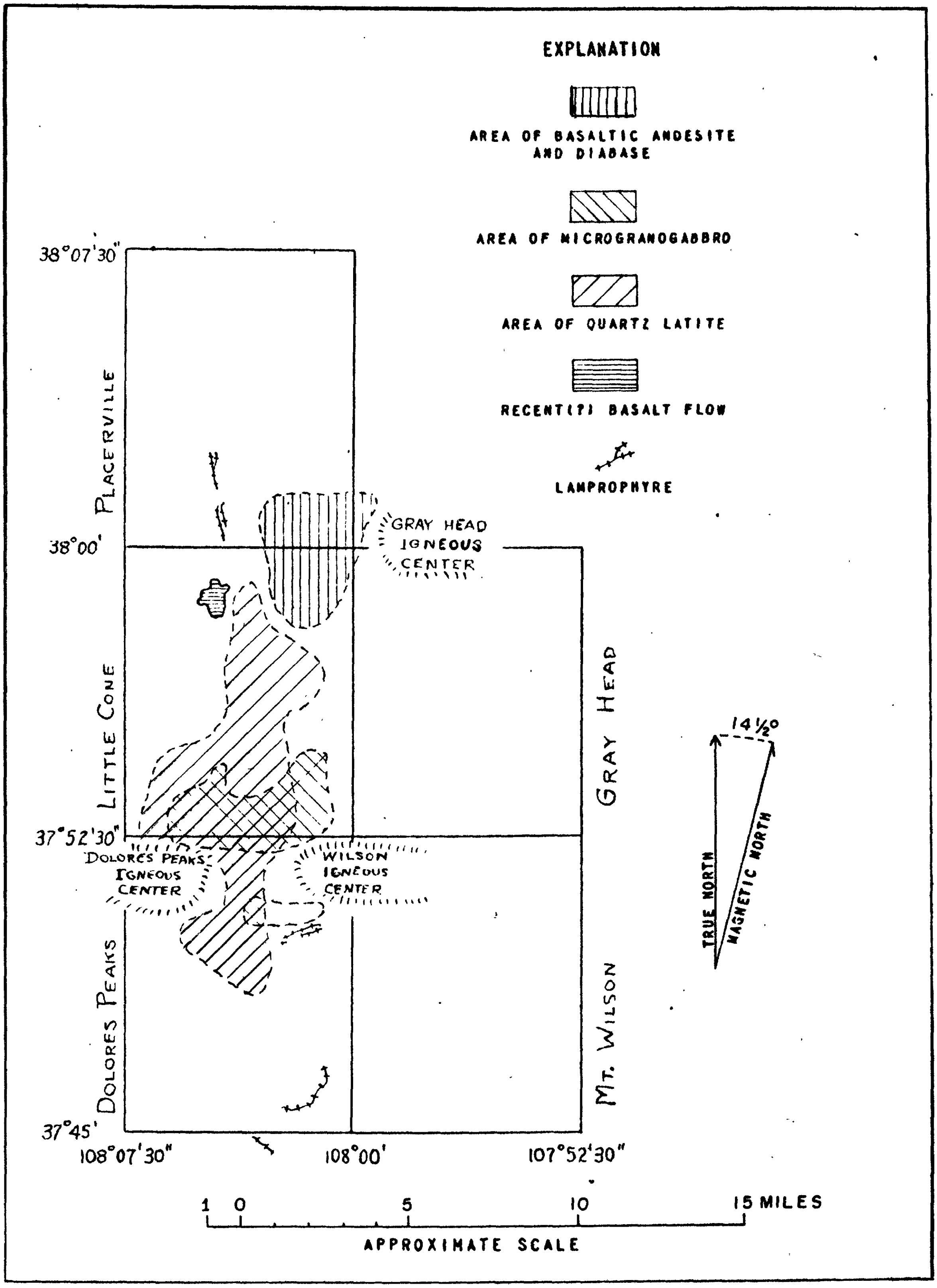


FIG. 5— SKETCH MAP OF A PART OF THE WESTERN SAN JUAN MOUNTAINS, SHOWING SOME OF THE AREAS UNDERLAIN BY IGNEOUS ROCKS AND THEIR RELATION TO CENTERS OF IGNEOUS ACTIVITY.

related to the Gray Head center (fig. 5). This center includes the Gray Head laccolith and other large intrusive masses. The sills and dikes are classified as microgabbro (diabase) and basaltic andesite.

The Wilson igneous center, in the northeastern corner of the Dolores Peaks quadrangle and the northwestern part of the Mt. Wilson quadrangle, consists of the Wilson stock and other smaller intrusions. The Wilson stock is a zoned mass with a border zone of pyroxene granogabbro (quartz-orthoclase gabbro). The intermediate zone is pyroxene quartz monzonite, which may grade into granite in the center of the stock. The cause of the zoning has not been established, but a combination of multiple intrusion and marginal and vertical differentiation is most probable. All specimens of the stock that have been examined show close affinities to the pyroxene granogabbro of the border zone; alkalies and silica are enriched toward the center of the stock, and the mafic minerals progressively change from hypersthene and augite to hornblende and then to biotite from the border to the center of the stock. Minor pluglike intrusives nearby are of granogabbro, and are probably closely related to the Wilson stock.

A small quartz monzonite stock, also a part of the Wilson igneous center, is northwest of the Wilson stock. It too is zoned, with a border of porphyritic quartz-latite and a center of quartz monzonite. The central parts show late stage enrichment in potash feldspars; porphyroblastic perthite crystals have replaced earlier minerals, and plagioclase has been veined by potash feldspar.

Numerous sills and dikes of microgranogabbro (microgranular quartz-orthoclase gabbro) and of quartz latite (ranging to rhyodacite) are present in the Little Cone quadrangle. Sills and dikes of microgabbro and basaltic andesite, mentioned above, are present only in the northeastern corner.

The microgranogabbro sills are probably related to the Wilson stock; the textures and mineral composition are almost identical to the border rocks of the stock. The microgranogabbro is distinguished by strongly zoned labradorite crystals in a groundmass of feldspars and quartz, and by a hypidiomorphic-granular texture.

The igneous center from which the quartz latite sills were derived is not definitely known. The sills have phenocrysts of andesine set in an aphanitic groundmass. The sills are probably not related to the small adamellite stock, despite the fact that the stock has a border zone of porphyritic quartz latite. Quartz phenocrysts are absent in the sills, and the sill feldspars show little zoning, in contrast to the strong oscillatory zoning of the stock feldspars. Similar quartz latite sills are also found in the central part of the Dolores Peaks quadrangle. It is possible that these sills were derived from the Dolores Peaks igneous center (fig. 5) of which little is as yet known.

A small number of lamprophyre dikes and sills are also present; they include augite minette, biotite vogesite, limburgite and monchiquite. They apparently are later than, and not directly associated in genesis with the intermediate intrusives. A Recent(?) vesicular basalt flow in the Little Cone quadrangle represents the last igneous activity.

Ute Mountains, Colorado
By E. B. Ekren and F. N. Houser

A petrographic study of the igneous rocks of the Ute igneous complex was begun during the report period. This study, together with geologic mapping and spectrographic and chemical analyses of samples, will provide basic data on possible relations between the intrusive igneous rocks and uranium deposits in the sediments of the area.

Most of the rocks studied are diorite or andesite porphyries. Dacites, quartz monzonites, and a lamprophyre (spessartite?) are indicated by modal analyses. The groundmass of most specimens is too fine grained to be fully evaluated by microscope techniques. In most of several thin sections treated with sodium cobaltinitrite, potash feldspars are confined to the dense groundmass. The average anorthite content of the plagioclase phenocrysts is 30 to 60 percent, whereas groundmass plagioclase ranges in composition from about 20 to 30 percent anorthite. Zoning of the plagioclase feldspars is pronounced; some basic cores are 82 percent anorthite whereas outer zones are 15 percent anorthite. Zoned epidotes are present in some specimens. Zeolites in the lamprophyre type are common; the most prevalent appears to be thomsonite.

Some rocks are considerably altered. For example, one rock from the vicinity of Sentinel Rock in the extreme southeastern part of the Ute igneous complex contains plagioclase altered to calcite, sericite, biotite, and chlorite, and hornblende altered to chlorite, biotite, and calcite. Apatite is seemingly more abundant in altered specimens than in unaltered rock of similar type.

The most conspicuous structural feature of the Sentinel Peak NE 7-1/2 minute quadrangle is a doming of the sedimentary rocks in the extreme northeastern part of the quadrangle, which is believed to indicate a buried laccolith. The dome is several miles in diameter and extends into quadrangles to the north and west. Northeast-trending, high angle normal faults of 25 to 50 feet displacement cut the southwest flank of the dome. The oldest sediments exposed on the dome are mudstones and sandstones of the Brushy Basin member of the Morrison formation. It is believed that this buried laccolith is intruded into a shale or mudstone facies as are many of the known intrusives of the Utes and other laccolithic groups on the Colorado Plateau. The abrupt steepening of dip around the flanks of the dome suggests that the laccolith is not buried deeply, and it may have been intruded into mudstones and siltstones of the Chinle formation of Triassic age or the Summerville formation of Jurassic age.

The rocks of the rest of the Sentinel Peak NW 7-1/2 minute quadrangle dip gently to the southwest as shown by elevations obtained at the base of the Mancos shale. Superimposed on the regional dip are several minor flexures, the largest of which is a structural nose that trends southwest across the northwest part of the quadrangle and plunges with the regional dip.

No abnormal radioactivity was noted in surface rocks in the Sentinel Peak NW quadrangle either along bedding or along fractures. The Salt Wash member, the Recapture member, and the Westwater member of the Morrison formation, the most likely hosts for uranium deposits in the region, are not exposed in the quadrangle. The Salt Wash member is exposed several miles to the north in the Moqui SW quadrangle and the Westwater and Recapture members are exposed to the east in the Sentinel Peak NE quadrangle. The Salt Wash and Westwater members where exposed appear to be favorable for uranium mineralization.

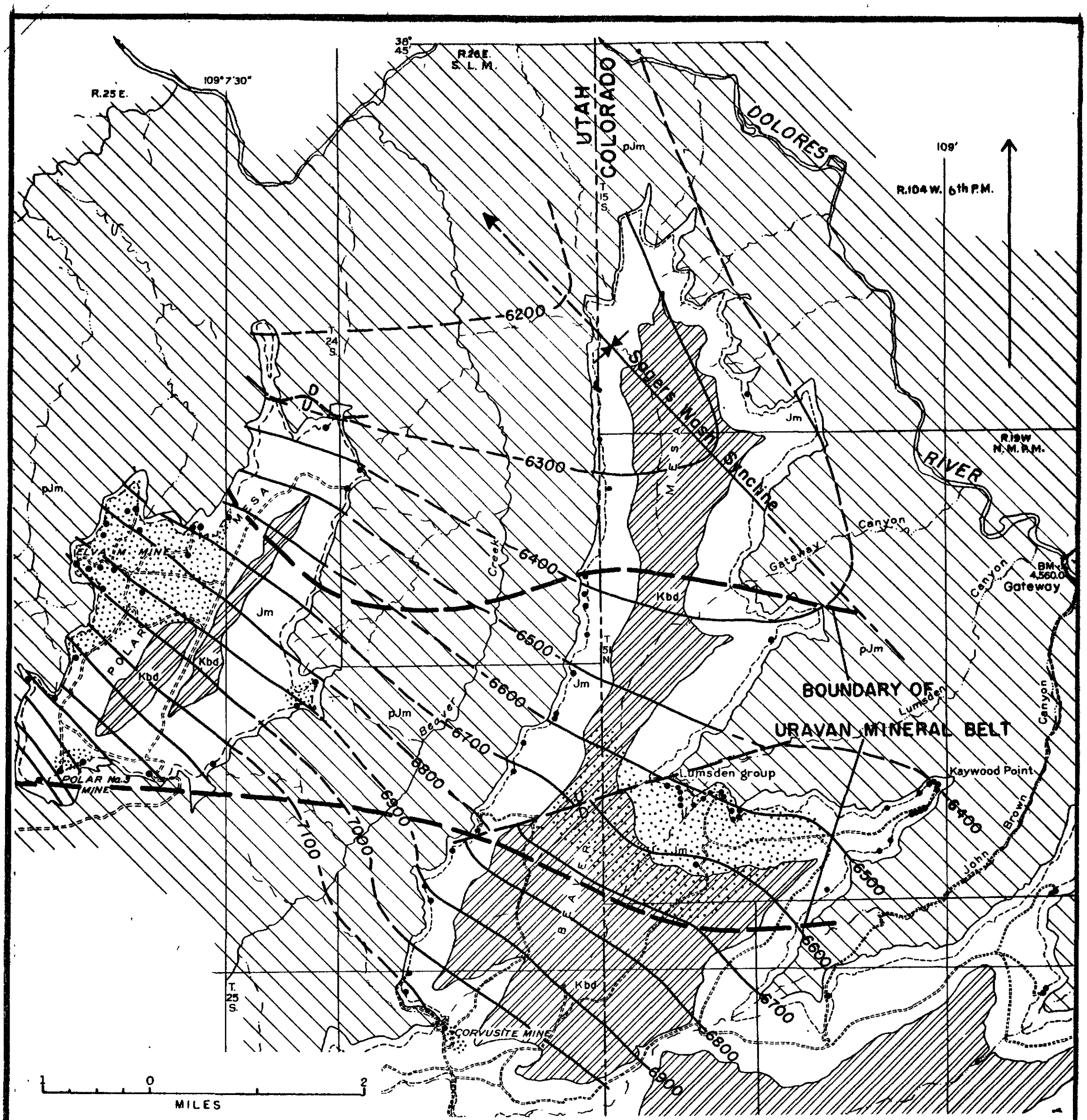
Gateway district, Mesa County, Colorado, and Grand County, Utah
By L. J. Eicher and G. A. Miller

Field work in the western part of the Gateway district, west of the Dolores River and on the northeast flank of the La Sal Mountains, was completed in November 1955. Beaver and Polar Mesas, where geologic work was concentrated, are on the southwest limb of the Sager's Wash syncline (fig. 6). Preparation of areal and structural geologic maps of the area (scale 1:24,000), maps of the larger mines (scale 1:240), and study of polished sections of mineralized material from several mines constituted the major part of the work during the report period.

The rocks on Polar Mesa and the southern two-thirds of Beaver Mesa strike N. 55°-60° W. The average dip on Polar Mesa is about 4° NE. The dip flattens to about 2° on the southern two-thirds of Beaver Mesa. The axis of the Sager's Wash syncline crosses the northern end of Beaver Mesa (fig. 6).

The major uranium-vanadium producing area on Beaver Mesa is in a structural low that is superimposed on the generally northeastward dipping beds. This structural low trends N. 70°-80° E. and is 1 to 1.5 miles wide. It is bounded on the northwest by a vertical fault of about 90 feet displacement and on the southeast by a gentle monoclinal fold.

Most of the known uranium-vanadium deposits containing more than 500 tons of ore in the western part of the Gateway district are in sandstone lenses in the upper half of the Salt Wash member of the Morrison formation of Jurassic age. The most favorable host rock within this part of the Salt Wash is a light gray or light brown, medium-fine to medium-grained sandstone that contains carbonaceous material and thin splits, seams, and/or pebbles of green mudstone. One to five feet of green mudstone



EXPLANATION

Kbd

DAKOTA AND BURRO CANYON FORMATIONS (CRETACEOUS)

Jm

MORRISON FORMATION (JURASSIC) BASE OF MAIN ORE BEARING SANDSTONE SHOWN BY DASHED LINE; DOTTED WHERE INFERRED

pJm

PRE-MORRISON FORMATIONS (JURASSIC AND OLDER)

Note: Base map from Stokes, Russell, Fischer, Butler 1943

U / D

FAULT, DASHED WHERE APPROXIMATELY LOCATED; (U, UPTHROWN SIDE; D, DOWNTHROWN SIDE)

7000

STRUCTURE CONTOUR DRAWN ON TOP OF ENTRADA FORMATION

URANIUM-VANADIUM MINE OR PROSPECT

AREA UNDERLAIN BY CLOSELY SPACED URANIUM-VANADIUM DEPOSITS

FIG. 6--GEOLOGIC MAP OF THE WEST GATEWAY DISTRICT, MESA COUNTY, COLORADO, AND GRAND COUNTY, UTAH.

generally overlie and underlie the lenses of host sandstone. These favorable sandstone lenses are normally at least 25 feet thick.

Production records show that the V_2O_5 - U_3O_8 ratio in the ores of the west Gateway district ranges from 3:1 to 7:1 and averages about 4:1. The most important ore minerals, uraninite, coffinite, montroseite, and corvusite, are of the low to middle valent type. Carnotite and similar high valent minerals are common in deposits that have little overburden or because of fracturing have been exposed to oxidation.

The paragenetic relationship suggested by a study of polished sections is as follows: The host rock contained grains of quartz, partly weathered feldspars, and black opaque minerals, as well as logs and macerated plant debris, carbonates, and clay size particles. After coalification of the woody material, pyrite formed, and was followed by the low valent ore minerals montroseite, coffinite, and uraninite. Uraninite and coffinite were localized in the coalified material. Later oxidation has developed corvusite, carnotite, and tyuyamunite.

Sage Plain, Utah and Colorado
By L. C. Huff and F. G. Lesure

Compilation of data on the uranium-vanadium mines in the Sage Plain area shows that about 65 percent of the uranium-vanadium ore produced from the Salt Wash member of the Morrison formation has come from within 50 feet of the outcrop and that five mines in the area have each produced more than 1,000 tons of ore. A small area in the central part of the Sage Plain contains about 35 percent of the known deposits, has produced 73 percent of the ore, and contains 75 percent of the estimated reserves. This "favorable" area is approximately at right angles to but could be within a possible extension of the Uravan mineral belt.

Preliminary geologic maps of the Verdure 1 SW, 2 SE, 3 NE, 3 SE, 4 NW, and 4 SW quadrangles at a scale of 1:24,000 have been compiled on topographic bases that became available in September 1955. A description of the geologic formations exposed in the Sage Plain area was given in the last semiannual report (TEI-590, p. 38-40).

A qualitative study of the bleaching of red sandstone and mudstone of the Salt Wash member of the Morrison formation in the Sage Plain has been started. Samples of Salt Wash sandstone (light moderate brown, 5YR5/4)[1/] and mudstone (grayish red, 10R4/2) were crushed and sieved. Various combinations of sediment, carbonaceous material from the Morrison formation, peat, water, and dilute mineral acids were tested and the color changes observed. Reactions were allowed to proceed in open test tubes at room temperature for several months. The most rapid color change was noted in the test tubes containing sand, peat, and water (either distilled or tap). After 10 to 14 days the sand began to change color from the light moderate brown (5YR5/4) of the original to a mottled medium dark gray (N4) or olive gray (5Y4/1). As bleaching continued a brown colloidal precipitate formed either near the surface of the peat or on the test tube walls. This precipitate, which gives a strong iron test, is probably a hydrous ferric oxide. The organic matter probably causes a reduction and solution of the ferruginous coating on the sand grains so that the iron diffuses upward and is oxidized and reprecipitated near the water-air surface.

1/ All colors with number designations were determined by comparison with the National Research Council Rock-color chart, Goddard and others, 1948.

The solutions with peat contain at least two types of protozoa. In an attempt to determine the influence of microorganisms on the reducing capacity of the peat-water solutions some peat was heated over boiling water for an hour and one sample was boiled in water for an additional hour. The peat heated for one hour produced visible color change in sand in the same length of time as a control sample with unheated peat. The boiled peat took several weeks longer to produce visible color change.

The carbonaceous material (peat or lignite) of the Salt Wash sandstones that originally was chemically active possibly caused much of the bleaching of the red-beds associated with the uranium-vanadium ores. Further experiments are planned to discover possible optimum conditions for red-bed bleaching.

References

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Goddard, E. N., and others, 1948, Rock-color chart: National Research Council, Washington, D. C.

La Sal Creek area, Montrose County, Colorado
and San Juan County, Utah
By W. D. Carter and J. L. Gualtieri

In 1952-1954 the Geological Survey conducted an exploration drilling program in the vicinity of La Sal Creek to stimulate uranium-vanadium mining in the Salt Wash member of the Morrison formation and to find new deposits. The program began with close-spaced drilling behind mine faces to determine the size, configuration, and orientation of the deposits. Later, wide-spaced drilling outlined ground favorable for the occurrence of ore deposits and partially developed deposits in a large favorable area on the north side of La Sal Creek Canyon. A total of 505 diamond drill holes were completed on the north and south sides of the canyon within an area covering approximately 42 square miles. The area was described in a previous semiannual report (TEI-540, p. 36-38).

The drilling program was reappraised during the report period and a structure contour map was drawn on the base of the ore-bearing sandstone (fig. 7). Most of the ore deposits are aligned approximately parallel to the trend of the Salt Wash streams and appear to be clustered along the irregular bottom of one of these stream courses, which lies within the belt of ground favorable for concealed uranium deposits outlined by drilling. The largest deposits appear to be localized in shallow depressions or scours and on the flanks of "noses" or ridges which project into the stream course. Maximum relief of the bottom is slightly more than 30 feet along the margins of the streams. The depressions may be likened to scours in braided streams of the present day and the noses to cuspate projections along the margins of such streams. Such depressions and projections create eddies and whirlpools in which woody debris collects, becomes waterlogged, and is dropped. During floods similar debris is rafted onto the higher bars and cusps within and along the margins of the channels. If this procedure took place in Salt Wash time it would account for the placement of a majority of the "trash-pocket" accumulations of carbonaceous debris with which uranium-vanadium ores are associated in the Salt Wash member of the Morrison formation in the La Sal Creek area.

In summary it appears that bars, scours, and cusps were formed in and along former stream courses at the base of the ore-bearing sandstone of the Salt Wash. These irregularities in the basal surface are at least partly responsible for the placement of "trash-pocket" accumulation of

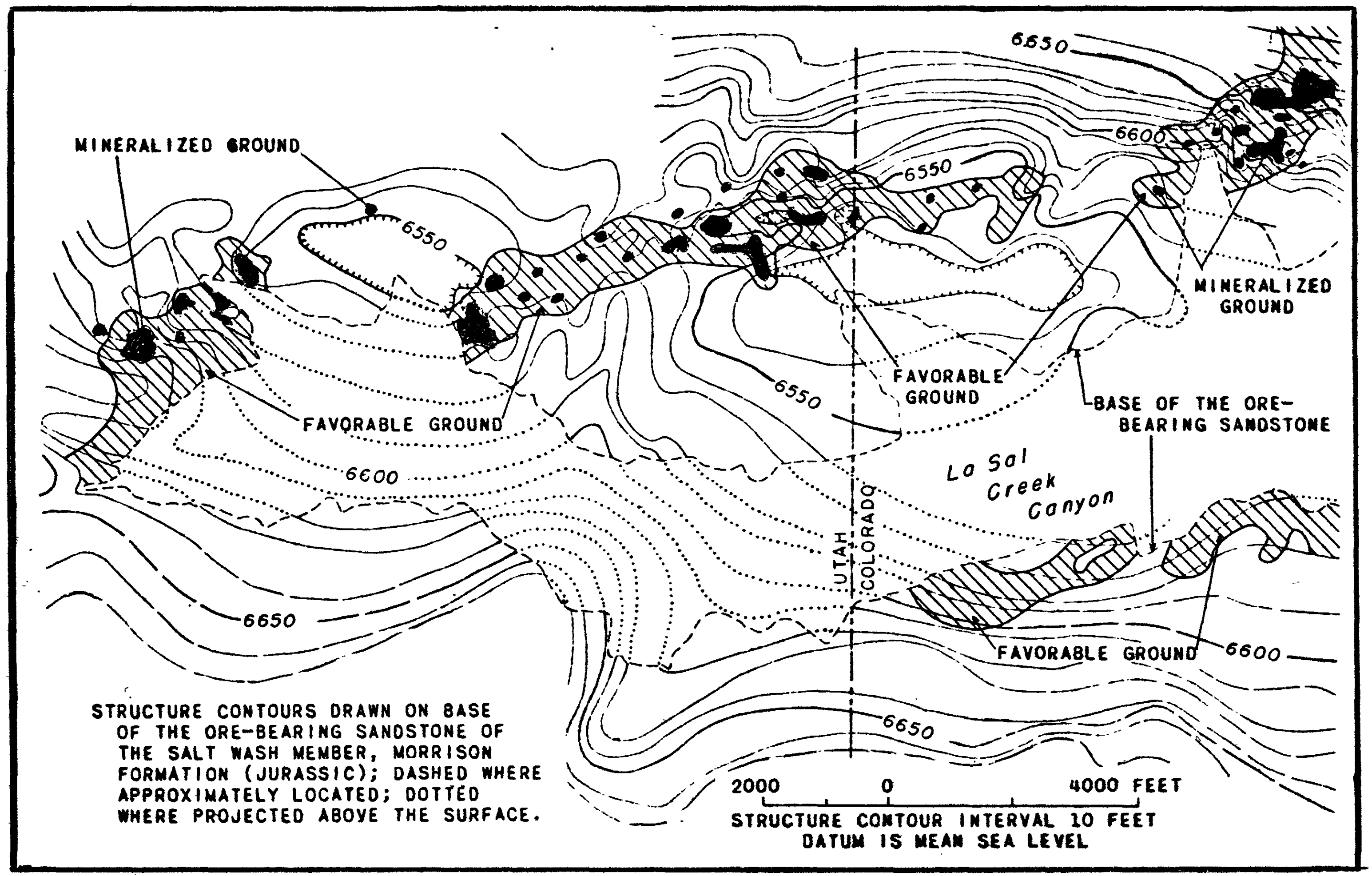


FIG. 7—STRUCTURE CONTOURS, MINERALIZED GROUND, AND GROUND FAVORABLE FOR VANADIUM-URANIUM DEPOSITS, PART OF LA SAL CREEK AREA, SAN JUAN COUNTY, UTAH, AND MONTROSE COUNTY, COLORADO.

carbonaceous debris with which uranium-vanadium ores are associated. These features can be used in conjunction with the lithologic guides described by Weir (1952) to narrow the search for uraniferous deposits in the ore-bearing sandstone stratum of the Salt Wash.

Reference

Weir, D. B., 1952, Geologic guides to prospecting for carnotite deposits on the Colorado Plateau: U. S. Geol. Survey Bull. 988-B.

Lisbon Valley, Utah and Colorado
By G. W. Weir, V. C. Kennedy, and C. L. Dodson

During the report period geologic data on the Mt. Peale 2 SW, 3 NE, 3 NW, 3 SW, and 3 SE quadrangles, Utah, was transferred from photographs to topographic bases with the aid of a Kail plotter. Field work was resumed in May, when the office compilations were partly field checked and geologic mapping of the Mt. Peale 4 SW quadrangle was completed.

The exposed sedimentary rocks in Lisbon Valley range from the upper limestone member of the Hermosa formation of Pennsylvanian age to the Mancos shale of late Cretaceous age. Much of the area is covered by Pleistocene and Recent surficial deposits.

A distinctive chert is present in most uranium ore deposits in the Chinle formation (Triassic) and is found near the base of the Chinle in some outcrops near mines along Big Indian Wash and South Lisbon Valley. This chert, which has not been noted in unmineralized areas, is reddish orange in color and has a dull to subvitreous luster; it is brittle and breaks easily into irregular fragments. The microscope shows the mineral to have a peculiar radial structure approaching spherulitic. The chert has replaced sandstone and in places is intergrown with pyrite and possibly ore minerals. It is believed to have been deposited by the ore solutions, and though generally present only in small amounts may serve as a useful guide in prospecting for uranium.

The surficial deposits of the Lisbon Valley area include some rubble and landslide deposits of earliest Pleistocene or possibly later Tertiary age. The rubble deposits consist mainly of small to large blocks of resistant quartzite and sandstone derived from the Burro Canyon formation and Dakota sandstone of Cretaceous age, and colored chert fragments from the Summerville formation of late Jurassic age. The rubble deposits are commonly cemented in part by pink caliche and rest on an irregular erosion surface that probably slopes gently toward the present Colorado River.

The landslide deposits are similar in composition to the rubble deposits but retain traces of landslide topography and contain mudstone derived from the Brushy Basin member of the Morrison formation of late Jurassic age.

The rubble deposits which now occur only in scattered outcrops may have been derived from the landslide deposits by mass transport, perhaps by mudflow. The pink caliche of these deposits may correlate with grayish pink caliche noted by Baker (1933, p. 57) in the Moab and Green River Desert areas. Baker suggested the caliche zone marks an erosion surface of Tertiary(?) age. Continued study of the surficial materials may help in solving the geologic history of the Lisbon Valley anticline area.

A sample of recent stream sediment derived from a supposedly barren area of Salt Wash sandstone outcrop has been divided into several fractions by use of heavy liquids and magnetic separation. Comparison of these fractions with similar fractions of sediment from a mineralized area may indicate the form in which ore-vanadium is carried in stream sediments.

In the general vicinity of the Lisbon Valley fault copper, mainly as malachite, is present. Malachite can be detected in very low concentrations in stream sediments, for it concentrates in the fraction that is slightly magnetic and heavier than bromoform. One sample from a modern stream sediment contains about 0.04 percent copper, whereas the slightly magnetic fraction of the sample that was heavier than bromoform contained an estimated 20 percent copper. Such a technique of concentrating copper minerals may be of use in reconnaissance prospecting in areas where uranium and copper are closely associated.

Reference

Baker, A. A., 1933, Geology and oil possibilities of the Moab district, Grand and San Juan Counties, Utah: U. S. Geol. Survey Bull. 841.

Moab-Inter-river area, San Juan County, Utah
By E. N. Hinrichs

Mapping, chiefly of the Triassic rocks, in about four complete quadrangles and parts of two others in the Moab area has been compiled during the report period.

Formations exposed in the Moab-Inter-river area range from the Hermosa limestone of Pennsylvanian age to the Carmel formation of Jurassic age. The uranium deposits in the area are in the Rico and Cutler formations of Permian age and the Chinle formation of Triassic age. Two features common to all the deposits are the presence of copper minerals and a high content of calcium carbonate. On the basis of structure and the vanadium-uranium ratio, the deposits can be divided into two groups.

Deposits of the first group are of the bedded type, occur in the Cutler and Chinle formations, are apparently not associated with faults, and occur in localities of low dip. The ratio of vanadium to uranium in this group is about 1:4. Deposits in the Cutler formation are in gray parts of otherwise dusky red lenses of arkose, and many are associated with small intraformational folds. Green and yellow copper-uranium minerals are conspicuous. Among the minerals present are cuprite, chalcocite, and according to Dix (1953), troegerite, uranophane, and zeunerite.

The bedded deposits in the Chinle formation are in the Moss Back member. The minable deposits are in channels cut into the underlying Moenkopi formation and filled with conglomeratic sandstone. Minerals in the Chinle deposits include uraninite, beta-zippeite, schroeckingerite, andersonite, pyrite, galena, sphalerite, and in one deposit erythrite(?) and ilsemannite(?). Microscopic examination of polished sections of ore from one of the deposits in the Moss Back has revealed that the uraninite is younger than the sulfides and most of the calcite.

Deposits of the second group are in the Rico, Cutler, and Chinle formations along faults on the Cane Creek anticline. The ratio of vanadium to uranium in this type of deposit is about 2:1. Brecciated rock along faults as close as 10 feet apart contains uranium, vanadium, and copper minerals. Minerals identified to date are uraninite, becquerelite, beta-zippeite, carnotite, metatyuyamunite, schroeckingerite, andersonite, bayleyite, chalcocite, secondary copper minerals, pyrolusite(?), and barite.

The eight-fold difference in ratio of vanadium to uranium between the two types of deposits can be explained possibly by accumulation from crude oil. The uranium deposits along faults of the Cane Creek anticline are within 3-1/2 miles of oil wells. The vanadium in metallo-organic complexes in crude oil (Treibs, p. 172), may have migrated upward along faults on the anticline.

References

Dix, G. P., Jr., 1953, Reconnaissance of the uranium deposits of the Lockhart Canyon-Indian Creek area, San Juan County, Utah: U. S. Atomic Energy Comm. RME-4038, Tech. Inf. Service, Oak Ridge, Tenn., p. 14.

Treibs, A., 1935, Chlorophyll- und Haminderivate in bituminosen Gesteinen, Erdolen, Kohlen, and Phosphoriten: Ann. der Chemie, v. 517, p. 172.

Orange Cliffs area, Utah

By F. A. McKeown and C. C. Hawley

The results of mapping and compilation of unpublished data support the suggestion that in Happy and Hatch Canyons uranium occurrences are geographically associated with several geologic features. Most of the known occurrences of uranium minerals in Happy and Hatch Canyons are in an area that has the following geologic features: (1) large northwest-trending faults and a prominent set of westerly trending faults aligned en echelon to the northwest; (2) pinchout zones of the Monitor Butte and Moss Back members of the Chinle formation; and (3) rather ill-defined structural terraces or monoclines contiguous with terraces.

Though the above associations are valid for the Happy and Hatch Canyon areas, uranium also occurs in parts of the Orange Cliffs area as yet unmapped. Accordingly, general inferences concerning localization of ore deposits based on these features are not justified.

Mineralized chert is sparse but widely distributed within a few feet of the contact of the Moenkopi and Chinle formations in the Orange Cliffs and San Rafael Swell areas. Study of polished sections of this chert indicates the following paragenetic sequence: chert (earliest mineral), pyrite, sphalerite, digenite, covellite, tetrahedrite or tennantite, calcite (latest mineral). Uraninite is tentatively identified in some chert on the basis of optical properties in reflected light and autoradiographs. The position of the uraninite(?) in the paragenetic sequence is indeterminate in the available polished sections.

Megascopically the chert is orange-red banded or patched yellow. It replaces the enclosing siltstone or sandstone. Small amounts of green copper minerals are found in some of the chert but much of it does not contain copper minerals. Very little of the chert tested from the Orange Cliffs area is radioactive. Nevertheless, observations to date indicate that orange-red chert along the Moenkopi-Chinle contact in the Orange Cliffs and San Rafael Swell areas may be a guide to mineralized rock containing uranium and copper. Guides such as carbonaceous material and gray-green bleaching of mudstone may be useful indicators of favorable host rock; they are not reliable indicators of mineralized ground in the Orange Cliffs area.

Purple-white alteration of the lower part of the Chinle formation (TEI-590, p. 47) seems to be genetically related to silicification and the orange-red chert. Several samples collected in the San Rafael Swell consist of purple and white mottled siltstone with veinlets of orange-red chert. The chert occurs only within white parts of the rock; the width of white rock around a chert veinlet is directly proportional to the width of the chert veinlet. If purple-white alteration is related to chert and chertification is related to uranium and copper mineralization, it follows that only an indirect relationship exists between alteration of this type and uranium deposition. Field observations indicate that economic concentrations of uranium are not closely associated with purple-white alteration; such alteration is commonly lacking immediately below uranium deposits. Much purple-white alteration, however, may be present within a quarter or half mile of a deposit.

Much field work remains to be done before the validity of the above apparent relationships is known.

San Rafael Swell, Utah
By R. C. Robeck

The period was spent in compiling data in preparation for reports on the mapping done to date in the San Rafael Swell. Isopach maps have been prepared of the upper part of the Moenkopi formation using mapped marker beds in the Moenkopi as datum surfaces. These maps indicate that a Permian anticlinal fold, oriented northwest-southeast across the center of the Swell, may have been rejuvenated at the end of Moenkopi time. The following features are associated with this fold: (1) the thickness of the Moenkopi above a prominent marker bed ranges from minus 15 feet on the fold to about plus 140 feet in the northeastern part of the Swell; (2) the Temple Mountain member (referred to in TEI-590, p. 49 as the "mottled siltstone unit") of the Chinle formation tends to be thicker in the northern part; (3) the Monitor Butte member of the Chinle formation thins from the 100-foot section on the south to a knife edge parallel to the Permian high; and (4) there is a greater amount of mudstone at the base of the Moss Back member of the Chinle formation along the crest of the fold than in adjacent areas, and the greatest concentration of uranium deposits in the San Rafael Swell is along this same trend. All these facts seem to indicate that slight and variable uplift along the Permian fold may have had some influence on the factors which caused the concentration of uranium deposits along the trend which, in a very general way, is parallel to a line between Temple Mountain and Green Vein Mesa to the northwest.

This slight uplift may have had some influence on deposition during Chinle time which eventually resulted in some areas being more favorable for uranium deposits than others.

Circle Cliffs area, Utah

By E. S. Davidson, D. A. Brew, and L. D. Carswell

The principal uranium ore in the Rainy Day mine in the Circle Cliffs area is localized in the Moenkopi formation, on the crest of a bank of a paleochannel scoured in the top of that formation. The overlying Shinarump member of the Chinle formation contains no ore grade material at the mine. Semiquantitative spectrographic analyses of samples from the mine show that lead, copper, nickel, cobalt, silver, molybdenum, zinc, yttrium, and ytterbium increase proportionately with uranium and it is inferred that these elements were introduced with the uranium. The principal low valent uranium mineral is uraninite. The principal sulfide minerals associated with uraninite are pyrite, sphalerite, chalcopyrite, marcasite, and galena, in approximately that order of abundance. Although the paragenetic sequence is not completely known, uraninite appears to have been deposited last. No unusual alteration or extraordinary amounts of clay or chloritic minerals were observed in or near the ore zone. Preliminary work on the fold structures near the mine has produced no definite evidence of correlation of the ore body and structure, but study of this possibility is being continued.

Elk Ridge area, Utah

By R. Q. Lewis and R. H. Campbell

Preliminary map compilation is complete for the Elk Ridge 1 NW, 1 SW, 2 NW, 2 NE, 2 SW, 2 SE, 3 SW, 3 NW, 3 NE, and 3 SE quadrangles. Compilation of these quadrangles has assisted in the delineation of two areas where sandstones of the Chinle formation of Triassic age are favorable for uranium ore deposits (fig. 8).

One of these favorable areas crosses Elk Ridge in an east-northeasterly direction and is a band of sigmoidal shape with trends varying from nearly east-west in the southwestern part of the area, through northeast across the central part, to about east-northeast at the east side. This band is continuous with a belt of favorable ground previously delineated across White Canyon and Deer Flat (Finnell, 1956, personal communication). Within this band uranium ore is localized in a series of discontinuous basal sandstone lenses of the lower part of the Chinle formation. The basal Chinle sandstone lenses are lithologically very similar to other sandstone lenses in the Chinle below the Moss Back member; however, uranium deposits are known only where sandstone lenses in the lower part of the Chinle lie directly on the Moenkopi. In a few of the deposits, uranium minerals and asphaltite blebs are disseminated in the Moenkopi or coat fractures in the Moenkopi immediately below mineralized lower Chinle sandstone. The basal Chinle sandstones probably correlate in part with units mapped as Shinarump in the Deer Flat and White Canyon areas; however, because the sandstones are quite lenticular and discontinuous over most of Elk Ridge the correlation is tentative at best, and it is possible that individual lenses on the Moenkopi erosion surface in one place may be better correlated with sands higher in the lower part of the Chinle formation elsewhere.

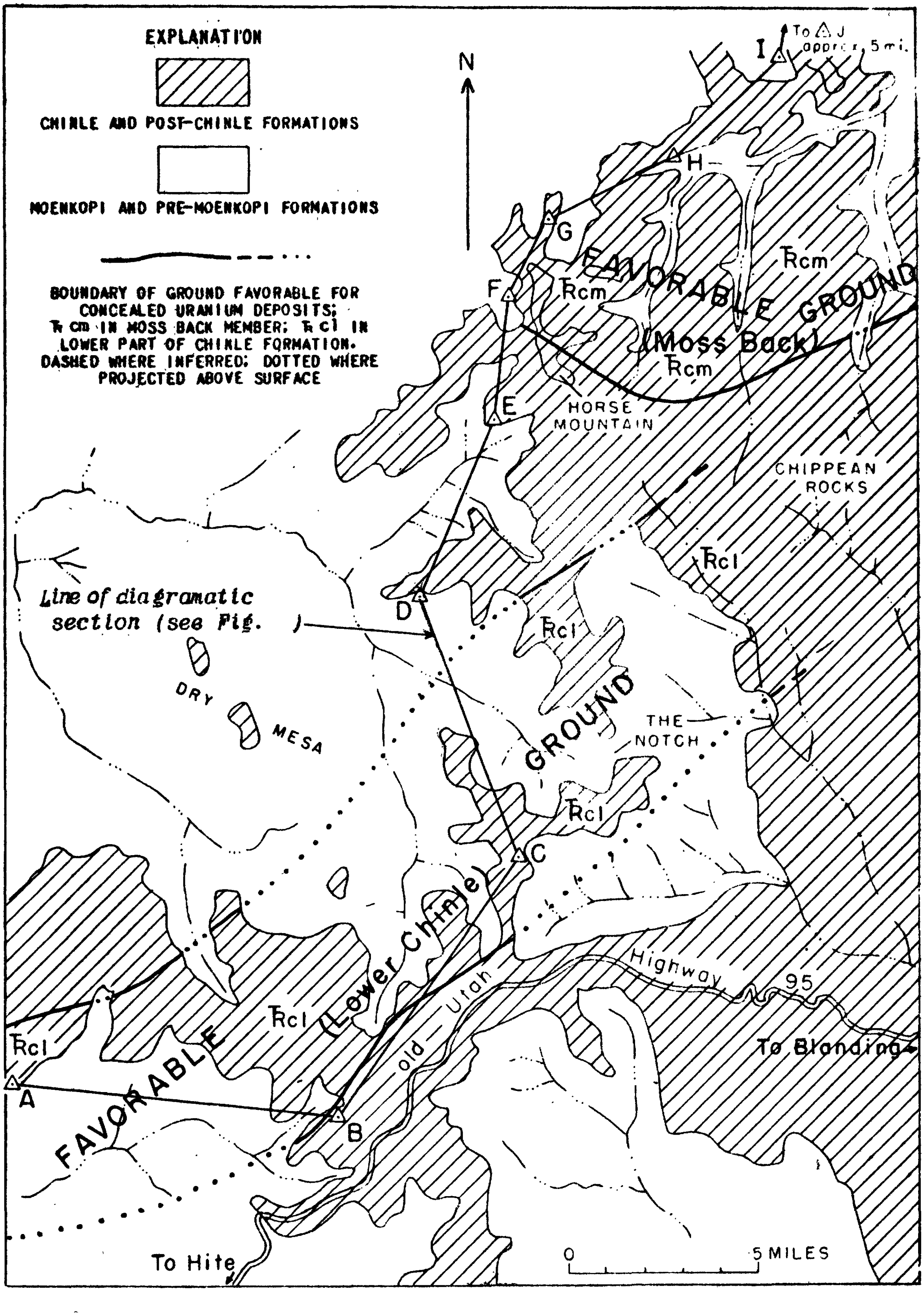


FIG. 8 --GROUND FAVORABLE FOR CONCEALED URANIUM DEPOSITS IN THE MOSS BACK MEMBER AND THE LOWER PART OF THE CHINLE FORMATION, ELK RIDGE AREA, SAN JUAN COUNTY, UTAH.

In the vicinity of Horse Mountain the lower part of the Chinle thins abruptly, and in the Lavender Canyon-Indian Creek area, adjacent to Elk Ridge on the north, it pinches out (fig. 9). Several mines have been developed in the Moss Back member in the Lavender Canyon-Indian Creek area and although no important deposits are known in the Elk Ridge area, several prospects and one small deposit have been found in the Moss Back where the underlying Lower Chinle is thinned to less than about 30 feet. This part of the Elk Ridge area is, accordingly, considered favorable ground for concealed uranium deposits (fig. 9).

This thinning of the lower part of the Chinle formation is suggestive of structural deformation in the northern part of the Elk Ridge area following the deposition of the Moenkopi formation and preceding deposition of the Moss Back member. This interpretation implies that in the area south of this structural "high" the lower part of the Chinle formation was deposited in a structural basin which continued to deepen during early Chinle time.

Figure 9 shows the stratigraphic position of the known mines and prospects in the Elk Ridge area and adjacent areas to the southwest and northeast. Stratigraphically, all of the mines and important prospects are at or very near the top of the Moenkopi formation. Lithologically, all of the mines and important prospects are in sandstone and conglomerate of the Moss Back member and lithologically similar lenses in the lower part of the Chinle formation, except for local deposits in the upper part of the Moenkopi as previously mentioned.

In any hypothesis concerning the path of solutions from which uranium minerals might be deposited, the following factors must be considered: (1) the stratigraphic positions of the ore deposits appear to be related

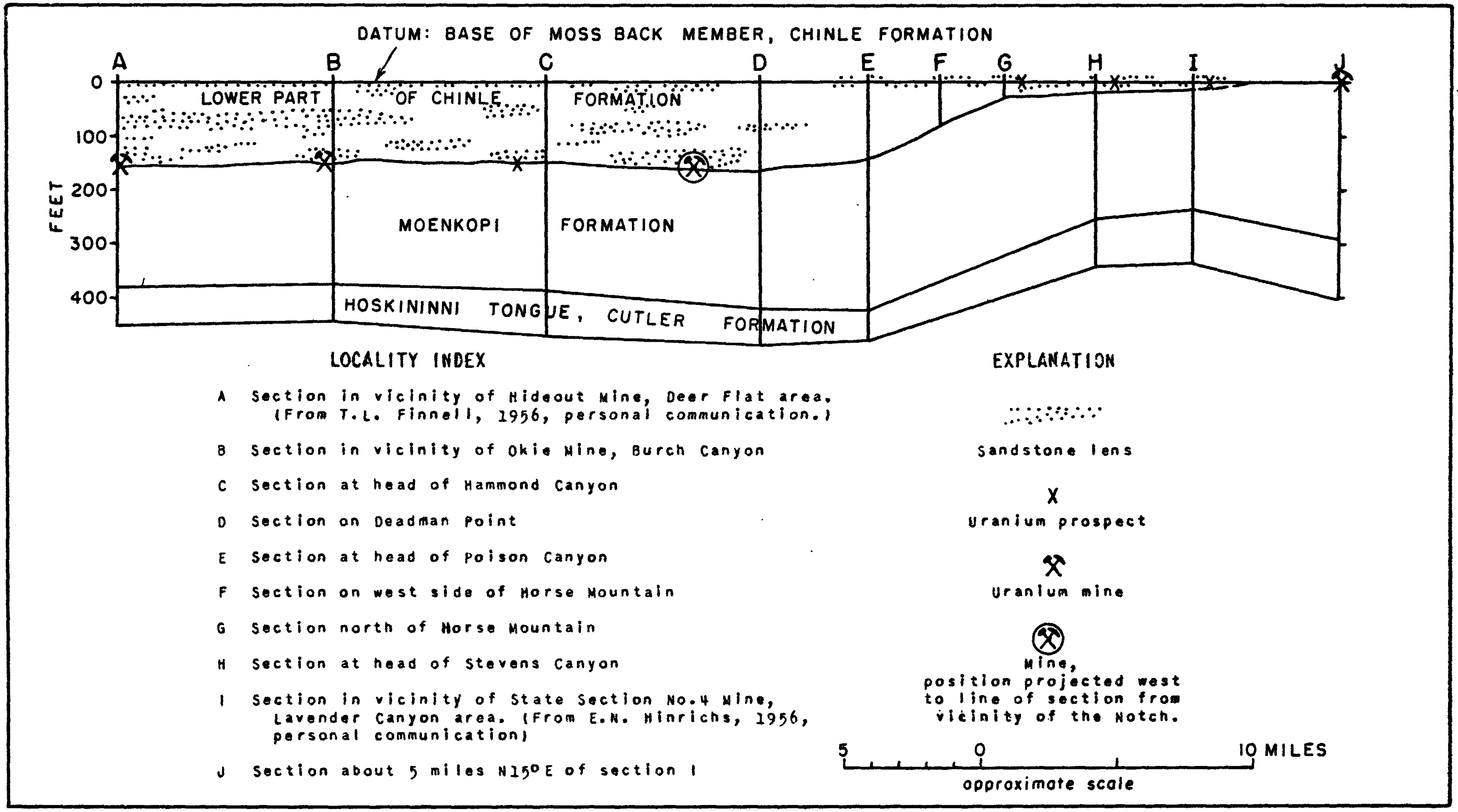


FIG. 9 --DIAGRAMMATIC CROSS SECTION (LOCATED ON FIG. 8) SHOWING THINNING OF LOWER PART OF CHINLE FORMATION AND STRATIGRAPHIC POSITIONS OF URANIUM MINES AND PROSPECTS, ELK RIDGE AREA AND VICINITY, SAN JUAN COUNTY, UTAH.

to the top of the Moenkopi; (2) Chinle lithologic types that contain ore at this horizon are not known to contain ore in higher stratigraphic positions; (3) the sandstones of the lower part of the Chinle formation are surrounded by mudstones and sandstones containing considerable amounts of clay, and the unit as a whole is much less permeable than the Moenkopi and/or the other subjacent rocks.

The evidence suggests that the ore solutions may have been introduced from below and that they then migrated through the Moenkopi rather than laterally through the Chinle. Some lateral migration may have taken place locally in Chinle sandstone following introduction of the solutions from the underlying Moenkopi, but this lateral migration was probably largely restricted to individual sandstone lenses of the Chinle formation that were in contact with the Moenkopi. A combination of impounding lithologic traps in the Chinle, pressure drop at the contact between the lenses of coarser-grained Chinle sandstone and the finer-grained rocks of the Moenkopi formation, and perhaps chemical conditions in the Chinle, including such features as carbonaceous material, may have caused the precipitation of the ore minerals.

Abajo Mountains, Utah
By I. J. Witkind

The compilation of geologic data gathered during the 1955 field season indicates that the general structure of the Abajo Mountains is similar to that of the Henry Mountains as described by Hunt (1953). The main mass of the Abajo Mountains is formed by a major igneous intrusive near the geographic center of the mountains. On the north, east, and south, the mountains are rimmed by domelike structures tentatively classified as laccoliths. Some of the domes are as much as 5 miles in diameter, although most are smaller and average 1-1/2 miles in diameter. Locally the sedimentary cover has been removed exposing igneous dikes, sills, and small plugs.

Wherever exposed, the igneous rock that forms both the main mass of the mountains as well as the laccoliths seems to be uniform in mineralogic composition. It is tentatively classified as a porphyritic hornblende latite, and consists of subhedral to euhedral phenocrysts of andesine (An_{43}) and hornblende in an exceedingly fine-grained groundmass. It has not been possible to identify all the minerals in the groundmass, but X-ray diffractometer studies suggest the presence of plagioclase feldspar, an alkalic feldspar, mica, and some quartz. Chemical analyses of igneous rocks from the Abajo Mountains indicate that the CaO content ranges from 1.67 to 8.42 percent; the Na_2O content from 0.05 to 5.04 percent; and the K_2O content from 1.22 to 3.96 percent. Staining techniques suggest that most of the potassium is contained in the groundmass and very little in the phenocrysts.

In the Abajo Mountains area all of the uranium-vanadium mines are in the Salt Wash member of the Morrison formation of Jurassic age and in general, have vanadium-uranium ratios of about 10:1. Sample analyses from both uranium-vanadium mineralized exposures and ore deposits indicate that both the uranium and vanadium content are low, and the carbonate content is high.

<u>Reference</u>

Hunt, C. B., 1953, Geology and geography of the Henry Mountains region, Utah: U. S. Geol. Survey Prof. Paper 228.

East Vermillion Cliffs area, Arizona
By R. G. Petersen and J. D. Wells

Most of the uranium mineralization in the East Vermillion Cliffs area occurs in channel scours in the Shinarump member of the Chinle formation and in the Moenkopi formation at or near the contact between the two units. Small pockets of uranium minerals, however, occur in sandstone lenses in the Petrified Forest member of the Chinle.

Most of the uranium minerals sampled from the Shinarump and the Petrified Forest members were identified as metatorbernite. One sample from the Shinarump contained betazippeite, and another sample from the same member contained an unknown uranium mineral that may be a new mineral.

Chemical analyses of ten uranium samples from the Shinarump and the Petrified Forest members of the Chinle formation show that the equivalent uranium is lower than the chemical uranium. This suggests that the uranium minerals in the samples are possibly less than one million years old. The copper content in the samples ranges from 0.04 to 5.87 percent with an arithmetical average of 1.54 percent. The V_2O_5 content is 0.10 percent or less.

X-ray analysis of a sample from a limestone bed in the Owl Rock member of the Chinle formation shows that the carbonates are principally calcite with a minor amount of dolomite. The clay minerals in the limestone are mostly illite with some montmorillonite and an unknown mixed-layer clay.

Examination of thin sections of the Shinarump member and of selected pebbles from the Shinarump shows that a variety of material comprises this unit. The most common type of pebble consists of a red to gray, fine- to very fine-grained quartzite. Some of these pebbles contain veins of comb quartz. Other pebbles consist of a breccia in which the open spaces have been filled or partially filled with quartz crystals. Igneous rocks represented in the pebbles are a pink, medium-grained, micrographic granite, a pink porphyritic rock, and a probable pyroclastic rock. Judging from the rocks described in the literature by Wilson (1939) and Anderson (1951), this material could have been derived from the Precambrian rocks of the Mazatzal Mountains or a similar terrain in central Arizona.

References

Anderson, C. A., 1951, Older Precambrian structure in Arizona: Geol. Soc. America Bull., v. 62, p. 1331-1346.

Wilson, E. D., 1939, Pre-Cambrian Mazatzal revolution in central Arizona: Geol. Soc. America Bull., v. 50, p. 1113-1164.

Grants area, New Mexico
By R. E. Thaden

Analysis and correlation of many measured sections of the Morrison formation show that the Westwater Canyon and Brushy Basin members are highly lenticular. The Westwater varies in thickness from 92 feet to 165 feet in distances of less than one mile, and the Brushy Basin varies from 64 feet to 127 feet in distances of less than two miles.

A steeply crossbedded pink sandstone which thickens westward from Haystack Butte is matched by a corresponding thinning of the Recapture member of the Morrison formation. This pink sandstone is probably not a tongue of the Cow Springs sandstone, as previously thought.

A geologic map of the Jurassic rocks in the western part of the area has been compiled on a planimetric base. The configuration of the outcrops and the orientation of the beds shown on the map suggest that the large ore deposits may be concentrated in shallow synclines. The synclines appear to trend northeastward and to be about 5 miles apart. Continued mapping and accumulation of structural data will supply more information concerning this apparent relationship of ore deposits to structure.

Analytical data obtained from samples collected from ore deposits in the Morrison formation indicate a relative sparsity of some trace metals in ore. For instance, calcium, chromium, strontium, magnesium, and titanium seem to be concentrated in a halo above ore, whereas barium, beryllium, cobalt, gadolinium, molybdenum, lead, and other metals, in addition to uranium and vanadium, are concentrated in the ore. Manganese, vanadium, and especially nickel, are concentrated above the ore on the downdip side, indicating either an original asymmetric distribution of the metals or a differential post-ore leaching (or ionic or capillary diffusion). It appears that the leaching or diffusion, if any, was too minor to have diluted to below commercial grade any large quantity of uranium ore.

Laguna area, New Mexico

By R. H. Moench and W. P. Puffett

During the report period preliminary geologic maps were compiled for the Laguna 4 NW and 4 SW 7-1/2 minute quadrangles; a statistical study of the fractures was made from data obtained in the field during the preceding report period; and a petrographic study was begun on thin sections of the igneous rocks exposed in the Laguna project area.

The mapped area includes Mesa Gigante and the zone of folding and faulting which delineates the eastern boundary of the Colorado Plateau in the area.

In the statistical study of the fracture system data, special attention was directed to the fractures confined to the igneous intrusives as compared to those of the sedimentary rocks, in an attempt to date the age of the intrusives with respect to the regional structures.

The following tentative conclusions result from the structural and petrographic study:

(1) In the Laguna project area, the most prominent fracture pattern comprises two nearly vertical joint sets, with 10 to 12 percent Schmidt net maxima at N. 37° E. and N. 13° W., and high angle faults, striking north-northeast, approximately bisecting the acute angle between the two joint sets.

Dikes have been intruded parallel to the regional fracture pattern; and sills, which contain the same rock type as the dikes, have been cut by the same fracture sets. This suggests that the intrusion of the igneous rocks and the formation of the fracture pattern was essentially contemporaneous.

(2) The lava flows are olivine basalts and slightly younger olivine andesites. The sills and dikes are also basaltic and andesitic in composition, but apparently contain little or no olivine; however, sparse pseudomorphs of serpentine after olivine have been found. The lava flows are composed of the same rock types as the volcanic plugs in the area, but from structural evidence, probably post-date the intrusion of the dikes and sills.

(3) In the Sandy mine area, the sills are multiple or composite, comprising alternating diabasic gabbro and diorite, with relatively late aplitic and locally pegmatitic rocks of granitic to syenitic composition. These sills have effected marked metamorphism of the enclosing sedimentary

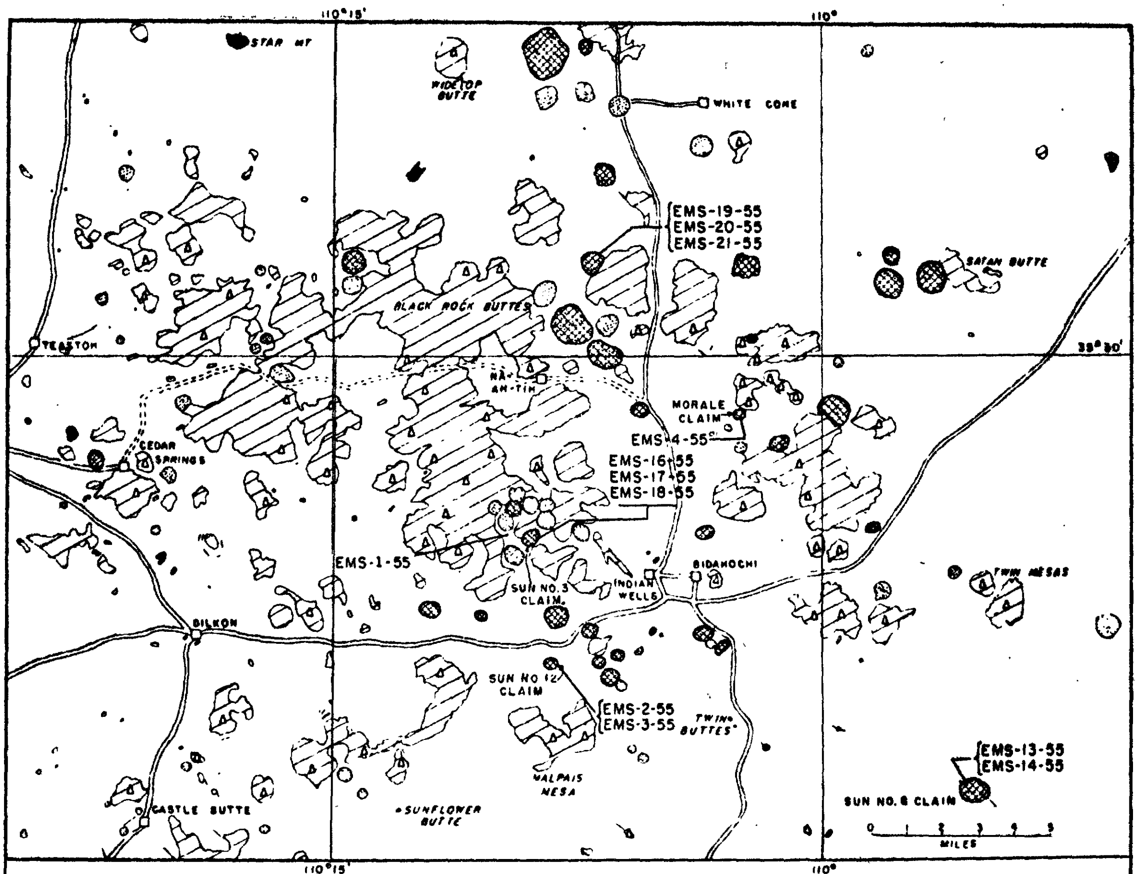
rocks in zones as much as 10 feet thick. Grossularite, diopside, and vesuvianite have developed in the limestones and calcareous sandstone; cordierite(?) and small aggregates of potassic feldspar have developed in the noncalcareous siltstone and shale.

(4) Pitchblende(?) of the ore deposits in the Sandy mine area appears to have formed contemporaneously with the growth of the contact metamorphic minerals.

Diatremes on the Navajo and Hopi Reservations, Arizona
By E. M. Shoemaker

Petrographic and chemical investigations of uraniferous sedimentary rocks from diatremes in the Hopi Buttes area, Arizona (fig. 10), have been initiated in order to determine the lithologic and geochemical affinities of the uranium-bearing beds in the diatremes.

The mineralized rocks range from relatively pure carbonate rocks to calcareous tuffs and siltstones (table 1). One mineralized bed of silt grain size consists of about 75 percent iron oxides, chiefly goethite(?). The carbonate in the rocks is extremely fine grained and cannot be identified in thin section. Chemically determined $CaCO_3$ generally accounts for only about half of the acid soluble fraction of the rocks and, according to spectrographic analyses, the magnesium content is commonly in the range of 5 to 10 percent. A considerable fraction of the carbonate may be dolomite. It is suspected that the carbonate rocks have been derived in part by evaporation of thermal solutions and could therefore be properly referred to as travertine; they are here referred to by the noncommital term limestone. The insoluble clastic fraction of the limestones is generally composed chiefly of quartz of silt size and only subordinate amounts of volcanic debris. An eolian origin for much of the silt seem likely.



EXPLANATION

EXTRUSIVE ALKALINE BASALT

INTRUSIVE MONCHIQUTTE(FILLING VOLCANIC NECK)

DIATREME (FILLED CHIEFLY WITH PYROCLASTIC DEBRIS)

DIATREME KNOWN TO CONTAIN URANIFEROUS SEDIMENTARY ROCKS

PROBABLE LOCATION OF BURIED DIATREME OR VOLCANIC NECK

N

SOURCES OF DATA: OUTLINE OF EXTRUSIVE AND INTRUSIVE ROCKS MODIFIED AFTER UNPUBLISHED MAPS BY C.A. REPENNING AND OTHERS, U.S. GEOLOGICAL SURVEY. DIATREMES AFTER J.T. HACK, 1942, GEOL. SOC. AMERICA BULL., V. 53, PLATE 1, AND P. 36B, WITH ADDITIONS BY E.M. SHOEMAKER

Fig. 10.—MAP OF VOLCANIC ROCKS IN THE HOPI BUTTES AREA, ARIZONA, SHOWING LOCATION OF ANALYSED SAMPLES.

Table 3. Grain size and chemical analyses of uraniferous sedimentary rocks from diatremes in the Hopi Buttes, Arizona
(Sample localities shown on fig.10)

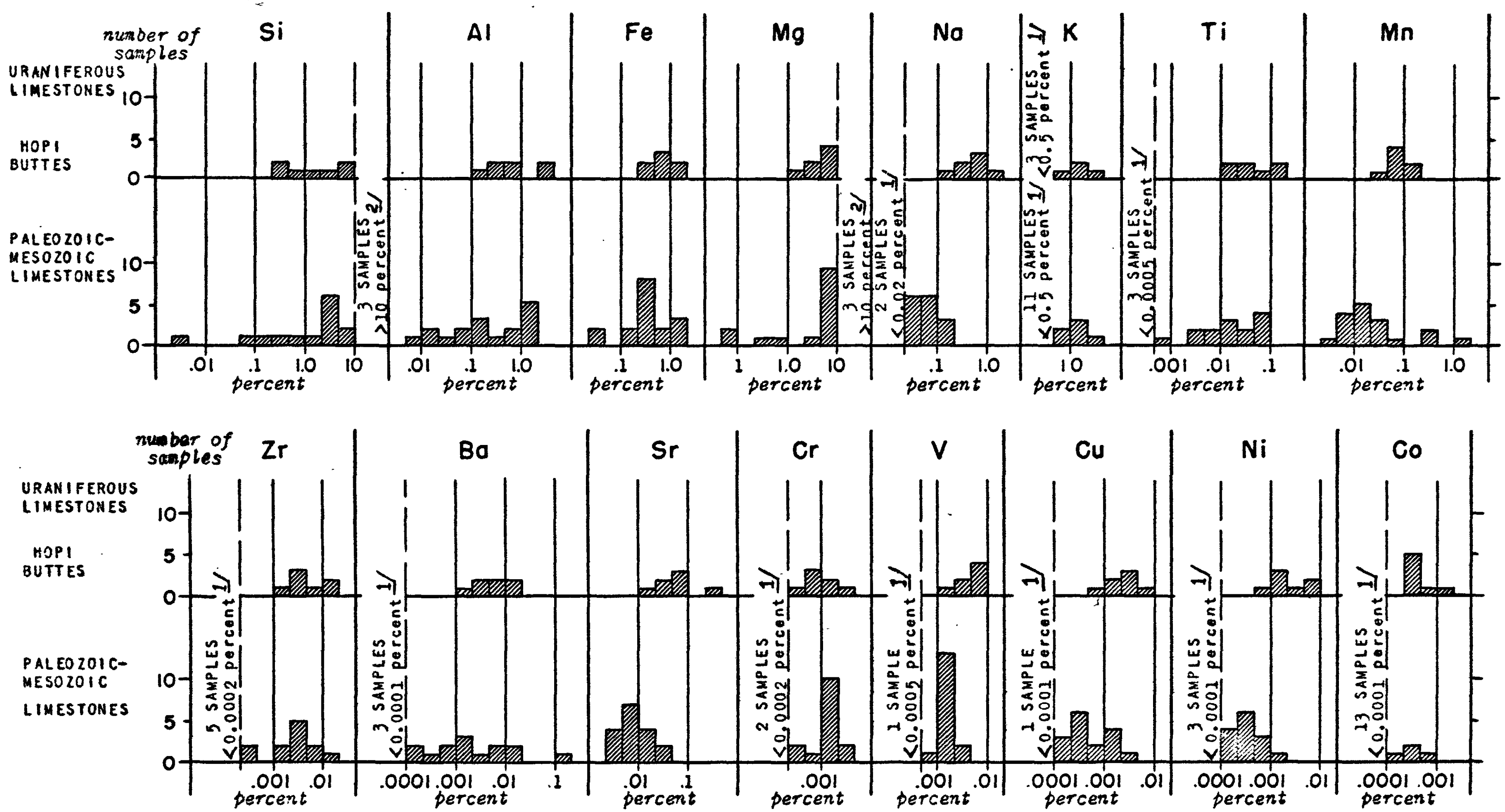
Sample number	Laboratory number	Rock type	Mean grain diameter of insoluble residue(mm)	Acid soluble constituents (percent)	$CaCO_3$ (percent)	P_2O_5 (percent)	U (percent)	As (percent)	Se (percent)
EMS-1-55	227193	Claystone	0.002	21.77	----	0.18	0.001	----	----
EMS-2-55	227194	Limestone	0.008	92.82	----	0.30	0.002	----	----
EMS-3-55	227195	Ferruginous siltstone	0.068	18.35	----	0.38	0.012	----	----
EMS-4-55	227196	Tuffaceous siltstone	0.019	21.04	----	0.46	0.041	----	----
EMS-13-55	238063	Limestone	0.004	85.89	51.1	0.056	0.0098	0.0010	0.0002
EMS-14-55	238064	Calcareous siltstone	0.007	44.72	19.7	0.13	0.0037	0.0024	0.0050
EMS-16-55	238065	Limestone	0.021	77.08	67.8	0.14	0.011	0.0030	0.0002
EMS-17-55	238066	Limestone	0.007	83.32	44.1	0.13	0.0024	0.0009	0.00005
EMS-18-55	238067	Silty limestone	0.013	61.63	28.0	0.22	0.0028	0.0017	0.0001
EMS-19-55	238068	Calcareous tuff	0.044	39.71	19.4	0.67	0.0050	0.0025	0.00005
EMS-20-55	238069	Limestone	0.007	96.58	57.0	0.21	0.0059	0.0005	<0.00005
EMS-21-55	238070	Limestone	0.018	92.68	55.5	0.25	0.0023	0.0005	<0.00005

Analysts: F. H. Spence, C. Angelo, R. Cox, J. Wilson, J. Schuch, W. Coss, G. Burrow.

Compared with Paleozoic and Mesozoic limestones of the Colorado Plateau, which are chiefly of marine origin (fig. 11) the limestones of the Hopi Buttes diatremes are strikingly richer in sodium and tend to have higher concentrations of strontium, vanadium, copper, nickel, and cobalt, as well as of uranium and molybdenum (not illustrated). In addition, the limestones of the Hopi Buttes contain, on the average about 5 times as much phosphorus as the average limestone and significantly more arsenic and selenium (table 1) than the average limestone or other sedimentary rocks listed by Rankama and Sahama (1950, p. 226). Part of these differences may be due to contamination of the limestones by monchiquite detritus which has been found to be rich in several of the elements present in unusual abundance in the limestones (TEI-590, p. 76-85). Certain elements in the limestones, such as iron, titanium, zirconium, and chromium, are clearly related to the amount of insoluble detrital constituents (fig. 12). Vanadium, copper, nickel, and cobalt, however, as well as other elements not illustrated, are independent of the detrital insoluble fraction (fig. 12). Colorimetric analysis of the leachate has revealed that a large part of the vanadium, copper, nickel, and cobalt contained in the limestones goes into solution with a hot citric acid leach. It is inferred that the major part of each of these elements is in the carbonate fraction.

The ferruginous siltstone composed mainly of goethite contains, in addition to uranium, more than 0.01 percent each of nickel, cobalt, molybdenum, and zinc.

Of all the elements that are present in unusual abundance in the uraniferous rocks, only molybdenum has been found to have a definite correlation with uranium (fig. 13). On the average, molybdenum tends to be about half as abundant as uranium.



1/ LOWER LIMIT OF SENSITIVITY FOR THE ELEMENT BY THE SPECTROGRAPHIC METHOD.
2/ SPECTROGRAPHIC ANALYSIS AS REPORTED.

FIG. 11--ABUNDANCE OF ELEMENTS DETECTED BY THE SPECTROGRAPHIC METHOD IN URANIFEROUS LIMESTONES FROM THE HOPI BUTTES, ARIZONA, AND IN PALEOZOIC-MESOZOIC LIMESTONES FROM THE COLORADO PLATEAU.

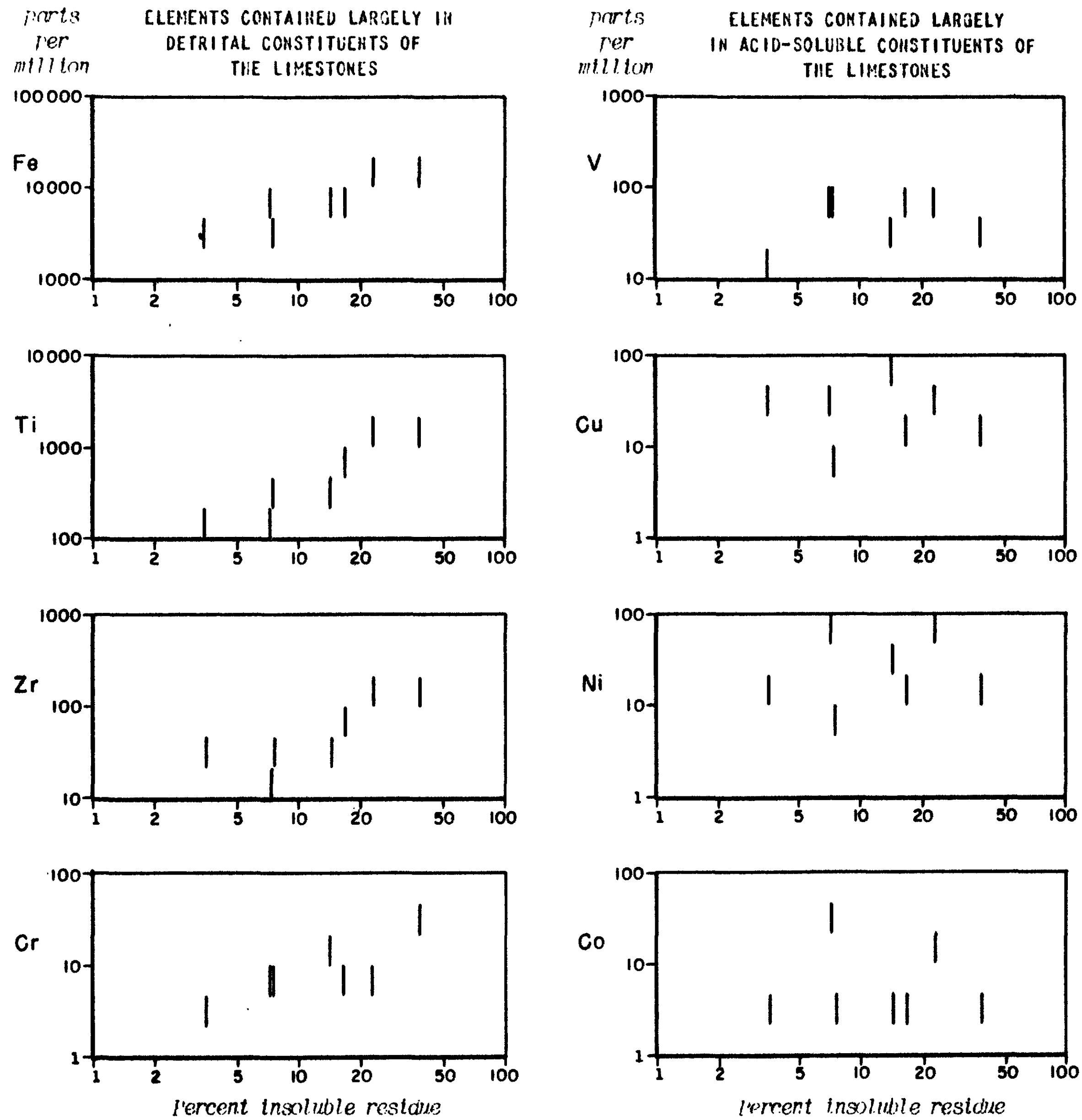


FIG. 12--CORRELATION OF ELEMENTS WITH INSOLUBLE DETRITAL FRACTION IN URANIFEROUS HOPI BUTTES LIMESTONES.

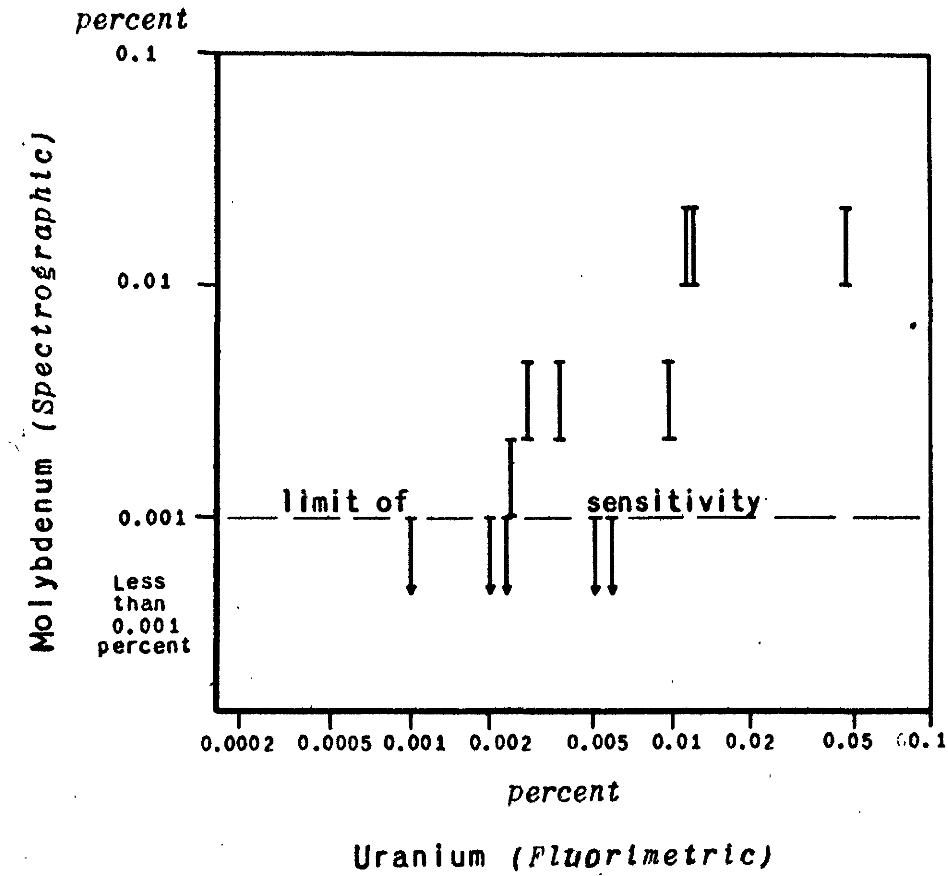


FIG. 13--CORRELATION OF MOLYBDENUM AND URANIUM IN URANIFEROUS SEDIMENTARY ROCKS FROM DIATREMES IN THE HOPI BUTTES AREA, ARIZONA.

The occurrence of the elements of unusual abundance varies from one diatreme to the next. The uraniferous rocks sampled (EMS-13-55, EMS-14-55) at the Sun No. 6 claim (fig. 10) contain unusual concentrations of silver and selenium. Those (EMS-2-55, EMS-3-55) at the Sun No. 12 claim (fig. 10) are abnormally high in cobalt, nickel, and manganese. Detectable concentrations of molybdenum are curiously absent in the moderately uraniferous rocks (EMS-19-55, EMS-20-55, EMS-21-55) of one diatreme about 3-1/2 miles (?) northeast of Na-ah-tin (fig. 10).

The fact that the limestones tend to contain unusual concentrations of sodium, phosphorus, strontium, vanadium, copper, nickel, and cobalt, elements which are relatively abundant in the monchiquitic volcanic rocks of the Hopi Buttes, suggests that the solutions from which the limestones were formed were genetically related to the igneous rocks. Further chemical study is planned to define the pattern of variation of the elements among the diatremes and to investigate the relation between the composition of the uraniferous rocks and the associated igneous rocks.

The following paper was published during the report period:

Shoemaker, E. M., 1956, Occurrence of uranium in diatremes on the Navajo and Hopi Reservations, Arizona, New Mexico, and Utah, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 413-417: New York, United Nations.

Reference

Rankama, Kalervo, and Sahama, Th. G., 1950, Geochemistry: Chicago, University of Chicago Press.

Photogeologic mapping
By W. A. Fischer

Mapping of quadrangles along the Utah-Arizona border, using high-altitude photography (scale 1:60,000) in conjunction with the Kelsh plotter, continued during the report period. The maps printed at the scale of 1:24,000 show the stratigraphy and structure of rocks ranging in age from Permian to Tertiary.

Isopachous mapping of the Moenkopi-Hoskinnini interval in the White Canyon 4 SE and parts of the White Canyon 4 NE, 4 NW and 4 SW quadrangles in Utah was completed during the period. Detailed stratigraphic measurements using 1:20,000 scale photography and the Kelsh plotter located several channels or swales that had not been mapped by field parties previous working in the area. Field checking of the photogeologic mapping confirmed the presence of these swales.

The status of the Geological Survey's photogeologic mapping program is shown on the index map, figure 14. During the report period 32 maps of 7-1/2 minute quadrangles at a scale of 1:24,000 were completed, and 50 such maps, completed in this and previous periods, were published by the Geological Survey in the Miscellaneous Geologic Investigations Map series. These maps are listed below, by number and title.

No.	Title
I-111	Woodside-12 quadrangle, Emery County, Utah
I-113	Tidwell-5 quadrangle, Emery County, Utah
I-115	Tidwell-16 quadrangle, Emery and Grand Counties, Utah
I-116	Moab-10 quadrangle, Grand County, Utah
I-117	Moab-12 quadrangle, Grand County, Utah
I-118	Moab-13 quadrangle, Grand and Emery Counties, Utah
I-119	Moab-14 quadrangle, Grand County, Utah
I-120	Desert Lake-14 quadrangle, Emery County, Utah
I-121	Desert Lake-15 quadrangle, Emery County, Utah
I-122	Desert Lake-16 quadrangle, Emery County, Utah
I-123	Woodside-13 quadrangle, Emery County, Utah

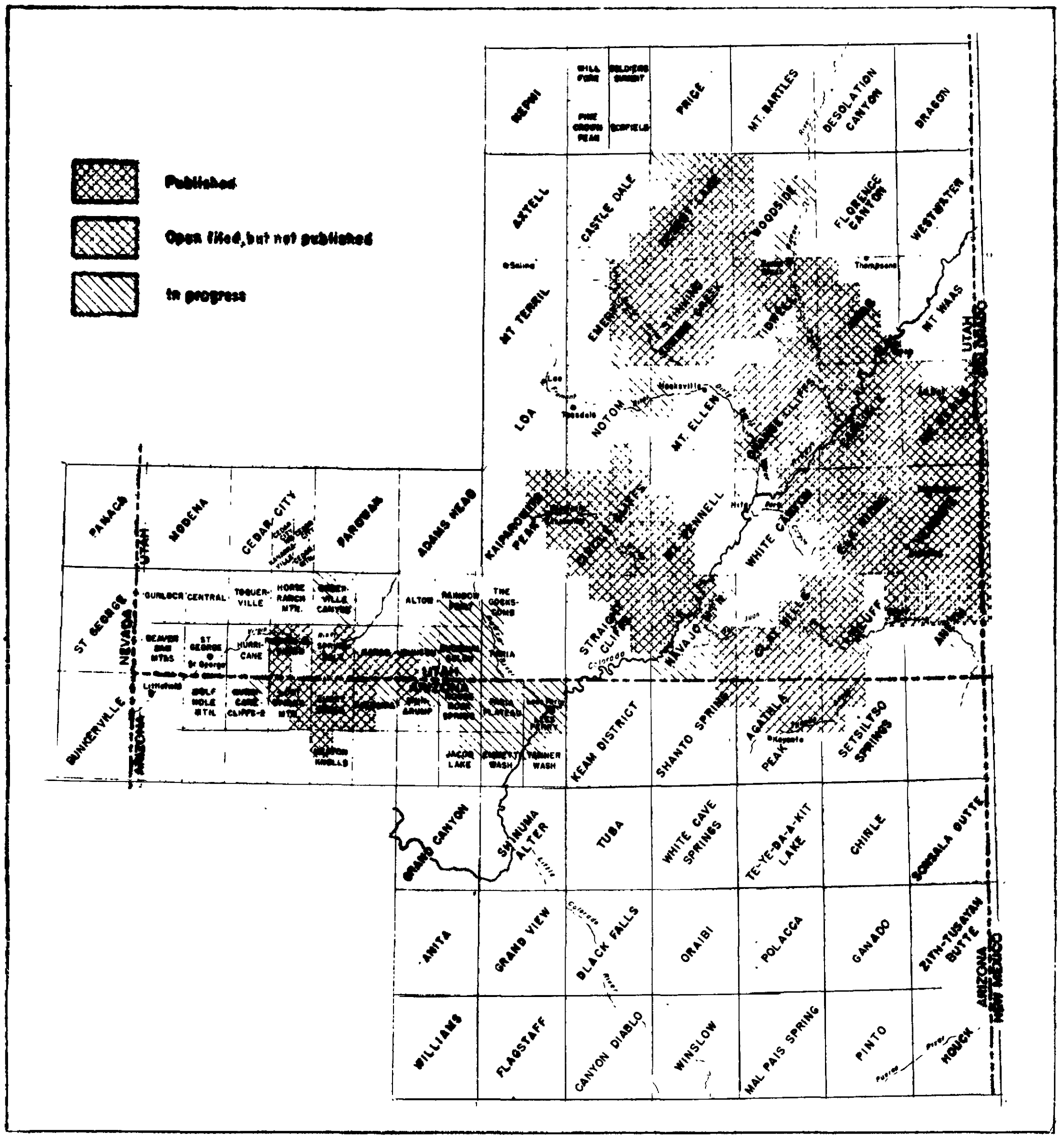


FIGURE 1. INDEX MAP OF PART OF THE COLORADO PLATEAU AREA, SHOWING LOCATION OF PHOTOGEOLOGIC QUADRANGLE MAPS PUBLISHED, IN OPEN FILE BUT NOT PUBLISHED, AND IN PROGRESS AS OF MAY 30, 1956.

No.	Title
I-124	Castle Dale-16 quadrangle, Emery County, Utah
I-125	Elk Ridge-3 quadrangle, San Juan County, Utah
I-126	Elk Ridge-8 quadrangle, San Juan County, Utah
I-127	Elk Ridge-9 quadrangle, San Juan County, Utah
I-128	Moab-15 quadrangle, Grand County, Utah
I-131	Springdale SE quadrangle, Kane County, Utah
I-132	Springdale SW quadrangle, Washington and Kane Counties, Utah
I-133	Fredonia NW quadrangle, Coconino County, Arizona
I-134	Kaiparowits Peak-1 quadrangle, Garfield County, Utah
I-135	Kaiparowits Peak-2 quadrangle, Garfield County, Utah
I-136	Kaiparowits Peak-7 quadrangle, Garfield County, Utah
I-137	Kanab SE quadrangle, Kane County, Utah
I-138	Kanab SW quadrangle, Kane County, Utah
I-139	Shinarump NW quadrangle, Kane County, Utah
I-140	Short Creek SW quadrangle, Mohave County, Arizona
I-141	Short Creek NW quadrangle, Mohave County, Arizona
I-142	Short Creek NE quadrangle, Mohave County, Arizona
I-143	Heaton Knolls NW quadrangle, Mohave County, Arizona
I-144	Lost Spring Mountain SE quadrangle, Mohave County, Arizona
I-145	Lost Spring Mountain NE quadrangle, Mohave County, Arizona
I-146	Lost Spring Mountain NW quadrangle, Mohave County, Arizona
I-147	Virgin SW quadrangle, Washington County, Utah
I-148	Springdale NE quadrangle, Kane County, Utah
I-149	Virgin NW quadrangle, Washington County, Utah
I-150	White Canyon-8 quadrangle, San Juan County, Utah
I-151	Elk Ridge-4 quadrangle, San Juan County, Utah
I-152	Elk Ridge-5 quadrangle, San Juan County, Utah
I-153	Short Creek SE quadrangle, Mohave County, Arizona
I-154	Desert Lake-13 quadrangle, Emery County, Utah
I-157	Mt. Peale-9 quadrangle, San Juan County, Utah and Montrose and San Miguel Counties, Colorado
I-158	Mt. Peale-10 quadrangle, San Juan County, Utah
I-159	Mt. Peale-11 quadrangle, San Juan County, Utah
I-160	Fredonia SW quadrangle, Mohave County, Arizona
I-161	Virginia NE quadrangle, Washington County, Utah
I-162	Tidwell-2 quadrangle, Emery and Grand Counties, Utah
I-163	White Canyon-7 quadrangle, San Juan County, Utah
I-164	Johnson SW quadrangle, Kane County, Utah
I-165	Mt. Peale-1 quadrangle, Grand and San Juan Counties, Utah and Montrose County, Colorado
I-166	Emery-1 quadrangle, Emery County, Utah

Subsurface geologic investigations by drilling

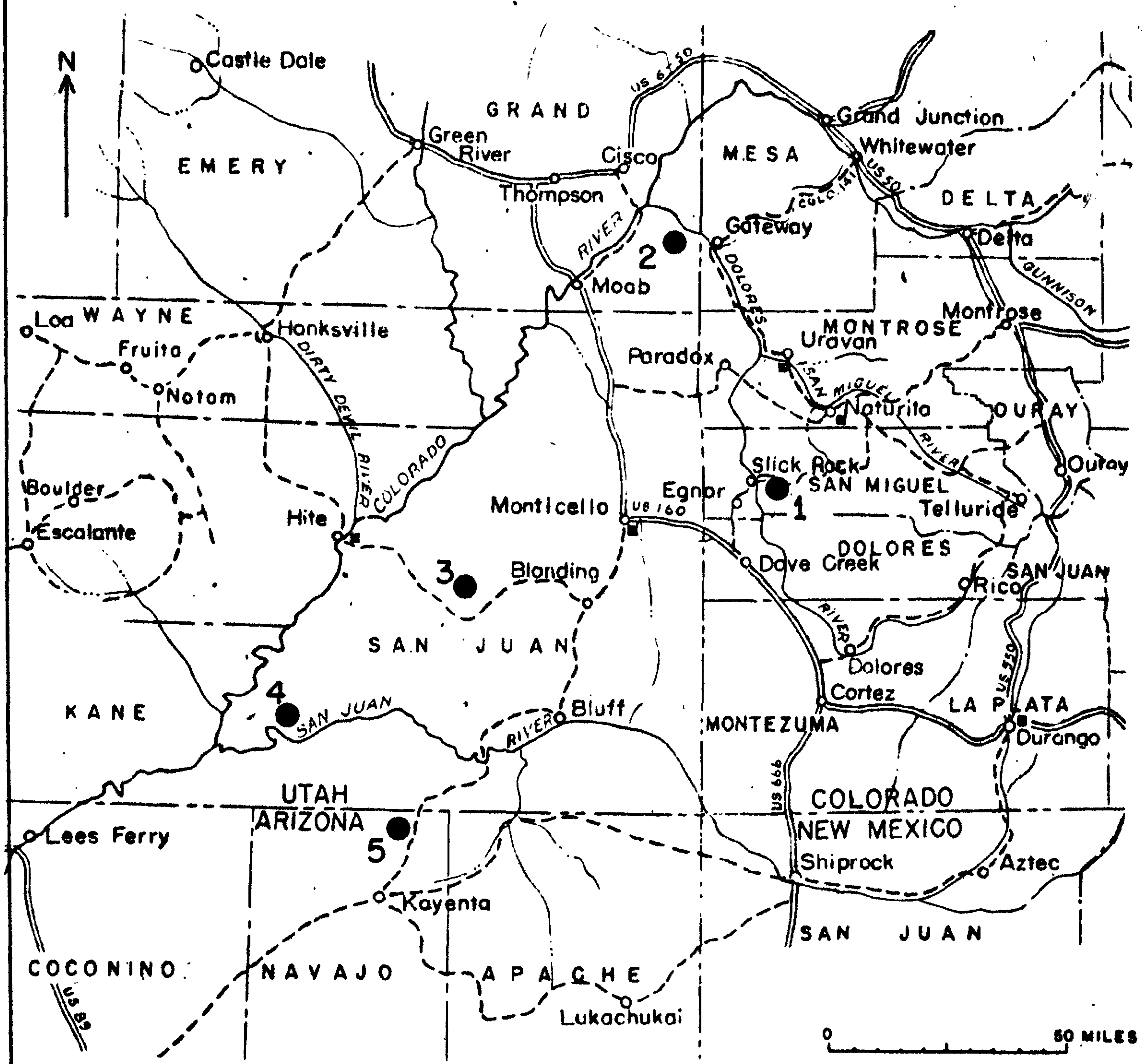
By D. A. Phoenix and P. C. Franks

Diamond drilling designed to test geologic concepts in five areas in the Colorado Plateau was completed in March 1956. These areas are: Disappointment Valley, San Miguel County, Colorado; Kirk's Basin-Taylor Creek, Grand County, Utah; Deer Flat, San Juan County, Utah; Clay Gulch, San Juan County, Utah; and El Capitan Flat (Oljeto Wash), Navajo County, Arizona (fig. 15).

The data for all areas in which drilling was undertaken are being compiled and will be contained in various reports by the Geological Survey; only the highlights are described in this report.

Core from drill holes that penetrated Jurassic and Cretaceous formations on the northeast side of Disappointment Valley is being studied in the laboratory. These cores have furnished mineralogic, paleontologic, and stratigraphic information that is being integrated with a comprehensive study of the stratigraphy and ore deposits in the Slick Rock district; this information is reported in the section on the Slick Rock district in this report. Two drill holes in Disappointment Valley are about 2,000 feet deep and are being used to measure the geothermal gradient. Core samples from one of these drill holes have also been selected for geochemical measurements.

In the Kirk's Basin-Taylor Creek area widely spaced diamond drill holes were drilled to test the Morrison formation for favorableness for ore deposits, and for geologic control in areas of complex geology. One drill hole encountered rock favorable for the occurrence of uranium deposits, and the remaining holes provide control for structure cross-sections across the northern end of the Sinbad Valley salt anticline complex.



LOCALITIES INDEX

1 DISAPPOINTMENT VALLEY

2 KIRK'S BASIN-TAYLOR CREEK [1]/

3 DEER FLAT [1]/

4 CLAY GULCH [1]/

5 EL CAPITAN FLAT (OLJETO WASH) [1]/

[1]/ DRILLING COMPLETED BEFORE REPORT PERIOD

FIG. 15 --INDEX MAP OF PART OF THE COLORADO PLATEAU SHOWING AREAS DRILLED TO TEST GEOLOGIC CONCEPTS.

On Deer Flat diamond drill holes penetrated at least five channels, two of which crop out on the edge of the mesa. In addition, the drill hole data show that the Shinarump member of the Chinle formation is absent beneath the northern part of Deer Flat and that the large uranium deposits in the Shinarump member are from one-half to 1 mile south of the wedge-edge of this member.

A structure contour map of the top of the Moenkopi formation on Deer Flat, based on drill hole and outcrop data, shows a structural terrace in the Moenkopi formation. This terrace may have controlled the shape and trend of a large channel. It may also be significant that the largest ore deposit on Deer Flat is found where the structural terrace and the channel are closely associated (see TEI-540, p. 31-34).

The results of diamond drill exploration for the Shinarump member of the Chinle formation in Clay Gulch, indicate that between Clay Gulch and exposures about 2 miles east, along Red House Cliffs, a dominantly continuous blanket of the Shinarump member wedges out northeast of a line trending N. 15° W. It is likely that the wedge-edge of the Shinarump member continues northward below younger formations capping the Red Rock Plateau and is the same as that mapped in the White Canyon area about 20 miles to the north. It has previously been suggested that ore deposits are localized along this wedge-edge in the White Canyon area (TEI-490, p. 29).

In the El Capitan Flat area (Oljeto Wash) diamond drilling based on geophysical data has led to the discovery of three uranium deposits. These deposits are in conglomerate and sandstone of the Shinarump member that fills a channel in the underlying Moenkopi formation. The channel is known to be continuous for at least 1 mile and may be longer. The channel thins and thickens and the ore deposits are clustered in its deeper parts. The mineralogic relations within these and nearby ore deposits are believed to vary with the ground water environment.

In the El Capitan Flat area the Shinarump member of the Chinle formation is composed of lenticular sandstone strata separated by local disconformities. Some strata are narrow and elongate, others are broad and flat; their individual thicknesses rarely exceed 15 feet. Each stratum contains sedimentary structures oriented in a prevailing direction and each stratum is presumed to represent a period of aggradation during which the depositing stream was essentially fixed in position. In these respects the sedimentary framework of the Shinarump conglomerate is like that of the ore-bearing sandstone of the Morrison formation. These basic geologic data are being correlated with various geophysical measurements to provide an appraisal of the geophysical methods used for exploration in the El Capitan Flat area as well as in other areas.

Stratigraphic studies

General studies
By L. C. Craig and D. D. Dickey

Summary of stratigraphic features associated with uranium deposits of the Colorado Plateau (Craig, 1955) shows that groups of ore deposits are associated with a number of regional stratigraphic features and that habits of single ore deposits are related to small-scale stratigraphic features. Regional features that coincide with groups of ore deposits include certain major depositional environments, gross facies characteristics, margins of deposition, certain lithofacies, formational thicknesses, and sorting of sandstones. Small-scale stratigraphic features related to the position or elongation of ore deposits are channels, thicker parts of sandstone beds, sedimentary structure orientations, and characteristics of color, texture, and composition.

The association of uranium deposits with continental sediments, particularly with fluvial sandstones, focuses attention on the field interpretation of depositional environments. The Morrison formation of Jurassic age, for example, is considered dominantly fluvial because of the presence of scour surfaces, the close association of scour surfaces with the filling sandstone, and, in turn, the close association and alternation of the sandstone units with the lenticularly bedded mudstones of the formation. These characteristics may be developed in other environments; the small amount of additional evidence supporting the interpretation of the fluvial environment of deposition emphasizes the need for additional observation of deposition in modern continental environments.

Paleontologic records dating from 1948 and oil test data have been compiled and incorporated in the records of the general stratigraphic studies, and a dry hole map of the Colorado Plateau has been compiled. A noteworthy result of the examination of cuttings from several drill holes from the San Juan Basin was the satisfactory recognition of the Recapture, Westwater Canyon, and Brushy Basin members of the Morrison formation in the cuttings, and the establishment of subsurface corroboration of the correlation of these members from the west side of the San Juan Basin to the southern and eastern margins of the Basin.

A series of isopach maps of Jurassic and Lower Cretaceous formations of the Colorado Plateau was prepared to serve as cumulative records of thicknesses of these formations. It is planned during the next report period to extend the map coverage to include Cretaceous and Tertiary formations. Compilations of approximate thicknesses from the geologic and topographic quadrangle maps of southwestern Colorado have shown that the thicknesses of the Salt Wash and Brushy Basin members of the Morrison formation and of the Burro Canyon formation are controlled by the salt anticlines in varying degrees. Prior to this crude compilation, thickness control was so sparse that little regional relation between structures and stratigraphic thickness was apparent. The cumulative isopach maps will provide accurate and sufficient control and should allow more exact interpretation of the structural history of the Plateau.

The following report was published during the period:

Craig, L. C., and others, 1955, Stratigraphy of the Morrison and related formations, Colorado Plateau region, a preliminary report: U. S. Geol. Survey Bull. 1009-E, p. 125-168.

Triassic studies

By J. H. Stewart, F. G. Poole, R. F. Wilson, and William Thordarson

Study of the Triassic rocks of the Colorado Plateau has followed four lines of investigation: regional stratigraphy, lithofacies studies, sedimentary structure studies, and pebble studies.

Study of regional stratigraphy was confined during the report period to an investigation of the Wingate sandstone along the north and east side of the Defiance uplift in northeastern Arizona and in the Ft. Wingate and Zuni areas in west-central New Mexico (fig. 16). At the north end of the Defiance uplift, the Wingate sandstone is composed of two members, the Rock Point member and the overlying Lukachukai member. The Rock Point member is composed chiefly of pale reddish brown and light brown, structureless or horizontally bedded siltstone. The Lukachukai member is composed of light brown, very fine- to fine-grained sandstone which is dominantly cross-stratified

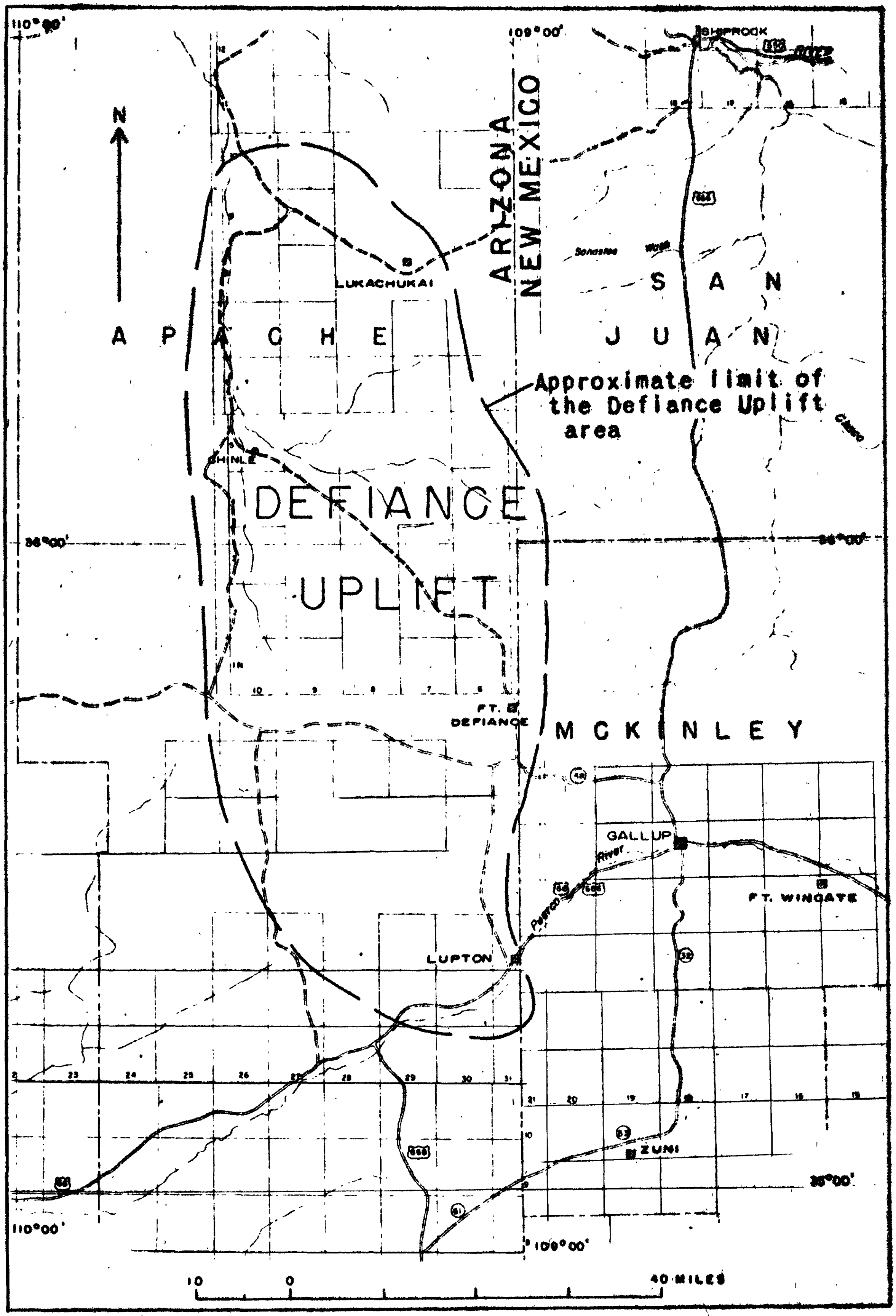


FIG. 16 -- INDEX MAP OF NORTHEASTERN ARIZONA AND NORTHWESTERN NEW MEXICO.

with large scale, high angle cross-laminae. The Rock Roint member is 344 feet thick (Harshbarger, Repenning, and Irwin, written communication, 1955) in the northernmost part of the Defiance uplift and thickens southeastward to 573 feet near the town of Lukachukai in the northeast part of the Defiance uplift. It thins gradually southward from Lukachukai to 199 feet at Zuni. At Lukachukai and in exposures as far south as Ft. Defiance in the southeastern part of the Defiance uplift, the Rock Point member contains beds which are lithologically similar to the Lukachukai member and are generally from 5 to 50 feet thick. The beds have been interpreted by Harshbarger, Repenning, and Irwin (written communication, 1955) to be tongues of the Lukachukai member. Preliminary study indicates that some of these beds coalesce with the Lukachukai member but that others appear to have no physical connection with the Lukachukai along any exposure. Possibly the beds coalesce with the Lukachukai member elsewhere, for example in areas where the Triassic rocks are covered by younger sediments, or possibly they may be separate lenses within the Rock Point member and have no physical continuity with the Lukachukai member.

Near Zuni, the Rock Point member is composed mainly of light brown, very fine- to fine-grained sandstone which is horizontally laminated and contains low angle, medium scale cross-laminae. Similar beds are found in exposures at Lupton in the southernmost part of the Defiance uplift. These beds are interpreted to be fluvial units derived from the south and interfingering to the north with the more dominant siltstone of the Rock Point member.

The Lukachukai member is 352 feet thick (Harshbarger, Repenning, and Irwin, written communication, 1955) in the northernmost part of the Defiance uplift, thins to the south, and in interpreted to pinch out in exposures

20 miles southeast of Lukachukai. Preliminary study suggests that the pinchout of the Lukachukai member as well as the thinning of the Rock Point member beyond the limit of the Lukachukai is caused by truncation of the strata of the Wingate by erosion prior to deposition of the overlying Entrada sandstone. The Wingate sandstone at Ft. Wingate, therefore, may be equivalent to only the lowest part of the Rock Point in the northern part of the Defiance uplift. Harshbarger, Repenning, and Irwin have correlated strata 355 feet thick at Ft. Wingate with the Lukachukai member but did not recognize any Rock Point member there.

Lithofacies data are being compiled on three main units in the Triassic rocks: (1) the Moenkopi formation, (2) the lower part of the Chinle formation consisting of the Shinarump, Monitor Butte, Moss Back, Petrified Forest members and their correlatives, and (3) the upper part of the Chinle formation consisting of the Owl Rock and Church Rock members. With the upper part of the Chinle formation are included in this study the Rock Point member of the Wingate sandstone and the Dolores formation. Insufficient data about the lower part of the Chinle formation have been compiled to show any significant facts. For the lithofacies studies the rocks of the Moenkopi formation and of the upper part of the Chinle formation are classified into three main lithologic types; (1) horizontally laminated and structureless mudstone which is interpreted to represent quiet water deposits, (2) ripple-laminated siltstone which is interpreted to be formed by current action, and (3) cross-stratified sandstone and conglomerate which are interpreted to be fluvial deposits. Limestones constitute a small part of these units in most places and are treated separately. McKee (1954) used a similar grouping in studying the Moenkopi formation in northern Arizona and southern Utah. Ideally, the fluvial deposits might be expected near the source area of the sediments, the ripple-laminated siltstone away from the source area, and the structureless mudstone farther away from the source in the deeper part of the basin of deposition that was probably covered by water.

Preliminary results of the lithofacies study of the Moenkopi formation suggest that the Moenkopi is composed dominantly of horizontally laminated and structureless mudstone in southwestern Utah and northwestern Arizona and grades irregularly to the northeast, east, and southeast into areas where all three lithologic types are intermixed in fairly equal proportions. Along the eastern margin of the Moenkopi, near St. Johns in east-central Arizona and near Gateway in west-central Colorado, the Moenkopi is composed dominantly of cross-stratified sandstone and conglomerate.

The lithofacies study of the upper part of the Chinle formation in southeastern Utah shows a predominance of horizontally laminated and structureless mudstone in the Circle Cliffs, Capitol Reef, and southern San Rafael Swell areas and a large amount of cross-stratified sandstone in the eastern San Rafael Swell, Moab, and Big Indian Wash areas. Between the region containing predominantly horizontally laminated and structureless mudstone and the region containing predominantly cross-stratified sandstone, the three lithologic types are intermixed irregularly.

Compilation of field data on sedimentary structure studies yielded the following results. The Holbrook member (Hager, 1922) of the Moenkopi formation in east-central Arizona shows a dominantly westerly direction of sediment transport. The Shinarump member of the Chinle formation shows a westerly direction of sediment transport in the Hurricane Cliffs area of southwestern Utah and in southeastern Nevada, and a northeastern trend along the Mogollon Rim in east-central Arizona. In the Defiance uplift, the Shinarump shows a variable direction of transport ranging from northeast, through northwest, to southwest. Cross-strata studies in various sandstone units in the Petrified Forest member of the Chinle formation in northern Arizona, southwestern Utah, and southeastern Nevada show a northeasterly to northwesterly direction of sediment transport. The Sonsela sandstone bed of the Petrified Forest member shows a northeasterly direction of transport throughout most of its extent in northeastern Arizona and northwestern New Mexico. The so-called tongues of the Lukachukai member in the Rock Point member, and the Lukachukai member itself in northeastern Arizona and northwestern New Mexico show a dominantly southeasterly direction of sediment transport. The basal unit of the Dolores formation in southwestern Colorado, in general, shows a northwesterly direction of sediment transport. The Navajo sandstone in southwestern Utah, northwestern Arizona, and southeastern Nevada shows a southwesterly direction of sediment transport, whereas the Navajo elsewhere was transported southeasterly.

From 40 to 95 percent of the pebbles in the Shinarump member along the northeastern part of the outcrop of the member (southeastern Utah) are composed of quartz; the rest of the pebbles are dominantly quartzite and chert. From 55 to 95 percent of the pebbles in the Shinarump along the southwestern part of the outcrop of the member (northwestern Arizona) are composed of quartzite and chert; the rest of the pebbles are dominantly quartz. This change of pebble components takes place gradually but irregularly.

Igneous pebbles are a sparse component of the Shinarump member in the area from Flagstaff to Lees Ferry, central and north-central Arizona. Most of the igneous pebbles consist of rhyolite tuff and trachyte tuff although some consist of rhyolite(?) and trachyte vitrophyre(?).

At least 95 percent of the pebbles in the Gartra grit member of the Stanaker formation of Thomas and Krueger (1946) in the Uinta Mountains area, northeastern Utah, consist of quartz. These pebbles are smaller and more angular than the pebbles from the Shinarump member. The Gartra grit member has been called Shinarump conglomerate by Kinney (1955).

At least 90 percent of the pebbles in the Sonsela sandstone bed of the Petrified Forest member of the Chinle formation in northeastern Arizona and northwestern New Mexico generally consist of chert. These pebbles are more angular than the pebbles in the Shinarump member.

Igneous pebbles were found in the Sonsela sandstone bed in northeastern Arizona. They consist of porphyritic rhyolite, porphyritic dacite, rhyolite or trachyte vitrophyre, rhyolite tuff, and trachyte tuff.

The following report on the Triassic stratigraphy of the Colorado Plateau was published during the period:

Poole, F. G., and Williams, G. A., 1956, Direction of transportation of the sediment constituting the Triassic and associated formations of the Colorado Plateau, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy —v. 6, Geology of uranium and thorium, p. 326-330: New York, United Nations.

References

Hager, Dorsey, 1922, Oil possibilities - Holbrook area - Arizona: Mining and Oil Bull., v. 8, no. 1, p. 23-26, 33-34; no. 2, 71-74, 81, 94; no. 3, p. 135-140.

Kinney, D. M., 1955, Geology of the Uinta River - Brush Creek area, Duchesne and Uintah Counties, Utah: U. S. Geol. Survey Bull. 1007.

McKee, E. D., 1954, Stratigraphy and history of the Moenkopi formation of Triassic age: Geol. Soc. Am. Memoir 61, 133 p.

Thomas, H. D., and Krueger, M. L., 1946, Late Paleozoic and early Mesozoic stratigraphy of Uinta Mountains, Utah: Am. Assoc. Petroleum Geologists Bull., v. 30, no. 8, p. 1255-1293.

Entrada study
By J. C. Wright and D. D. Dickey

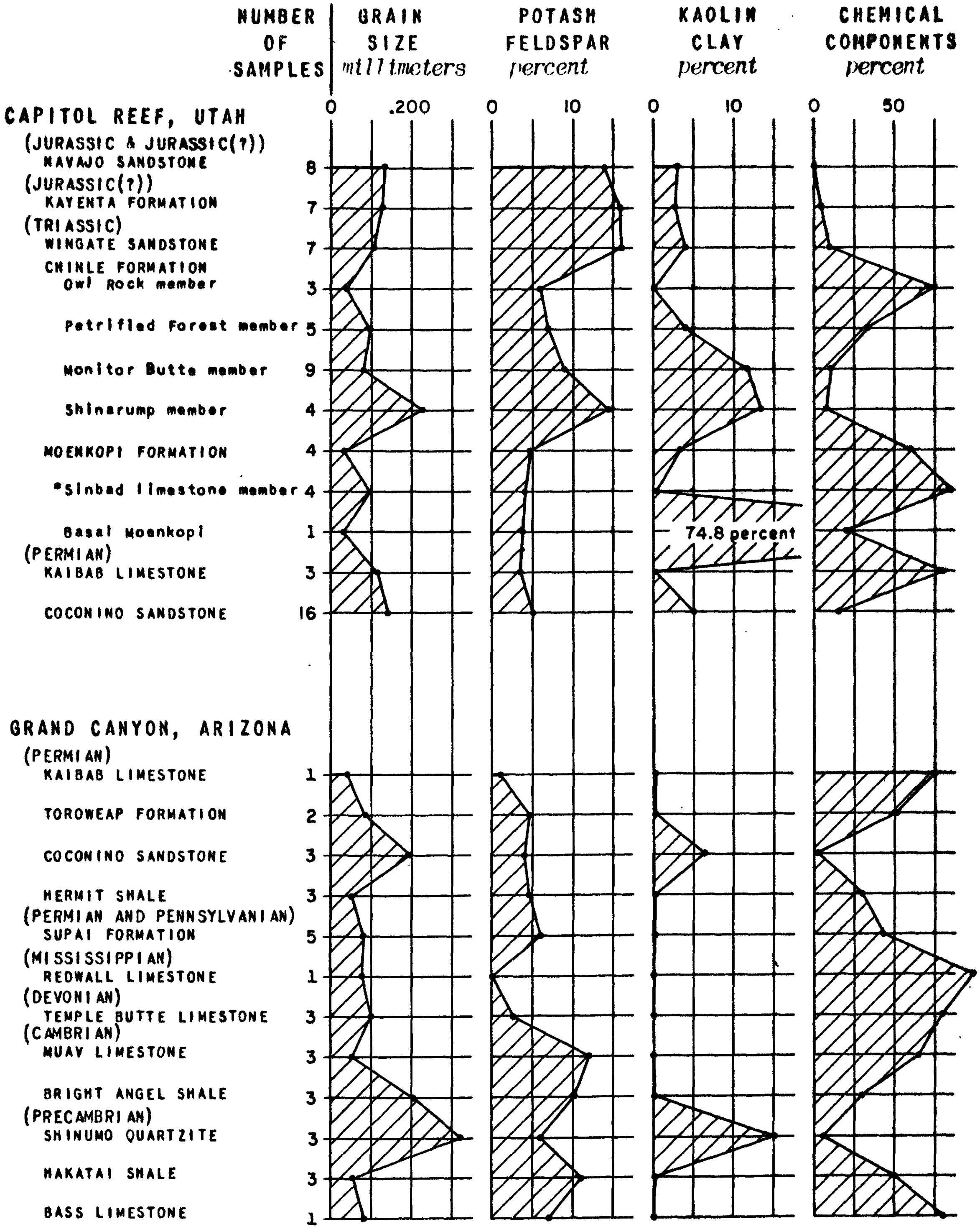
The study of the San Rafael group, including the Entrada sandstone, was begun in late June 1955, and preliminary results of field work in 1955 were reported in the semiannual report for the period ending November 30, 1955 (TEI-590, p. 79-80). Most of the current report period has been occupied by review of selected literature and compilation of data. The work has been carried on in close collaboration with the general stratigraphic studies project, and the results are in part included in the report on general stratigraphic studies.

Lithologic studies
By R. A. Cadigan

The petrographic study of sedimentary formations on the Colorado Plateau was extended to rocks older than those of Triassic age to determine if any of the older formations had characteristics similar to those of the known ore-bearing horizons in formations of Triassic age.

A suite of samples from the Grand Canyon of the Colorado River was selected for this study. In the upper part of figure 17 are plotted the results of analysis of samples from Triassic and adjacent Permian and Jurassic formations in the southern part of the Capitol Reef National Monument in central Utah; in the lower part is a comparable set of analyses of the suite of samples from the Grand Canyon. The figure shows names of the formations and their age and location; the parameters presented for comparison include grain size, potash feldspar content, kaolin clay content, and chemical components.

The definitions of the terms are as follows: grain size is represented by the average modal grain diameter determined by sieve and



Öolites in lower part treated as detrital grains for grain size analysis.

FIG. 17 --COMPARISON OF PARAMETERS OF SEDIMENTARY ROCK UNITS AT CAPITOL REEF NATIONAL MONUMENT, UTAH, AND GRAND CANYON NATIONAL PARK IN ARIZONA.

pipette analyses; potash feldspar content is the mean percent of sodium cobaltinitrite-stained feldspar measured in thin sections of the rock samples; kaolin clay is the mean percent of kaolinite clay plus ground-up quartz, feldspar, and mica, measured in thin sections; chemical components include the mean percent of calcite, dolomite, other carbonates, interstitial silica, iron oxides, and other rock components precipitated from solutions either during or after deposition of the detrital components. Measurements of composition were made on thin sections of the rock samples using the point count method introduced by Chayes (1949). Five hundred counts were made on each thin section. The percentages shown in the graphs (fig. 17) represent percentages of the total rock composition; the percentages of other components such as quartz, plagioclase, micas, and micaceous clays are not shown.

The coarsest-grained units are the Shinarump member of the Chinle formation at Capitol Reef and the Coconino sandstone and Shinumo quartzite at Grand Canyon. The units richest in potash feldspar are the Navajo sandstone, Kayenta formation, Wingate sandstone and Shinarump member at Capitol Reef and the Muav limestone, Bright Angel shale and Hakatai shale at Grand Canyon. The units richest in kaolin are the Monitor Butte and Shinarump members, and a single sample of basal Moenkopi formation at Capitol Reef, and the Shinumo quartzite at Grand Canyon. The units containing the least chemical components are the Navajo sandstone, Kayenta formation, Wingate sandstone, Monitor Butte and Shinarump members and the Coconino sandstone at Capitol Reef, and the Coconino sandstone and Shinumo quartzite at Grand Canyon.

The ore horizon at Capitol Reef is represented by the Monitor Butte and Shinarump members of the Chinle formation. The units at Grand Canyon which most nearly resemble these two units are the Coconino sandstone and the Shinumo quartzite; of these, the one most likely to contain uranium ore deposits of the type found in the lower part of the Chinle formation, is the Shinumo quartzite.

Items of general interest in the study were: (1) a cyclical sequence of dominantly chemical and dominantly detrital sedimentary units in the strata studied, that no doubt is related to the tectonic background of the conditions of deposition; and (2) the presence of from 1 to 3 percent glauconite in the rock in the Temple Butte limestone, the Muav limestone, and the Bright Angel shale.

Reference

Chayes, Felix, 1949, A simple point counter for thin-section analysis: The American Mineralogist, v. 34, nos. 1 and 2.

Regional synthesis

The regional synthesis program is designed to compile and synthesize all available geologic and economic data on the relation of known uranium deposits on the Colorado Plateau to stratigraphic units, lithologic character of host rocks, tectonic structures, and geochemical environment. Such a synthesis will make possible a comprehensive appraisal of the uranium resources of the region, and point to areas in which combinations of geologic factors suggest the presence of concealed deposits.

For the purposes of the regional synthesis program, the Colorado Plateau has been divided into three arbitrary geographic areas. Results of work in each of these areas are reported below.

Northwestern Colorado and northeastern Utah
By R. T. Chew, III

The larger uranium deposits in the Salt Wash member of the Morrison formation in the Thompson district, Grand County, Utah, appear to be localized in thicker sandstone lenses in an ancient stream channel system. Sedimentary structure studies indicate that this northeasterly trending channel system was deflected slightly to the north by the Salt Valley anticline, a salt structure which was mobile during the time of deposition of the Salt Wash sediments (fig. 18). Over the crest of the Salt Valley anticline, Salt Wash streams deposited only thin sandstone lenses, and sedimentary trends are highly variable. Within the channel system on the northern flank of the anticline, sandstone lenses are relatively thick, and sedimentary trends are more consistent. Most of the important uranium deposits now known in the Thompson district are within this channel system in the Yellow Cat area, and ground relatively favorable for uranium deposits in the district is thought to be essentially confined to this channel system and its projection north-northeastward towards the town of Cisco, Utah. In the vicinity of Cisco the Salt Wash is present at a depth of about 900 feet.

Northwest New Mexico
By L. S. Hilpert and A. F. Corey

During the report period a map showing the known uranium deposits of northwestern New Mexico was compiled, and a study was made of the relations of radon contamination in drill holes to uranium deposits.

To gain a better understanding of the habits of the uranium deposits in northwest New Mexico it is necessary to evaluate their tonnage and

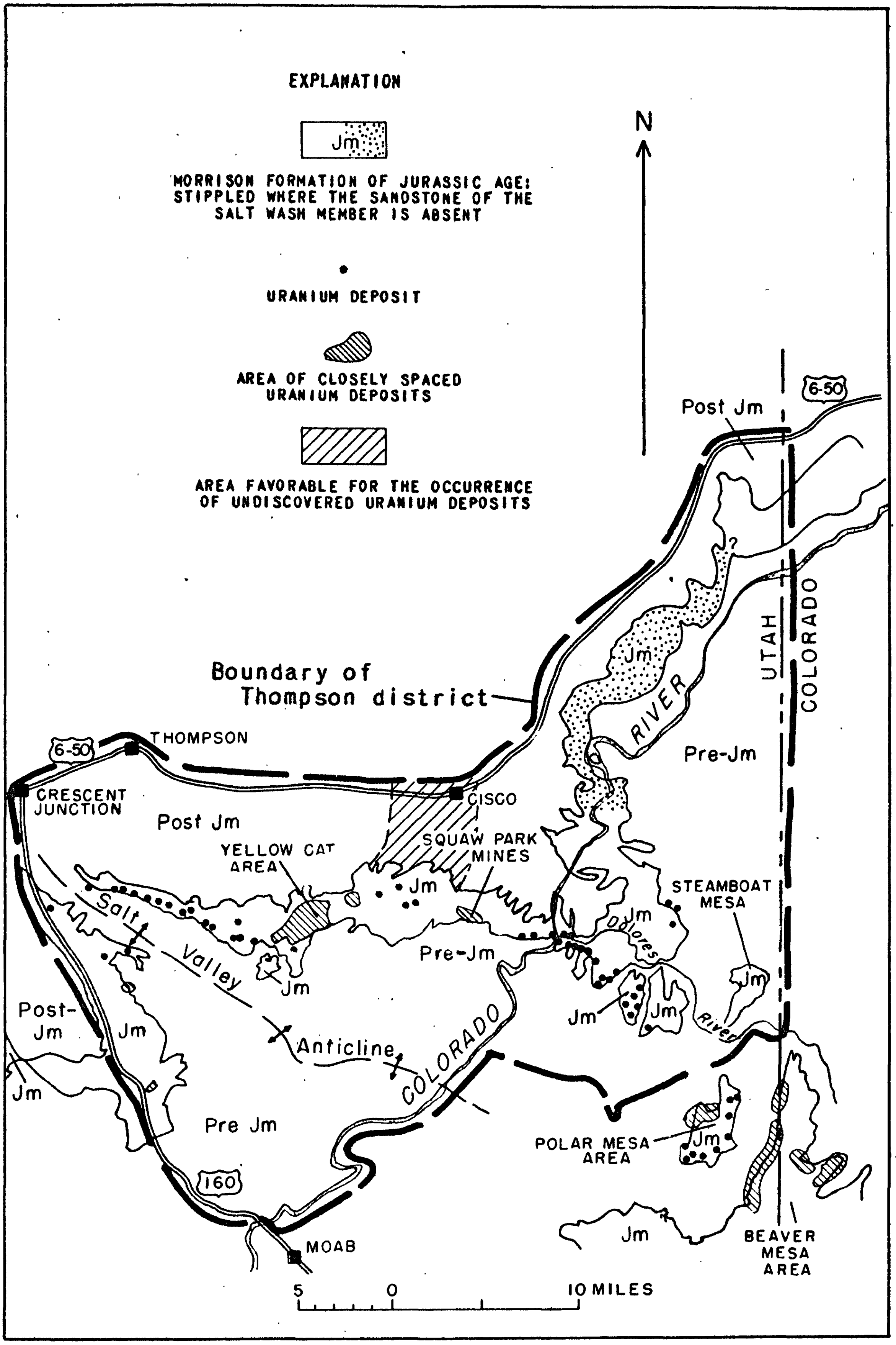


FIG. 18 --URANIUM DEPOSITS AND GROUND FAVORABLE FOR CONCEALED DEPOSITS IN MORRISON FORMATION, THOMPSON DISTRICT, GRAND COUNTY, UTAH.

grade. Much of the available assay information is only "in-hole" gamma-ray data, and such information has proved to be unreliable in many places. The gamma-ray logs of many holes can not be duplicated by re-logging, and often, when chemical assay data of cores are available for comparison, it has been found that the uranium content and thickness of ore inferred from the gamma-ray data are excessive.

It appears likely that the anomalous radioactivity and measurements of equivalent uranium of the logs in the Grants area are caused in part by the accumulation of radon gas in the holes. This was not generally suspected by many miners, although some used compressed air to flush out radon from the holes. However, radon was apparently not actually identified as the contaminating agent in the Todilto uranium deposits, and little data were available on the behavior of radon in holes drilled in and near uranium deposits.

During the fall of 1954 gamma-ray logs were obtained of drill holes on properties near Grants, New Mexico. Shortly thereafter, A. B. Tanner of the U. S. Geological Survey took air samples from selected holes and identified radon in relatively high concentrations (Tanner, written communication, 1955). Gamma-ray logs of the same holes in which he found high concentrations of radon showed characteristics that made it possible to recognize radon-contaminated holes. In order to learn the relations of the radon to the uranium deposits, including such items as the content of radon and how best to flush it from the holes, about 600 gamma-ray logs taken from about 500 drill holes were evaluated. C. M. Bunker of the Geological Survey assisted in the evaluation.

The logging instrument used was truck mounted and calibrated for accurate determination of sample thickness and percent equivalent U_3O_8.

The logs were made on a strip-chart recorder between November 1954 and April 1955. The holes, which are in the Todilto limestone, range from 30 to about 400 feet in depth, and have a diameter of about 4 inches. All the properties on which the work was done are in sec. 30, T. 13 N., R. 9 W., McKinley County, New Mexico, about 10 miles north of Grants.

About 20 percent of the holes logged were found to have abnormal concentrations of radon, referred to here as contamination. The number of holes contaminated related directly to the uranium content of the mineralized material in the holes and accordingly is spatially related to the deposits. Nearly all of the contaminated holes are within deposits, and none was found that was more than about 50 feet from known mineralized ground. The number of holes contaminated also relates directly to the time that elapsed between drilling and logging (table 2). The contamination ranges from amounts too low to detect on a gamma-ray log to amounts that would be attributable to ore-grade material.

Most holes were cleared of contamination by blowing them out with compressed air for periods ranging from 15 minutes to about two hours. A few were not successfully cleared of contamination by this method. The most effective means for avoiding contamination is to log the holes immediately after they are drilled.

Adding water to contamined holes also seems to be an effective means of reducing the radon, perhaps more so than flushing with air. The water, however, reduces the count rate and the indicated thickness of the individual mineralized layers to less than that obtained in air. In 13 selected holes, water reduced the total sample thickness from about 95 feet to about 80 feet (a difference of 15 percent) and reduced the weighted mean grade by about 10 percent, for material that ranged from about 0.02 to 10.0 percent eU_3O_8.

Table 2.—Numbers of holes logged and the numbers and percentages found to be contaminated, relative to grade and elapsed time of logging after drilling

Elapsed time after drilling	Number of holes logged and contaminated and percent contaminated — Grade cutoffs									Totals by elapsed time brackets		
	<0.01% U_3O_8 or <0.02% eU_3O_8			0.01 to 0.099% U_3O_8 or 0.02 to 0.149% eU_3O_8			0.1% or more U_3O_8 or 0.15% or more eU_3O_8					
	Logged	Contaminated No.	Contaminated Percent	Logged	Contaminated No.	Contaminated Percent	Logged	Contaminated No.	Contaminated Percent	Logged	Contaminated No.	Contaminated Percent
<1 hour	68	1	1	41	2	5	71	3	4	180	6	3
1-24 hours	55	2	4	42	11	26	40	10	25	137	23	17
>24 hours	68	9	13	43	19	44	52	45	87	163	73	45
Totals by grade brackets	191	12	6	126	32	25	163	58	36	480	102	21

The radon contamination in the drill holes apparently results from the holes tapping the open fractures and spaces in the Todilto limestone, where radon has accumulated by diffusion from the parent uranium minerals. The holes serve as conduits through which the radon can flow, the concentration being affected by variations in atmospheric pressure. Higher levels of contamination occur at times of relatively low atmospheric pressure (Tanner, written communication, 1955).

As fracturing and relatively high permeability of rocks seem to be principal factors in causing radon contamination, any uranium-bearing host rock should be considered a potential source for radon contamination of drill holes where the rocks lie above the water table.

The following paper on the appraisal of uranium deposits in northwest New Mexico was published during the period:

Hilpert, L. S., and Freeman, V. L., 1956, Guides to uranium deposits in the Gallup-Laguna area, New Mexico, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 346-349: New York, United Nations.

Utah and Arizona

By H. S. Johnson

Work during this period was confined to the preparation of a geologic report on the Green River and Henry Mountains districts, Utah. The Chinle formation and the Salt Wash member of the Morrison formation have been the source of essentially all the uranium ore produced to date from these districts and contain all the districts' indicated and inferred reserves. Primary sedimentary features, especially channels and the relative discontinuity of beds near regional pinchouts, are thought to be the principal ore controls; and significant uranium deposits are more likely to be found in the following places:

(1) In the Shinarump member of the Chinle formation on the flanks of channels in the Circle Cliffs and Capitol Reef areas and in a 10 to 20 mile-wide belt of relatively favorable ground related to and paralleling the northwesterly trending line of regional pinchout of the member in the Henry Mountains district (fig. 19).

(2) In the Monitor Butte member of the Chinle formation in sandstone lenses having a thickness of 30 feet or more in a 25 mile-wide belt of relatively favorable ground parallel to and bounded by the northeastern line of pinchout of the member (fig. 19).

(3) In the Moss Back member of the Chinle formation along an inferred southeastern extension of the Temple Mountain channel system and in a 10 mile-wide belt of relatively favorable ground bounded by and paralleling the northeastern pinchout of the member in the area between the Green and Colorado Rivers (fig. 19).

(4) In an inferred narrow belt of thicker and more sandy sediments in the basal Chinle on the southwest flank of the Moab anticline (fig. 19).

One of the more interesting areas in the Green River and Henry Mountains districts is in the area between the Green and Colorado Rivers. In the Seven Mile area, in the easternmost part of the Green River district, small uranium deposits occur in mudstones, limy siltstones, and lime pebble conglomerates in the lower part of the Chinle formation where this unit is exposed high on the southwest flank of the Moab anticline. Ore deposits occur as small pods of uraninite and minor amounts of copper sulfides scattered through otherwise barren rock. The absence of large, well defined ore bodies may be due to the lack of good sandstone host rocks and continuous, permeable sandstones in the Chinle at this locality. Because the Moab anticline was rising just prior to Chinle deposition, rose again after

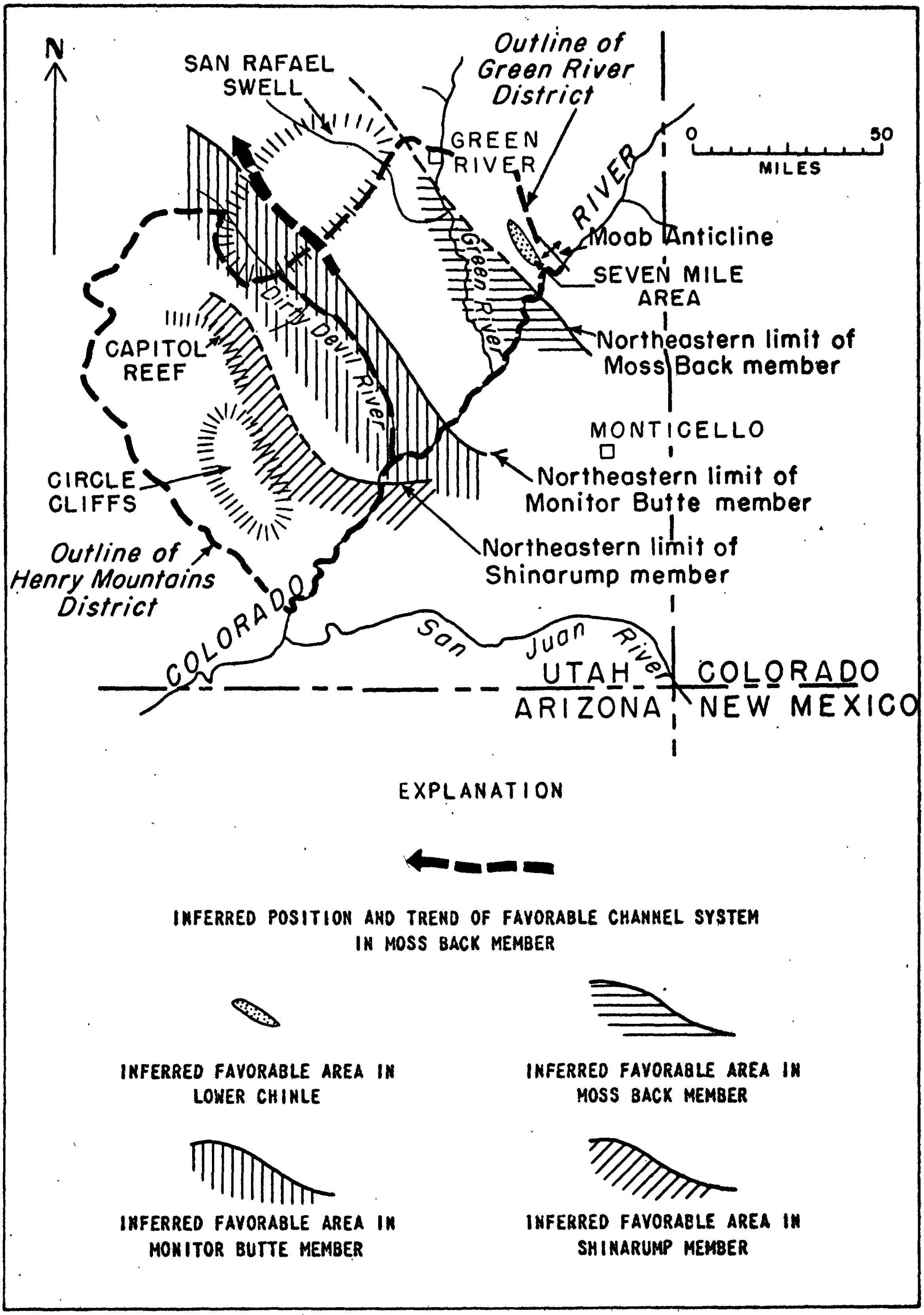


FIG. 19--INFERRED AREAS OF GROUND RELATIVELY FAVORABLE FOR URANIUM DEPOSITS IN THE CHINLE FORMATION IN THE GREEN RIVER AND HENRY MOUNTAINS DISTRICT, UTAH.

Chinle time, and may well have been slowly rising intermittently during Chinle deposition, it seems likely that Chinle drainage was influenced by the rising structure and that there may be a concentration of sandy stream deposits paralleling the axis of the anticline somewhere down the southwest flank of the structure. These relatively more sandy sediments or the interfingering between them and finer grained clastics up structure could provide more favorable host rocks for large uranium deposits than the mudstones, siltstones, and lime pebble conglomerates higher up on the anticline. Ore deposits larger than 100,000 tons in size may be present in the sandy belt, and potential reserves may be large. So far, the concept of a favorable belt on the southwest flank of the Moab anticline has not been thoroughly tested.

Although potential ore reserves of the Green River and Henry Mountains districts are thought to be many times the combined production and indicated plus inferred reserves, depths of 1,000 feet or more to the ore-bearing unit in many of the more favorable areas may make it economically unfeasible to explore for and mine these reserves.

Botanical studies

Research
By H. L. Cannon

The development of botanical prospecting methods in the search for uranium has been described in previous semiannual reports (TEI-540, p. 72-73; TEI-590, p. 118-119). The program has demonstrated that the most useful indicator plant for uranium deposits on the Colorado Plateau is Astragalus pattersoni, a poisonvetch that absorbs toxic amounts of both selenium and molybdenum from the uranium deposits. Prospecting by indicator plants such as Astragalus pattersoni is most effective where the cover is open, the ore horizon is at an average depth of about 40 feet beneath the surface, and the ore contains about .01 percent uranium.

The program has also shown that prospecting by tree analysis is the most effective botanical method in forested areas at higher altitudes. The method has been tested by the collection and analysis of more than 10,000 tree samples. In most areas, amounts of 1 ppm uranium or more in tree foliage is indicative of mineralized ground. Tree analysis may be used effectively to outline mineralized ground to an average depth of 70 feet.

A new method of analysis of plant ash is being developed by A. Marranzino of the Geological Survey. The method is chromatographic and is being designed as a field test to be run on plant ash by the prospector. It should be easy to operate and sensitive to 1 ppm uranium. It is anticipated that the total equipment needed will not cost more than $5.00.

Pioneer work on the analysis of plant material for radium has been carried on in the Denver Trace Elements Laboratory. Unusual amounts of radium were found in vegetation growing in the Penasco Hot Springs near San Ysidro, Sandoval County, New Mexico. The largest content was 9.2×10^{-12}g Ra ^{226}/g in ash which is 300 times higher than would be expected if the radium content were in equilibrium with uranium.

The following reports on botanical prospecting were published during the period:

Cannon, H. L., and Starrett, W. H., 1956, Botanical prospecting for uranium on La Ventana Mesa, Sandoval County, New Mexico: U. S. Geol. Survey Bull. 1009-M, p. 391-406.

Cannon, H. L., and Kleinhampl, F. J., 1956, Botanical methods of prospecting for uranium, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 801-805: New York, United Nations.

Prospecting
By F. J. Kleinhampl and Carl Koteff

Evaluation of the plant analysis method of prospecting continued during this report period. The evaluation is based on data from plant sampling programs conducted at Elk Ridge, San Juan County, and San Rafael Swell, Emery County, Utah; Grants district, McKinley and Valencia Counties, New Mexico; and at the Uranium Peak area, near Meeker, Rio Blanco County, Colorado.

Studies of Elk Ridge data indicate that cutoffs in parts per million (ppm) used to define botanical anomalies differ for different tree species (table 3). At some localities on Elk Ridge these smallest cutoffs were replaced or complemented by larger cutoffs because sampling and analytical errors make reported assay values unreliable in the range of the smaller cutoffs. The larger cutoffs shown on the table classify the uranium content of the plant more reliably. Any figure for the uranium content for each species between the small and large cutoffs is indeterminately anomalous. That is, the uranium content of the sample may or may not be anomalous, depending on the preciseness of the reported analyses and on whether or not the collected sample is representative of the plant.

It appears that a prospector, lacking precise information, could use a 1.0 ppm content of uranium in plant ash as a cutoff for most evergreen species and be moderately successful in locating botanical anomalies. The refined cutoffs (table 3) serve chiefly to define more sharply botanical anomalies that would be found if only a 1.0 ppm cutoff were used.

A study of aspen sample data indicates that this deciduous species may have a cutoff as low as 0.5 ppm uranium in ash of leaves and twigs. This cutoff is significantly lower than the 1.0 ppm cutoff for uranium in

Table 3.—Classification of uranium content in different trees, Elk Ridge, San Juan County, Utah

Tree	Background uranium content (ppm) 1/	Cutoff (ppm) 1/	Indeterminately anomalous uranium content (ppm) 1/	Cutoff (ppm) 1/	Reliably anomalous uranium content (ppm) 1/
Ponderosa pine	< 0.9	0.9	0.9 to < 1.3	1.3	> 1.29
Pinyon pine	< 0.9	0.9	0.9 to < 1.1	1.1	> 1.09
Douglas fir	< 0.7	0.7	0.7 to < 1.0	1.0	> 0.99
White fir	< 0.7	0.7	0.7 to < 1.0	1.0	> 0.99
Juniper	< 0.7	0.7	0.7 to < 1.0	1.0	> 0.99

1/ All samples were branch tips; the figure reported is ppm (parts per million) uranium in the ash.

evergreens, and many botanical anomalies might remain unnoted by using the 1.0 ppm cutoff where aspen constitute a large proportion of sampled trees. Because aspen sampling may be useful in searching for uranium deposits in many parts of the United States, it is here tentatively recommended that a 0.5 ppm cutoff be used. Also, because aspen appears to have a shallow root system, trees for sampling should be selected as close as possible to the test horizon.

Mineralogic studies

Ore mineralogy
By Theodore Botinelly

Detailed and reconnaissance studies (see TEI-540, p. 74-75; TEI-590, p. 122-124) of a number of deposits in the Salt Wash member of the Morrison formation indicate that the uranium-vanadium deposits are similar in mineralogy. In unoxidized ore the ore minerals are uraninite, coffinite, montroseite, and vanadium silicates, and the gangue minerals are quartz, clay minerals, gypsum, calcite, dolomite and barite. Metallic minerals associated with the ore are pyrite, marcasite, and galena; some of the deposits contain sphalerite, clausthalite, molybdenite, and chalcopyrite.

Uraninite and coffinite, the more important uranium minerals in the unoxidized ore, are best developed where they replace coalified wood. Under this condition, the uraninite and coffinite are mixed intimately and are associated with montroseite and the remnants of the coalified wood. Montroseite, the most conspicuous vanadium mineral, occurs as acicular or bladed crystals in the matrix of the host sandstone. Some montroseite crystals penetrate the overgrowths on the quartz grains of the sandstone, and rarely have been found penetrating the original quartz grains.

Much of the clay matrix between the quartz grains in ore is composed of vanadium clay minerals. These vanadium silicates are clay-size mica and chlorite, and mixed-layered mica-montmorillonite with vanadium in substitution for aluminum (Hathaway, J. C., written communication, 1955). The clay minerals probably contain more vanadium than is present as oxides and vanadates, and the clays persist through the oxidation process with no apparently alteration.

Of the gangue minerals, pyrite is most abundant and is present as individual crystals, nodules, and replacements of coalified wood. Apparently two generations of pyrite are present in the ores; an early pyrite, probably diagenetic, and a late pyrite, probably deposited by the ore solutions. Marcasite is present in most pyrite masses; occasionally nodules of almost pure marcasite are found. Marcasite is present in most specimens of ore that contain sulfides.

Galena occurs typically in the gangue as minute grains in high-grade ores. Some of the grains show crystal faces; others are irregular, conforming to the shape of the interstices between quartz grains. Clausthalite is present in small amounts in many of the deposits and typically forms thin zones or layers of limited extent. Molybdenite, chalcopyrite, and sphalerite are rare.

Coalified wood is an almost universal accessory material in the Salt Wash ores; many pods of high-grade ore are replacements of coalified wood. Some woody material close to ore, however, contains neither radioactive material nor vanadium minerals. The coalified wood associated with uranium and vanadium minerals is black, has a high luster, and is anisotropic in polished section. At some places the woody structure is preserved by replacement by pyrite or by vanadium or uranium minerals; at other localities the material has lost its woody structure and shows a "microcline" twinning effect under crossed nicols. Coalified wood that does not contain radioactive material of microscopically visible vanadium minerals is brown, somewhat translucent, and isotropic. The woody structure is usually well preserved and the ash content is low.

Oxidation of the Salt Wash deposits apparently does not produce any appreciable change in grade or vanadium-uranium ratio. There may be some local movement of vanadium and uranium but no extensive leaching of either metal has taken place.

The mineralogical changes that take place during oxidation have been discussed by Garrels (1953, 1955) and by H. T. Evans (1956, unpublished data).

References

Garrels, R. M., 1953, Some thermodynamic relations among the vanadium oxides and their relation to the oxidation states of the uranium ores of the Colorado Plateaus: Am. Mineralogist, Nov.-Dec., v. 38, p. 1251-1265.

____________, 1955, Some thermodynamic relations among the uranium oxides and their relation to the oxidation states of uranium ores of the Colorado Plateaus: Am. Mineralogist, Nov.-Dec., v. 40, p. 1004-1021.

Studies of clays in Triassic rocks
By L. G. Schultz

The common clay constituents in the Triassic formations of the central part of the Colorado Plateau are kaolin minerals ranging from fire-clay kaolinite to well-crystallized varieties of kaolinite, and dioctahedral illite, montmorillonite, mixed-layer clay, and chlorite. By studying prepared mixtures of these several types of clays, methods have been developed to evaluate the relative amounts of each clay within 10 percent, by means of X-ray diffraction traces of the natural clay mixtures.

In the past six months X-ray patterns of an additional 300 samples have been run to augment clay mineral data already obtained in southeastern Utah, to extend the area studied into southwestern Colorado, and to learn whether the clays from mineralized rocks differed from those in adjacent, nonmineralized areas.

Samples from several sections along the southeastern flank of the Monument Upwarp contain the hornblende-type clay mineral, palygorskite. All the palygorskite-bearing samples are from a transitional zone between the montmorillonite-rich Petrified Forest member and the highly calcareous Owl Rock member of the Chinle formation.

The mineralogical composition of the Triassic rocks of southwestern Colorado and some nearby areas in Utah differs considerably from equivalent strata previously studied in southeastern Utah. Kaolinite is a characteristic clay mineral in southeastern Utah, both in the Moenkopi and the lower part of the Chinle formations. Three sections in Colorado and one in Lisbon Valley, Utah, contain no kaolinite, but instead contain chlorite as a characteristic component. The chlorite from different lithologies varies somewhat; that from claystone is not mixed-layered and comprises a small amount of the total clay content, whereas that from sandstones is more abundant relative to the other clay minerals and is usually mixed-layered with montmorillonite. In a few samples the chlorite is regularly interlayered with an equal amount of montmorillonite. This chloritic phase encroaches on some sections along the eastern margin of the Monument Upwarp, and may have been derived from the Uncompahgre area.

Clays from the White Canyon uranium mines are highly kaolinitic and are similar to the clays in nearby unmineralized rocks. In Lisbon Valley also, all clays, mineralized or not, are chloritic.

Studies of clays in Jurassic rocks
By W. D. Keller

During the report period about 150 samples of mudstone from the Morrison formation of Jurassic age were analyzed by X-ray methods for clay minerals. Considerable experimentation with laboratory procedures was necessary to determine the best approach to obtaining data applicable to the objective of the program, which is a detailed study of the clay mineral stratigraphy and petrology of the Morrison mudstones, with particular emphasis on comparisons of mudstones from ore-producing localities with those from barren areas. The program is part of a comprehensive study of the clays of the Colorado Plateau (see Schultz, L. G., preceding section of this report). Some research in the methods used still remains to be done, as the instrumental response of the minerals being analyzed varies depending upon the processing of the fresh mudstone before it is analyzed. Therefore, further modifications of technique and procedure will continue as the work continues.

Clay mineral analyses have been partially completed (part in bulk, and part in the minus 2-micron fractions) for the stratigraphic sections at Duma Point, south of Floy, Grand County, Utah, which is the type locality of the Salt Wash member of the Morrison formation; the Hatt Ranch on the San Rafael River on the east edge of the San Rafael Swell, Emery County, Utah; Oak Creek on the east side of the Carrizo Mountains, Apache County, Arizona; the Dolores group of mines and Lone Tree (Blue) Mesa near Uravan, Montrose County, Colorado; Sapinero, Gunnison County, Colorado; and Slick Rock, San Miguel County, Colorado. These geographically scattered sections were selected for study in order to survey the problem broadly over a wide area.

The preliminary analytical results, combined with study of thin sections, point toward the following conclusions and problems:

(1) The clay minerals found so far in the Salt Wash member of the Morrison formation are mainly in the illite (hydrous mica) group. Although this fact indicates that illites generally characterize the Salt Wash member, it is realized that perhaps the illites should be examined in more detail in an effort to determine whether they originated only from pre-existing sedimentary rocks, or whether they are the result in part of the alteration of volcanic ash.

(2) Mudstones of the Brushy Basin member contain much montmorillonite, but in some sections contain also considerable chloritic clay, some illite, a small amount of kaolinite, and possibly glauconite. Too few stratigraphic sections have been analyzed to permit a sound interpretation of the distribution and proportions of the clay minerals of the Brushy Basin. The variety of clay minerals indicates that the Brushy Basin has an important geologic record yet to be unravelled.

The abundance of montmorillonite in the Brushy Basin also brings up the question of its origin. Although montmorillonite is usually considered to have been derived from volcanic ash, the only evidence in the mudstone indicating such an origin is the presence in thin sections of shards, or relics of shards. Most mudstones are altered to such an extent that original textures and structures are not preserved; but where the ash was strongly silicified early during its alteration, shard structure may be preserved, as in samples collected near Tidwell Ranch, Emery County, Utah. In the stratigraphic section on Oak Creek in northeastern Arizona, shards are well preserved by carbonate replacement. Thin sections show the development of analcite, a probable alteration product of volcanic ash, in the section at Lone Tree (Blue) Mesa, north of Uravan, Colorado. The finding of shards along with montmorillonite leads to another problem, as yet unsolved: did the volcanic ash fall in place or was it carried by streams to its present location?

Mineralogy of uranium deposits
By A. D. Weeks

The reconnaissance study of the mineralogy of uranium deposits in sandstone now includes most of the mining districts of the Colorado Plateau, and part of the Wind River and Powder River basins in Wyoming, the southern Black Hills in South Dakota, and the Karnes County area in Texas. Emphasis is being placed on detailed mineralogic and paragenetic studies of a few important uranium mining districts where field mapping is being done by the Geological Survey.

In the Colorado Plateau an overall picture has been obtained of the distribution of the types of ore, the nature of the primary ores, the sequence of oxidation, the distribution of minerals, and the problems of leaching and enrichment during oxidation.

Recent studies of the mineralogy and paragenesis of the primary (unoxidized) uranium ores lead to two important and fruitful fields of investigation. In studying the minor and trace element content of sulfides associated with the sandstone-type uranium ores it was found that selenium commonly substitutes for sulfur to an extent not previously known. Sulfide samples (mostly pyrite and marcasite) from sandstone-type deposits in the Colorado Plateau, Wyoming, and South Dakota were divided into two types according to their position with respect to the unoxidized uranium-vanadium ore deposits: (1) sulfides in barren rock that are assumed to be pre-ore, and (2) sulfides in mineralized rock (containing >0.01% U_3O_8) that are assumed to be contemporaneous with ore deposition. A summary of the analytical results is given in table 4.

Table 4.--Average selenium content of pyrite and marcasite associated with sandstone-type uranium deposits

Location	Wyoming	Colorado South Dakota Wyoming	Colorado Plateau	Colorado Plateau
Age	Tertiary	Cretaceous	Jurassic	Triassic
Formations	Wind River fm. Wasatch fm.	Mancos fm., Fall River ss., Fuson fm., Minnewaste ls., Lakota ss.	Morrison formation	Chinle formation
Total no. samples	48	19	38	55
Average % Se	0.03	0.0058	0.17	0.0015
No. samples from mineralized rock	18	6	20	27
Average % Se	0.09	0.0048	0.20	0.0019
No. samples from barren rock	30	13	18	28
Average % Se	0.0015	0.0064	0.14	0.0012

In the Morrison and Chinle formations no significant differences in selenium content between sulfides from barren rock and from mineralized rock were found, whereas in the Tertiary sediments the sulfides from mineralized rock contain about sixty times as much selenium as sulfides from barren rock. The selenium in the Tertiary sulfides seems to have been introduced during the time of uranium mineralization. The selenium in the Morrison and Chinle formations may have been derived from volcanic debris and emanations during Jurassic and Chinle times of deposition. Those deposits high in selenium contain selenides, including clausthalite (PbSe), eucairite (CuAgSe), ferroselite ($FeSe_2$), and cobaltian ferroselite $(Fe, Co)Se_2$.

Mineralogical evidence was found that suggests a temperature of formation of the Colorado Plateau uranium deposits. The unoxidized uranium deposits are considered to represent primary ore which formed under equilibrium conditions. Therefore, the unoxidized ore minerals should exhibit physical and chemical properties conditioned by the existing temperature, pressure, and composition of the ore-forming fluids. Uraninite, coffinite, low-valent vanadium oxides, and sulfides presumably were deposited by the ore-forming fluids. Since little is known of the pressure-temperature stability ranges of the uranium and vanadium minerals, these cannot at the present time be used as temperature indicators. The associated sulfides, however, offer a good starting point for study of temperature of formation.

Fairly accurate determinations of the temperature of formation may be made on naturally occurring sphalerite if it is known from polished section study that excess FeS (either as pyrrhotite or pyrite-marcasite) was present when the sphalerite formed (Kullerud, 1953). Determinations were made on sphalerite purified from ore samples collected from the Happy Jack mine, San Juan County, the Hidden Splendor (Delta) mine, Emery County, Utah, and the Cashin copper mine, Montrose County, Colorado, all in Triassic rocks. These sphalerite samples all indicate temperatures of formation below 138°C. The equilibrium diagram for the FeS-ZnS system is incomplete below 138° and a precise temperature cannot be established. However, a range between 55° and 110° is indicated. Although much more work on the temperature of formation is needed, the close approximation of this preliminary determination to the temperature expected from a normal geothermal gradient at a depth of burial of several thousand feet is of interest.

Mineralogic study (J. R. Houston, unpublished data) of ore samples collected by A. D. Weeks in 1955 from the Grants-Laguna district of New Mexico indicates that these uranium ores with low vanadium content have a great variety of minerals. Zippeite and zippeite-like minerals, uranopilite, tyuyamunite and metatyuyamunite, meta-autunite, and phosphuranylite were identified from the Morrison formation and uranophane, tyuyamunite and metatyuyamunite, liebigite, fluorescent opal, fluorite, and barite from the Todilto limestone.

Preliminary study of samples from the Coastal Plain of Texas (A. D. Weeks and A. H. Truesdell, unpublished data) suggests that the mineralogy of uranium deposits in the Goliad sand and Catahoula formation differs somewhat from that of the deposits in the upper Jackson formation, and it may indicate differences in uranium deposition in marine and non-marine host rocks. Volcanic ash is associated with all of the deposits and seems to be more completely altered in the marine than in the non-marine rocks. Calcareous soils or thick caliche and zones of intensely silicified (opal and chalcedony) sandstone are typical of the Coastal Plain area where uranium deposits have been found. Deposits in the upper Jackson formation (Eocene age) near Tordilla Hill, Karnes County, contain meta-autunite and related uranyl phosphates and arsenates, carnotite, tyuyamunite, metatyuyamunite, and fluorescent opal as well as pyrite, marcasite, psilomelane, iron oxides, jarosite, ilsemannite, and yellow molybdenum minerals. Mineralized surface outcrops of the Catahoula formation (Miocene age) in Gonzales and Duval Counties contain carnotite, tyuyamunite, uranophane, and fluorescent opal. A tentative working hypothesis of origin is the leaching of uranium and other trace elements from volcanic ash by carbonate ground waters.

Many new occurrences of uranyl tricarbonate minerals were found through study of ore samples collected in 1955, and these give new evidence on the leaching and migration of uranium in the Colorado Plateau and the basins of Wyoming.

A miniature glass flotation (Mayeda) cell has proven very useful in the purification of small samples (a few tenths of a gram) of sulfides.

The following papers on the mineralogy of uranium ores were published during the period:

Coleman, R. G., 1956, The occurrence of selenium in sulfides from sedimentary rocks of the western United States (abs.): Econ. Geology, v. 51, p. 112.

Thompson, M. E., Roach, C. H., and Braddock, W. A., 1956, New occurrence of native selenium: Am. Mineralogist, v. 41, p. 156-157.

Thompson, M. E., and Roach, C. H., 1955, Mineralogy of the Peanut mine, Montrose County, Colorado (abs.): Geol. Soc. America Bull., v. 66, p. 1625.

Thompson, M. E., Ingram, Blanche, and Gross, E. C., 1956, Abernathyite, a new uranium mineral of the metatorbernite group: Am. Mineralogist, v. 41, p. 82-90.

Thompson, M. E., Weeks, A. D., and Sherwood, A. M., 1955, Rabbitite, a new uranyl carbonate from Utah: Am. Mineralogist, v. 40, p. 201-206.

Weeks, A. D., Thompson, M. E., and Sherwood, A. M., 1955, Navajoite, a new vanadium oxide from Arizona: Am. Mineralogist, v. 40, p. 207-212.

__________, 1955, Mineralogy of the Colorado Plateau uranium ores: published on behalf of the Nuclear Engineering and Science Congress by American Institute of Chemical Engineers, reprint no. 283.

__________, 1955, Oxidation of the Colorado Plateau ores and its relation to recent geologic history (abs.): Geol. Soc. America Bull., v. 66, p. 1625.

__________, 1956, Mineralogy and oxidation of the Colorado Plateau uranium ores, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy—v. 6, Geology of uranium and thorium, p. 525-530: New York, United Nations.

Reference

Kullerud, Gunnar, 1953, The ferrous sulfide-zinc sulfide system, a geologic thermometer: Norsk Geol. Tidsskr., v. 32, p. 61-147. (English text).

Distribution of elements
By A. T. Miesch and J. J. Connor

Investigation of the distribution of elements in sandstone of the Salt Wash member of the Morrison formation in the Henry Mountains mining district was continued during the report period. The purpose of the investigation is to determine which elements are most useful in tracing patterns of metal dispersion around uranium deposits as well as the factors that control the dispersion of the metals. The investigation is being conducted on three scales: a district-wide scale, a detailed scale, and an intermediate scale. Preliminary samples have been collected and analyzed for V, Cu, Pb, Zn, Co, Ni, As, Se, Mo, U, and equivalent U. Fractions of the samples soluble in 1N hydrochloric acid at room temperature (for 30 minutes) have been analyzed for V, Cu, Pb, and Zn.

Figure 20 shows the locations of samples collected on the district-wide scale. They are all north or west of the productive part of the district and are one-half mile to 10 miles from known uranium ore. All of the samples identified on figure 20 are of sandstone of the Salt Wash member, but were selected without regard to stratigraphic position within the Salt Wash. Samples of each pair are from the same stratigraphic position and about 20 feet apart.

Detailed studies of the distributions of elements near ore were made at the Blitz and Jim Dandy mines (fig. 20). The sampling programs at these mines are illustrated in figures 21 and 22. A third detailed study was made

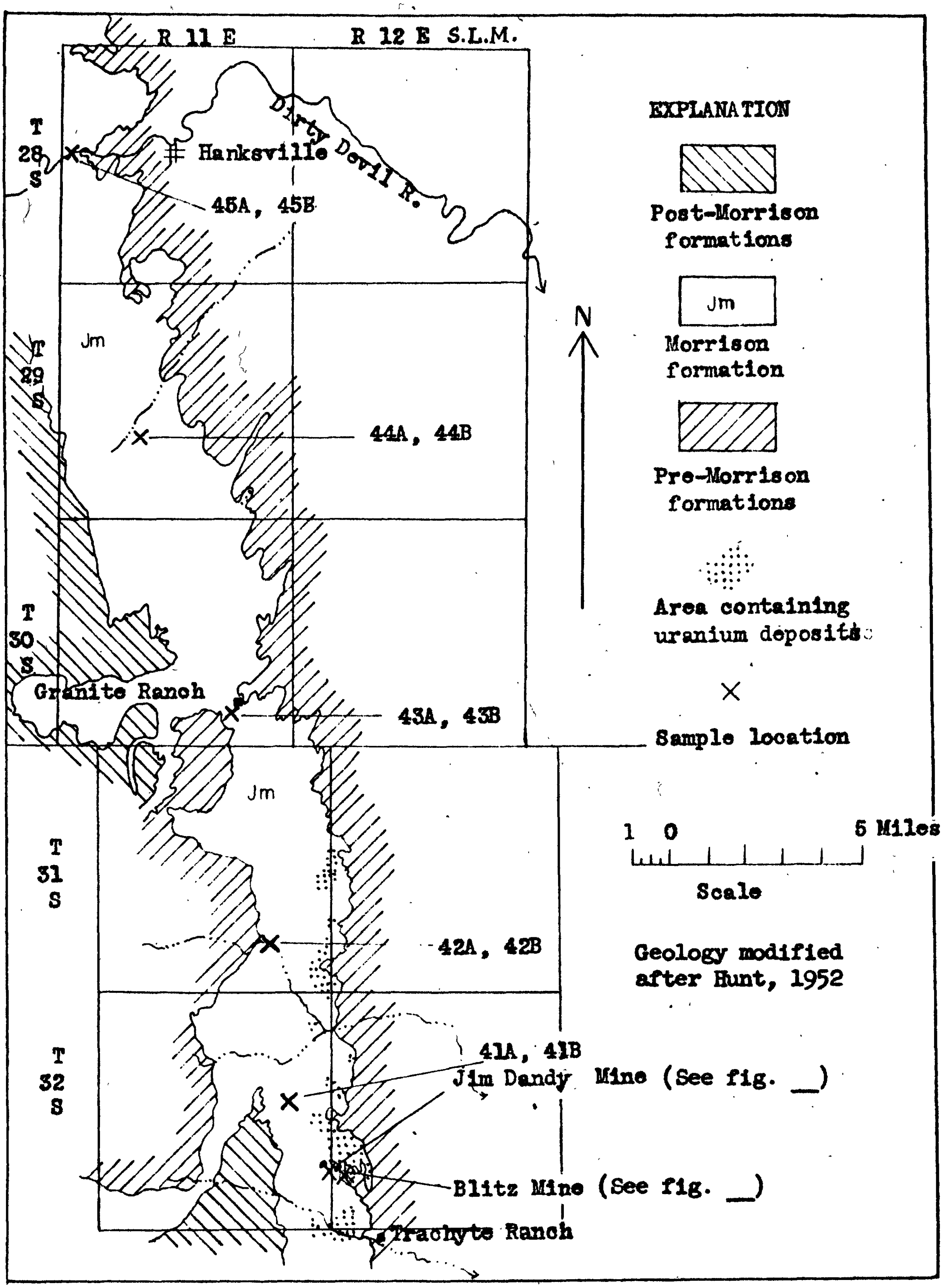


Fig. 20--Geologic map of part of the Henry Mountains Mining District showing sample locations.

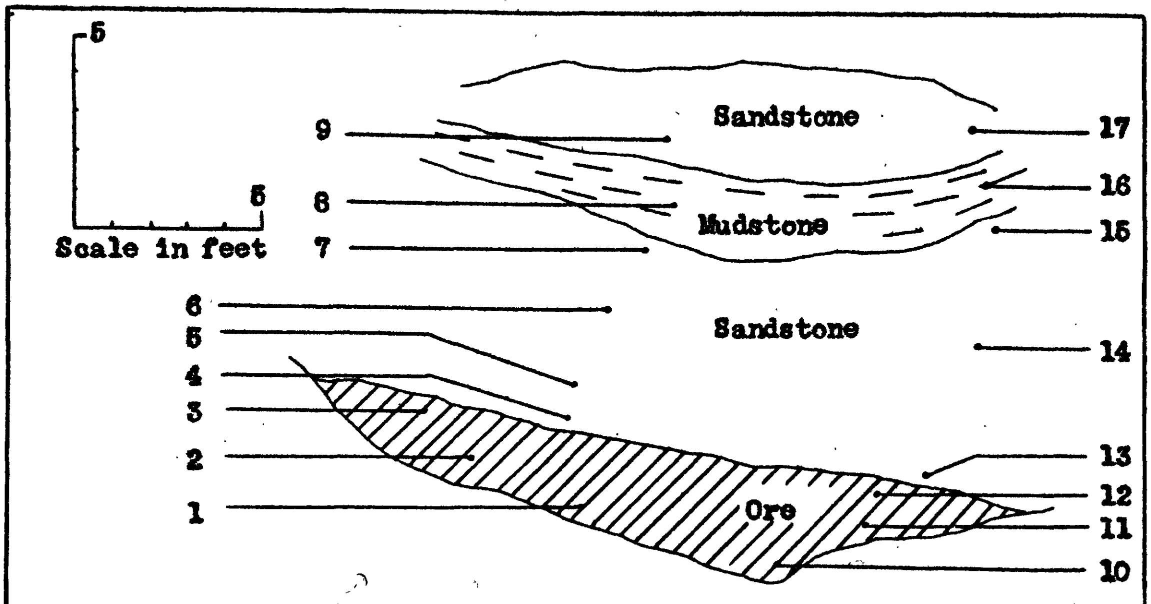


Fig. 21 -- Cross section of an open pit face at the Blitz mine showing sample locations.

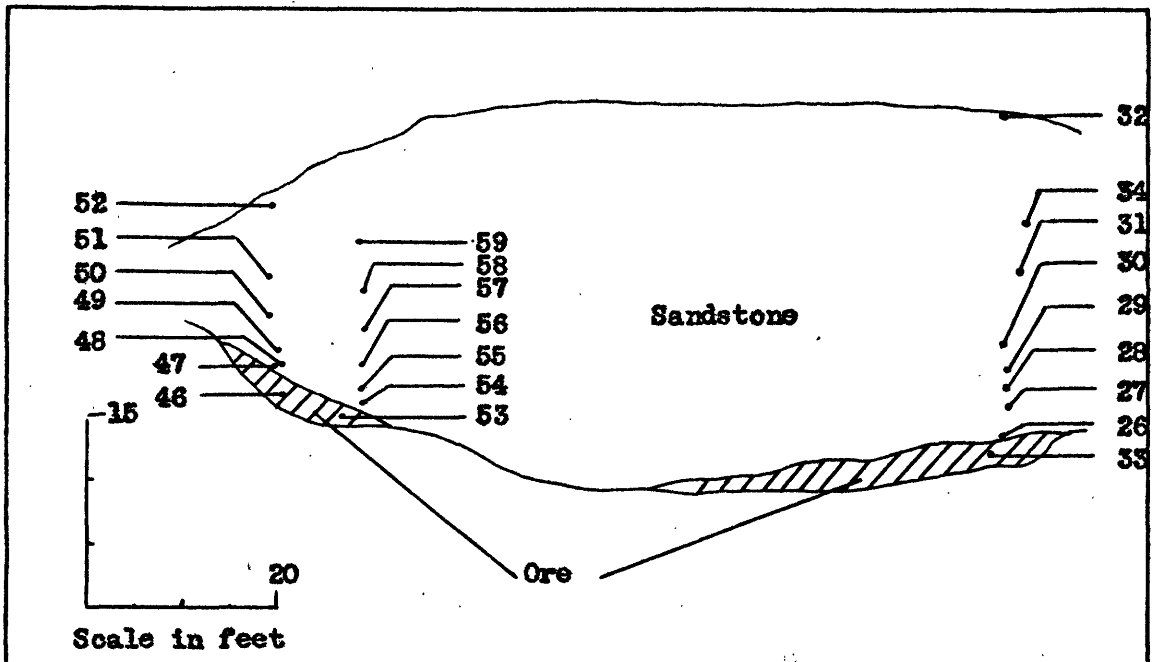


Fig. 22 -- Cross section of an open pit face at the Jim Dandy mine showing sample locations.

of the distribution of elements adjacent to a mineralized log near the Blitz mine.

Six pairs of samples, for the intermediate scale of investigation, were taken 100 to 500 feet from known ore in the district. They are from the principal ore-bearing sandstone in the Salt Wash.

Analytical methods

All analyses for V, Cu, Pb, Zn, Co, Ni, and As were done by J. J. Connor in the Geological Survey laboratory in Grand Junction. The colorimetric analytical techniques employed were developed by the chemists of the Geological Survey in the Denver laboratory. The analyses were done in close coordination with these chemists; H. W. Lakin, J. H. McCarthy, and H. E. Crowe. In addition, all samples were analyzed by similar methods in Denver for Mo and Se, and for uranium and equivalent uranium (by C. Angelo, R. Cox, and H. Lipp).

Six selected samples were analyzed for minor elements in their various soluble fractions. Twenty grams of each of the six samples were agitated in flasks containing 50 ml of hydrochloric acid ranging in concentration from 0.01N to 4N, and in flasks containing 50 ml of nitric acid ranging in concentration from 0.01N to 3N. These mixtures were then filtered and aliquots of the solutions ranging from 1 to 10 ml were taken and analyzed for V, Cu, Pb, Zn, and Co with the same techniques employed in the analyses of the bulk samples. The residue of each leached sample was weighed and the weight of the soluble material removed from each sample was computed. The sensitivities of the analyses vary with the amounts of soluble material in the samples. Analytical results are expressed as parts per million (ppm) in the soluble fraction of the sample (tables 5 and 6). Sample 27 is of sandstone 1 foot from ore; 18A is of sandstone about 10 feet from ore;

Table 5.—Minor elements in six sandstone samples and various soluble fractions (HCl) of sandstone samples from the Henry Mountains mining district, Utah

Sample no.	VANADIUM parts per million						
	Total Rock	Soluble fraction NCl					
		0.01N	0.1N	0.5N	1N	2N	4N
27	880	500	900	>1700	750	>1100	>1000
18A	40	<300	800	430	250	200	390
34	25	<300	150	230	220	220	680
23A	15	<300	<150	630	370	330	>1250
35A	15	<300	100	130	130	110	330
44A	<15	<300	< 75	30	<15	<17	58

Sample no.	LEAD parts per million						
	Total Rock	Soluble fraction NCl					
		0.01N	0.1N	0.5N	1N	2N	4N
27	<12	< 50	<25	84	100	110	100
18A	<12	<50	50	36	42	25	39
34	<12	<50	< 25	6	22	11	14
23A	<12	<50	50	84	31	28	62
35A	< 12	<50	17	33	25	22	28
44A	< 12	<50	<13	<5	4	<4	4

Table 5.—Continued

Sample no.	COPPER parts per million Total Rock	Soluble fraction HCl 0.01N	0.1N	0.5N	1N	2N	4N
27	<5	<50	50	50	20	19	25
18A	5	<50	50	7	3	3	5
34	5	<50	25	6	5	3	10
23A	<5	<50	25	13	9	8	<4
35A	<5	<50	17	<8	4	3	8
44A	5	<50	<13	<5	2	1	2

Sample no.	ZINC parts per million Total Rock	Soluble fraction NCl 0.01N	0.1N	0.5N	1N	2N	4N
27	40	150	830	830	750	830	1000
18A	<25	<100	100	35	42	17	<8
34	<25	<100	50	31	28	28	9
23A	<25	<100	<50	95	83	37	<13
35A	<25	<100	<33	17	13	11	<11
44A	<25	<100	<25	10	<4	13	<2

Table 5.—Continued

Sample no.	COBALT parts per million						
	Total Rock	Soluble fraction NCl					
		0.01N	0.1N	0.5N	1N	2N	4N
27	20	20	300	530	200	170	50
18A	1	100	70	22	4	5	< 2
34	1	30	50	25	11	11	< 2
23A	< 1	30	20	5	< 3	2	< 3
35A	1	20	23	8	3	2	< 2
44A	< 1	20	5	2	< 0.8	0.8	< 0.4

Table 6.—Minor elements in six sandstone samples and various soluble fractions (HNO_3) of sandstone samples from the Henry Mountains mining district, Utah

Sample no.	VANADIUM parts per million					
	Total Rock	Soluble fraction HNO_3				
		0.01N	0.1N	0.5N	1N	3N
27	880	800	270	2900	3500	5000
18A	40	< 300	400	360	420	600
34	25	< 300	< 15	130	200	360
23A	15	< 300	100	420	400	500
35A	15	< 150	< 75	140	120	150
44A	< 15	< 300	< 100	25	< 16	7

Table 6.—Continued

Sample no.	LEAD parts per million					
	Total Rock	Soluble fraction HNO_3				
		0.01N	0.1N	0.5N	1N	3N
27	<12	<50	<17	83	150	200
18A	<12	<50	<25	24	33	54
34	<12	<50	<25	<6	6	14
23A	<12	<50	17	42	67	50
35A	<12	<25	<13	42	67	50
44A	<12	<25	<17	<4	<3	14

Sample no.	COPPER parts per million					
	Total Rock	Soluble fraction HNO_3				
		0.01N	0.1N	0.5N	1N	3N
27	<5	<50	<17	69	80	80
18A	5	<50	<25	7	<5	<7
34	5	<50	<25	<5	<5	<7
23A	<5	<50	<17	8	10	10
35A	<5	<25	<13	<8	<7	<7
44A	5	<50	<17	<4	<3	1

Table 6.--Continued

Sample no.	ZINC parts per million					
	Total Rock	Soluble fraction HNO_3				
		0.01N	0.1N	0.5N	1N	3N
27	40	170	670	830	1500	2000
18A	<25	<100	50	36	25	14
34	<25	<100	50	28	28	14
23A	<25	<100	<33	83	75	40
35A	<25	< 50	<25	17	14	<14
44A	<25	<100	<33	< 8	< 5	2

Sample no.	COBALT parts per million					
	Total Rock	Soluble fraction HNO_3				
		0.01N	0.1N	0.5N	1N	3N
27	20	20	100	250	400	400
18A	1	20	10	14	10	14
34	1	20	20	11	17	22
23A	<1	20	10	5	4	4
35A	1	<10	5	12	6	6
44A	<1	<20	10	<2	<1	<0.5

34, sandstone 12 feet from ore; 23A, sandstone 300 feet from known ore; 35A, sandstone 500 feet from known ore; 44A, sandstone 4 miles from known ore.

The results given on tables 5 and 6 suggest that, in general, the fractions of the samples soluble in 1N hydrochloric acid have large and consistent variations 1/ of detectable minor element concentrations. Fractions of samples soluble in 1N nitric acid, however, show equally large or larger variations in minor element concentration, but copper was not detected in five of the six analyses. Cobalt appears to be more highly concentrated in weaker acid "leachates".

Distribution of various elements

Uranium.--All of the samples taken north and west of the productive part of the district (fig. 20) are reported to contain 1 ppm uranium (table 7). Half of the samples taken in the interval 100 to 500 feet from ore (table 11) and 23 of 25 samples taken in the interval 1 to 28 feet above ore (tables 8, 9, and 10) contain more than 1 ppm uranium. The ratio of the uranium content of sandstones near ore to that in sandstones distant from ore is not large, but the absence of high concentrations distant from ore suggests that the element may be used to outline areas favorable for prospecting on an intermediate or detailed scale.

1/ "Variations", as used here, refers to proportional variations between samples near ore and those distant from ore.

Table 7.—Minor element content (in parts per million) of Salt Wash sandstone samples and of soluble fractions of Salt Wash sandstone samples collected for the district-wide scale of investigation. Sample locations are given in figure 20.

Sample No.	Total Rock (ppm)											Soluble fraction 1N HCl (ppm)			
	eU	U	V	Cu	Pb	Zn	Co	Ni	As	Se	Mo	V	Cu	Pb	Zn
41A	<10	1	<15	20	<12	<25	<1	<10	<5	3	<2	100	50	17	33
41B	10	1	15	<5	<12	<25	<1	<10	<5	<1	<2	150	<25	25	<50
42A	<10	1	<15	<5	<12	<25	<1	<10	<5	<1	<2	<17	<3	<3	<6
42B	<10	1	<15	<5	<12	<25	<1	<10	<5	<1	<2	<16	<3	<3	<5
43A	<10	1	15	<5	<12	<25	3	<10	<5	<1	<2	<18	<3	<3	9
43B	<10	1	15	<5	<12	<25	2	<10	<5	<1	<2	18	<3	3	6
44A	<10	1	<15	5	<12	<25	<1	<10	<5	1	<2	<15	2	4	<4
44B	<10	1	<15	<5	<12	<25	<1	<10	<5	<1	<2	<16	<3	<3	<5
45A	<10	1	15	5	<12	<25	<1	<10	<5	<1	<2	<16	<3	<3	<5
45B	20	1	<15	<5	<12	<25	<1	<10	<5	3	<2	<16	<3	3	<5

Table 8.—Minor element content (in parts per million) of Salt Wash sandstone and mudstone samples and of soluble fractions of Salt Wash sandstone and mudstone samples collected at the Blitz mine. Sample locations are given in figure 21.

Sample No.	Total Rock (ppm)											Soluble fraction 1N HCl (ppm)			
	eU	U	V	Cu	Pb	Zn	Co	Ni	As	Se	Mo	V	Cu	Pb	Zn
1	13,000	20,100	9,600	40	40	300	400	60	300	400	80	>2,900	15	59	300
2	130	160	240	20	<12	25	13	75	10	5	4	200	3	5	50
3	140	140	360	15	18	50	20	20	10	3	8	1,800	290	360	360
4	20	11	30	10	<12	<25	1	<10	<5	3	<2	15	5	<3	13
5	10	5	30	10	<12	<25	3	<10	5	5	<2	170	14	36	110
6	<10	4	40	10	<12	<25	3	<10	<5	<1	<2	710	4	9	180
7	10	2	40	10	<12	25	5	10	<5	<1	<2	670	3	8	250
8	30	7	40	10	<12	25	3	10	10	5	<2	400	130	130	35
9	<10	2	15	5	<12	<25	<1	<10	<5	3	<2	110	<3	3	59
10	840	1,200	4,800	20	18	75	50	40	25	30	34	>17,000	43	330	250
11	1,400	2,000	1,250	20	40	50	15	75	100	70	40	28	<3	<3	9
12	290	270	1,250	20	40	50	15	40	25	3	32	1,100	38	63	63
13	20	9	60	5	<12	<25	3	<10	8	<1	<2	<14	<2	<2	9
14	10	5	40	10	<12	<25	2	10	<5	<1	<2	830	8	21	210
15	<10	6	60	20	<12	<25	1	<10	5	<1	<2	830	17	21	250
16	30	25	15	5	<12	<25	<1	10	<5	3	<2	160	80	50	20
17	<10	2	15	5	<12	<25	<1	<10	<5	3	<2	42	<3	<3	5

Table 9.—Minor element content (in parts per million) of Salt Wash sandstone samples and of soluble fractions of Salt Wash sandstone samples collected at the Jim Dandy mine. Sample locations are listed in the order given in figure 22.

Sample No.	Total Rock (ppm)											Soluble fraction 1N HCl (ppm)			
	eU	U	V	Cu	Pb	Zn	Co	Ni	As	Se	Mo	V	Cu	Pb	Zn
32	<10	2	25	10	<12	<25	8	10	10	1	<2	80	<3	3	10
34	20	14	25	5	<12	<25	1	<10	<5	1	4	220	5	22	28
31	<10	2	<15	5	<12	<25	1	<10	<5	3	<2	130	<8	<8	17
30	<10	3	90	5	<12	25	2	<10	5	5	<2	280	<3	<3	21
29	20	4	60	<5	<12	<25	4	<10	<5	10	<2	200	8	83	50
28	30	18	150	5	<12	25	10	10	8	7	<2	17	<3	<3	70
27	100	80	875	<5	<12	40	20	10	17	20	4	750	20	100	750
26	490	820	1,250	5	<12	50	30	20	8	10	4	710	36	71	1,100
33	1,400	2,200	35,000	10	25	50	25	40	120	7	120	>22,700	2	<2	91
52	<10	2	60	<5	<12	<25	3	<10	<5	<1	<2	230	<5	<5	15
51	<10	1	40	5	<12	<25	3	<10	<5	3	4	200	8	8	42
50	20	2	90	<5	<12	<25	<1	<10	<5	1	<2	160	<10	100	<20
49	10	4	250	<5	<12	<25	<1	10	10	5	2	1,250	<13	85	<25
48	20	5	900	5	<12	25	7	40	40	5	<2	9,400	25	250	50
47	20	13	480	5	<12	<25	7	10	<5	7	<2	670	33	330	<33
46	300	120	3,500	20	50	25	150	150	175	100	8	12,500	250	500	125
59	<10	1	50	<5	<12	<25	3	<10	8	3	<2	170	<7	<7	14
58	20	2	125	5	<12	25	3	<10	<5	<1	<2	320	<5	6	30
57	20	2	60	<5	<12	<25	1	<10	5	1	<2	880	13	31	43
56	20	3	125	<5	<12	<25	2	<10	<5	<1	<2	240	10	50	20
55	20	4	125	<5	<12	25	10	10	<5	<1	<2	3,200	4	54	71
54	40	13	240	5	<12	40	50	40	<5	5	<2	1,500	50	380	3,800
53	270	230	8,300	10	<12	50	25	20	85	150	40	12,500	33	170	670

Table 10.--Minor element content (in parts per million) of Salt Wash sandstone samples and of soluble fractions of Salt Wash sandstone samples collected adjacent to a mineralized fossil log near the Blitz mine.

Sample No. 1/	Total Rock (ppm)											Soluble fraction 1N HCl (ppm)			
	eU	U	V	Cu	Pb	Zn	Co	Ni	As	Se	Mo	V	Cu	Pb	Zn
40	< 10	3	25	< 5	< 12	< 25	2	15	< 5	< 1	< 2	890	< 7	12	43
39	10	3	40	< 5	< 12	< 25	2	< 10	< 5	1	< 2	180	7	36	14
38	20	5	90	< 5	< 12	< 25	5	< 10	5	1	< 2	1,300	130	330	83
37	130	140	480	10	45	25	10	20	10	3	< 2	8,800	400	1,000	310
36	560	630	900	10	25	50	13	20	25	70	8	> 50,000	1,000	2,000	3,500

1/ Sample No. 40 taken 4' above mineralized log.
Sample No. 39 taken 1.5-1.8' above mineralized log.
Sample No. 38 taken 5"-8" above mineralized log.
Sample No. 37 taken 0-2" above mineralized log.
Sample No. 36 taken from mineralized log.

Table 11.—Minor element content (in parts per million) of Salt Wash sandstone samples and of soluble fractions of Salt Wash sandstone samples collected for the intermediate scale of investigation

Sample No. 1/	Total Rock (ppm)											Soluble fraction 1N HCl (ppm)			
	eU	U	V	Cu	Pb	Zn	Co	Ni	As	Se	Mo	V	Cu	Pb	Zn
21A	<10	1	<15	<5	<12	<25	5	<10	<5	1	2	60	<4	7	10
21B	<10	1	25	<5	<12	<25	<1	<10	<5	1	2	830	<6	11	110
22A	<10	5	15	5	<12	<25	2	<10	<5	1	2	40	<3	10	13
22B	20	5	30	<5	<12	<25	1	<10	5	1	2	60	<3	10	10
23A	<10	1	15	<5	<12	<25	<1	<10	<5	3	2	370	9	31	83
23B	<10	1	15	<5	<12	<25	<1	<10	<5	1	2	500	7	29	31
24A	<10	2	25	5	18	<25	2	<10	<5	1	2	90	<3	5	13
24B	<10	2	25	<5	<12	<25	<1	<10	<5	1	2	400	6	22	33
25A	<10	2	15	5	<12	<25	<1	<10	<5	1	2	630	13	31	94
25B	<10	1	15	5	<12	<25	2	<10	<5	1	2	840	17	33	18
35A	<10	2	15	<5	<12	<25	1	<10	<5	1	2	130	4	25	13
35B	<10	2	<15	<5	<12	<25	<1	<10	<5	1	4	33	<3	<3	7

1/ Sample nos. 21A, 21B, 24A, 24B, 25A, 25B taken 100 feet from known ore.
Sample nos. 23A and 23B taken 200 feet from known ore.
Sample nos. 22A and 22B taken 300 feet from known ore.
Sample nos. 35A and 35B taken 500 feet from known ore.

Vanadium.--None of the samples taken north and west of the productive part of the district (fig. 20) contain more than 15 ppm vanadium in the total rock (table 7) and only four of twelve samples taken in the interval 100 to 500 feet from ore contain more than this amount (table 11). However, 21 of 25 samples taken in the interval 1 to 28 feet above ore contain vanadium in the range 15 to 250 ppm. Vanadium in the total rock may be useful in prospecting on a detailed scale.

Vanadium in the soluble fraction of the sandstone (1N HCl) may be a very useful guide to ore on a broader scale. Sample nos. 42A to 45B (fig. 20, table 7) all contain less than 18 ppm vanadium in their soluble fractions. Samples nos. 41A and 41B, taken nearer ore, contain 100 and 150 ppm in their soluble fractions. Examination of table 11 shows that the average vanadium content of the soluble fractions of the samples is, in general, inversely proportional to the distance of the sample from ore in the interval 100 to 500 feet from ore. Curiously, however, soluble fractions of sandstone samples taken 1 to 28 feet from ore do not generally contain much more vanadium than those taken 100 or 200 feet from ore. It appears that vanadium in the soluble fractions of sandstones may serve to delineate areas, in the order of several hundred feet across, that are favorable for detailed prospecting, and will almost certainly prove useful in defining boundaries of potentially productive areas somewhat larger in size.

Copper.--The copper contents of the total rock samples taken more than a foot from ore are generally 5 or less than 5 ppm and the copper content of the total rock, accordingly, cannot serve as a useful guide to ore. The amount of copper in the soluble fractions of samples taken north and west of the productive part of the district (fig. 20), however, is generally lower than that in samples from within the productive part of the district. Copper in the soluble fractions may, accordingly, be useful in delineating broader areas for detailed prospecting.

Lead.--Nearly all samples taken more than a foot from ore contain less than 12 ppm lead. In eight of the ten samples taken north and west of the productive part of the district (fig. 20) lead ranges from 3 to 4 ppm in the soluble fractions. The other two samples (41A and 41B) taken about one-half mile from the productive part of the district, however, contain 17 and 25 ppm lead, respectively, in the soluble fraction. Soluble fractions of samples taken 100 to 500 feet from ore (table 11) contain, for the most part, 10 to 33 ppm lead although the lead content of soluble fractions of samples taken closer to ore is highly variable. Lead in soluble fractions of the sandstone may be a useful guide to broad areas worthy of more detailed prospecting.

Zinc.--Nearly all samples taken more than a foot from ore contain less than 25 ppm zinc in the total rock. Zinc, however, is commonly more highly concentrated in the soluble fractions of the samples. The zinc content ranges from 7 to 110 ppm in the soluble fractions of samples taken 100 to 500 feet from ore (table 11) and from less than 5 to 9 ppm in soluble fractions of samples taken more than one-half mile from ore (table 7). Zinc, like lead, may serve as a guide to broad areas worthy of more detailed prospecting.

Cobalt.--Samples taken more than a few feet from uranium deposits generally do not contain more than several parts per million cobalt and the element is probably not useful as a prospecting guide. Curiously, however, an outcrop sample taken 28 feet above the ore at the Jim Dandy mine (sample no. 32, table 9) contains 8 ppm cobalt. Possibly, cobalt was carried to the surface by capillary solutions and deposited with a caliche crust. Further investigation of this possibility will be made.

Except for the six samples listed on tables 5 and 6, cobalt was not determined in the soluble fractions.

Nickel.--Samples taken more than a foot from uranium deposits generally do not contain more than 10 ppm nickel, the lowest amount detectable, and the element cannot be considered a useful prospecting guide with the colorimetric techniques of analysis presently available. The content of nickel in the soluble fractions of the samples is generally not detectable (<10 ppm).

Arsenic.--Samples taken more than a foot from uranium deposits generally do not contain more than 5 ppm arsenic. Sample no. 32, however, which contains 8 ppm cobalt, contains 10 ppm arsenic and it is possible that both arsenic and cobalt are deposited with caliche salts. Sample no. 32 was the only weathered outcrop sample taken close to ore. The concentrations of arsenic in the soluble fractions of the samples are generally not detectable (<10 ppm).

Selenium.--Most samples taken more than a few feet from uranium deposits contain less than 1 ppm selenium. The element cannot be considered a useful guide to ore using this method of prospecting.

Molybdenum.--Even though the ores sampled contain up to 120 ppm molybdenum, nearly all samples of sandstone, regardless of their proximity to ore, contain less than 2 ppm. The concentrations of molybdenum in the soluble fractions of the samples are generally not detectable (<75 ppm).

These preliminary results suggest that vanadium in either the total rock or the soluble fraction; copper, lead, and zinc in the soluble fraction; or uranium in the total rock can serve to delineate broad areas favorable for more detailed prospecting. Of these, vanadium in the soluble fraction will probably prove the most useful. Vanadium in soluble fractions of samples taken more than 100 feet from known ore varies from less than 15 to 840 ppm and is roughly inversely proportional to the distance from ore. Of copper, lead, and zinc in the soluble fractions of sandstones, lead will probably be the most useful. Uranium in the total rock appears useful in that no concentrations greater than 1 ppm were found more than 500 feet from known ore.

Detailed geochemical prospecting within a selected area may be possible by analyzing for vanadium in the total rock or by determining cobalt or arsenic in the soluble fraction.

Localization and origin of vanadium-uranium ores on the Colorado Plateau

By R. P. Fischer

Studies of problems relating to the localization and origin of the Colorado Plateau uranium-vanadium deposits are in progress. During the report period special attention has been paid to problems relating to the deposits in the Entrada sandstone along the eastern part of the Plateau region in Colorado, with particular attention to the deposit at Rifle, Colorado. These deposits are amenable to study because they are well exposed by mine workings, and although similar in many respects they differ in others.

The geologic habits, mineralogic character, and grade of all these Entrada deposits are similar. In each deposit one or more layers of vanadium-uranium ore is associated with layers of chromium-bearing sandstone; fine grains of a mixture of galena and clausthalite also are concentrated in narrow bands bordering the ore bodies at Rifle. The host sandstone is clean and fine-grained, with no recognized fossil wood. In contrast to these similarities, the major tectonic structure in each area of Entrada deposits differs, as do the formations associated with the Entrada.

The following papers on the localization and origin of the Colorado Plateau uranium ores were published during the period:

Fischer, R. P., 1955, Vanadium and uranium in rocks and ore deposits (abs.): Geol. Soc. America Bull., v. 66, no. 12, pt. 2, p. 1558.

______________, 1956, Uranium-vanadium-copper deposits on the Colorado Plateau, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 605-614: New York, United Nations.

Geophysical Investigations

Regional geophysical studies
By H. R. Joesting, P. E. Byerly, and D. Plouff

Regional aeromagnetic and gravity surveys are being made on the Colorado Plateau as part of a study of the regional geology, with the eventual aim of gaining information on regional controls of the occurrence of uranium. Geothermal measurements are also being made to permit comparison of thermal gradients and heat flow in various parts of the Plateau with those in other geologic provinces.

Aeromagnetic contour maps covering about 8,000 square miles of the southern part of the Colorado Plateau are in the final editing stage and will soon be available for analysis. Aeromagnetic maps of about 4,300 square miles of the northern part of the Plateau, between the San Rafael Swell on the west and the Uncompahgre Plateau on the east, have been completed to the editing stage. Aeromagnetic maps of the Inter-river area of Utah, the Boundary Butte area of Utah and Arizona and the western part of the Carrizo Mountains, Arizona also have been essentially completed. These areas total about 1,500 square miles. Compilation has been started of airborne magnetic data covering the area from Hanksville and the Henry Mountains on the west to the Colorado River and the Abajo Mountains on the east.

Compilation of regional gravity data has about kept pace with the field work. Complete Bouguer anomaly maps were prepared during the past winter of the Lisbon Valley-La Sal area, Utah, covering about 580 square miles, and of the Carrizo Mountain area, Arizona and New Mexico, covering about 900 square miles. A simple Bouguer anomaly map of the Orange Cliffs area, Utah, was prepared on the basis of a preliminary gravity survey. This area covers about 1,200 square miles.

Temperature measurements were carried on intermittently during the winter in deep diamond drill holes in Disappointment Valley, Colorado, and representative cores were collected for measuring thermal conductivity. The holes in Disappointment Valley have apparently not yet returned to normal temperatures.

It has usually been necessary to insert small-diameter black iron pipe in the holes in place of drill pipe to keep the holes open over a period of six months or longer while they are returning to steady-state temperature conditions. Attempts to insert pipe in drill holes on Monogram Mesa, Colorado, were unsuccessful because the holes caved immediately after pulling the drill pipe.

Thermal conductivities of several hundred specimens from the Colorado Plateau will be measured as soon as facilities are available in the Physical Properties Laboratory.

As has been pointed out in earlier semiannual reports (TEI-490, p. 85-92; TEI-540, p. 93-96), the magnetic anomalies observed on the Colorado Plateau are related to several main geologic causes: to contrast in the magnetization and hence probably in the composition of the basement rocks, to relief of the basement along the great faulted monoclines, and to intrusive igneous rocks. The gravity anomalies are related to contrasts in the density of the sedimentary as well as the crystalline rocks, and to large-scale relief of the basement. Gravitational effects of the sedimentary rocks are relatively large in the Paradox Salt Basin, because of the large contrasts between the piercement salt structures of Paradox, Gypsum, Moab and other salt valleys, and the higher density limestone and clastic rocks into which the salt has intruded. Outside of the salt basin the largest anomalies are related to contrasting density and hence to contrasting composition of the basement rocks.

On the basis of preliminary analysis of data thus far available, it appears that characteristic magnetic patterns are associated with the great monoclinal upwarps and intervening basins, which are among the dominant structures of the Colorado Plateau. Additional data and more thorough analysis will be necessary to determine the extent to which this pattern holds throughout the Plateau. Large anomalies caused by relatively magnetic rocks are found along the flanks of the Uncompahgre Upwarp and the San Rafael Swell, and along the gently tilted northern end of the Monument Upwarp. In addition the magnetic pattern is generally sharper and more complex over the uplifts than over the basins, owing apparently to greater variability in composition of the basement rocks as well as to shallower depths of burial in the uplifted areas.

Available gravity data from areas outside the Paradox Salt Basin tend to corroborate the magnetic evidence that basement rocks in the uplifts and along their flanks are of a different character from those in the adjoining basins. Additional evidence, however, is required to test the validity of this indication. Within the salt basin the gravity effects of the salt tend to mask those of the basement rocks.

In the Lisbon Valley area the magnetic trends cross the trend of the Lisbon Valley fault, indicating no measurable change in the magnetic character of the basement rocks on either side of the fault. This does not necessarily indicate that the basement was not involved in the faulting, but it does indicate that in all probability the displacement of the basement was comparatively small, and that most of the displacement of the rocks exposed at the surface was due to flowage of salt. On the other hand, magnetic data indicate increased depths to basement several miles northeast of the fault.

Regional gravity data outline a small piercement salt anticline about 5 miles east of the town of La Sal, Utah. The indicated structure is on the northwest extension of the axis of the Gypsum Valley salt anticline. A strong gravity gradient over the Lisbon Valley fault conforms with the large displacement. The minimum of the Lisbon Valley gravity anomaly is somewhat south of the crest of the faulted anticline, as determined by surface structure.

Geophysical studies in uranium geology, Monument Valley, Arizona
By. R. A. Black

Compilation and interpretation of geophysical data obtained in Monument Valley, Arizona (TEI-590, p. 132-137) has progressed steadily during the period. Seismic refractions in parts of Monument Valley, where the Monitor Butte member of the Chinle formation is absent, thin, or weathered, have proved useful in delineating the trends of both large and small Shinarump channels. Delay time analyses of the seismic data has proved the most useful method of interpretation.

A seismic profile over a Shinarump channel, with the accompanying delay time analysis, is shown in figure 23. Velocities of 11,000 ft. per sec. and 12,000 ft. per sec. were used to obtain the best delay-time match. Using the shot-point depths (computed by conventional means) for control, the depth to the Shinarump-Moenkopi contact under each detector position was computed from the adjusted delay-time curve. The geologic cross section based on these depths is shown in figure 23, along with the channel configuration as determined by drilling. The method of delay time analysis outlined in the preceding paragraph is a modification of an interpretation procedure suggested by Barthelmes (1946). Where sections of unweathered Monitor Butte overlie the Shinarump, the Monitor Butte often has a higher velocity than the Shinarump, and the resulting velocity inversion makes a quantitative determination of the Shinarump-Moenkopi contact impossible. It has sometimes proved possible, however, to obtain a qualitative picture of the contact by using relative delay time plots.

To provide data on the average vertical acoustic velocity in the Shinarump, and to determine the range in vertical velocity, velocity logs were obtained in 62 drill holes in the Oljeto Wash area. The number of velocity logs plotted versus the Shinarump velocities determined from these logs, is shown in figure 24. The velocities range from as low as 3,500 ft. per sec. to 10,500 ft. per sec., but nearly 70 percent are in the range from 5,000 ft. per sec. to 7,500 ft. per sec. The average velocity determined from the 62 velocity logs is 6,600 ft. per sec.

From electric logging data and from resistivity values determined by matching theoretical curves with field resistivity data obtained by vertical profiling, it has been found that (1) the Monitor Butte member has a very

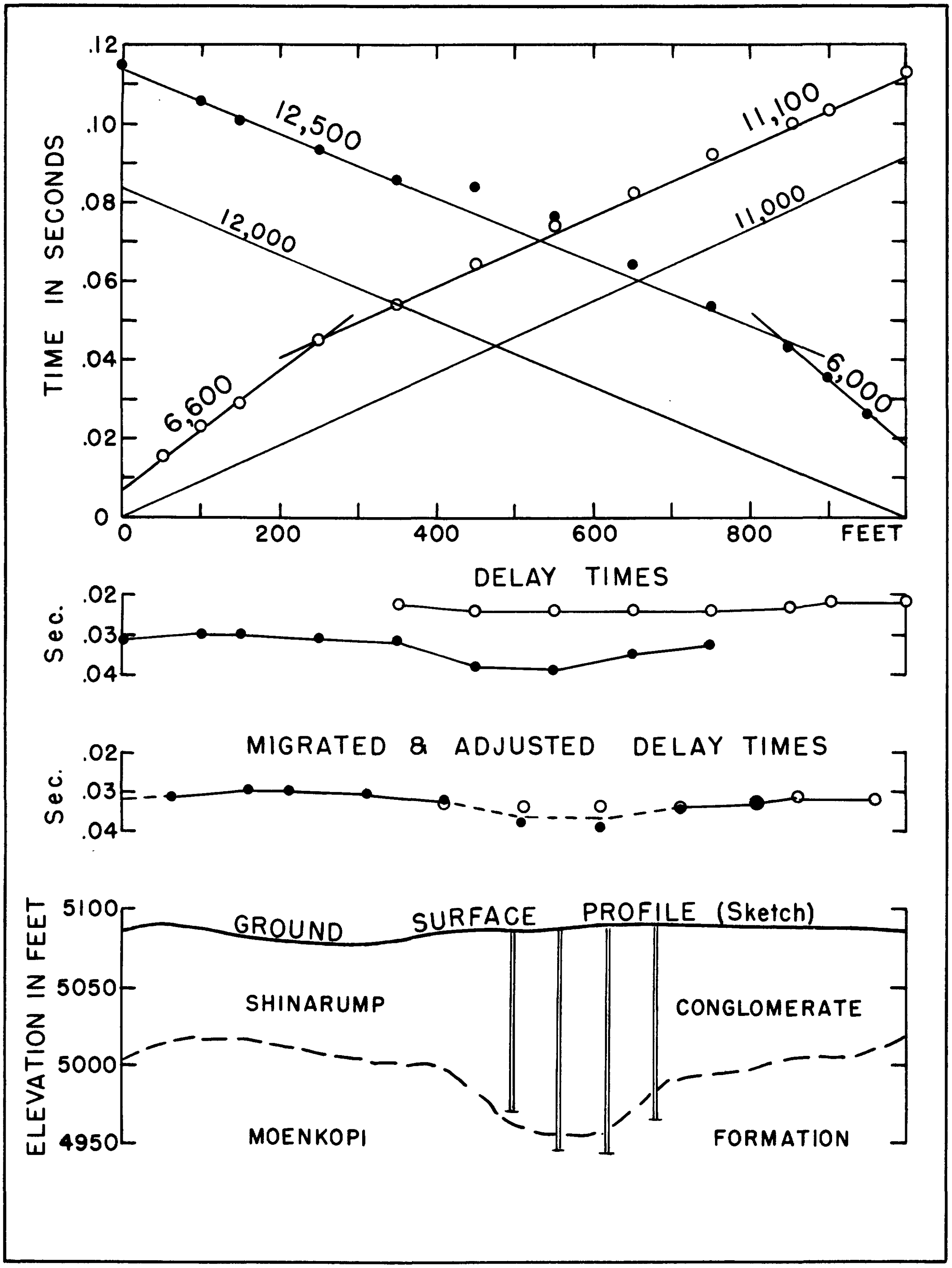


FIG. 23 TRAVEL TIME PLOT AND CORRESPONDING GEOLOGIC CROSS SECTION AS DETERMINED BY DELAY TIME ANALYSIS FOR SEISMIC TRAVERSE OVER BURIED SHINARUMP CHANNEL

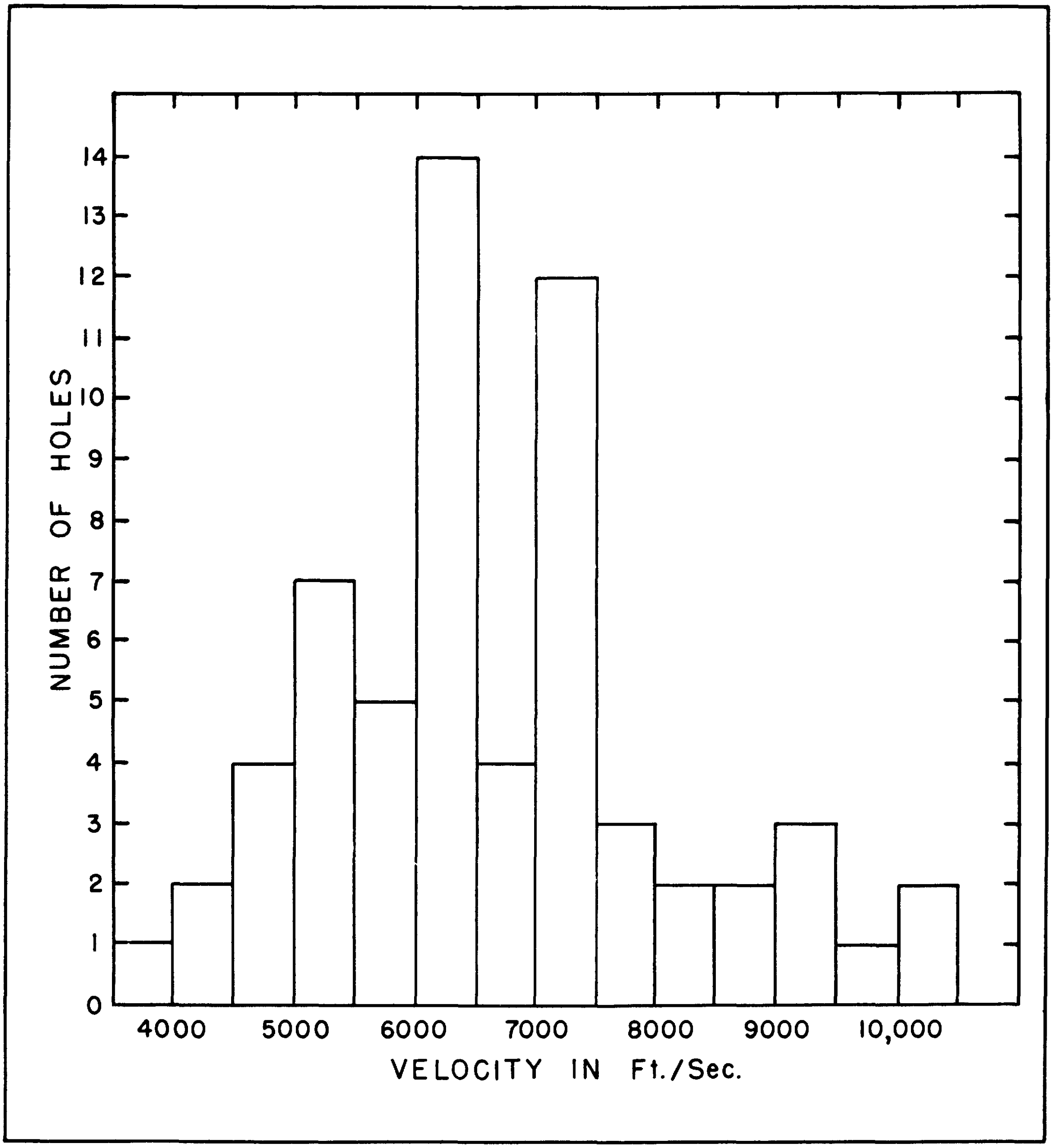


FIG. 24 GRAPH SHOWING THE FREQUENCY OF OCCURRENCE OF ACOUSTIC VELOCITIES IN SIXTY-TWO HOLES THAT WERE DRILLED IN THE SHINARUMP CONGLOMERATE

low resistivity (5-10 ohm-meters) where present in the form of shales or siltstones; (2) the Shinarump, although variable in resistivity, is principally composed of highly resistant sandstones (200-1,000 ohm-meters); and (3) the Moenkopi has a low resistivity of perhaps 10-20 ohm-meters. Scours cut into the Moenkopi and filled with Shinarump would thus form high resistant masses within the Moenkopi.

A number of electrical resistivity horizontal profiling methods, including d-c and commutated current measurements with the Lee partitioning configuration and Resistolog measurements, were tested over a large Shinarump channel in Oljeto Wash. The position of this channel had previously been determined by drilling, and it was known that 40-80 feet of the Monitor Butte member of the Chinle formation was present above the Shinarump. A resistivity horizontal profile made over the channel with d-c equipment and the Lee-partitioning configuration at an electrode separation of 200 feet is shown on figure 25. This resistivity profile is similar to a number of others that were obtained over the same channel on traverses parallel to the one illustrated. In figure 25 the channel cross section is nearly semicircular, and it is possible to compare the field resistivity profile over this channel section with the theoretical profile obtained over the center of a hemispherical sink of high resistivity material and a diameter of four times the electrode separation. For purposes of comparison the theoretical curve shown by Cook and Van Nostrand (1954) for a hemispherical sink with a diameter equal to four times the electrode separation and a resistivity ratio of 1/5 for the low and high resistivity material was used. The curve shown by Cook and Van Nostrand is for a low resistivity sink and a high resistivity surrounding medium. The theoretical curve was reversed to represent a high resistivity sink and a low resistivity

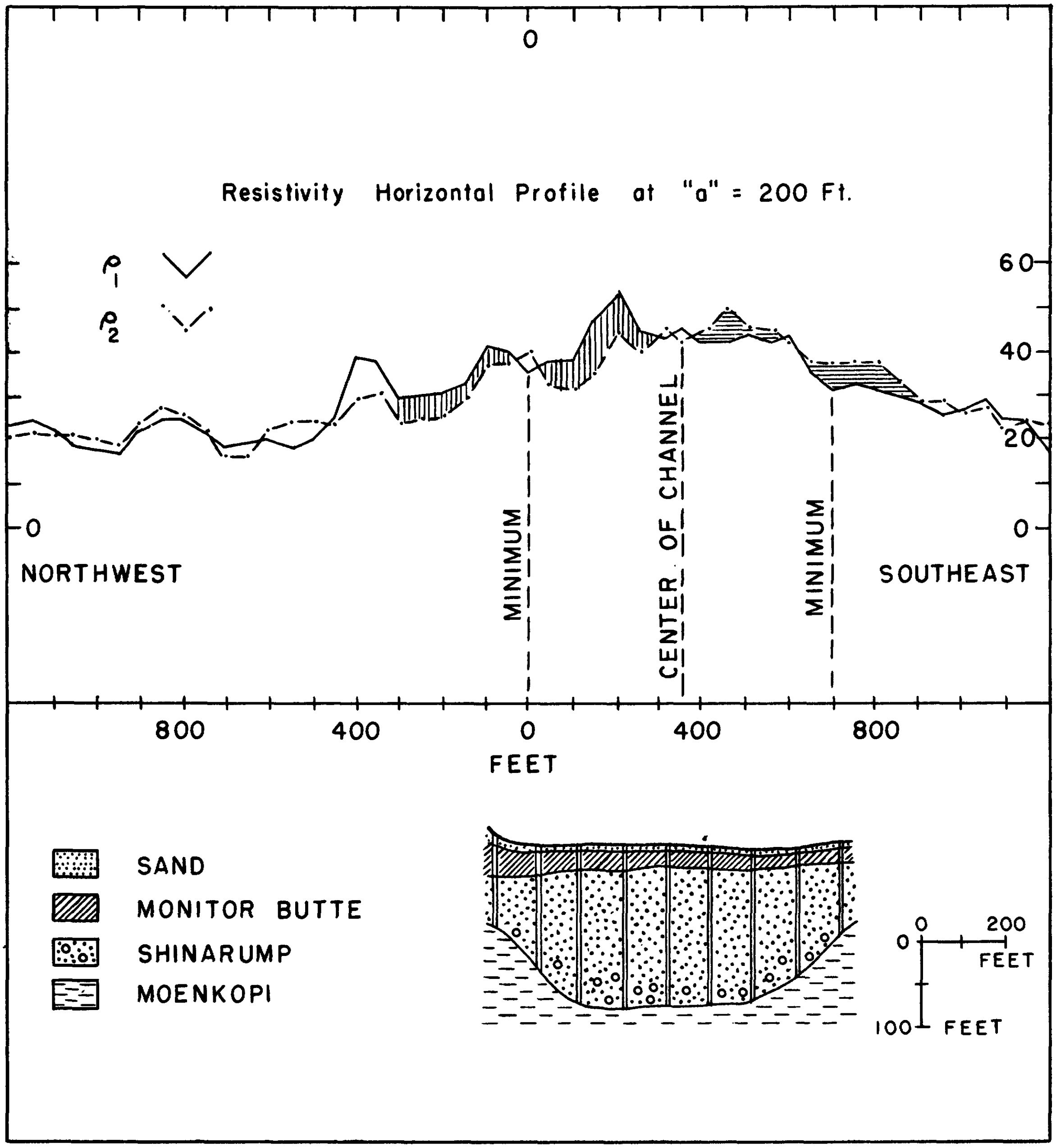


FIG. 25 RESISTIVITY HORIZONTAL PROFILE OVER A BURIED SHINARUMP CHANNEL MADE WITH THE LEE-PARTITIONING CONFIGURATION AT AN ELECTRODE SEPARATION OF 200 FEET

medium, to accord with the known geology here.

The field curve shown in figure 25 cannot be compared quantitatively with the theoretical curve but qualitatively, such a comparison shows marked similarities: (1) both show pronounced high-resistivity anomalies over the high-resistivity medium; (2) both Lee curves for ρ_1 and ρ_2 cross at the center of the high-resistivity medium; (3) on each side of the central high are minimums and maximums; and (4) the leading half of the Lee partitioning configuration shows the highest magnitude in resistivity on approaching the edge of the sink, reaches a maximum over the center of the sink, and becomes smaller than the lagging half of the configuration as it continues across the sink.

On the resistivity horizontal profile shown in figure 25, the ρ_1, or leading half of the configuration, has a higher amplitude than ρ_2, the lagging half of the configuration, from approximately 500 NW to 300 SE. The ρ_1 and ρ_2 curves cross at 300 SE and ρ_2 has a higher amplitude than the ρ_1 half. The area between the curves on either side of 300 SE has been shaded to make this relationship easier to see. The characteristic minimums are located at 0 and 700 south respectively. According to the Cook-Van Nostrand method of computing, in which the edges of the sink are a distance of a/4 (where a = electrode separation) toward the center of the anomaly from the flanking minimums, the edges of the channel would be at 50 SE and 650 SE respectively. The center of the channel would be at ρ_1 ρ_2 crossover, or 350 SE. These values agree reasonably well with the cross section as determined by drilling.

The resistivity horizontal profiles measured on the other traverses, while not all as readily capable of comparison with theoretical curves, all show anomalous features that can be correlated with the channel.

The Resistolog and Gish-Rooney measurements correlated well with the d-c resistivity measurements. It seems probable that, where surface conditions provide good electrical contact, resistivity methods can be very useful in delineating channel trends, especially in areas where seismic refraction measurements are rendered unreliable because of Monitor Butte cover.

In addition to standard resistivity measurements, experimental measurements were made over Shinarump channels with a modification of the potential drop-ratio method. For these measurements, a 400 cycle current of 1-1.5 amperes was introduced into the ground at two electrodes positioned on opposite sides of the channel and separated by a distance of three times the channel width. Three potential electrodes, separated by constant 50-foot intervals, were positioned collinear with the line connecting the current electrodes, and the ratio of the potential drops between each of the outermost potential electrodes and the center potential electrode was measured. Keeping the current electrodes fixed, the three potential electrodes were moved along the traverse line and the measured ratios were plotted at the center electrode position. To emphasize anomalous conditions along the profile, the theoretical potential distribution curve for points at 50-foot intervals along the line connecting the current electrodes was computed for homogenous ground. From this curve the theoretical potential drop ratios were computed for points corresponding to those for which there were field ratio measurements.

The ratio of the field ratio R_f to the theoretical ratio R_t is plotted as R_f/R_t in figure 26. From this plot the ratio of the field potential difference V_f to the theoretical potential difference V_t was computed by assuming V_f/V_t equal to 1 for the interval 100-150 on the R_f/R_t plot. Knowing the

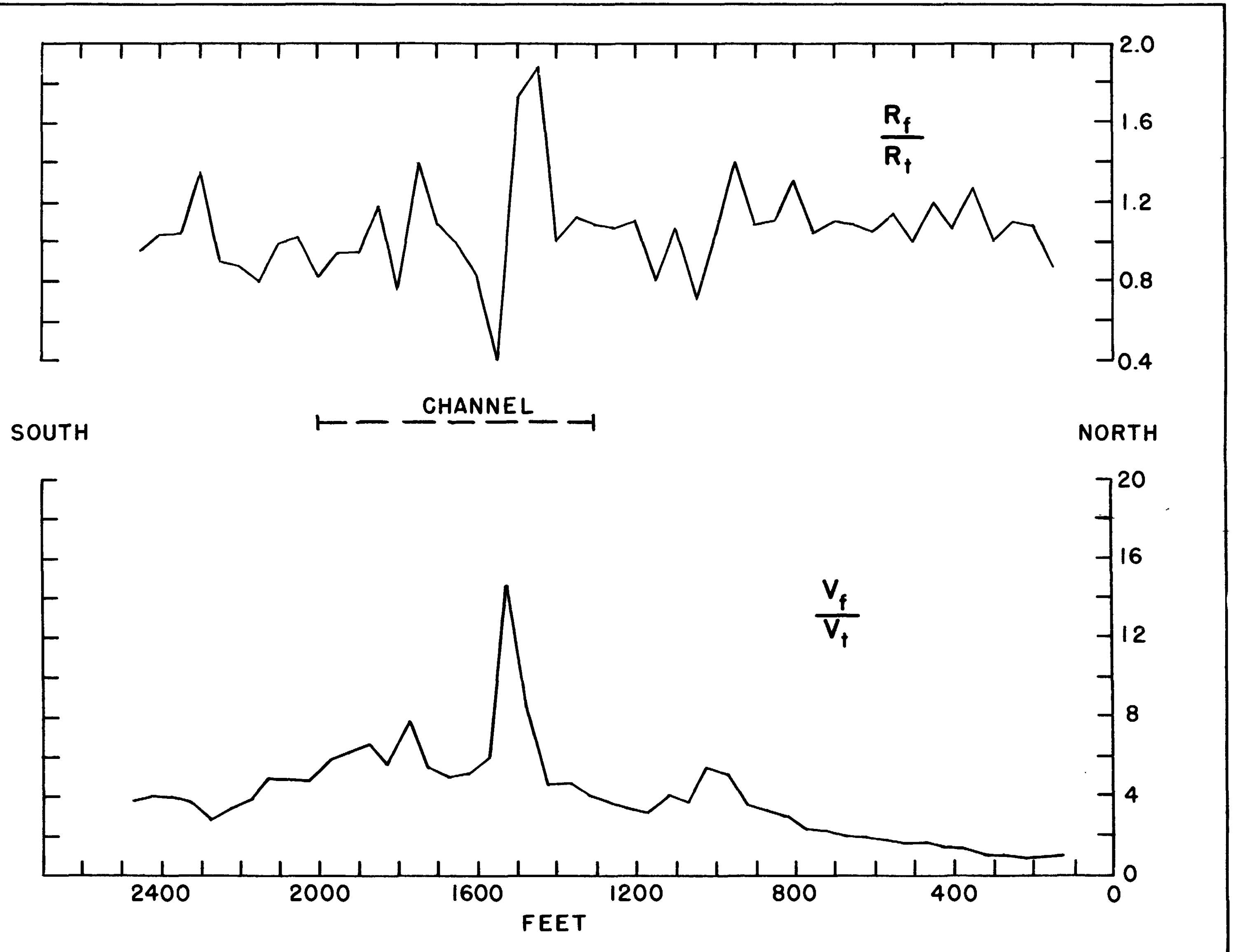


FIG.26 PLOTS OF RATIOS OF FIELD DATA TO THEORETICAL DATA FOR EXPERIMENTAL TRAVERSE OVER BURIED SHINARUMP CHANNEL WITH A MODIFICATION OF THE POTENTIAL DROP-RATIO METHOD OF GEOPHYSICAL INVESTIGATION

ratio R_f/R_t at 150 equals 0.86, the V_f/V_t for the interval 150-200 could be computed, and thus the remainder of the V_f/V_t values plotted as the bottom curve on figure 26 were computed. The resultant potential difference ratio curve shows a strong anomaly over the channel area. The results of these experimental measurements are encouraging, and in view of the ease of making this type of field measurement, additional work will be done to further test its application to geologic problems.

The following paper on geophysical exploration was published during the period:

Black, R. A., 1956, Geophysical exploration for uranium on the Colorado Plateau, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 766-771: New York, United Nations.

A geologic report on the Monument Valley area was also published during the period:

Witkind, I. J., 1956, Channels and related swales at the base of the Shinarump conglomerate, Monument Valley, Arizona, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 368-370: New York, United Nations.

References

Barthelmes, A. J., 1946, Application of continuous profiling to refraction shooting: Geophysics, v. 11, no. 1, p. 24-42.

Cook, K. L., and Van Nostrand, R. G., 1954, Interpretation of resistivity data over filled sinks: Geophysics, v. 19, no. 4, p. 761-790.

Original-state core studies

By G. E. Manger

Analyses of physical properties of cores from experimental drill holes in Lisbon Valley, Utah, and interpretations of the results, were received during the period from the San Francisco office of the U. S. Bureau of Mines. These results and interpretations, in conjunction with data obtained previously by the Geological Survey and the Bureau of Mines, are of great value in determining the relationships of ground water saturation and salinity and of permeability to the position of mineralized ground and the degree of mineralization. The analyses of the Lisbon Valley drill holes are given in table 12.

Table 12 shows that the position of mineralized ground and uraninite ore with reference to permeability and amount and salinity of interstitial water in the Lisbon Valley drill holes is similar to these relationships in the carnotite terrain of the Uravan district (TEI-590, p. 144-145) and in the "blue-black" terrain of the Bitter Creek area (TEI-540, p. 98-99).

In all three localities the core analyses show a desaturated sandstone with pore water of high salinity immediately above a permeable sandstone more saturated with pore water of lower salinity. In this permeable sandstone containing the ore the water saturation generally remains high and the salinity low, although streaks of low water saturation and higher salinity are present in the ore.

In Long Park immediately below the ore and in a downward continuation of the permeable sandstone, ground water drainage is evident, because measurements show that the residual water saturation considerably exceeds the capillary "irreducible minimum" (TEI-590, p. 145). Similar measurements are not available for the cores of Bitter Creek "blue-black" drill holes. In Lisbon Valley, drill hole LVX-2 is 50 feet downdip from drill

Table 12.—Physical properties of cores from the Lisbon Valley experimental drill holes, section 36, T30S, R25E, San Juan County, Utah

Depth, feet	Water,[1] percent in pore space	Porosity, percent of bulk volume	Permeability, dry air, millidarcies	Solubles, assigned to pore water mg/l	Radio-activity,[2] core count
		DRILL HOLE LVX-1			
		Chinle formation			
		Clay - shale			
85.51-90.51 6 samples	63.2	11.6	0	69,840	125
		Fine-grained quartzite sandstone			
90.51-94.85 5 samples	41.3	4.66	0.015	320,000	315
		Permeable sandstone, excluding ore zone at base			
94.85-100.45 7 samples	72.1	17.6	62.8	36,770	1,520
		Ore zone, excluding ore at base, each sample			
100.45-101.36					
(top)	49.8	11.3	164.0	61,300	3,700
(bottom)	84.8	16.6	82.9	33,200	5,450
		Ore, each sample			
101.36-102.26					
(top)	100	13.9	63.1	20,600	25,030
(bottom)	4.22	7.61	88.4	1,070,000	49,370
102.26-103.10					
(top)	30.8	10.6	350.0	156,000	79,010[3]
(bottom)	62.9	9.83	0.02	78,800	58,270
		Sandstone below ore			
103.10-108.75 6 samples	68.7	9.63	0.10	63,040	56
		Cutler formation			
		Argillaceous siltstone			
108.75-122.14 15 samples	47.0	11.8	0.016	58,680	23

Table 12.--Continued

		Argillaceous fine-grained sandstone			
122.14-126.50 5 samples	38.8	11.7	0.018	115,880	15
		Bottom of hole, 126.50'			
		DRILL HOLE LVX-2			
		Chinle formation			
		Shaly siltstone			
77.36-86.42 10 samples	69.0	12.5	0.075	51,450	35
		Medium-hard sandstone			
86.42-102.50 22 samples	39.2	6.72	1.23	234,320	298
		Permeable sandstone, including "ore zone" at base, ore absent			
102.50-110.25 10 samples	72.2	17.6	3,115	46,010	47
		Sandstone below "ore zone"			
110.25-112.96 3 samples	73.5	10.3	0.18	52,170	116
		Cutler formation			
		Siltstone and argillaceous very fine-grained sandstone			
112.96-132.09 22 samples	71.9	7.89	0.047	83,660	70
		Bottom of hole, 132.09'			

1/ Cored with oil-base mud.
2/ By scanning in laboratory. Because of statistical variation, counts of about 100 or less are not above background.
3/ Bore-hole gamma-ray log is interpreted as showing 1.5% eU_3O_8 in the interval from 102.4 to 103.3 feet.

hole LVX-1. The top of the permeable sandstone in LVX-2 is structurally at about the level of the bottom of the permeable sandstone (bottom of ore) in LVX-1 (table 12). Permeability in this sandstone in LVX-2 reaches the phenomenal value of 18 darcys (18,000 millidarcies) with a residual water saturation of 70.7 percent, and 3,000 millidarcies with a residual water saturation of 97.9 percent. Obviously ground water is circulating through the permeable sandstone at the location of LVX-2, but the permeability - residual water saturation relationships in the permeable sandstone at LVX-1 indicate that ground water is not circulating there, at least not through the ore. It seems that in the permeable sandstone in both Long Park and Lisbon Valley ground water now circulating immediately below the ore may have swept out all radioactive materials (table 12 and TEI-590, p. 145). It is of course possible that no radioactive materials were ever deposited in the very permeable rock.

It is evident that in Lisbon Valley the ore is where the permeability changes rapidly. The permeable sandstone at drill hole LVX-2 is 7.75 feet thick, averages 3,115 millidarcies in permeability and is completely barren. At drill hole LVX-1, 50 feet updip, this sandstone is 7.83 feet thick, averages 99 millidarcies in permeability, contains about 1-3/4 feet of ore of which about 1 foot average 1.5 eU_3O_8 according to the bore hole gamma-ray log.

URANIUM IN SANDSTONE-TYPE DEPOSITS OUTSIDE THE COLORADO PLATEAU

Black Hills uplift, South Dakota-Wyoming

Southern Black Hills

By G. B. Gott, E. V. Post, D. A. Brobst, and N. P. Cuppels

Results of recent exploration

The thermoluminescence of calcium carbonate nodules from a channel sandstone from the uranium producing area of the southern Black Hills has been photographed in several dozen samples. These photographs show concentric thermoluminescent bands alternating with non-thermoluminescent bands that resemble the growth bands within a calcium carbonate nodule. The variation of visible thermoluminescence suggests that differential radiation damage occurred at various times during the growth of the nodules. If it can be assumed that the thermoluminescence is in proportion to the radiation damage and that the radiation source was uranium, the thermoluminescent calcium carbonate indicates the pathway through which the uranium-bearing solution moved. It further indicates that the uranium and calcium carbonate were transported by a common solution. Because of the solubility of uranium in a carbonate solution, the uranium should have been precipitated after the calcium carbonate. The localization of uranium, therefore, should be marginal to the larger masses of calcium carbonate cemented sandstones.

To determine whether a significant amount of uranium is present along the outer margins of these thermoluminescent calcium carbonate cemented bodies, a limited experimental core-drilling program was undertaken. The Rapid City office of the Exploration Branch, Division of Raw Materials, AEC, furnished the drill rigs, etc. for this work. In addition there has been informal cooperation with the Geophysical Research and Development Branch of the AEC which is engaged in a geochemical prospecting project in this area. A channel sandstone that contains a segment of carbonate cemented rock was selected as the target for the drilling. The channel is exposed in two canyons about 3-1/2 miles apart and is buried in the intercanyon divide. The sandstone is almost completely impregnated with calcium carbonate where it is exposed in the westernmost canyon but contains only a negligible amount in the canyon to the east. The principal objective was to determine the margin of the cement in the intercanyon divide and to determine whether uranium minerals are associated with it.

The drill holes were placed about one-half mile apart (fig. 27). To date one uncemented segment of the channel more than a mile long has been discovered by the drilling. Four core-holes penetrated the channel. Two of the four cores disclosed uraninite and an unidentified black uranium mineral in the top part of the channel sandstone. Private drilling later showed that uranium minerals are present throughout the length of the uncemented portion of the channel. Most of the holes that have been drilled are mineralized. The eU_3O_8 content of mineralized rock ranges from 0.01 to 3.0 percent.

One of the drill holes encountered the top of the Morrison formation about 200 feet above the anticipated depth, but the base of the Fall River formation was in its normal position. This indicates that the pre-Fall River and post-Morrison Inyan Kara rocks are equivalently thin in this area. Although more subsurface data will be required to interpret the structure accurately, it seems probable that the thinning of the lower Inyan Kara rocks

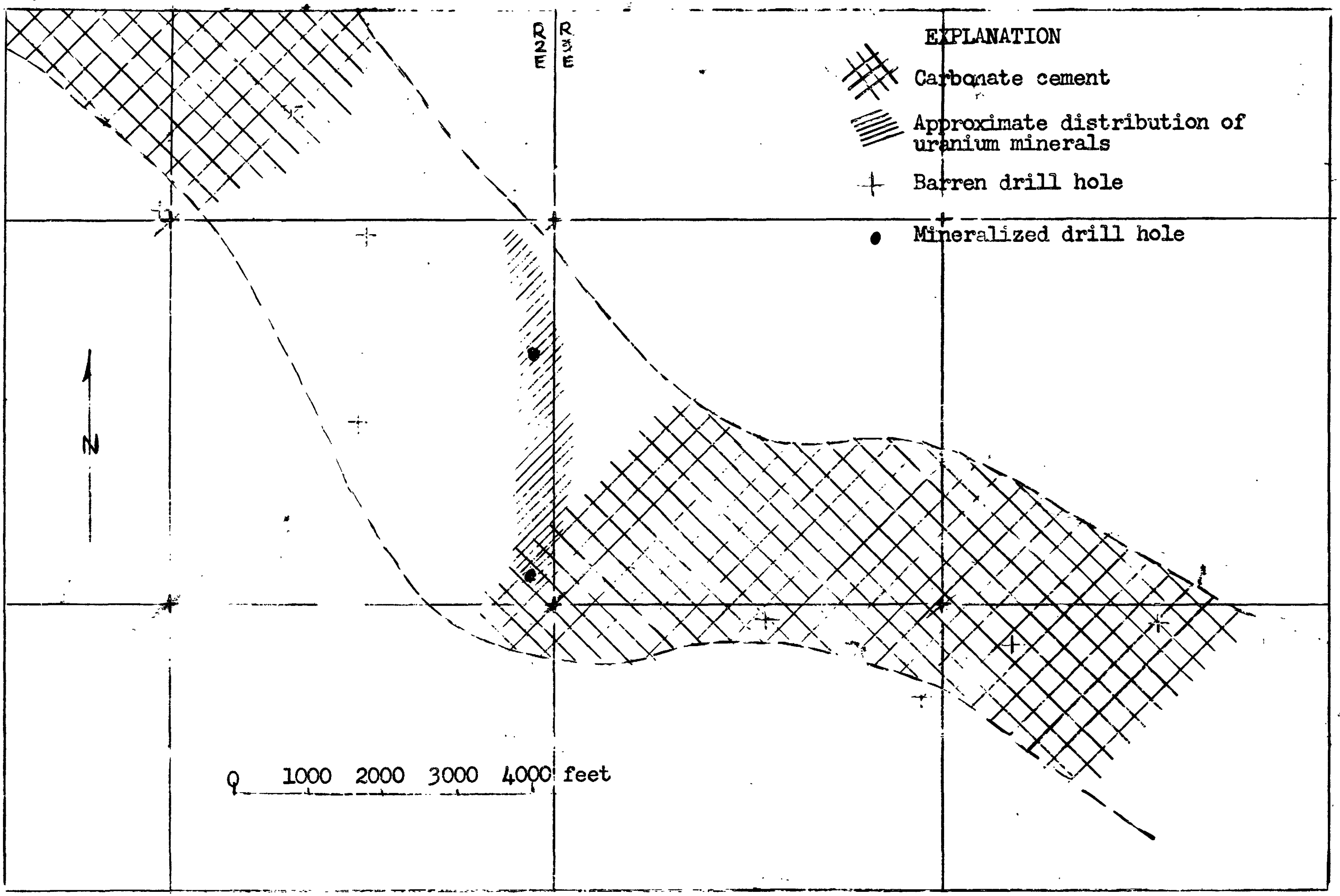


FIG. 27 —DISTRIBUTION OF URANIUM MINERALS AND CARBONATE CEMENT IN A CHANNEL SANDSTONE.

is the result of doming during post-Morrison and pre-Fall River time.

The drilling is still in progress and will be evaluated more thoroughly at a later time upon its completion.

Petrology of Inyan Kara rocks and dune sand

Thin sections of 18 specimens of sandstone from the Inyan Kara group of early Cretaceous age in the Dewey quadrangle, South Dakota-Wyoming were examined. The sandstones studied contain as much as 95 percent quartz. Microcline and plagioclase occur only in accessory amounts, less than 5 percent. The other accessary minerals include traces of magnetite and other iron oxides, rutile, zircon, and hornblende. Chert fragments also occur in some specimens. Fine-grained particles of clay occur interstitial to the quartz or form small aggregates of about the same size as the quartz grains. One green sandstone derived its color from minute crystals of chlorite interstitial to quartz.

The sandstones are friable to well cemented. The cementing material is silica, calcite, or clay, or some combination of these. Fine-grained silica fills the interstices of the sand grains producing silicification in various degrees. Quartz grains in some specimens have secondary overgrowths of silica.

Mechanical analyses.--Mechanical analyses have been made of 35 samples of sandstone from the Inyan Kara group collected in the Edgemont NE and Flint Hill quadrangles, Fall River County, South Dakota. The analyses were made primarily to provide a check on the stratigraphic correlation of various rock units as mapped, both within a given quadrangle and between two quadrangles.

In addition to the analyses of Inyan Kara sandstone, nine samples from the Burdock and Cascade Springs quadrangles of unconsolidated sand previously mapped by Darton and Smith (1904) as dune sand were analyzed in an attempt to find evidence to support field indications that these deposits are surficially modified alluvial terrace deposits of the Cheyenne River, rather than eolian deposits.

Inyan Kara sandstones.--The 35 Inyan Kara sandstone samples were collected from the Fall River sandstone and three units in the Lakota-Fuson formation undivided--a prominent channel sandstone, a white massive sandstone below the channel sandstone, and the lower part of the Lakota sandstone. The numerical distribution of these samples is shown in table 13. The three samples from the lower Lakota sandstone were considered too few to be considered in the statistical study.

Calcite cements the grains and forms as much as 30 percent of some sandstones. The calcite commonly corrodes the quartz grains. Large scattered calcite concretions in the shape of oblate spheroids as much as 8 feet across are common in many places in Fall River sandstone, the upper unit of the Inyan Kara group. The sandstone outside of these concretions may be devoid of calcite.

The generally good sorting and uniform roundness of the sand grains and the high content of quartz in the sandstones suggest that the original sediment was transported a considerable distance. If this is true, conditions within the distributive province would have caused the removal of the physically and chemically unstable minerals and brought about a downstream concentration of the most stable minerals. Thus the possibility that the sandstones of the Inyan Kara group were derived from the reworking of preexisting sandstones cannot be discounted. Sedimentary structures suggest that the source area was to the southeast.

Table 13.--Average and range of values for three parameters of grain-size frequency distribution for Inyan Kara rocks and other sediments

Stratigraphic unit	No. of samples	Median diameter (Md) Avg.	Median diameter (Md) Range	Coeff. of sorting (So) Avg.	Coeff. of sorting (So) Range	Coeff. of skewness (Sk) Avg.	Coeff. of skewness (Sk) Range
		mm.	mm.				
Fall River	6	0.25	0.17-0.30	1.12	1.04-1.29	0.98	0.91-1.11
Channel	14	0.24	0.14-0.54	1.20	1.1-1.5	0.99	0.85-1.21
White massive	12	0.13	0.09-0.23	1.25	1.20-1.35	0.92	0.77-1.20
Dune sand (?)	9	0.22	0.15-0.45	1.64	1.26-2.12	1.16	0.98-1.93
Sand Dunes Nat'l Monument	1	0.24	---	1.14	---	1.14	---
Alluvial terrace sand	2	0.18	0.14-0.22	2.27	2.20-2.35	1.69	0.99-1.40

A rare conglomeratic claystone contains grains of chert and quartz and rock fragments embedded in a matrix of yellow to green clay. The rock fragments are as large as 1 cm. across and contain grains of quartz and chert in a fine-grained groundmass similar to the clayey matrix of the claystones.

Table 13 gives the average and range of values for three parameters of grain size frequency distributions--namely: Md, the median diameter; So, the coefficient of sorting; and Sk, the coefficient of skewness. The values for median diameters indicate that the Fall River and channel sandstones are medium- to fine-grained, and the white massive sandstone is fine- to very-fine-grained. Two of the three lower Lakota sandstones examined are fine-grained, and one is a siltstone.

The average coefficients of sorting of the Inyan Kara rocks range from 1.12 to 1.25—the coarser Fall River sandstones being somewhat better sorted than the white massive sandstone. Pettijohn (1949, p. 23-24) states that rocks with a coefficient of sorting less than 2.5 are well-sorted; the Inyan Kara sandstones thus may be considered very well sorted.

The average skewness for the three types of Inyan Kara sandstone was less than 1.00, indicating a slightly greater admixture of grains finer than the median. The white massive sandstone, with an average skewness of 0.92, contains a characteristically higher admixture of fine material than either the Fall River or channel sandstones.

This study of the grain-size distribution of certain Inyan Kara sandstones indicates that there are characteristic differences in the median diameter, sorting, and skewness of the sands that corroborate the differentiation of these three rock units in the field. Further studies of this sort—especially of ore-bearing versus barren sandstones—may disclose other characteristic differences of significance in the search for sandstone-type uranium deposits.

Little evidence was found in this study of grain-size distinction to confirm or refute the supposed fluviatile origin of the sandstones in the lower part of the Inyan Kara group.

One byproduct of the mechanical analyses of these sandstones is worthy of note. All the Fall River sandstone samples were found to be micaceous. The mica is much more prominent in the disaggregated sand than in the hand specimen. This characteristic of the Fall River sandstones may be of considerable use to geologists engaged in field work in the areas of Inyan Kara outcrop.

Dune sands.--The coefficient of sorting appears to be most significant in the evaluation of Darton's supposed dune sands as being of true eolian origin. A wind-laid sediment probably should be better sorted than a sediment of fluviatile origin; yet, the average coefficient of sorting for Darton's dune sands was 1.64, as compared to 1.19 for the Inyan Kara rocks examined and only 1.14 for the sand collected at Sand Dunes National Monument, Colorado. The range of sorting coefficients for Darton's dune sands was 0.86, as compared with 0.25, 0.14, and 0.15, respectively, for the Inyan Kara rocks. The poorer sorting, as compared to known dune sand and probable fluviatile sandstones, when combined with the coefficient of skewness of 1.16, indicating a greater admixture of material coarser than the median grain size, tends to confirm the conclusion that the surficial material mapped by Darton as dune sand is actually alluvial terrace material that has been surficially modified by the wind, producing blowouts and some sand dunes. The statistical parameters of the dune sand size distribution approach more closely those of the sand from alluvial terrace gravels, as shown on table 13, than those of the dune sand from Sand Dune National Monument.

Mineralogy and paragenesis of uranium ores

Approximately 20 thin sections of ore specimens from various mines in the Edgemont NE quadrangle were examined for information about the paragenesis of the minerals but with inconclusive results. Calcite, pyrite, iron oxides, yellow uranium minerals, and carbonaceous material are interstitial to the grains of quartz that make up the bulk of the host rock. The mutual embayments of these interstitial materials suggest that all of them might be nearly contemporaneous.

Black prismatic crystals of a uranium mineral were found in the heavy mineral separate from a drill core of a channel sandstone in the NE¼ sec. 1, T. 8 S., R. 2 E., of the Edgemont NE quadrangle, South Dakota. The crystals are less than 1 mm. in length and yield a positive reaction in the flux test for uranium. Under the microscope, the crystals are dark red and have high birefringence, an index of refraction greater than 1.80, and parallel extinction. The crystals also are insoluble in acid. The X-ray diffraction pattern is not similar to those of the well-known black uranium minerals. Further tests to identify this minerals are underway.

Polished thin sections from a drill core in a channel sandstone in NE¼ sec. 1, T. 8 S., R. 2 E., contain fine-grained uraninite in aggregates 1 to 2 mm. in length. Associated minerals are pyrite, iron oxides, calcite, and clay minerals. The aggregates of uraninite are concentrated around pods of green pyritic clay in a quartzose sandstone. The pyrite near the margins of the pods is euhedral in contrast to the more massive grains within. The relations of the minerals suggest that the pods of pyritic clay were formed in place before the uraninite. The occurrence of massive and euhedral pyrite suggests two generations of pyrite, the euhedral type originating perhaps at the time of the deposition of the uraninite. The relative ages of the calcite and pyrite are not clear. The iron oxides are post-pyrite. The close association of all these minerals interstitial to the quartz suggests that all of them might be essentially contemporaneous.

A radioactive sample of ferruginous sandstone from the Wicker-Baldwin mine, sec. 16, T. 42 N., R. 60 W., Weston County, Wyoming, contains no uraniferous minerals visible to the eye. The red-brown, medium-grained sandstone was disaggregated by means of a sonic separation and screened into size fractions. The various size fractions were then put through a Franz separator and the material with the greatest radioactivity was concentrated in the magnetic part of the -200 mesh +400 mesh fraction. The radioactive material occurs as red, anisotropic grains of resinous luster that give a positive reaction in the flux test for uranium. Qualitative spectrographic tests indicate that the chief constituents are iron and vanadium with some titanium and uranium. Results of X-ray work indicate that the material is amorphous. Cubes of jarosite pseudomorphous after pyrite are associated with the red uraniferous mineral in the magnetic part of the -200 +400 mesh fraction of the sample.

The Gould mine

A carnotite-type ore body at the Gould mine, Fall River County, South Dakota, is being investigated to determine ore controls and surficial indications of the ore body. The mine is on the dip slope of the lower Cretaceous Inyan Kara group of land-laid sediments which forms a hogback peripheral to the Black Hills. The deposit is associated with local scours near the southern edge of a massive, elongate sandstone unit of the Inyan Kara group. Carnotite, tyuyamunite, and metatyuyamunite, the ore minerals, and oxides of iron are the only authigenic minerals that have been concentrated in or near the deposit. Although final localization of the ore probably was controlled by differential permeability of the rocks, a more obscure and probably earlier control is suggested by relationships between the ore and a local unconformity at the base of a silt-gall conglomerate.

The mineralogy of the ore deposit is relatively simple. Detrital quartz is the dominant mineral in all sediments, with kaolinite as an important constituent of the silt-galls of the conglomerate. No correlation has been found between the degree of uranium mineralization and the abundance of kaolinite. Tyuyamunite and metatyuyamunite are the dominant ore minerals in the western part of the mine whereas carnotite is the chief ore mineral in the eastern part of the mine. Yellow- to red-brown oxides of iron have been concentrated in the ore interval. Arsenic and selenium have been detected in quantities ranging from 50 to 1,600 ppm for arsenic and 1 to 20 ppm for selenium. No correlation has been observed between the abundance of these elements and other features of the deposit. Carbonaceous material is entirely absent.

Final movement of ore-bearing solutions has apparently been controlled by differential permeability. Evidence for this control can be observed at loci of deposition in weakly cemented parts of the sandstone, poorly-packed or well-sorted facies of the sandstone, along bedding planes, at the interface between the relatively impermeable silt-galls and the matrix of the silt-gall conglomerate, and along fractures at places where the fractures tighten or terminate. A study of the configuration of the boundaries of mineralized rock along the mine walls indicates that, at different places, the ore-bearing solutions moved either upward, downward, or horizontally. As a consequence of joint control, the ore tends to occur in elongate bodies oriented with their long dimension parallel to the master set of joints, which strike N. 30° to 40° W. The ore bodies are grouped in a westerly-trending en echelon pattern. Although the evidence for permeability control is reasonably clear, this control is probably incidental to a more fundamental control.

This more basic control is suggested by the spatial relation between a local unconformity at the bottom of a silt-gall conglomerate and the vertical and horizontal distribution of the ore-bearing rocks. The top of the ore is commonly parallel with, and a few feet below the base of the conglomerate. The interval between the top of the ore and the base of the conglomerate widens with increase in altitude of the conglomerate. Minimum altitude of the conglomerate is in the western part of the mine (fig. 28), where the workings follow the ore into the conglomerate, but in the eastern part of the mine, ore was mined chiefly from the underlying sandstone. Horizontal distribution of the ore-bearing rock appears to be related to the configuration of the erosion surface at the base of the conglomerate. If an isopach map of the ore interval is superimposed on a structure contour map drawn on the base of the conglomerate (fig. 29), the thickest ore (represented by the 8-foot isopach) is found near the heads of buried scours. Thickest ore in the eastern part of the mine tends to lie on the flanks of a scour, and in the central part of the mine, the ore tend to follow the axis of another scour. This relationship between the scours and thick ore is obscured by extensions of the ore along fractures that are transverse to the scours.

Preliminary results of this investigation indicate that direct evidence of differences in chemical environments needed for precipitation of ore minerals is lacking. For this reason the physical aspects of the environment appear to have been most important in localization of the ore. Physical relation between the ore and sedimentary structures suggest that favorable results could be obtained by setting up a program of exploration in mineralized areas to delineate buried drainage divides and drilling offset holes parallel to the divides.

Stratigraphic dating of mineralization

Reworked fragments of Inyan Kara sandstone containing a yellow uranium mineral and uraniferous carbonaceous debris have been found in gravels mapped by Darton and Smith (1904) as the Chadron formation (basal White River) of Oligocene (?) age at an altitude of 4,090 feet in NE$\frac{1}{4}$ SW$\frac{1}{2}$ sec. 31,

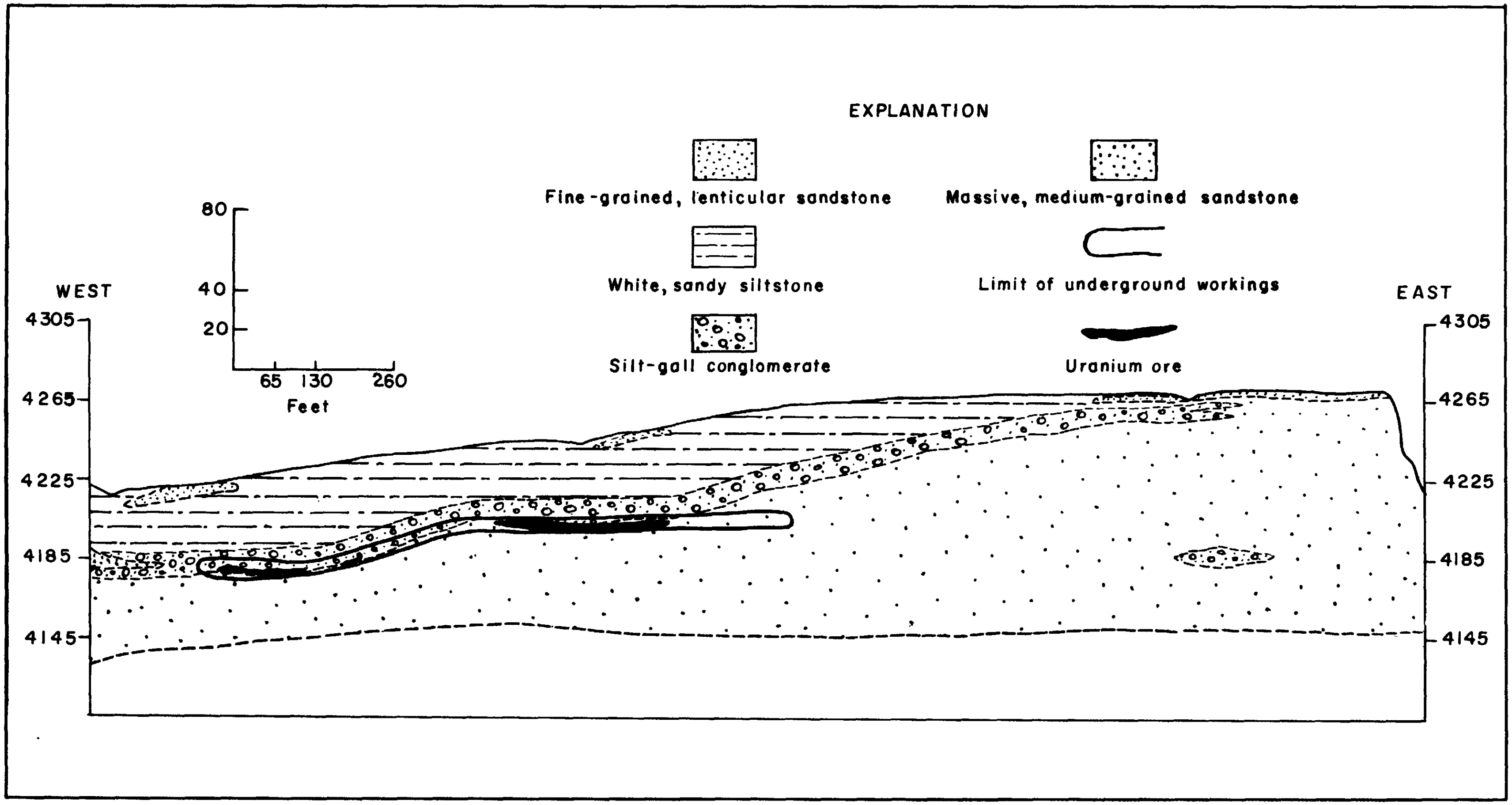


FIG. 28 — GEOLOGIC SECTION, GOULD MINE, FALL RIVER COUNTY, S. DAK.
Datum is mean sea level

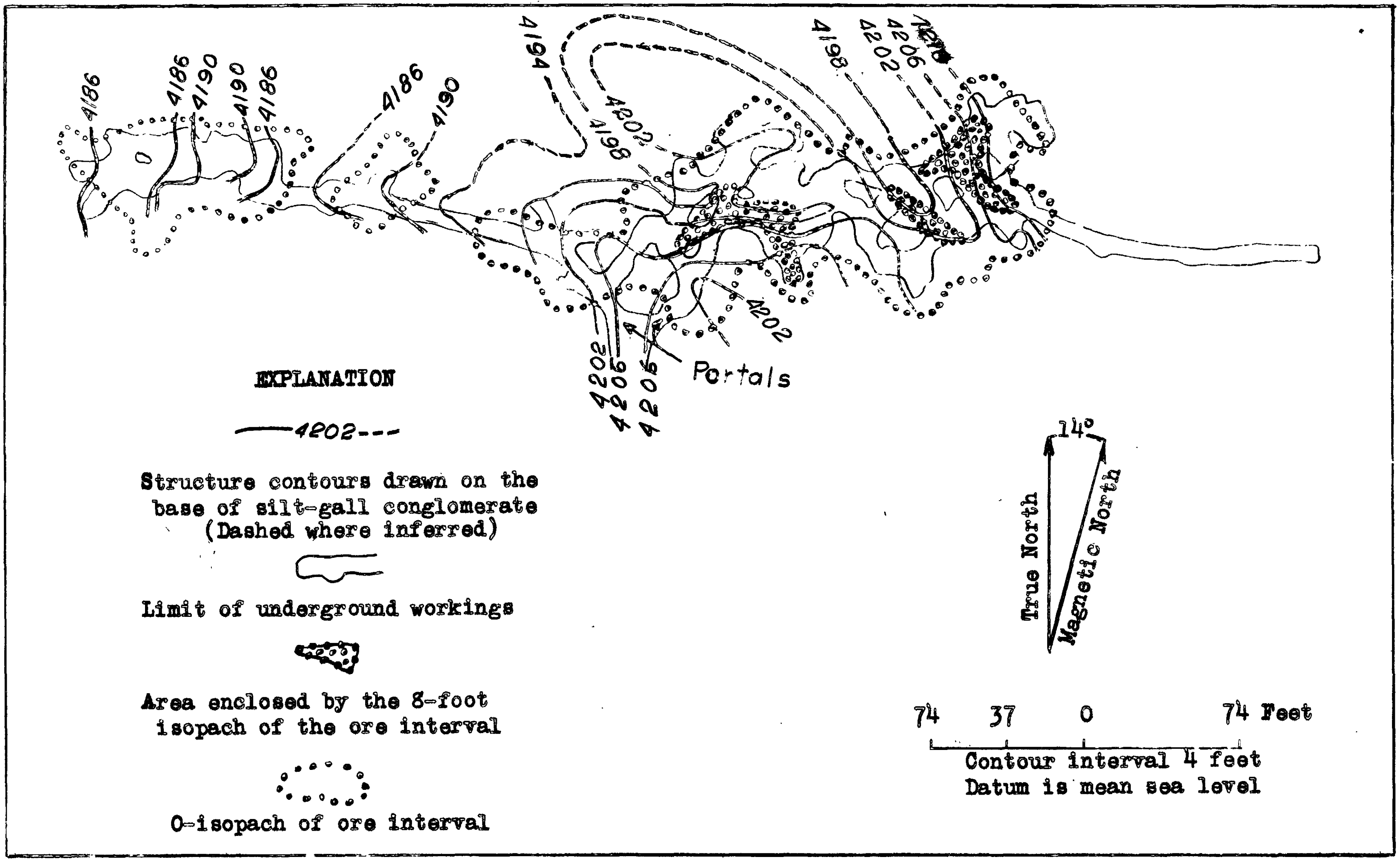


FIG. 29.--MAP SHOWING RELATIONSHIP BETWEEN SILT-GALL CONGLOMERATE AND URANIUM ORE AT THE GOULD MINE, FALL RIVER COUNTY, S. DAK.

T. 7 S., R. 3 E., Edgemont NE quadrangle, South Dakota. One of these sandstone fragments contains 0.15 percent eU. This occurrence indicates that the uranium mineralization occurred between Inyan Kara (Early Cretaceous) and White River (Oligocene) time.

The following reports on geologic investigations in the southern Black Hills were published during the period:

Bell, Henry, and Bales, W. E., 1955, Uranium deposits in Fall River County, South Dakota: U. S. Geol. Survey Bull. 1009-G.

Bell, Henry, Gott, G. B., Post, E. V., and Schnabel, R. W., 1956, Lithologic, structural, and geochemical controls of uranium deposition in the southern Black Hills, South Dakota, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy—v. 6, Geology of uranium and thorium, p. 407-411: New York, United Nations.

Braddock, W. A., 1955, Map showing distribution and occurrences of uranium deposits in part of the Edgemont mining district, Fall River County, South Dakota: U. S. Geol. Survey Mineral Investigations Map MF-39.

Gott, G. B., and others, 1955, Geologic and structure contour maps of parts of the Minnekahta, Flint Hill, Edgemont, and Edgemont NE quadrangles, Edgemont mining district, South Dakota: U. S. Geol. Survey Open File Report.

Schnabel, R. W., 1956, Geology and uranium deposits, southern Black Hills, South Dakota: The Mines Mag., v. 46, no. 4, p. 32-36.

Thompson, M. E., Roach, C. H., and Braddock, W. A., 1956, New occurrence of native selenium: Am. Mineralogist, v. 41, p. 156-157.

<u>References</u>

Darton, N. H., and Smith, W. S. T., 1904, Edgemont, South Dakota-Nebraska: U. S. Geol. Survey Geologic Atlas of the United States, folio 108.

Pettijohn, F. J., 1949, Sedimentary rocks: New York, Harper and Brothers.

Carlile quadrangle, Wyoming
By M. H. Bergendahl and R. E. Davis

The geology of the Carlile 7-1/2 minute quadrangle, which comprises an area of about 50 square miles in southwestern Crook County, Wyoming, is being mapped at a compilation scale of 1:12,000. Plane-table mapping at larger scales is done where additional detail is needed. The mapping program was started in the 1955 field season and is scheduled for completion during the 1956 field season.

Several areas of anomalous radioactivity are known in the Carlile quadrangle, which contains also in its northwestern part the Carlile mine of the Homestake Mining Company. A discussion of the general geology of the area, and a brief description of the uranium deposits at the Carlile mine were given in the preceding semiannual report (TEI-590, p. 159-164). Analyses of field and analytical data made during the report period suggest that the following factors were instrumental in localizing the uranium ore at the Carlile mine: (1) Regional structure—the deposits are on a structural terrace on rocks which have a gentle westerly regional dip; (2) a relative abundance of carbonaceous material—the mineralized sandstone unit contains significantly more carbonized wood than the other rock units in the immediate area; and (3) relatively permeable beds—the mineralized sandstone bed is enclosed within relatively impermeable claystone and clayey siltstone units, a situation which would permit considerable lateral movement of uranium-bearing solutions through the sandstone.

Storm Hill quadrangle, Wyoming
By R. C. Vickers and G. A. Izett

Mapping of the Storm Hill 7-1/2 minute quadrangle, in Crook County, Wyoming, was started in the 1955 field season and the significant geologic information gained during the field work was reported in the preceding semiannual report (TEI-590, p. 164-165). Work during the present report period has been confined to compilation of field data and laboratory studies. Mapping of the quadrangle will be completed during the 1956 field season.

Aladdin area, Crook County, Wyoming and Butte County, South Dakota
By R. C. Vickers

Red alteration of the basal sandstone unit of the Fall River formation and its value as a guide to uranium deposits in the Belle Fourche area, Butte County, South Dakota, was reported in the previous semiannual report (TEI-490, p. 209-210). Red altered sandstone is present also in the same stratigraphic unit in the Aladdin area (about 7 miles west of the Belle Fourche area) in secs. 18, 19, 20, 29, and 30, T. 54 N., R. 60 W., Crook County, Wyoming, and in secs. 17 and 18, T. 8 N., R. 1 E., Butte County, South Dakota. This area, which is on both sides of the Wyoming-South Dakota state line, is commonly referred to as The Forks. All known uranium deposits in the basal Fall River sandstone unit are at or immediately adjacent to the change in color of the sandstone from red to buff, and many small radioactivity anomalies are found at the color change. Although no large uranium deposits have been found in the Fall River sandstone in the area, several small deposits are present. The contact between red and buff sandstone in the basal Fall River sandstone unit thus is a guide to additional uranium deposits.

The following reports on the northern Black Hills were published during the period:

Mapel, W. J., and Bergendahl, M. H., 1956, The Gypsum Spring formation, northwestern Black Hills, Wyoming and South Dakota: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 1, p. 84-93.

Vickers, R. C., 1955, Wall-rock alteration as a guide to carnotite deposits and their origin, northern Black Hills, South Dakota (abs.): Econ. Geology, v. 50, no. 7, p. 795-796.

Powder River Basin, Wyoming

Southern Powder River Basin
By W. N. Sharp

The results of field mapping to date in the Southern Powder River Basin were reported in the previous semiannual report (TEI-590, p. 148). Activity during the winter included preparation of an adequate base map for the area and analyses of a number of samples.

As no good base map on which to compile geologic data is available for most of the Southern Powder River Basin, the Special Maps Branch of the Geological Survey is compiling from existing USGS and AMS manuscripts a topographic base at a scale of 1:48,000 covering the area between latitudes 42°45' and 43°37'30" N., and longitudes 105°15' and 106°07'30" W. Copies of this base should be available for use before the next field season.

X-ray studies confirm the preliminary report (TEI-590, p. 150) that montmorillonite is the predominant clay in the notably white sandstone lenses, some of which are ore-bearing zones, that are prominent in parts of the Southern Powder River Basin. Where volcanic material is most abundant in sandstone lenses, its alteration to montmorillonite has changed the sandstone to a whitish color, regardless of whether the original color was red or drab. Consequently, the limit of red color in sandstones or the red-drab color contact, which has been employed as a basic ore guide, may be effectively masked in these sandstones. An example of this condition is the D-7 deposit in sec. 28, T. 37 N., R. 73 W., which is in a coarse-grained white sandstone lens; here the general color is due to abundant white clay. A very close scrutiny, however, discloses residual pink coloring at a few places in the mine pit. This seems to indicate that the general close relationship of uranium-bearing sandstone and red-drab color zones is still a good basic guide. However, in parts of the Southern Powder River Basin color features are altered, and much care is necessary in outlining likely areas for detailed exploration. The Monument Hill area is affected to a lesser degree by the alteration of color in sandstone. The original color, red to drab, is present but mottled generally with white.

Analyses of samples from several deposits in the area indicate that the average vanadium-uranium ratio is about 1:1, the same as in the Pumpkin Buttes area. The ratio ranges from 3:1 to 1:10. The predominant ore minerals are the uranium vanadates; however, uranophane and uraninite are locally prominent. Coalified material in deposits contains as much as 3 percent uranium. The prevalence of these essentially non-vanadiferous minerals and materials in samples causes much of the range in vanadium-uranium ratios.

Selenium and arsenic appear to be slightly concentrated in the uranium deposits in the Southern Powder River Basin as is the case in the Pumpkin Buttes area, where selected samples contain as much as 3 percent selenium. However, so far, nothing in the southern area has approached this value.

Equilibrium of the uraniferous material is erratic, although in general uranium values tend to be slightly higher than predicted by radioactivity. Radioactive material in which uranium minerals can be detected or in which coaly material is prominent, is consistently beneficiated in uranium. Radioactive ferruginous material essentially without visible evidence of uranium should be evaluated radiometrically with caution.

The following paper on the geology of the Powder River Basin was published during the period:

Sharp, W. N., McKeown, F. A., McKay, E. J., and White, A. M., 1956, Geology and uranium deposits of the Pumpkin Buttes area, Powder River Basin, Wyoming, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 403-406: New York, United Nations.

Wind River Basin, Wyoming

Gas Hills area, Fremont and Natrona Counties, Wyoming
By H. D. Zeller and P. E. Soister

The uranium ore in the Gas Hills area is restricted to the upper coarse-grained facies of the early Eocene Wind River formation in fluviatile sandstone, conglomerate, and associated siltstone, clay, and mudstone. Autunite is the principal uranium mineral in the oxidized zone; uraninite is the most important mineral in the unoxidized zone.

During the report period mining began on several new uranium deposits, and the outline of several previously known ore bodies was extended by drilling. On May 15, 1956, a new open-pit mine in sec. 28, T. 33 N., R. 89 W., Fremont County, was approximately 1,200 feet long, 200 feet wide at the top, and 120 feet deep. The ore zone in that area is about 20 feet thick.

A mine in sec. 22, T. 33 N., R. 89 W., Natrona County, is in a narrow horst-like structure between a small fault and a possible fault where the top of the ore coincides with the top of the perched water table, 20 to 30 feet below the ground surface. The ore is mainly coarse-grained dark-gray sandstone with lesser amounts of blue-green clay and siltstone which contain much pyrite and/or marcasite. Blooms of ilsemmanite (hydrous molybdenum oxide) and green, yellow, or orange uranium minerals form soon after exposure of the ore during mining.

The top of an ore body at the Lucky Mc mine coincides with the nearly horizontal present-day water table and the ore appears to transect beds of the Wind River formation which dip about 2 degrees to the south.

Several faults have been exposed in the new mine pits in sec. 22, T. 33 N., R. 89 W., Natrona County, the largest of which is indicated by a lineation on aerial photographs. Other lineations on aerial photographs may be useful in further exploration, because the faults have controlled the ground-water movement and apparently have afforded obstructions to the flow of solutions containing uranium. An example of this can be seen at an open-pit mine in sec. 22, T. 33 N., R. 89 W. where a coarse-grained fluviatile sandstone containing uranium ore appears to be in fault contact with a bluish-green clay containing abundant pyrite and/or marcasite. Precipitation of uranium there may have taken place with a change in the pH of the mineralizing solution.

Selenium is found in association with uranium ore at many new localities. A carbonaceous silt-shale 1 to 2 feet thick in sec. 6, T. 32 N., R. 90 W., Fremont County, contains 0.062 percent selenium and 1.3 percent uranium. A black sandstone 1 foot thick in the unoxidized zone of the Vitro mine contains 0.42 percent selenium and 2.33 percent uranium. At the Upetco mine a gray sandstone contains 0.36 percent selenium. In the Conant Creek area (sec. 6, T. 32 N., R. 94 W., Fremont County) a tuffaceous siltstone 1 foot thick near the top of an unnamed sequence of Middle and Upper Eocene rocks contains 0.1 percent uranium and 0.01 percent selenium. At the Aljob mine in Natrona County, small black spots and laminae occurring in the gray siltstone ore have been identified as uraninite. The amount of visible black material is used successfully by the operators to estimate the grade of the ore. Pyrite is associated with uraninite throughout much of the area.

Two 7-1/2 minute quadrangles in the Gas Hills area have been mapped by photogeologic methods as part of a program designed to test the applicability of photogeologic methods to mapping in different terranes. In the mapped quadrangles rocks of Cody, Measverde, Lewis, Lance and Fort Union ages are overlain by the Wind River formation of Eocene age, which can be divided photogeologically into its upper and lower members. In addition, one major anticlinal structure, several minor folds, and numerous faults have been mapped.

The following map, published during the period, covers in part the Gas Hills area:

Van Houten, F. B., and Weitz, J. L., 1956, Geologic map of the eastern Beaver Divide-Gas Hills area, Wyoming: U. S. Geol. Survey Oil and Gas Investigations Map OM-180.

Geophysical studies, by R. A. Black

Interpretation of seismic refraction data obtained in the Gas Hills area (TEI-590, p. 168-170) proves that the seismic refraction method can be used to delineate both major and minor fault trends in this area. In the general area bounded by Puddle Springs, Coyote Springs, the Lucky Mc and Vitro mines, and Cameron Springs, the principal mineralized zone is underlain by a complex basin or series of basins resulting from (1) deep pre-Wind River erosion and (2) post-Miocene normal faulting. Results of the seismic work done in the area in September and October 1955 indicate that seismic refraction methods would be useful in exploration for another such basin.

Seismic measurements are currently in progress in the Gas Hills to test the ability of shallow reflection methods to map the buried Wind River-Cody contact, and to map additional fault patterns with refraction measurements.

Hiland-Clarkson Hill area, Natrona County, Wyoming
By E. I. Rich

The lower Eocene Wind River formation in the Hiland-Clarkson Hill area is divided into three facies consisting of (1) a "lower" variegated series of siltstone, claystone and intercalated sandstone; (2) a "middle" drab claystone and arkosic channel-type sandstone unit; and (3) an "upper" arkosic conglomerate which is thought to be equivalent, in part, to the uranium-bearing upper coarse-grained sandstone facies in the Gas Hills area.

Measurements made on the cross-bedded structures and in the linearity of the channel deposits suggest a general trend of stream flow and source areas of the sediments for each facies of the Wind River formation. The "lower" facies may represent a reworking of pre-Tertiary rocks exposed to erosion by regional deformation. Deep weathering of these older rocks and transportation of the debris by sluggish streams flowing normal to the edges of the basin gradually built up the variegated siltstone and claystone deposits of the "lower" facies. Granitic pebbles are found locally within the "lower" facies, which suggest the local granitic upland areas were exposed to erosion. The variegated beds may have been derived from red soils developed on the granitic uplands.

There appears to have been a change in the source area for the sediments during the deposition of the "middle" facies. This change may have been prompted by movement along the margins of the basin; and increased marginal dips and minor folding of the "lower" facies of the Wind River formation are interpreted as a record of this movement. Sedimentary structures and elongation of the channel sandstones of the "middle" facies in the Hiland area, suggest a west-to-east trend of the streams. This trend may reflect the main course of the basin drainage with most of the material derived from the west or northwest. A "sheet-sand" at the top of the "middle" facies in the southwestern part of the area was probably derived from the Granite Mountains and may reflect the beginning of "upper" facies deposition.

A thin discontinuous carbonaceous layer at the base of the "middle" facies may have resulted from temporary swampy conditions which probably existed along parts of the basin axis at the beginning of the "middle" facies deposition.

During the later part of early Eocene time the Granite Mountains to the south of the Hiland-Clarkson Hill area supplied most of the sediments which comprise the "upper" facies of the Wind River formation. The Rattlesnake Hills are postulated to have acted as a barrier to streams flowing northeastward and northwestward from the Granite Mountains. These streams were deflected around the ends of the Rattlesnake Hills and deposited a thick sequence of "upper" facies sediments east and west of this barrier. The "upper" facies in the Hiland-Clarkson Hill area may be stratigraphically equivalent in part to the upper coarse-grained facies in the Gas Hills and the sediments making up these facies may have had a common source area.

Radioactivity anomalies are found in the "middle" and "upper" facies of the Wind River formation; no anomalies have been found in the "lower" facies.

Data on 33 samples of water from streams, wells, and springs collected for uranium analyses are summarized below:

Unit sampled	No. of samples	Avg. U content (parts per billion)	Average pH
Oligocene White River fm.	8	3.4	7.73
Eocene Wind River fm.	25	10.0	7.71
Total samples	33		

Analyses of the water samples from the White River formation of Oligocene age range from less than 1 to 9 ppb and average 3.4 ppb uranium. The average is less than that in other areas for which data are available. Samples from the Wind River formation with the highest uranium content, none of which exceeds 28 ppb uranium, are centered around the town of Hiland.

Washakie Basin, Colorado and Wyoming

Baggs area, Carbon and Sweetwater Counties, Wyoming, and Moffat County, Colorado
By G. E. Prichard

The Baggs area includes about 475 square miles in southern Wyoming and northern Colorado. Outliers of the Browns Park formation of Miocene age, with an areal extent of about 80 square miles, are present in the area and probably were once continuous with the Browns Park of northwestern Colorado and northeastern Utah. Essentially all the uranium which occurs in more than trace amounts in the area is in the light-gray to yellowish-brown fine- to medium-grained cross-bedded sandstone that overlies the basal conglomerate of the Browns Park formation. To the present time no relationship has been found between the uranium occurrences and the primary structure of the host rock.

Petrographic studies by W. A. Chisholm of the Geological Survey show that most of the uranium deposits are associated with pyroclastic rocks and occur in or below the transition zone between the nontuffaceous and the overlying tuffaceous facies in the Browns Park formation.

The yellowish-brown oxidized zone in Poison Basin generally extends 20 to 70 feet below the surface. It is underlain by a bluish- to medium-gray unoxidized zone. The contact between the oxidized and the unoxidized rocks has no apparent close relationship to the present land surface or to the present water table. The contact appears to be related to an ancient water table that ranges from 10 to 90 feet above the present water table. In the oxidized zone, lenses of bluish-gray unoxidized hard, dense calcareous sandstone occur locally. Uranium minerals are noticeably absent in the lenses but commonly are disseminated through the adjacent porous, friable sandstone. Uranium, selenium, molybdenum, and arsenic occur together, locally, at the top of the unoxidized and in the lower 3 feet of the oxidized zone; the relationships are shown in table 14. Secondary uranium minerals are also present higher in the oxidized zone but selenium, molybdenum, and arsenic are either absent or present in only minute quantities. Finely divided carbonaceous material and a primary uranium mineral, coffinite, have been identified (J. W. Gruner, 1956, personal communication) in samples of drill cuttings from the oxidized zone.

Table 14.--Analyses of selected elements in samples of mineralized sandstone from the Poison Butte claim group sec. 4, T. 12 N., R. 92 W., Wyoming 1/

Field no.	Se (ppm)	As (ppm)	Mo (ppm)	U (ppm)	Position in relation to top of unoxidized zone
PW 4-27B	2	40	10	1,700	32' above
T-Se 109	50	50	40	400	40' above
T-Se 96	30	100	400	400	23' above (jarositic ss)
T-Se 99	30	200	400	800	8' above
T-Se 101	2,000	800	2,000	2,000	3' above
T-Se 106	2,000	1,600	>2,000*	3,500	2' above (a pink lense)
T-Se 104	3,000	400	600	2,500	top 1' of unoxidized zone

* Indicates that result is probably in excess of 0.5% Mo.
1/ Samples, except PW 4-27B, collected by A. F. Trites, Jr.

More than 100,000 feet of exploratory drilling by mining operators since December 1955 in Poison Basin has located and extended new uranium deposits in the area. A new strip mine was opened in sec. 32, T. 13 N., R. 92 W. during April 1956.

Maybell-Lay area, Moffat County, Colorado
By M. J. Bergin and W. A. Chisholm

The Maybell-Lay area includes approximately 220 square miles along the southern margin of the Washakie Basin in Moffat County, Colorado. Commercial uranium deposits occur in the Browns Park formation of Miocene age which rests with angular discordance on rocks ranging in age from Precambrian to Eocene. The Browns Park formation consists of a basal conglomerate, locally absent but as much as 120 feet thick, overlain by 1,000 feet or more of light- to bluish-gray, fine- to medium-grained, massive, cross-bedded sandstone, cemented by clay and calcium carbonate.

Uranium occurrences

Most of the deposits occur on the steep north flank of a syncline in the Browns Park formation where the uranium occurs as disseminated material in soft, poorly cemented sandstone near normal faults, fractures, diastems, or hard calcareous sandstone masses (fig. 30) (TEI-590, p. 176-179).

The following uranium minerals in the order of their apparent abundance have been identified in the deposits: meta-autunite, uranophane, tyuyamunite, an unidentified uranyl phosphate, zeunerite or torbernite, and carnotite(?).

Chemical analyses of as much as 0.80 percent uranium have been obtained in samples from several of the deposits (fig. 31). Private operators report that higher concentrations of uranium may be present in sandstone encountered in drilling to depths as much as 200 feet (TEI-590, p. 178). The relationships of the occurrence of uranium to lithology as well as to equivalent uranium, vanadium, and selenium contents are shown in figure 31. Preliminary studies show that, in general, uranium is concentrated in soft, poorly cemented sandstone rather than in hard, calcareous sandstone, and that most of the deposits are out of equilibrium in favor of chemical uranium. The vanadium and selenium contents of samples are generally low (fig. 31).

Semiquantitative spectrographic analyses of representative ore-grade samples are shown in table 15. These analyses show that in addition to uranium, relatively high amounts of barium, copper, and the rare earths are present. Heavy mineral studies of ore-grade samples show that a direct relationship exists between the uranium content and the number of barite crystals, and that the crystals are pleochroic yellow in highly mineralized samples.

Petrographic studies

Preliminary heavy mineral studies of the Browns Park formation in northwestern Colorado and adjacent parts of southwestern Wyoming distinguished locally correlatable zones which may have regional significance.

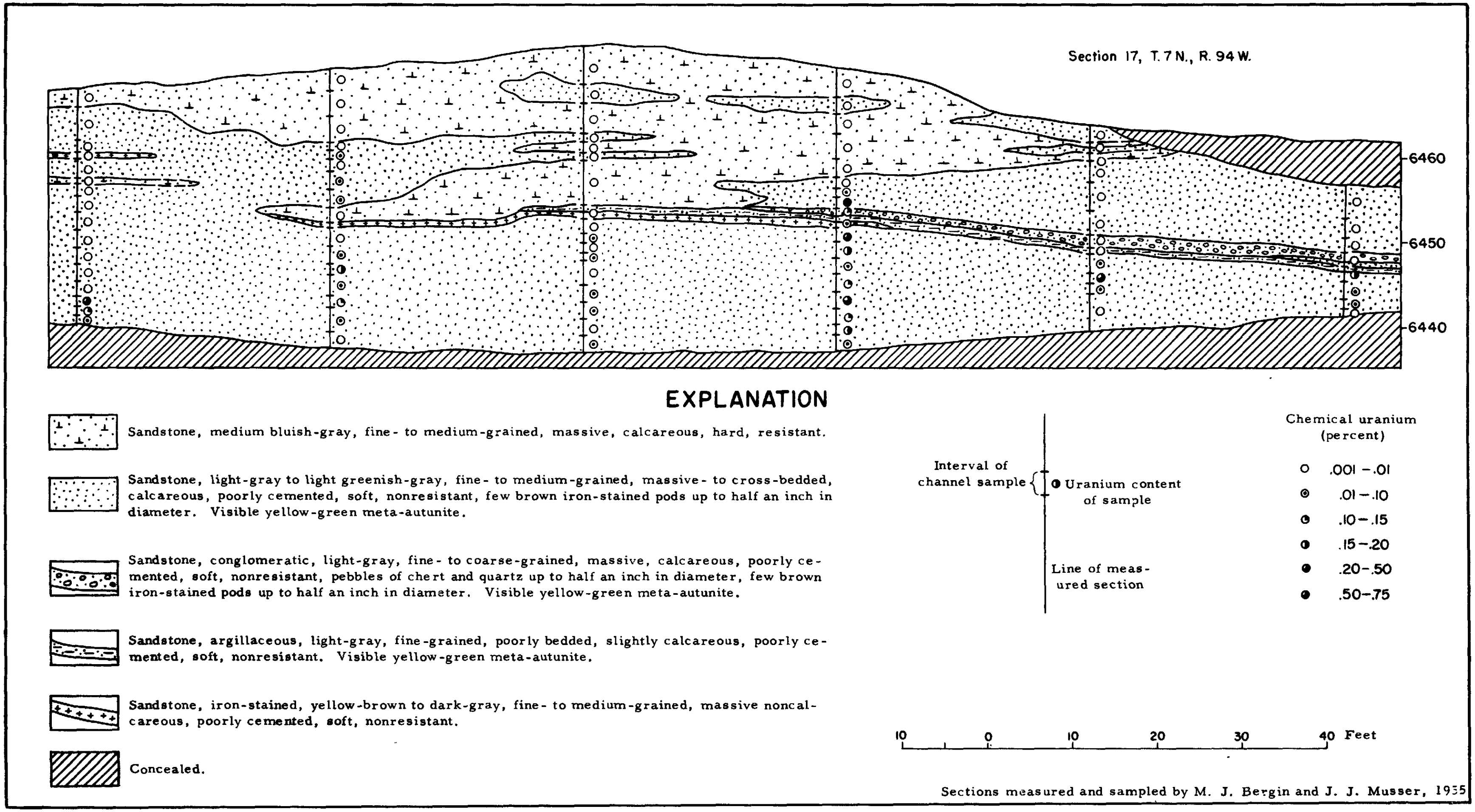
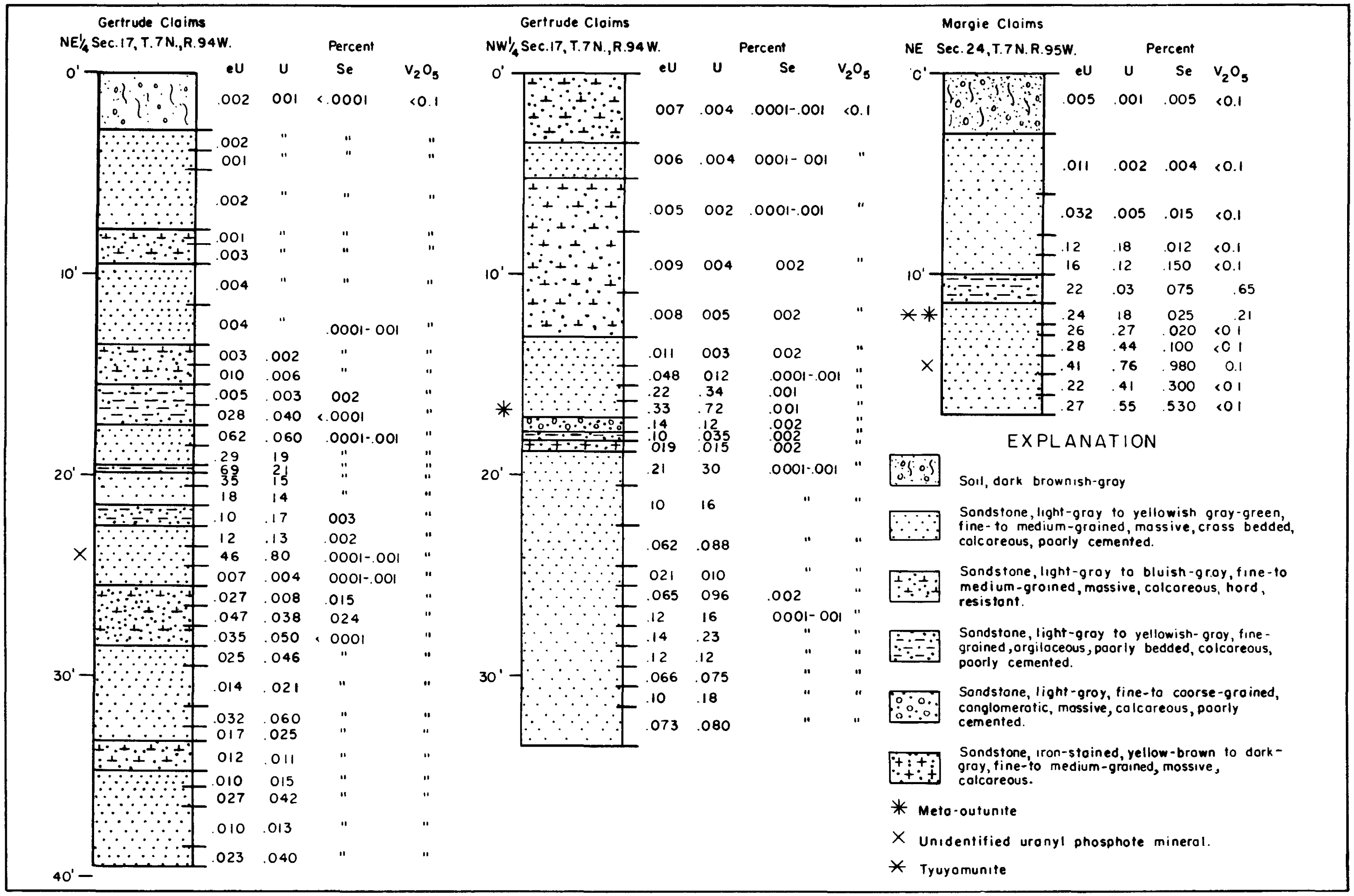


FIGURE 3a - CROSS SECTION OF DISCOVERY PIT AT THE GERTRUDE CLAIMS SHOWING VARIATIONS OF URANIUM CONTENT AND LITHOLOGY IN THE BROWNS PARK FORMATION, MAYBELL-LAY AREA, MOFFAT COUNTY, COLORADO 1956



M.J. Bergin and J. J. Musser, 1955

FIGURE 31 STRATIGRAPHIC SECTIONS SHOWING RELATIONSHIP OF URANIUM TO SELENIUM AND VANADIUM IN THE BROWNS PARK FORMATION, MAYBELL-LAY AREA, MOFFAT COUNTY, COLORADO

Table 15.—Comparison of semiquantitative spectrographic analyses of mineralized sandstone in the Maybell-Lay area

Sample from →	NW 1/4 sec. 17 T. 7 N., R. 94 W.	SE 1/4 sec. 8 T. 6 N., R. 94 W.	NE 1/4 sec. 24 T. 7 N., R. 95 W.	NE 1/4 sec. 24 T. 7 N., R. 95 W.
Uranium content (percent) 1/	0.23	0.25	0.55	0.76
Range (percent)				
10 +	Si	Si, Al	Si, Al	Si, Al
5 - 10	-	-	-	-
1 - 5	Al, Na, K, Ca	Na, K, Ca, Fe	Na, K, Ca, Fe	Na, K, Ca, Fe
.5 - 1	Fe	Ti	Mg	Mg
.1 - .5	Mg, Ti, Ba	Mg, Ba, Cu, V	Ti, Ba	Ti, Ba
.05 - .1	-	Sr, Zr	Sr	Sr
.01 - .05	Sr, B, Mn	Mn, Ce	Mn, Zr	Mn, V, Zr
.005 - .01	-	La, Nd, Ni, Pb, Y	V	-
.001 - .005	V, Zr, Mo, Pb, Cr, Cu, Ga, Ni	Co, Cr, Ga, Nb, Sc, Sn	Co, Cr, Ga, Pb, Y	Co, Cr, Cu, Ga, Pb, Y
.0005 - .001	-	Ge	Cu, Ni	-
.0001 - .0005	Yb	Be	Yb	Yb

1/ Determined by chemical analyses

The results of petrographic work demonstrate that in the Maybell-Lay area there are two distinct lithologic facies within the Browns Park formation: (1) a nontuffaceous facies which thickens to the east, and (2) a tuffaceous facies which thickens to the west (fig. 32). Most of the uranium deposits in the Maybell-Lay area, as well as in the Baggs area, 40 miles to the northeast, are associated with pyroclastic rocks and occur in or below the transition zone between the tuffaceous and nontuffaceous facies (see fig. 32). The areal distribution of these facies, therefore, is believed to be of primary significance and may serve as a useful guide in the search for new deposits. The areal relationship of the lithologic facies of the Browns Park formation indicates that the pyroclastic material was derived from a westerly source whereas the nontuffaceous material was derived from an easterly source. The striking similarity of the heavy mineral suites in the nontuffaceous facies in the Baggs and Maybell-Lay areas suggests that these clastic rocks probably were derived from the same source area, perhaps the Sierra Madre-Park Range. This range has previously been mentioned as the source area of the Browns Park formation west and north of the range by Christensen (unpublished data, 1942) and Theobald and Chew (unpublished data, 1955).

Petrographic studies show that three zones containing distinctive heavy minerals are present in the tuffaceous facies: (1) a basal zone 500 to 700 feet thick containing abundant augite; (2) a middle zone about 300 feet thick containing abundant hornblende; and (3) an upper zone about 500 feet or more in thickness containing abundant hypersthene (fig. 32).

Uranium in water

Water from springs, wells, reservoirs, and streams was collected for uranium analysis to outline areas favorable for additional prospecting. The

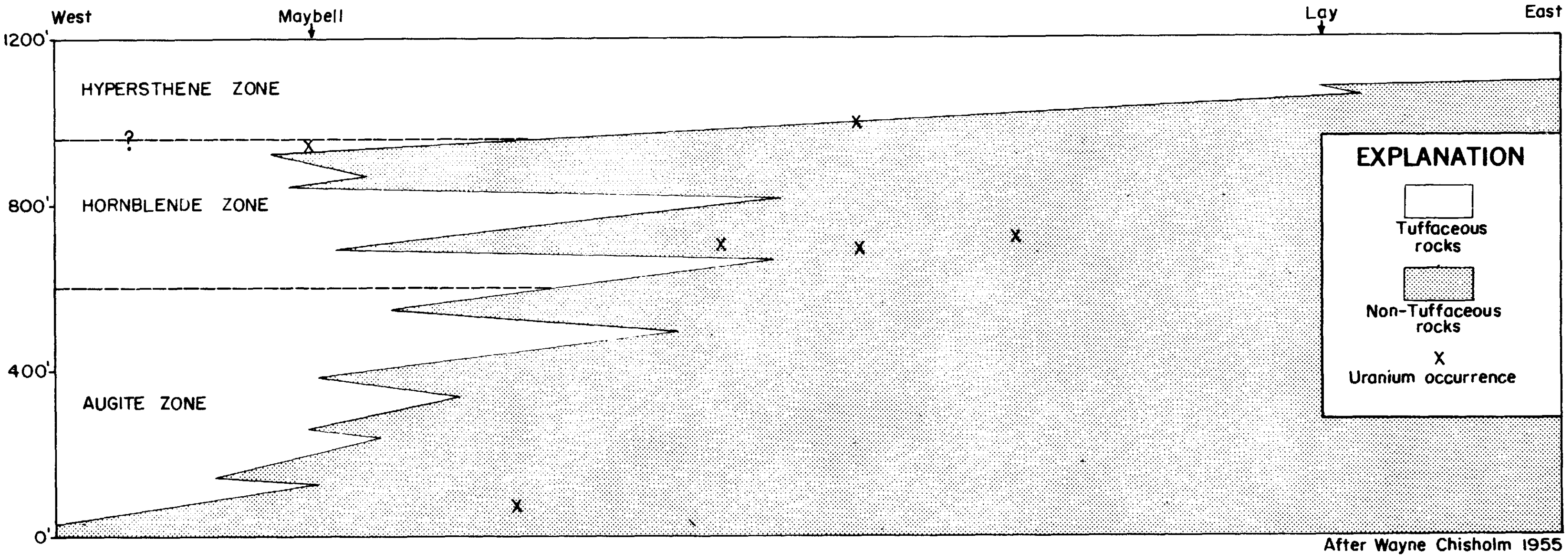


FIGURE 32.-PRELIMINARY CROSS SECTION SHOWING RELATIONSHIP OF URANIUM OCCURRENCES TO PYROCLASTIC FACIES IN THE BROWNS PARK FORMATION, MAYBELL-LAY AREA, MOFFAT COUNTY, COLORADO.

0 1 2 3 4 5 Miles

Horizontal scale

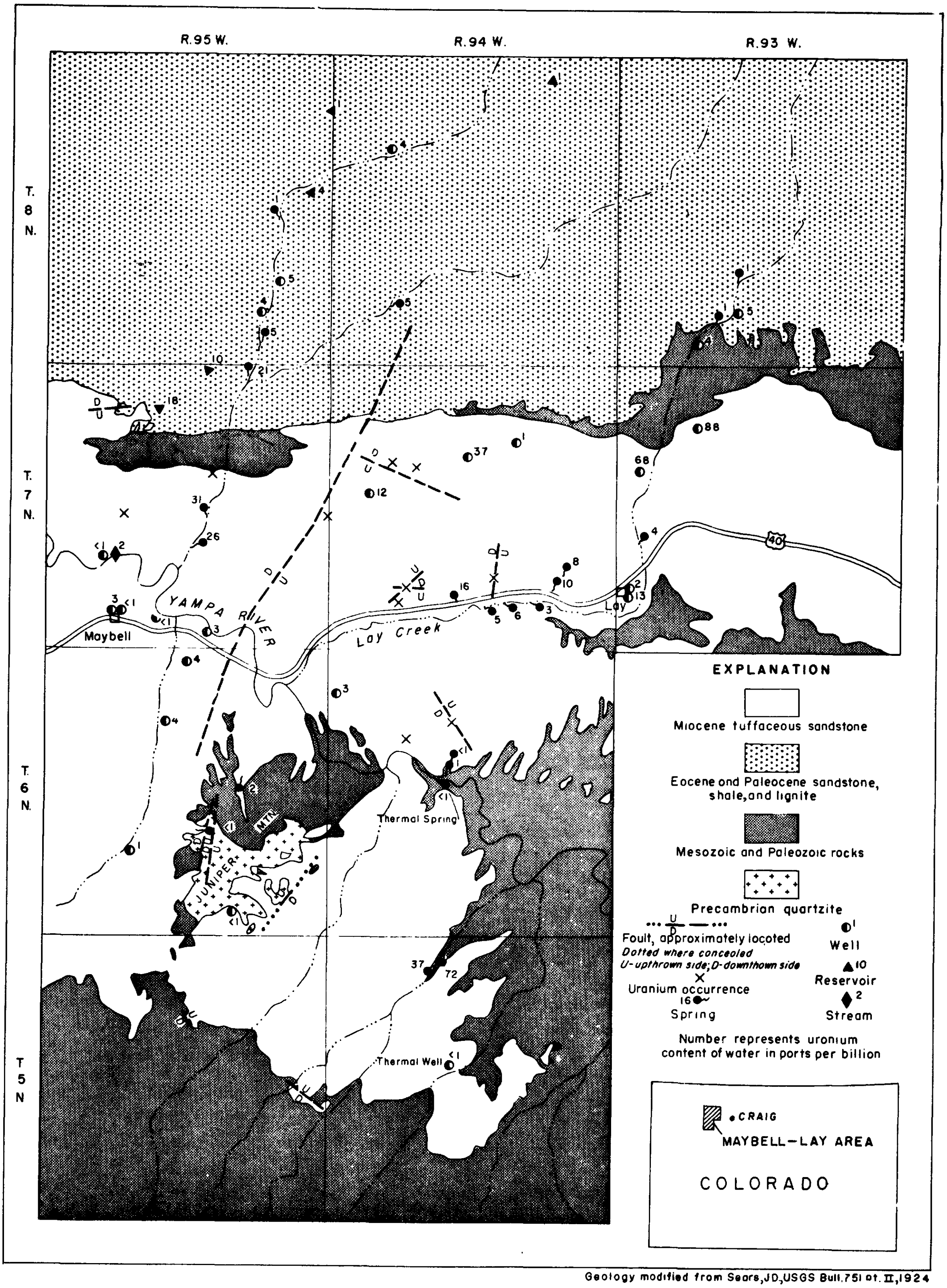
regional distribution of the uranium content of the water is shown on the generalized geologic map (fig. 33). The data on these water samples, excluding those samples from reservoirs and streams are summaried in table 16.

Table 16.—Results of water sampling, Maybell-Lay area

Unit from which water was sampled	No. of samples	Average U content (ppb)	Average pH
Miocene rocks (Browns Park fm.)	30	16	7.7
Eocene and Paleocene rocks	10	5	7.7
Pre-Paleocene rocks	5	2	7.8

Waters with high uranium contents of 31 and 26 ppb (center of T. 7 N., R. 95 W.) and 37, 16, and 12 ppb (western half of T. 7 N., R. 94 W.) drain from terrain containing known uranium deposits. The high uranium contents from sections 8 and 18, T. 7 N., R. 93 W. (88 and 68 ppb) and from section 4, T. 5 N., R. 94 W. (72 and 37 ppb) indicates that a careful search near these localities might be rewarding (fig. 33).

Four samples of water from wells in the Browns Park formation and one sample of hot spring water from pre-Paleocene rocks were analyzed for the selected trace elements shown in table 17. Water from the Browns Park formation contains relatively high contents of calcium, zinc, phosphorus, arsenic, and selenium, whereas the sample of water from the hot spring contains a high amount of sodium and only small amounts of the other elements.



Geology modified from Sears, J.D., USGS Bull. 751 pt. II, 1924

FIGURE 33—GENERALIZED GEOLOGIC MAP SHOWING URANIUM CONTENT OF WATER IN THE MAYBELL-LAY AREA, MOFFAT COUNTY, COLORADO.

0 1 2 3 4 5 Miles

1955

Table 17.—Analyses of selected elements in waters from the Maybell-Lay area

Location of sample	Unit from which water was sampled	pH	Concentration in water (ppb)							
			U	Na	Ca	Zn	P	As	Se	V
Well NE¼ sec. 8 7N-93W	Browns Park formation	7.6	88	128,100	544,400	600	<14	9,000	16,000	<32*
Well NE¼ sec. 18 7N-93W	do.	7.5	68	13,800*	99,200	4,900	6	<10	6	29*
Well SE¼ sec. 9 7N-94W	do.	6.8	37	506,800*	1,043,500	100	200	8	<4	<75*
Well SE¼ sec. 18 7N-94W	do.	7.4	12	28,800*	365,000	2,900	96	19	<4	6*
Hot spring SE¼ sec. 16 6N-94W	Pre-Paleocene rocks	7.8	<1	472,600	4,200*	13	6	<10	<1	<13*

* Determined from spectrographic analysis of residue—all other figures from chemical analysis.

Great Divide Basin, Wyoming

Crooks Gap area, Fremont County, Wyoming
by J. G. Stephens

The general geology of the Crooks Gap area was described in the previous semiannual report (TEI-590, p. 179-183). Recent work has shown that the Wasatch (?) formation in the area may be divided into two units, a lower folded sequence and an upper relatively undisturbed unit which generally masks the underlying folded structure. All of the major uranium deposits in the area occur in the lower folded unit. The ore bodies opened to date are small, of erratic distribution, and are composed of oxidized ore with only small nodules and specks of unoxidized minerals identified as uraninite and coffinite. Commercial drilling during the winter, however, has disclosed the existence at depth of deposits of unoxidized ore that apparently are larger and more significant than the oxidized deposits previously known.

Field data indicate that the Crooks Gap area has been subjected to several periods of structural activity: (1) folding during Late Cretaceous-pre-Paleocene time; (2) subsequent folding during post-Paleocene-pre-Eocene time; and (3) early Eocene thrust faulting accompanied by later Eocene compressional activity. A buried east-west thrust zone extends across the southern part of T. 28 N., R. 92 W. The thrust zone is indicated by gravimetric surveying by the Geological Survey and by subsurface data from an oil and gas test. The narrow east-west belt of oil producing Mesozoic strata in the Crooks Gap is believed to constitute a thrust block which has moved southward over the northern margin of the Great Divide Basin.

Geophysical studies, by R. A. Black

Final reduction of the gravity measurements made in the Crooks Gap area of Wyoming (TEI-590, p. 183-184) were carried out during the winter months. A total of 144 terrain corrections were made and a gravity contour map has been prepared. A combined elevation correction factor of 0.66 gravity units per foot, which assumes a density for the near-surface material of 2.2, was used to reduce the gravity data. A residual gravity map, prepared to remove the effect of the regional gradient, shows a number of gravity anomalies that were previously obscured by the strong regional gradient. One such anomaly, trending northwest across the northern part of the Crooks Mountain 7-1/2 minute quadrangle, is a prominent gravity low that has been interpreted as the southern edge of a high angle thrust fault extending into the area from the northeast.

Interpretation of the gravity data is in progress. A number of hypothetical geologic cross sections are being prepared by fitting field gravity profiles to theoretical gravity profiles as determined by a graticule for analyzing elongated structures. In the near future gravity measurements will be checked at a few stations; two gravity profiles south of the present gravity coverage will be run to determine the regional gradient in this area.

Seismic reflection and refraction measurements were made to provide depth control to facilitate the interpretation of gravity measurements previously made in this area. Difficulty was experienced in getting suitable reflections in this area because of poor shot hole conditions, but refraction shooting gave excellent results.

Southeastern Wyoming

Some uraniferous springs in the Wind River formation, Albany County, Wyoming
By J. D. Love

The Wind River formation of early Eocene age was deposited in steep-sided canyons and channels as much as 500 feet deep, that trend west and southwest off the east flank of the Laramie Mountains, northern Albany County, Wyoming. These canyons and channels were cut chiefly in Pennsylvanian, Permian, and Triassic rocks dipping westward about 6 degrees, and were filled with arkosic sandstone, conglomerate, variegated claystone, carbonaceous shale, and thin coal beds of the Wind River formation.

Water samples collected from ten springs emerging from a cross-section of one channel (sec. 29, T. 26 N., R. 75 W., fig. 34) contain a maximum of 3,100 ppb and a minimum of 140 ppb uranium. A 2-inch bed of carbonaceous conglomeratic sandstone at the base of the Wind River formation where it is in contact with the Chugwater formation (Triassic) on the southwest margin of this channel contains 0.24 percent eU and 0.13 percent U.

Prior to deposition of Oligocene rocks, steep-sided channels and valleys were cut in the Wind River formation and older rocks. During Oligocene time these channels were filled with white tuff, claystone, and lenticular conglomerates of the White River formation. The Recent cycle of erosion has stripped away much of the White River formation, and the present streams cut nearly at right angles across the pre-Wind River and pre-White River channels, exposing cross-sections of many of them. Water trapped in these channels is unable to sink down through the impervious Chugwater formation, Satanka shale (Permian), and limestones in the Casper formation (Pennsylvanian and Permian(?)), so it emerges as springs where the channels

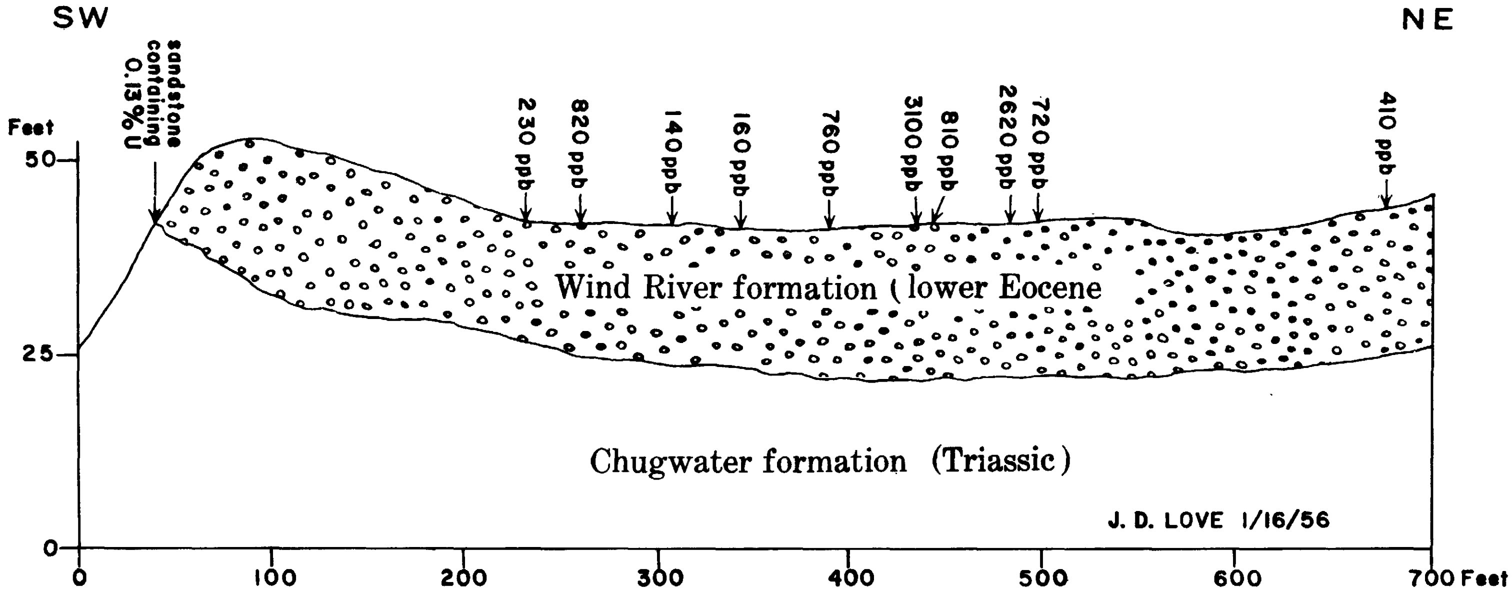


FIGURE 34 -- DIAGRAMMATIC CROSS SECTION SHOWING RELATIONSHIP OF URANIFEROUS SPRINGS TO CHANNEL DEPOSIT OF WIND RIVER FORMATION ON SHEEP CREEK, ALBANY COUNTY, WYOMING. Uranium content of water shown in parts per billion and of sandstone in percent determined by chemical analysis.

intersect the present stream valleys.

It is thought that the uranium now emerging in the spring water may have been leached out of the White River formation and then trapped in the Wind River formation until such time as the Recent cycle of erosion breached them. When the water table was cut, lateral movement of the uranium-charged water began and still continues.

Arizona

Dripping Spring quartzite
By H. C. Granger

Stratigraphic studies

Detailed stratigraphic studies of the Dripping Spring quartzite in Gila County, Arizona (fig. 35) have disclosed new data on the size and shape of the basin (Apache basin) in which the sediments were deposited, and on the petrographic features of the strata favorable for uranium deposits. It now appears that the northern part of the Apache basin was a northeasterly trending arm off the main basin to the south; the abrupt termination of the basin at the southeast flank of the Mazatzal Mountains as proposed by earlier investigators seems improbable. In addition, new evidence indicates that the source of all the clastics could hardly have been to the north as proposed earlier; it now appears that the major source probably was from the south. Preliminary data support the hypothesis that the original basin of deposition of the entire Apache group was much larger than the known outcrop area, and may have extended well into or beyond southwestern Arizona. The existence of an ancient land barrier, Mazatzal land, to the north is probable, but in Precambrian time it may have trended more to the west than to the southwest, its trend in Paleozoic time.

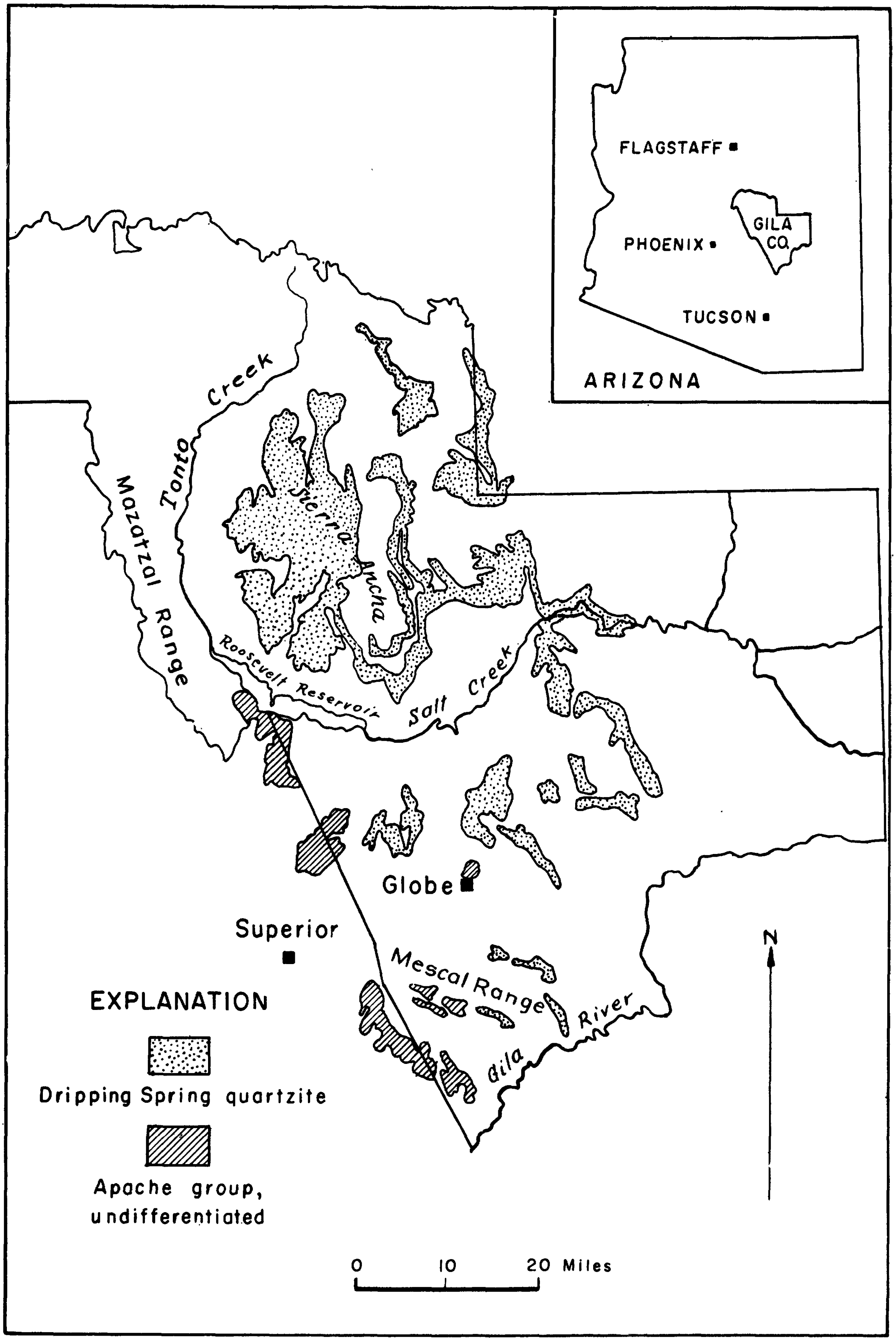


FIG. 35 — INDEX MAP OF GILA COUNTY, ARIZONA, SHOWING GENERALIZED STRIP MAP OF DRIPPING SPRING QUARTZITE

Uranium deposits in the Dripping Spring quartzite have been found only in areas where a recognizable dark-gray unit occurs in the upper member. In areas where the dark-gray unit is missing the comparable beds are generally strongly weathered and iron-stained, non-uraniferous, and faulted. It is possible that the strong weathering may have destroyed the carbon and pyrite in the fresh rocks and leached any uranium that may have been emplaced in them. A belt of this non-uraniferous equivalent of the dark-gray unit extends northeast and southwest through Globe and Superior (fig. 35).

Diabase differentiation

Differentiation of the rock-forming constituents of the diabase is shown on figure 36. In the differentiates silica, soda and potash increase as calcium, magnesium, ferrous oxides, and alumina decrease; this appears to be a normal order of differentiation.

Studies of the behavior of uranium and other metals during differentiation under the direction of G. J. Neuerburg suggest strongly that the diabase lost uranium during its cooling history (see Occurrence of uranium in veins and igneous rocks, this volume). Field relationships indicate that the uranium expelled from the diabase formed the primary uranium deposits in the Dripping Spring quartzite. The behavior of cobalt, copper and vanadium appears somewhat erratic and is difficult to interpret.

Age of the deposits

Lead-isotope age determinations by L. R. Stieff of the Geological Survey on two specimens of galena from the Red Bluff mine give apparently conflicting results. One specimen is largely non-radiogenic lead having isotope ratios closely comparable to galenas of Tertiary age; the other contains more than 90 percent radiogenic lead (believed to be one of the highest contents known) and the Pb^{207}/Pb^{206} ratio indicates an age of 1,125 million years. It is

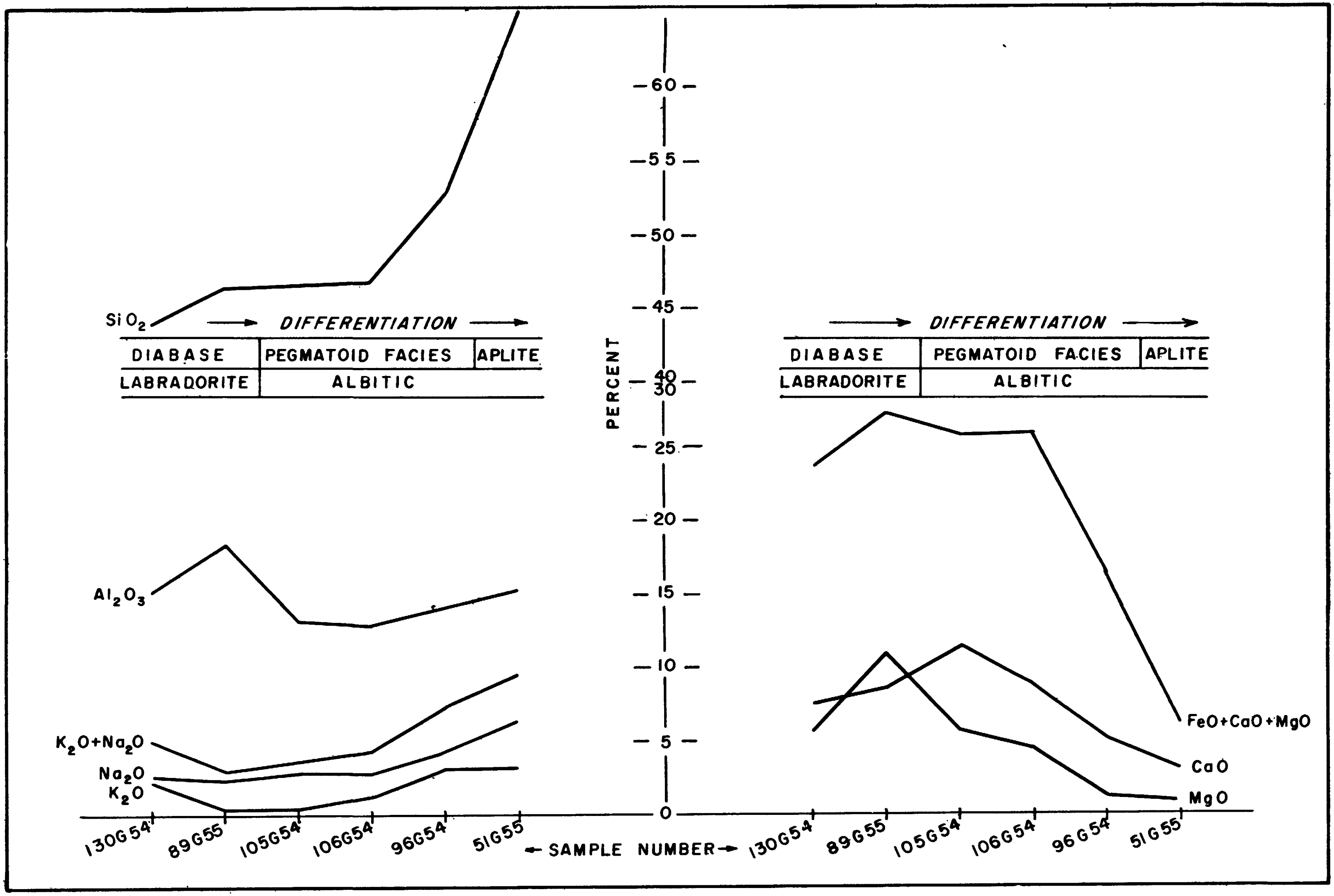


FIG. 36 —CHART SHOWING DIFFERENTIATION OF ROCK-FORMING OXIDES IN DIABASIC INTRUSIVES

possible that this galena consists largely of radiogenic lead derived from the uranium deposits and reconstituted as galena during Tertiary(?) time. It is extremely improbable, however, that the age of 1,125 million years can be applied directly to the age of the uranium deposits.

As a check on the age of the uraninite in the Dripping Spring quartzite a sample was studied by a method suggested by B. Wasserstein of Pretoria, South Africa. His thesis is that the unit cell of UO_2 shrinks with time because of the replacement of U by Pb, the shrinkage of the cell edge presumably being 0.0046 Å per 100 million years. Although Wasserstein's hypotheses concerning the chemistry of the various uranium oxides have been critized, there yet may be some relationship between the size of the unit cell of UO_2 and the age of the material. Extremely accurate measurements, however, are necessary to get limited accuracy in the age determinations.

In the study, part of a specimen of uraninite from the Black Brush adit was first analyzed for thorium, as the presence of thorium in the uraninite requires a correction factor. The thorium content of the sample, however, was negligible. Two remaining parts of the sample were then X-rayed, one without further treatment, the other after heating in a hydrogen bath to expel any oxygen that might have been acquired by weathering. Both films were measured independently by three persons and the cell edge calculated from their measurements. Results were in good agreement, 5.461 Å and 5.444 Å for the unheated and heated samples respectively. The difference probably indicates that interstitial oxygen due to weathering was removed from the heated sample by hydrogen reduction. According to Wasserstein a cell edge of 5.444 Å indicates an age of about 730 million years. Geologic evidence indicates an age closer to 500 million years, but as the host and associated rocks are poorly dated, the age of 730 million years cannot be ruled out.

Further research is needed to establish the reliability of ages calculated by this method.

Changes of composition in siltstone during metamorphism

In this report the rocks described in previous semiannual reports (TEI-490, p. 112-117; TEI-540, p. 128-134; and TEI-590, p. 187-190) as feldspathized rocks are designated hornfels and recrystallized hornfels. The hornfels is a fine-grained rock showing no appreciable increase in grain size from the original siltstone; the recrystallized hornfels is coarser-grained and appears to develop from the hornfels. Where the hornfels and recrystallized hornfels form alternating layers the rock is called lit-par-lit hornfels. Mobilized parts of the hornfels formerly called rheomorphic dikes are now called transition dikes.

A series of analyses from unaltered siltstone through recrystallized hornfels indicates that the metamorphic rocks were formed without any appreciable change in composition, as shown by the chart (fig. 37). The role of the hornfels and recrystallized hornfels as host rocks to uranium deposits has been discussed in previous semiannual reports (TEI-540, p. 129-134; TEI-590, p. 187-191).

New Mexico

Tucumcari-Sabinoso area
By R. L. Griggs

Uranium occurrences in the Tucumcari-Sabinoso area were described in the preceding semiannual report (TEI-590, p. 191-195). The area, which is in Quay and San Miguel Counties in east-central New Mexico, is a dissected portion of the Great Plains. The rocks are flat-lying to gently warped sediments of Triassic, Jurassic, Cretaceous, and Tertiary ages. A summary

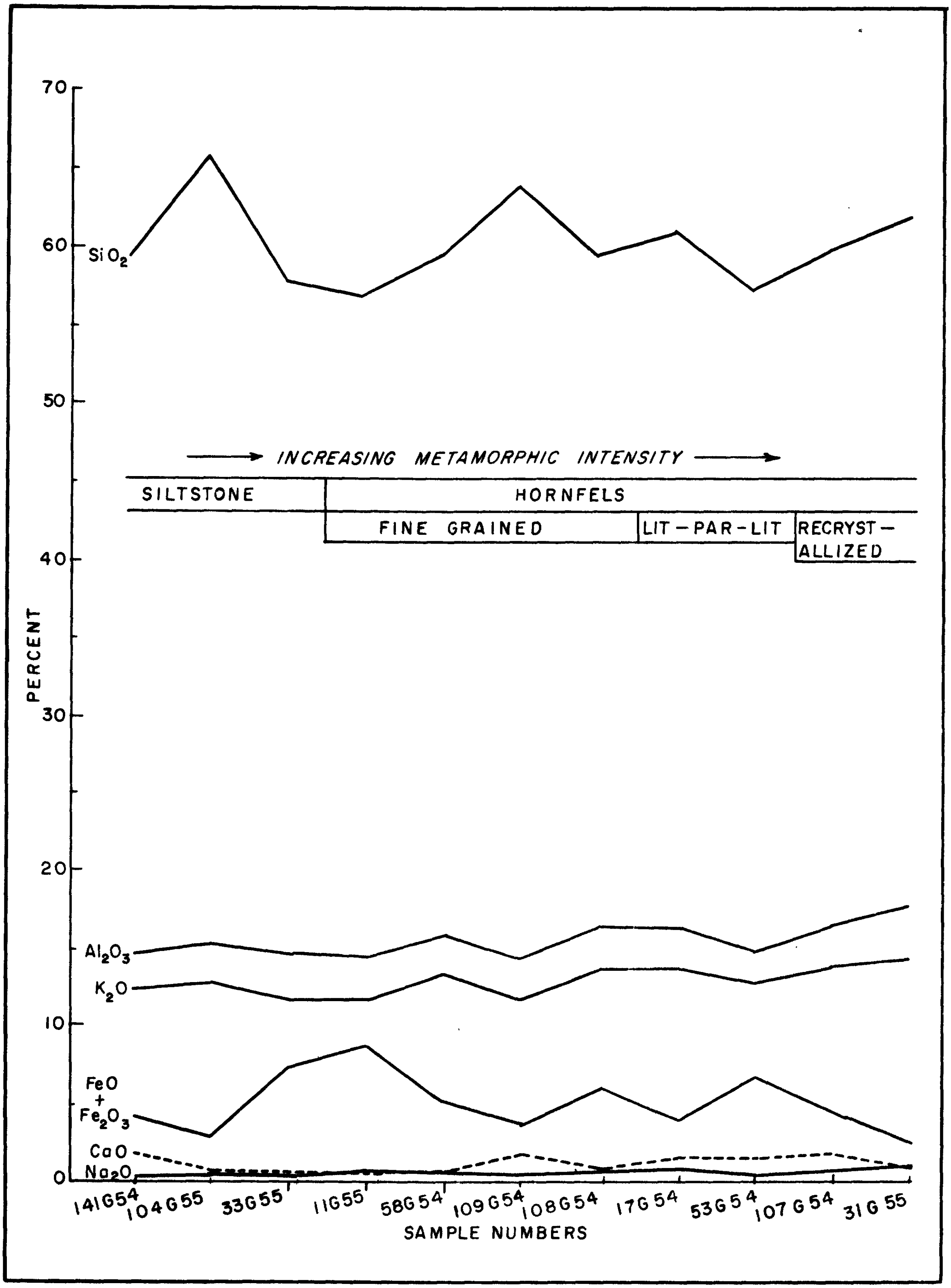


FIG. 37 — CHART SHOWING CONSTANCY OF COMPOSITION DURING THERMAL METAMORPHISM OF SILTSTONE

of the stratigraphy, based upon synthesis of data obtained during field mapping during the preceding report period, follows:

The Dockum group of Late Triassic age, the oldest rocks exposed in the area, is over 750 feet thick and underlies an area of about 700 square miles in the project area. The Dockum group has been subdivided into four mappable units of which two consist mainly of silty maroon shale and two consist mainly of gray conglomeratic sandstone. The conglomeratic sandstone units contain uranium mineralization along channels in association with carbonaceous and ferruginous material.

Resting conformably on the Dockum group is a sequence of orange-red sandstone and siltstone. This sequence is about 50 to 200 feet thick and is probably correlative with part of the Glen Canyon group, possibly the Wingate sandstone. It is tentatively placed in the Late Triassic.

Resting unconformably on the Late Triassic rocks is a sequence which probably is correlative with the San Rafael group. This part of the section has tentatively been subdivided into two units. The lower of these two units has been further subdivided into three smaller units. One of these units, about 35 to 65 feet thick, occupies the position of and is identical in lithology with the Entrada sandstone. A second unit ranges from the vanishing point to 60 feet thick. It consists of interbedded sandstone and siltstone and is similar to the Summerville formation of some localities. The third unit is a thinly bedded limestone which ranges from the vanishing point to about 10 feet thick. This unit, present in a very local area, is believed to be correlative with the Todilto limestone. The upper unit of the San Rafael (?) group is a massive white sandstone which ranges from the vanishing point to 120 feet thick. This unit is believed to be correlative with the Cow Springs, Junction Creek, and Bluff sandstones.

The Morrison formation is commonly exposed as a narrow band along steep cliffs in the northern part of the area. It also has similar exposures around mesas in the southeastern part of the area. This formation overlies the San Rafael (?) group conformably, and along the southeastern margin of the area it apparently intertongues with a sandstone unit of the San Rafael (?) group. The Morrison has been subdivided into four members: (1) a basal red shale member, (2) a light gray sandstone and variegated shale member, (3) a green shale (Brushy Basin-equivalent) member, and at the top, (4) a local member composed of white sandstone. Uranium minerals are present locally in the light gray sandstone and variegated shale member.

A section of marine sediments of Late Cretaceous age overlies the Morrison formation and the San Rafael (?) group unconformably. These marine sediments are about 150 feet thick and consist of dark gray shale and light gray sandstone.

The Ogallala formation of Tertiary age is as much as 200 feet thick. It consists of silt, sand, gravel, and, in places, caliche-like limestone.

Pennsylvania

Mauch Chunk quadrangle
By Harry Klemic and J. C. Warman

Field work in the Mauch Chunk quadrangle was recessed temporarily on October 1, 1955. Petrographic studies of rock samples from Mississippian and upper Devonian formations in that area are now being made. The studies are incomplete, and only a partial description is presented here.

Mauch Chunk shale (Mississippian)

Samples from this formation consist largely of red low-rank graywacke ranging from siltstone to coarse sandstone. Thin beds of coarse sandstone and conglomerate near the base of the formation are gray or tan. The size and abundance of clastic grains generally increase toward the base of the formation. In these samples, most of which are medium-grained sandstone, clastic grains of quartz, quartzitic rock fragments, and chert make up 48 percent to 96 percent of the rock and average 65 percent. Micaceous minerals form the matrix and are most abundant in the upper part of the formation. Silica and calcite are the cementing materials. Locally, near the base of the formation, feldspar makes up as much as 12 percent of the clastic material; the average is less than 2 percent. Common accessory minerals are zircon, tourmaline, leucoxene, and magnetite. Near the base of the section epidote, muscovite, sphene, biotite, garnet, and possibly idocrase are additional accessory minerals.

At several horizons in the section there are thin beds of conglomerate consisting of calcareous sandstone or sandy limestone pebbles and cobbles in a red mudstone matrix.

Samples of red shale and mudstone beds in the formation have not been studied.

Pocono formation (Mississippian)

Samples from this formation are gray to grayish tan low-rank graywacke and quartzite sandstone and conglomerate. Conglomerate is more abundant in the upper half of the section. Clastic grains of quartz, quartzite, and chert make up about 67 percent of the rock. Medium- to coarse-grained clastic grains are generally angular, but the pebbles in the conglomerate are well rounded. Phyllite chips are abundant locally. Feldspar is rare, except in silty or clayey sandstone units, where it may constitute 1 to 7 percent of the clastic grains. Silica is the cementing material. It forms thick overgrowths on the clastic grains, particularly in quartzite beds. Zircon and hydromica are accessory minerals.

Catskill formation (Devonian)

Samples from this formation consist of low-rank graywacke with minor amounts of quartzite. The rocks range from shaly siltstone to conglomerates and are gray, green, tan, or red. Conglomeratic rocks are more abundant in the upper half of the section. The rocks are generally medium-grained with an average of 57 percent of sub-angular clastic grains of quartz, quartzite, and other rock fragments, and chert. The matrix is commonly micaceous, and silica is the cementing material. Zircon, tourmaline, magnetite, leucoxene, vermiculite, and feldspar are accessory minerals. Limonitic and carbonaceous plant fossils are in some beds.

Samples from thick beds of red shale and siltstone in the formation have not been studied.

Penn Haven Junction uranium occurrence

Uraninite and clausthalite have been separated from radioactive sandstone in the Catskill formation of Devonian age at this locality and identified by X-ray. The uraninite appears to be in a minus 200 mesh size and adheres to larger grains of detrital minerals. In one sample, minute specks of uraninite are concentrated along heavy-mineral bands rich in zircon and magnetite and are disseminated in lesser amounts in the rest of the rock. Clausthalite occurs in a thin band within an inch of the strongly uraniferous band and in lesser amounts in other parts of the rock. Most of the material formerly thought to be galena in this rock is now believed to be clausthalite.

Experimental photogeologic mapping
By W. A. Fischer

Certain small areas in Colorado, Wyoming, and Oregon are currently being mapped by photogeologic methods to test the applicability of photogeologic techniques to mapping in different types of terranes, such as combinations of intrusive igneous, volcanic, and sedimentary rocks; areas containing numerous distinctive units within formations, and areas of unusually complex structures. Most of these experimental areas are those for which photogeologic coverage has been requested by the AEC. The other areas have been chosen on the basis of obtaining disinterested field checking by experienced geologists of all the types of terranes most likely to contain uranium deposits. To date, two 7-1/2 minute quadrangles in the Gas Hills area, Wyoming, have been completed. One major anticlinal structure, several minor folds, and numerous faults were mapped in an area where rocks of Cody, Mesaverde, Lewis, Lance, and Fort Union ages are overlain by the Wind River formation of Eocene age. The upper and lower members of the Wind River formation have been differentiated by photogeologic methods.

Other areas being mapped on an experimental basis to determine the feasibility of applying photogeologic techniques to various types of terranes, are the Baggs and Crooks Gap areas, Wyoming, the Cochetopa area, Colorado; the Owl Creek Mountains, Wyoming; and the Goose-Lake-Ebert Rim volcanic area, Oregon. All areas are being mapped at a scale of 1:20,000 except the Goose Creek-Ebert Rim area, which is being mapped at a scale of 1:250,000.

The location and status of photogeologic mapping outside the Colorado Plateau is shown in the index map, figure 38.

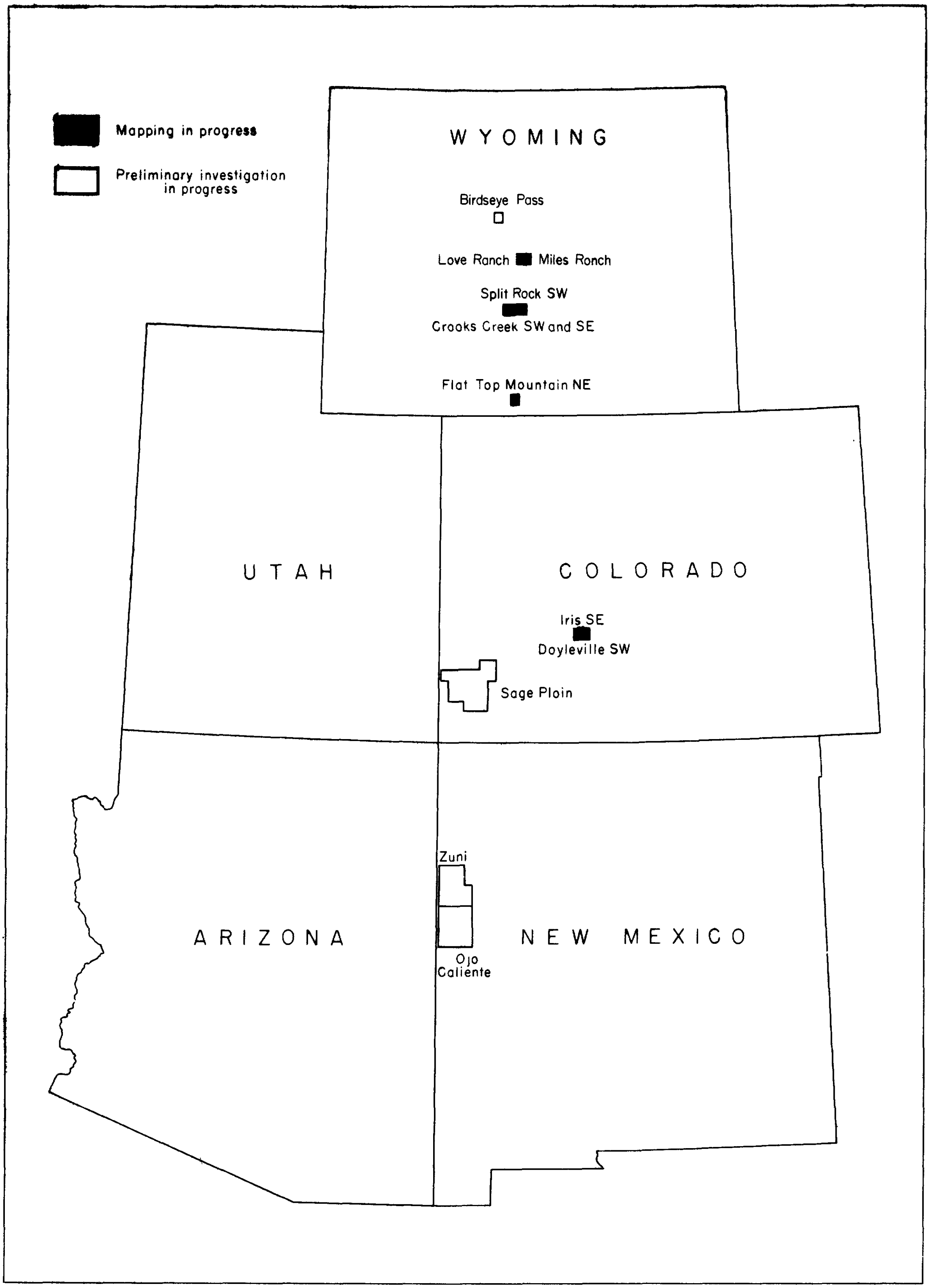


FIGURE 38 INDEX MAP SHOWING LOCATION OF PHOTOGEOLOGIC MAPPING IN WYOMING, COLORADO, AND NEW MEXICO AS OF MAY 30, 1956

URANIUM IN VEINS, IGNEOUS ROCKS, AND RELATED DEPOSITS

Colorado Front Range

By P. K. Sims

Field and laboratory data indicate that the Tertiary igneous rocks in the Front Range mineral belt were consolidated from two separate magma series, and that both uranium and thorium were concentrated in each series during differentiation. Maximum enrichment in uranium and thorium was reached in quartz bostonite, the youngest rock of the principal differentiation series (Phair, 1952). Faulting, which followed the consolidation of the quartz bostonite, provided channelways for the end-stage uranium-bearing hydrothermal solutions given off by the quartz bostonite magma. Uranium was deposited as pitchblende within relatively short distances from the separate shallow (?) quartz bostonite magmas, largely as a result of cooling of the solutions which permitted reducing conditions to set in.

Biotite-quartz latite, the youngest member of the minor differentiation series, may have been a source of uranium in certain vein deposits. Though it consolidated after the formation of the principal vein-fissures, it could have yielded solutions that moved through the existing fractures or entered the relatively local fractures that developed after its consolidation. This source could account for the uranium in the Alma-Lincoln, Stanley, and other mines near Idaho Springs, as the uranium minerals in those veins are known to be in part at least very late in the paragenetic sequence, and younger than the base-metal minerals.

The order of intrusion of the rocks constituting the Tertiary igneous sequence, as determined by crosscutting relations, is shown in figure 39. It can be seen that consolidation of the minor magma series, which consists of the hornblende granodiorite group, overlapped that of the major magma

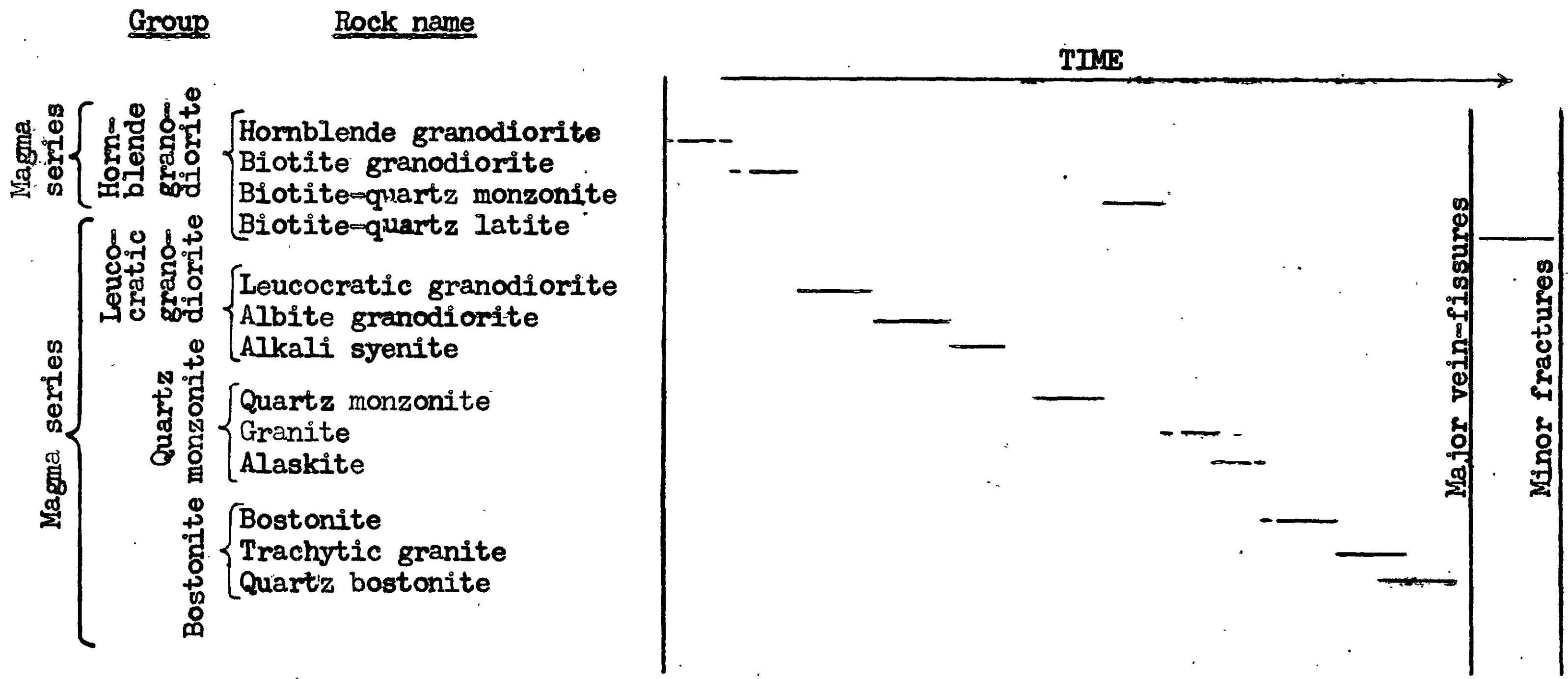


FIG. 39.—DIAGRAM SHOWING THE SEQUENCE OF INTRUSION OF THE TERTIARY PORPHYRITIC IGNEOUS ROCKS.

series, and that the youngest member of this group—biotite-quartz latite porphyry—consolidated after the formation of the vein-fissures.

The average content of equivalent uranium and uranium of the rocks in the sequence, as determined from more than 300 analyses, is given in figure 40. Phair (1952) has shown that the equivalent uranium (radioactivity) results from both thorium and uranium and that both the thorium and the uranium are in equilibrium. The analyses used in preparing figure 40 show an enrichment in uranium and thorium in the younger members of the sequence. The concentration of the radioactive elements is progressively greater in successively younger rocks of the minor magma series, but is discontinuous in the major magma series; the differentiates of each group within the series are progressively enriched in uranium and thorium.

Although uranium-bearing, late-stage, aqueous solutions could have been derived from differentiation of the magmas that formed each group of rocks (fig. 40), fractures that could serve as channelways for transportation and deposition of uranium deposits did not form until after the crystallization of the quartz bostonite magma. It is probable, therefore, that most of the uranium deposits were derived from a quartz bostonite source, as suggested previously (TEI-590, p. 200-202). A mechanism to account for the separation of uranium from thorium in the magmatic residuum has been given by Phair (1952).

The close geographic occurrence of uranium-bearing veins and quartz bostonite porphyry is interpreted to indicate that the uranium in the veins was derived from several relatively shallow bodies of quartz bostonite. The uranium was deposited as pitchblende within relatively short distances from the sources, probably largely because of cooling of the solutions which permitted reducing conditions to set it.

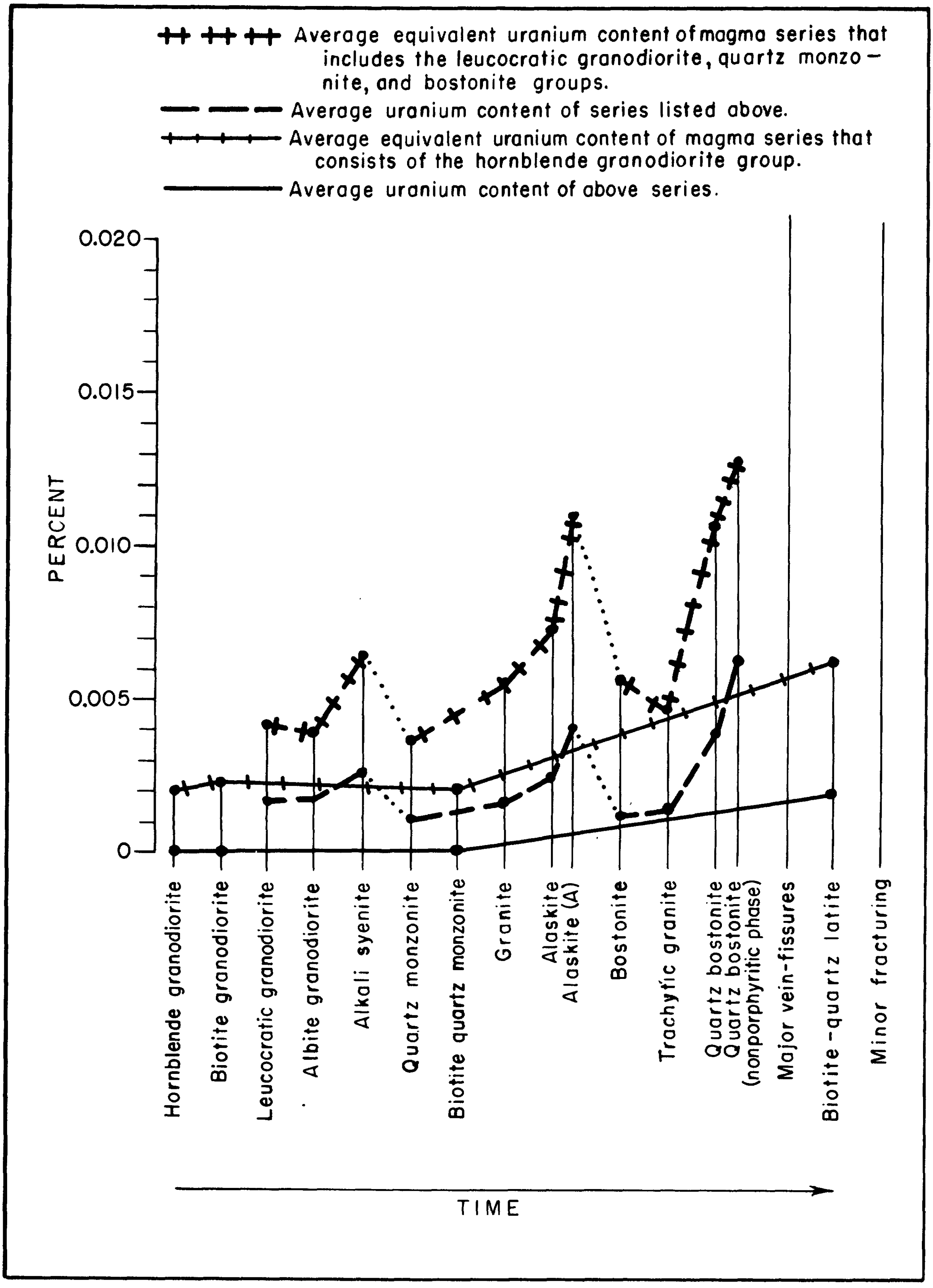


FIG. 4Q — DIAGRAM SHOWING VARIATION OF EQUIVALENT URANIUM (RADIOACTIVITY) AND URANIUM WITH ROCK TYPE AND AGE

The following papers on geologic work in the Colorado Front Range were published during the period:

Adams, J. W., and Stugard, Frederick, Jr., 1956, Wall-rock control of certain pitchblende deposits in Golden Gate Canyon, Jefferson County, Colorado, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy—v. 6, Geology of uranium and thorium, p. 279-282: New York, United Nations.

Drake, A. A., 1955, Occurrence of pitchblende at the Wood mine, Central City district, Gilpin County, Colorado (abs.): Geol. Soc. America Bull., v. 66, no. 12, pt. 2, p. 1673.

Harrison, J. E., 1955, Relation between fracture pattern and hypogene zoning in the Freeland-Lamartine district, Colorado: Econ. Geology, v. 50, p. 311-320.

Hawley, C. C., and Moore, F. B., 1955, Control of uranium deposition by garnet-quartz rock in the Fall River area, Clear Creek County, Colorado (abs.): Geol. Soc. America Bull., v. 66, no. 12, pt. 2, p. 1675.

Sims, P. K., 1955, Paragenesis and structure of pitchblende-bearing veins, Central City district, Gilpin County, Colorado (abs.): Econ. Geology, v. 50, no. 7, p. 794: Geol. Soc. America Bull., v. 66, no. 12, pt. 2, p. 1617.

Sims, P. K., and Tooker, E. W., 1955, Localization of metatorbernite in altered wall rocks, Central City district, Gilpin County, Colorado (abs.): Geol. Soc. America Bull., v. 66, no. 12, pt. 2, p. 1680.

______________, 1956, Pitchblende deposits in the Central City district and adjoining areas, Gilpin and Clear Creek Counties, Colorado, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy—v. 6, Geology of uranium and thorium, p. 265-269: New York, United Nations.

Tooker, E. W., 1955, Investigations of wall-rock alteration, Central City and Idaho Springs districts, Gilpin and Clear Creek Counties, Colorado (abs.): Geol. Soc. America Bull., v. 66, no. 12, pt. 2, p. 1682.

Reference

Phair, George, 1952, Radioactive Tertiary porphyries in the Central City district, Colorado, and their bearing upon pitchblende deposition: U. S. Geol. Survey TEI-247, issued by Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Ralston Buttes, Colorado
By D. M. Sheridan

A summary of the geologic features of the Ralston Buttes district, Jefferson County, Colorado, was reported in the previous semiannual report (TEI-590, p. 212-217). The district contains pitchblende deposits, most of which are in or near fault breccias of probable Tertiary age.

During the report period detailed mapping was done at two producing mines in the district and preliminary studies were made at three other prospects. The remainder of the period has been devoted to office and laboratory work, including petrographic studies, compilation of maps and illustrations, and work on manuscripts for the final reports.

Stevens County, Washington
By P. L. Weis

Project activities during the report period consisted of interpretation and evaluation of field data, compilation of a geologic map, thin-section study, preparation of a report covering the year's work in southern Stevens County.

Thin-section studies of the two major types of quartz monzonite found near the Midnight mine show that the porphyritic variety associated with the uranium deposits contains somewhat more biotite than the equigranular quartz monzonite found a few miles northwest of the Midnight mine. The porphyritic variety also appears to be somewhat more variable in its plagioclase and quartz content, but in other respects the porphyritic and non-porphyritic rocks are strikingly similar in composition. No explanation of the greater radioactivity of the porphyritic variety has been recognized. For additional information on the Midnight mine, see the preceding semiannual report (TEI-590, p. 223-224).

Black quartz, which is associated with uranium ore at the Midnight mine, has not yet been found elsewhere in southern Stevens County.

Faults are known at all of the uranium deposits in southern Stevens County, but their relation to ore deposition is not yet known. The relationship between faulting and ore deposits will be studied further during the coming year.

Tertiary sediments about 5 miles south of the Midnight mine contain torbernite-group minerals disseminated in tuffaceous sandstones and carbonaceous seams. Locally the uranium content appears great enough to constitute ore. The uranium-bearing sediments overlie porphyritic quartz monzonite that is a part of the same intrusive found at the Midnight mine, and are almost certainly overlain by Miocene Columbia basalt.

Limited work in the Mount Spokane area, Spokane County, Washington, shows that meta-autunite at the Daybreak mine is confined to an east-trending fault zone and its vicinity. The fault zone dips north at angles of 10 to 30 degrees, and is at least 40 feet thick. Hanging-wall cross-faults resembling tension fractures appear to have localized some of the uranium. Mineralogical and chemical studies of the meta-autunite have not yet established the age of the deposit.

Thomas Range, Utah

By M. H. Staatz

Results of previous geologic work in the Thomas and Dugway Ranges in central Juab and Tooele Counties, Utah, were given in the last semiannual report (TEI-590, p. 217-220). During the period covered by this report, most of the effort was devoted to laboratory studies of the volcanic rocks of the area.

Chemical analyses show that the volcanic rocks of the Thomas and Dugway Ranges belong to the calcic sequence, having an alkali-lime index of 61.7 which is similar to the volcanic rocks at Paricutin and Crater Lake. The rocks from the Thomas Range, however, are poorer in ferromagnesian minerals and are more salic than the average volcanic rock. Of the two groups of volcanic rocks in that Range, rocks of the older group are generally richer in magnesium, calcium and iron oxides and poorer in soda, potash, and silica than those in the younger group. Rocks that make up this younger group, which forms the greater part of the volcanics, show no systematic change in composition with relation to time.

Analyses of 25 volcanic rocks from the Thomas Range show that rocks of the older group average 0.001 percent uranium, and those of the younger group average between 0.003 and 0.004 percent uranium. As the average uranium content of 64 rhyolites in 40 counties in the western United States is roughly 0.001 percent, the older volcanic group thus has the same average uranium content as the western rhyolites but the younger group has a uranium content at least three times as large.

Age determinations made by H. W. Jaffe of the Geological Survey on zircons of a welded tuff of the older volcanic group indicate that the age of this rock is 19 million years, or middle Miocene. As Eocene volcanic rocks have been identified about 60 miles to the east, and Pliocene volcanic rocks about 60 miles to the northwest, volcanism seems to have occurred in western Utah throughout much of the Tertiary.

The following paper on the Thomas Range was published during the period:

Staatz, M. H., and Osterwald, F. W., 1956, Uranium in the fluorspar deposits of the Thomas Range, Utah, _in_ Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy—v. 6, Geology of uranium and thorium, p. 275-278: New York, United Nations.

Jarbidge, Nevada-Idaho
By R. R. Coats

Field work in the Jarbidge quadrangle, Nevada-Idaho, has shown the presence of four distinct sedimentary units of probable Paleozoic age. The oldest rocks in the quadrangle consist of a sequence several thousand feet thick of biotite-staurolite schist, grading upward into pure quartzite and mica schist. This sequence, tentatively correlated with the Prospect Mountain quartzite of Cambrian age, has been thrust over rocks of presumably younger Paleozoic age, consisting mostly of phyllite, quartzite, and limestone. All the Paleozoic rocks are intruded by stocks of coarse-grained granitic rocks, ranging in composition from biotite granite to biotite-hornblende quartz monzonite. The granite is presumably Late Mesozoic or Early Tertiary in age.

A gently northward-dipping sequence of volcanic rocks at least 4,000 feet thick rests upon the granite and the intruded rocks. The lower one-third of this sequence is biotite rhyolite welded tuff, and the upper two-thirds is coarse tuffaceous conglomerate. These rocks were eroded to a moderately even surface, intruded by a somewhat alkalic olivine basalt porphyry, and overlapped by a nearly horizontal sequence of about 450 feet of andesitic and rhyolitic tuff, at least 2,000 feet of rhyolite and rhyolitic welded tuff, and about 700 feet of dacite vitrophyre. The eroded surface carved into the rocks of this threefold sequence was diversified by the extrusion of a number of small domes of two distinctive types of dacite vitrophyre, which resulted in the accumulation, first of gravel and ultimately of tuff, in the drainage channels thus interrupted. Upon the surface, the refief of which had thus been somewhat subdued, a sequence of pyroxene rhyolite welded tuffs several hundred feet thick was erupted. Coarse gravels accumulated in channels eroded into these tuffs to depths of about 100 feet, and in the southern margin of a trough produced by their downwarping to the north along an eastward trending axis. These gravels are interstratified with the Snake River basalt. The subsequent geologic history is one of erosion of the older rocks, and the formation of relatively small bodies of landslide debris, talus, glacial moraine, and alluvium.

At least five distinct units of rhyolitic and dacitic composition are being studied in detail in order to assess the distribution with time of uranium and other trace elements in the volcanic rocks of this area.

The following paper on work related to studies in the Jarbidge quadrangle was published during the period:

Coats, R. R., 1956, Distribution of uranium and certain other trace elements in felsic volcanic rocks of Cenozoic age of the western United States, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 248-251: New York, United Nations.

Boulder Batholith, Montana

By G. E. Becraft

Field work in the Boulder Batholith was completed during the preceding report period (see TEI-590, p. 222-223). The period covered by this report has been spent in writing the final reports on the Jefferson City quadrangle, the north half of the Clancy quadrangle, and the west half of the Boulder quadrangle. Work on the Boulder Batholith is scheduled for completion by June 30, 1956.

The following papers on the geology of the Boulder Batholith were published during the report period.

Becraft, G. E., 1955, Reconnaissance examination of the uranium deposits northeast of Winston, Broadwater County, Montana: U. S. Geol. Survey TEM-917, issued by Atomic Energy Comm. Tech. Info. Service, Oak Ridge, Tenn.

Becraft, G. E., 1955, New field classification of the quartz monzonite and granodiorite of the Boulder Batholith (abs.): Geol. Soc. America Bull., v. 66, p. 1642.

____________, 1956, Uranium deposits of the Boulder Batholith, Montana, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 270-274: New York, United Nations.

Klepper, M. R., and Robertson, Forbes, 1956, Late magmatic phenomena in the northern part of the Boulder Batholith, Montana: Econ. Geology, v. 51, no. 1, p. 117.

Pinckney, D. M., 1955, Preliminary studies of some of the ore deposits in the northern part of the Boulder Batholith, Montana (abs.): Geol. Soc. America Bull., v. 66, p. 1659.

Robertson, Forbes, Pinckney, D. M., and Klepper, M. R., 1956, Notes on sequence of vein formation in the northern part of the Boulder Batholith, Montana: Econ. Geology, v. 51, no. 1, p. 124-215.

Kern River area, California
By E. M. MacKevett

Isabella granodiorite, the most abundant intrusive rock in the Kern River area, is predominantly granodiorite but ranges in composition from quartz monzonite to quartz diorite. A small part of the area is underlain by metamorphic rocks of the Kernville series which consist chiefly of quartz-mica schist of the amphibolite facies (Turner and Verhoogen, 1951, p. 446). Granite pegmatites are abundant. Euxenite and allanite are sparsely disseminated in a few pegmatites, and are the only radioactive minerals identified to date from these pegmatites.

The principal uraniferous deposits are epigenetic and consist chiefly of secondary uranium minerals localized discontinuously along regional fractures that cut Isabella granodiorite. The deposits are chiefly open-space fillings that coat fracture surfaces or form pods or veinlets. Minor disseminations of secondary minerals are found locally in gouge or altered wall rock. Most deposits are small, ranging from mere mineral occurrences to a few tons of material generally of subore grade. Minor podlike concentrations of ore, ranging from two to three tons to about 30 tons, are known at widely separated sites along both the Miracle and Kergon shear zones. A paucity of common gangue minerals characterizes all uranium deposits, which are generally accompanied by argillic alteration and iron staining.

The deposits are of two types, black ore and autunite-rich ore. The fine-grained, bluish-black, black ore is mostly in the Kergon shear zone, where it forms pods generally surrounded by autunite-rich aureoles. The friable black ores consist of sooty pitchblende; secondary molybdenum minerals, ilsemannite and jordisite; carbonaceous(?) matter; unidentified iron minerals, probably largely limonite; minor fluorite; and local minor coatings of gypsum and opal. Staining attributed to the secondary molybdenum minerals imparts a characteristic blue-black color. Analyses with an X-ray spectrometer reveal that the black ores are rich in Fe and Mo, contain moderate quantities of U and As, and weak to trace amounts of Mn, Eu, Y and Cu(?). As yet the mineral hosts for arsenic and mangenese are undetermined.

The autunite-rich deposits which constitute most of the uraniferous deposits in the area are generally fine-grained, but in places autunite crystals as large as 1.5 mm across are developed in veinlets. The deposits consist of autunite, minor (as yet unidentified) flecks of a dark uranium(?) mineral, limonite, and opal. These deposits are commonly associated with gouge and altered granodiorite rick in clay minerals. Carnotite is probably a minor constituent of the deposits but as yet has not been identified. Chemically the autunite-rich deposits contain abundant Si, Al, Fe, Na, K, Ca, and Mg; weak to abundant U; traces to moderate amounts of As, V, Sr, Ti, and Ba; traces to weak amounts of Ga, P, Sb, B, and Mn; and traces of Rb, Y, Cd, Zr, Ni, Eu, and Ho.

All Isabella granodiorite samples that were analyzed chemically by the Geological Survey contain abnormal amounts of uranium ranging from 10 to 30 ppm, or as much as 10 times the uranium content of the average granitic rock, which is 3 or 4 ppm (Larsen and Phair, 1954, p. 77). The uranium is principally associated with accessory xenotime and zircon. In speculating on the origin of the uranium deposits it is tempting to consider the possibility that uranium, leached from Isabella granodiorite, was deposited in the fractures.

References

Larsen, E. S., Jr., and Phair, George, 1954, The distribution of uranium and thorium in igneous rocks, in Nuclear Geology, edited by Henry Faul: New York, John Wiley and Sons.

Turner, F. J., and Verhoogen, Jean, 1951, Igneous and metamorphic petrology: New York, McGraw-Hill Book Co.

Occurrence of uranium in veins and igneous rocks

By G. J. Neuerburg

Analyses of 442 samples essentially complete all the investigations planned on the leaching technique outlined in a previous semiannual report (TEI-540, p. 151). When these data have been completely evaluated, work will be carried out to complete studies on the adsorption of uranium by zeolites and to a search for the "ideal" leaching solvent—one that will quantitatively discriminate between uranium contained in rock mineral structures and that present in a rock as uranium minerals and otherwise situated outside of rock mineral structures, such as adsorbed ions.

The data accumulated to date provide few positive generalizations concerning the uranium content of igneous rocks as a whole. No meaningful correlations of uranium content, uranium leachability, rock leachability, or petrographic character with one another are yet apparent. Positive information relating to the data as a whole consists of a few miscellaneous items. As examples: volcanic ash contains proportionately less leachable uranium than any other common rock type. Very little uranium, as a rule, can be leached from igneous rocks without solution of appreciable rock material. This rock material is principally and most commonly those minerals, like apatite, that are likely to contain more uranium than the essential minerals of the rock.

Experiments to explore the point-to-point variation of uranium content show that mechanical splits of pairs of samples from apparently homogeneous outcrops have considerable differences in uranium content and leachability. Even more variation is found by taking several splits of the sample. This situation has led to testing the feasibility of using single small fragments of rock, weighing about 4 to 5 grams, as an entire sample for analysis, thus obviating the probable errors due to fractionation and materials lost in mechanical splitting of a larger sample. The small fragment samples of an igneous rock, apparently irrespective of grain size, show far less variation in uranium content and leachability within single outcrops or within hand specimens as do split samples. Furthermore, many of the variations that appear in sample pairs from seemingly homogeneous outcrops are within the precision of the uranium analyses.

Three attempts were made to explore possible relations of uranium content and leachability to depth. In each case the point-to-point fluctuations in uranium content and leachability, even at a single depth, exceeded changes possibly due to depth to such an extent that the changes cannot be detected. Similar results were obtained in an attempt to study the relation of uranium content to metamorphic rank in selected horizons in metamorphosed andesite and dacite pyroclastics.

The same problem of point-to-point variation plagued all attempts to explore the effects of weathering, even in a single partly weathered outcrop. However, some information regarding the effect of weathering on uranium content may be deduced from data on the leaching experiments. Ratios of uranium contents of total rock and of undissolved residue are mostly between 0.9 and 1.2. This means that, in general, sufficient rock is dissolved along with uranium to make the uranium concentration of the residue essentially the same as the unleached rock. This observation, if directly applicable to "natural leaching" (as part of weathering), accounts for the observed lack of significant differences in the uranium contents of fresh and weathered equivalents.

From these data, it is concluded (1) that uranium is mostly evenly distributed and contained in the insoluble bulk minerals of most igneous rocks, and (2) little if any quantitatively significant amounts of uranium are likely to exist in the form of "interstitial" uranium (adsorbed uranium ions and uranium minerals) in most igneous rocks.

Studies of the uranium content of igneous rocks formed in part by assimilation provide interesting data on the origin of uranium in some igneous rocks. Trachybasalts that may have originated in assimilation of granitic materials by basaltic magmas have uranium contents of 2 to 10 ppm, like most granites. In contrast to these, trachybasaltic facies of stocks satellitic to the Boulder Batholith uniformly contain about 0.5 ppm uranium. These rocks may have originated by assimilation of non-uraniferous dolomite by quartz monzonite. Thus, the content of uranium in assimilated rocks may exert more control on the uranium content of the igneous products than does the chemical and/or mineralogic nature of the original intrusive.

Experiments conducted on the Apache diabase of the Dripping Spring, Arizona uranium district have been most profitable and significant. The Apache diabase is a slightly differentiated rock, consisting of (1) chilled or aphanitic selvage (a sample of the magma?), (2) the bulk diabase making up the sills, and (3) pegmatitic and aplitic dikes and segregations, comprising no more than 5 percent of the volume of diabasic rocks. Some of the diabase sills have crystallized in structural environments permissive of the conclusion that they could have been open systems; a few other are in environments indicative of closed systems during crystallization.

In closed system intrusives, almost no rock differentiation is evident. The uranium content of such a body is essentially uniform throughout its exposure, with no evident contrast between diabase and chilled selvage. Further, as seems predictable from geochemical theory, the proportion of leachable uranium is generally highest in a closed system body.

In open systems, differentiation is commonly well developed, with appropriate variation in uranium content among the several differentiates. Chilled selvages contain about twice as much uranium as the bulk diabase. Felsic differentiates contain the highest uranium concentrations. Plots of uranium content against specific gravity, a fair measure of felsic character among these rocks, yield smooth curves. Uranium leachability decreases with specific gravity, as does rock leachability, in such a manner as to indicate that increasing amounts and proportions of uranium are bound in the structures of the more insoluble rock minerals. The relation between rock and uranium leachabilities indicates that little, if any, so-called "interstitial" uranium exists in these rocks, especially in the more felsic varieties.

To clarify the numerous meanings possible in the uranium contrast between chilled selvage and bulk diabase, a traverse was made across a diabase contact out into and along a single quartzite bed in the Dripping Spring formation. The results demonstrate that there was no movement of uranium across the contact or relative to it at this point; thus the uranium contents of the chilled selvages of these diabase bodies are probably original.

Using simple numerical averages of uranium content and rock density, assuming a volume of 5 percent for the differentiates, and assuming the uranium content of the chilled selvage to be that of the magma, it was calculated that about 1,000 metric tons of uranium metal were lost from each cubic kilometer of diabase during crystallization.

Copper, cobalt, and vanadium behave differently from uranium. Each decreases with differentiation toward the felsic end of the series; what little occurs in the felsic rocks is loosely attached in the case of copper and strongly fixed in insoluble minerals in the cases of cobalt and vanadium. The behavior of these elements in open and closed system intrusives is not clear. The chilled selvage samples from one sill show higher concentrations in copper and cobalt (vanadium has not yet been analyzed). The behavior of the three elements along the diabase-quartzite traverse referred to above is variable and indicative of considerable movement relative to the contact. Copper appears to have migrated to the contact as a structural site for deposition from both the diabase and the quartzite. Cobalt may have migrated out from the diabase for a short distance into the quartzite. Variations of vanadium content along the traverse are so erratic as to be virtually meaningless, but it seems probable that movement of vanadium is involved.

Assuming that it was possible to select those samples whose element content is primary, losses of copper and cobalt from the system in amounts on the order of 20,000-25,000 metric tons of metal per cubic kilometer of diabase are indicated, while a doubtful gain of 50,000-100,000 metric tons of vanadium from the quartzite is calculated. Further sampling under more precise geologic controls is planned to clarify this aspect of the study.

The amounts of cobalt, copper, and vanadium decrease along an exponential curve as uranium increases. Copper and cobalt decrease equally, while vanadium varies independently of cobalt and copper. Only copper and uranium appear to show an unquestionable systematic relation as regards leachability; the leachability of copper decreases along an exponential curve as uranium leachability increases. Systematic relations may exist among the other two elements, but the threshold of sensitivity for cobalt and vanadium is too close to the analytical results to resolve this.

The following papers on uranium in igneous rocks were published during the period:

Neuerburg, G. J., 1956, Deuteric alteration and its possible significance to wall-rock alteration in some rocks of the Boulder Batholith, Montana (abs.): Econ. Geology, v. 51, no. 1, p. 122-123.

_______________, 1956 Uranium in igneous rocks of the United States of America, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy—v. 6, Geology of uranium and thorium, p. 231-239: New York, United Nations.

Smith, W. L., and Flanagan, F. J., 1956, Use of statistical methods to detect radioactivity change due to weathering of a granite: Am. Jour. Science, v. 254, p. 316-324.

URANIUM IN CARBONACEOUS ROCKS

Lignite investigations

Regional synthesis—eastern Montana and North and South Dakota
By J. R. Gill and N. M. Denson

The host rocks containing higher grade uranium occurrences in the plains area of eastern Montana and the Dakotas are in the Fort Union formation of Paleocene age. The available data indicate that the intensity of mineralization is markedly influenced by shallow late Tertiary synclinal structures, permeability of the strata enclosing the host rocks, and the proximity of these rocks to the pre-Oligocene surface.

Late Tertiary structural control of uranium deposits at Slim Buttes, South Dakota

In the Slim Buttes area (fig. 41) several significant deposits of lignite containing 0.1 to 0.5 percent uranium occur in the Ludlow member of the Fort Union formation. There, the lignite-bearing rocks are overlain by Oligocene and Miocene tuffaceous rocks that dip to the east and exhibit a series of shallow, well defined folds which plunge to the southeast. Except for two small occurrences of ore-grade lignite at Flat Top Butte in the southwest corner of T. 17 N., R. 9 E. (TEI-590, p. 238), all the known deposits containing commercial quantities of uranium at Slim Buttes are in the troughs of shallow synclines, some of which have a relief of less than 15 feet. The small ore-grade occurrences near Flat Top Butte are associated with surficial faulting resulting from landslides developed in Oligocene rocks prior to the deposition of Miocene strata. These faults bear no relation to uranium mineralization other than forming possible barriers or avenues for ground water circulation.

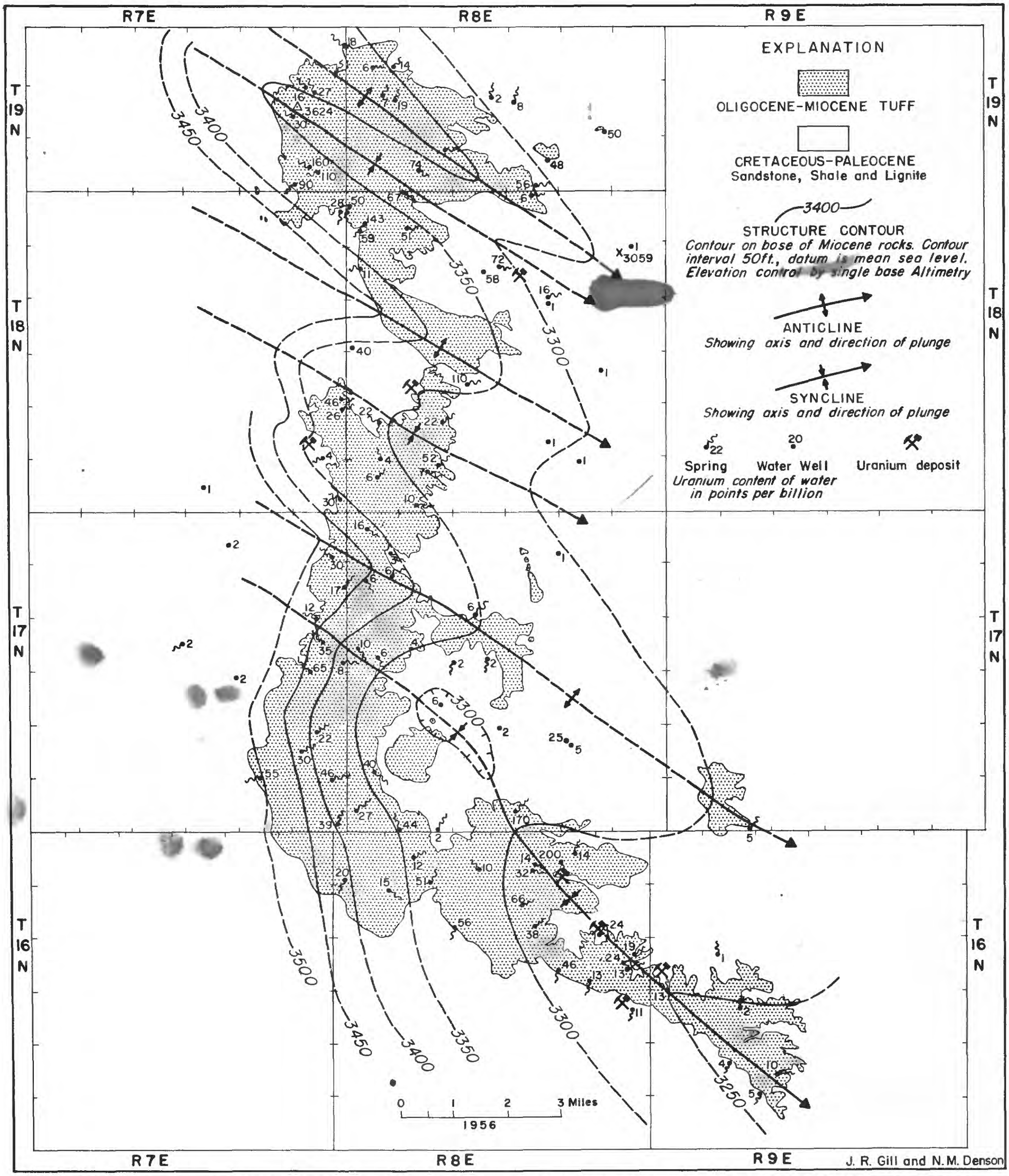


FIGURE 41 - PRELIMINARY MAP SHOWING RELATIONSHIP OF URANIUM DEPOSITS TO LATE TERTIARY STRUCTURE, SLIM BUTTES, HARDING COUNTY, SOUTH DAKOTA

Late Tertiary structures in the Little Badlands, North Dakota

In the Little Badlands of Stark County, North Dakota, the late Tertiary rocks have been folded into a well-defined arcuate series of anticlines and synclines similar to those at Slim Buttes. In the Little Badlands, however, the trends of the folds are to the northeast and normal to the major regional structure (fig. 42). No uranium deposits of commercial significance have been found as yet in the area, but uraniferous opal and carnotite in clay occur in the upper part of the Chadron formation in sec. 28, T. 138 N., R. 98 W., and a 0.6 foot bed of woody lignite containing 0.11 percent uranium occurs in sec. 31, T. 13 N., R. 97 W. (G. W. Moore, oral communication, 1954). As these occurrences have a structural and stratigraphic setting similar to the occurrences at Slim Buttes, it is possible that uranium deposits of commercial interest will be found in the area.

Geochemical investigations

In determining those elements that were introduced into the lignite at the time of uranium mineralization, two series of core samples from the Olesrud lignite at Slim Buttes were analyzed (fig. 43). A comparison of those elements detected by semiquantitative spectrographic methods in the lignite ash reveals that the uranium-bearing lignite contains appreciably greater amounts of arsenic, molybdenum, cobalt, iron, and nickel (core hole 18A) than does the lignite that is only slightly radioactive (core hole 36, TEI-440, p. 115-116). Little difference in the amounts of vanadium, lead, scanadium, aluminum, and silicon was detected except in the upper foot of the mineralized lignite where slightly greater amounts of these elements were found. It is possible that the lower amounts of calcium, sodium, magnesium, strontium, barium, and potassium in the mineralized lignite may be due to leaching during the period of pre-Oligocene erosion.

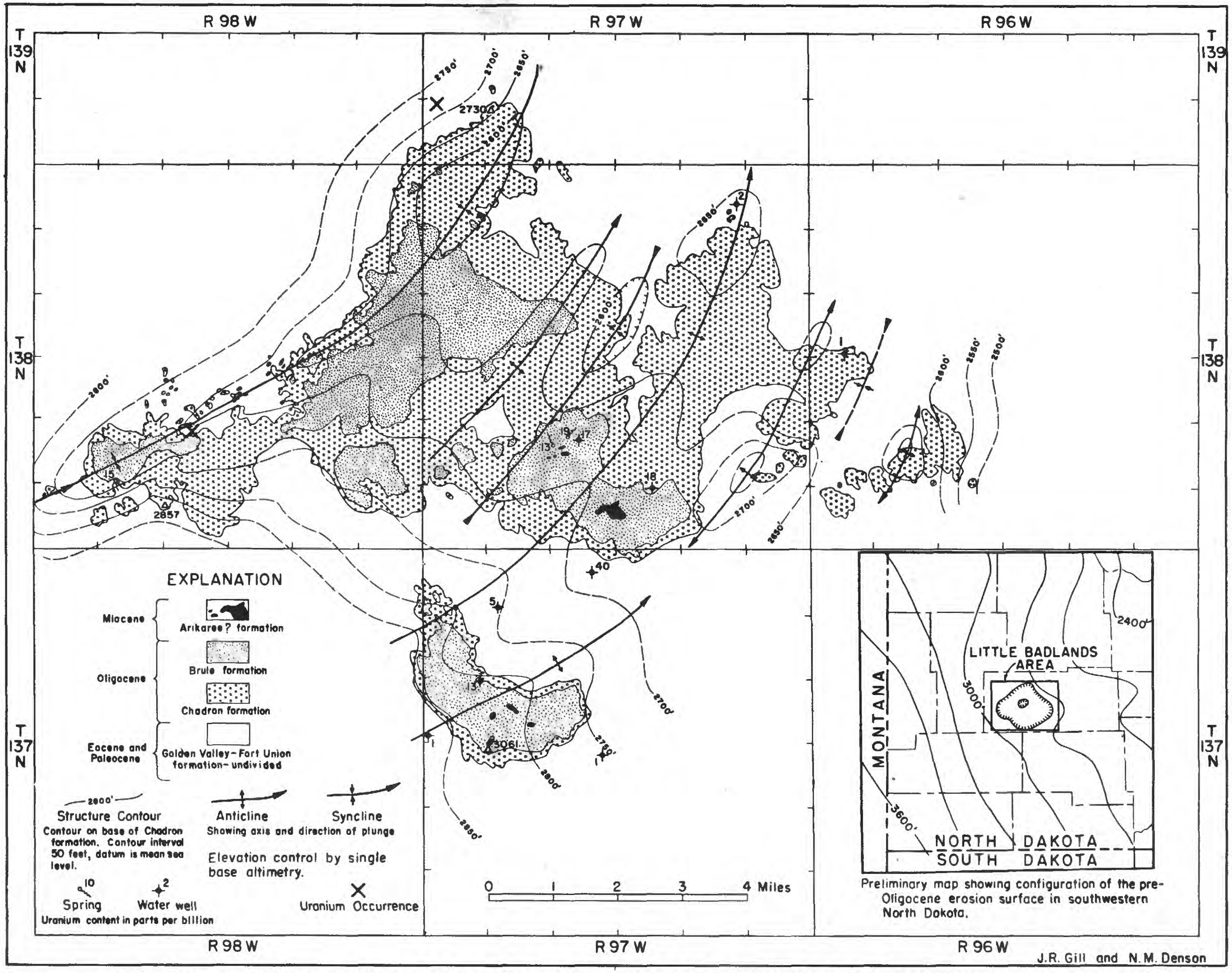


FIGURE 42 PRELIMINARY MAP SHOWING LATE TERTIARY STRUCTURE, LITTLE BADLANDS, STARK COUNTY, NORTH DAKOTA
1956

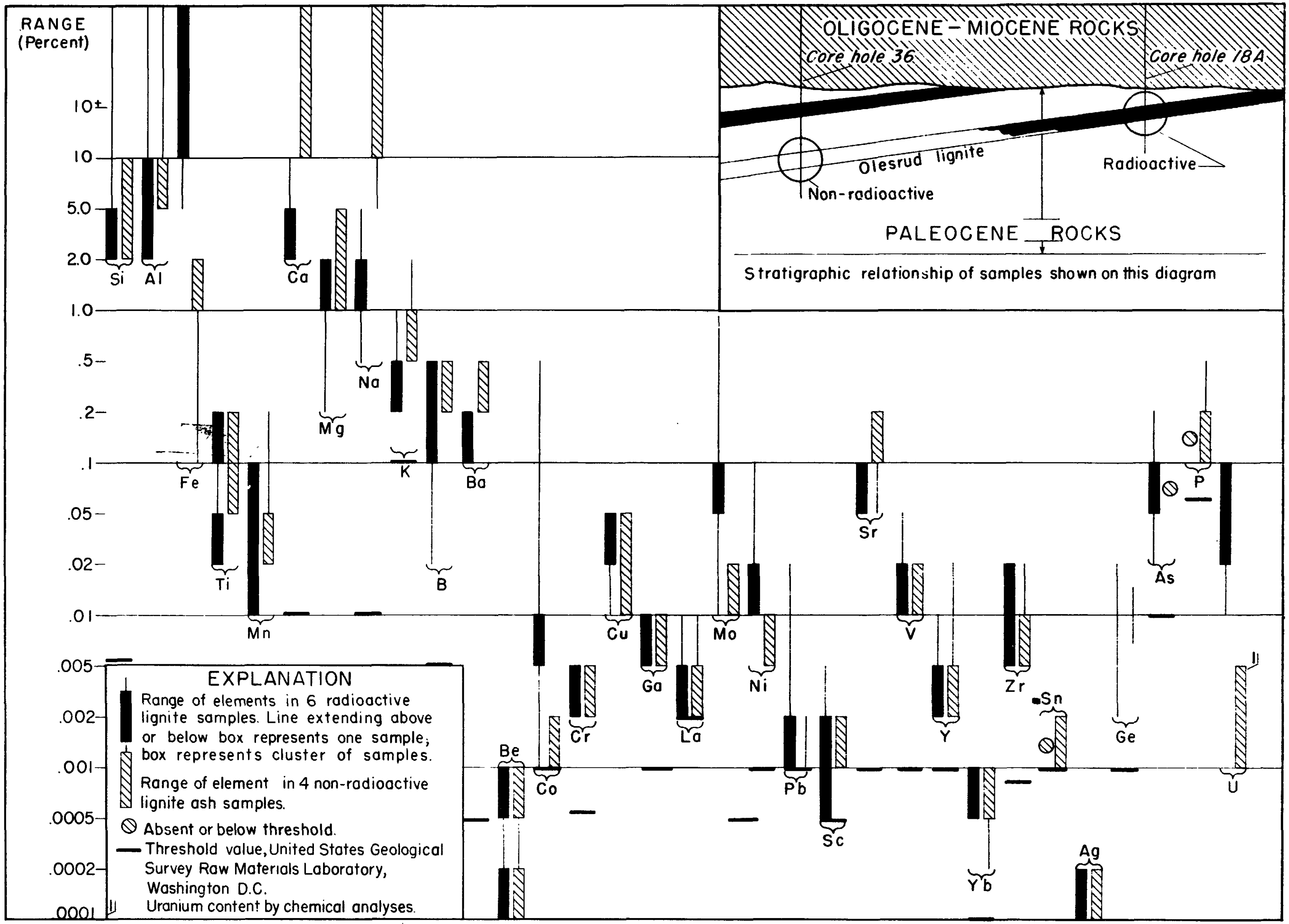


FIGURE 43—COMPARISON OF SEMIQUANTITATIVE SPECTROGRAPHIC ANALYSES OF RADIOACTIVE AND NON-RADIOACTIVE LIGNITE IN THE OLESRUD BED, SLIM BUTTES, HARDING CO., S. DAK.

More than 360 water samples have been collected in eastern Montana and the western Dakotas. All samples have been analyzed for uranium, and chemical and spectrographic determinations have been made for other elements in the residues of selected samples. Table 18 is a summary of analytical data for 322 samples showing the average uranium content of ground water from rocks of Cretaceous, Paleocene, Oligocene, and Miocene age. The localities sampled and the uranium content of 115 samples in the Slim Buttes and Little Badlands areas are shown in figures 41 and 42.

Table 18.--Summary of uranium analyses of water samples from eastern Montana and the Dakotas

Formation	Age	No. of samples analyzed	Average U content (ppb)	pH
Arikaree	Miocene	106	26	8.6
Brule, Chadron	Oligocene	61	16	8.2
Fort Union	Paleocene	123	4	8.2
Hell Creek	Cretaceous	32	3	8.1
	Total	322		

A list of 42 localities from which water samples not included in table 18 have anomalously high uranium contents is shown in table 19. Many of these samples are from localities where uranium deposits have not yet been discovered.

The composition of water from late Tertiary and Cretaceous rocks in the plains region of eastern Montana and the Dakotas as indicated by chemical and spectrographic analyses of their residues is shown in figure 44. Ground waters from the Cretaceous rocks contain about three times as much dissolved solids as those from the late Tertiary tuffaceous rocks, but water from the tuffs contains greater amounts of uranium, vanadium, arsenic, and molybdenum. The greater concentrations of these elements in radioactive lignite (fig. 43)

Table 19 Localities in eastern Montana and the Dakotas where water samples from the Upper Cretaceous Hell Creek and Paleocene Fort Union formations show anomalously high contents of uranium.

Serial no.	1/4 Sec.	Sec.	Location T.	R.	County	Source 1/	U(ppb)
				SOUTH DAKOTA			
232858	SE	22	16N	2E	Harding	W	42*
D-95070	SW	12	16N	8E	Harding	Sp	24
232851	SW	23	17N	2E	Harding	Sp	20*
232448	NE	35	17N	2E	Harding	W	660*
232449	NE	35	17N	2E	Harding	W	89*
D-95051	NW	26	17N	8E	Harding	W	25*
235058	SW	6	18N	8E	Harding	Sp	59
D-87596	C	9	18N	8E	Harding	W	58
210741	NE	9	18N	8E	Harding	Sp	72
D-93139	SW	18	18N	8E	Harding	W	40
D-95056	SW	21	18N	8E	Harding	Sp	110
217616	NW	4	21N	5E	Harding	St	26
231954	NE	19	21N	5E	Harding	W	31*
233526	NW	8	22N	4E	Harding	Sp	50
233522	NE	20	22N	5E	Harding	Sp	32
231948	NE	22	22N	5E	Harding	Sp	27
231950	NE	22	22N	5E	Harding	Sp	27
231951	NE	22	22N	5E	Harding	Sp	70
233529	SW	23	22N	5E	Harding	Sp	34
231957	SW	23	22N	5E	Harding	Sp	20
231956	NW	26	22N	5E	Harding	Sp	290
236926	NW	26	22N	5E	Harding	Sp	128
234973	SW	34	22N	5E	Harding	R	124
234976	SE	34	22N	5E	Harding	R	28
236923	NW	36	22N	5E	Harding	Sp	22
216361	SE	12	21N	11E	Perkins	Sp	83
216363	SW	15	21N	12E	Perkins	Sp	83
216364	NE	15	21N	12E	Perkins	St	38
216369	NW	20	22N	9E	Perkins	Sp	22
216373	NE	33	22N	12E	Perkins	W	38
				NORTH DAKOTA			
221934	SW	23	130N	97W	Adams	W	31
221914	SW	9	136N	93W	Hettinger	Sp	28
D-98159	SE	1	133N	101W	Slope	Sp	27
D-98158	C	10	134N	101W	Slope	Sp	54
D-98156	NW	28	134N	101W	Slope	Sp	37
D-98153	NE	30	134N	101W	Slope	Sp	55
D-98161	NW	31	134N	101W	Slope	Sp	29
D-98162	NE	34	134N	101W	Slope	Sp	27
236655	NE	4	137N	97W	Stark	W	40
				MONTANA			
217906	NW	28	1S	57E	Carter	Sp	21
221931	SE	4	2S	62E	Carter	Sp	30
217629	NE	14	1N	60E	Carter	W	95*

1/ Sp - Spring; W - Well; St - Stream; R - Reservoir or Pool.

* Sample is from Hell Creek formation; others are from Fort Union formation.

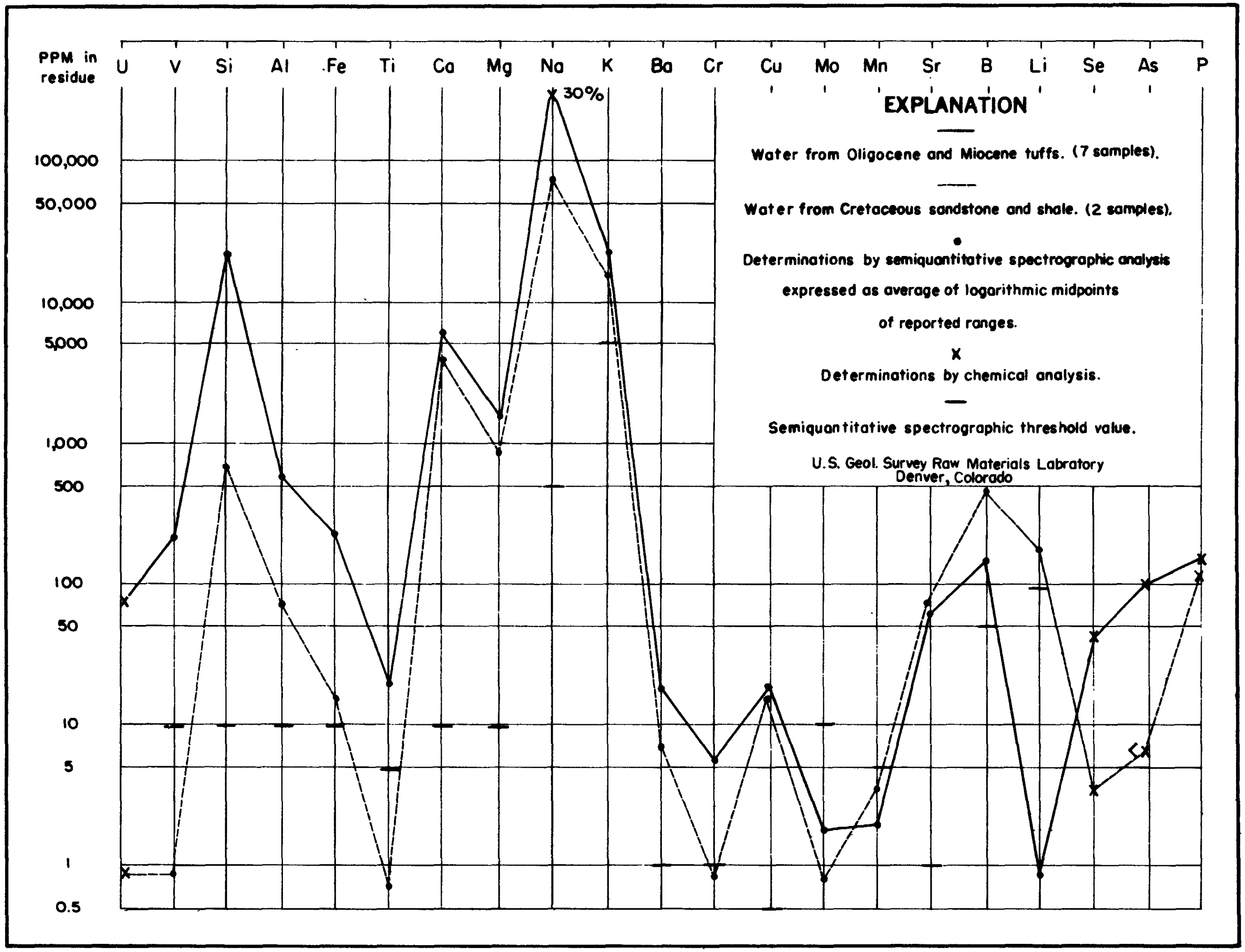


FIGURE 44.-DIAGRAM SHOWING COMPOSITION OF WATER RESIDUES FROM LATE TERTIARY AND CRETACEOUS ROCKS IN EASTERN MONTANA AND THE DAKOTAS.

suggests that they may have been derived from these tuffaceous rocks.

Chemical analyses of the probable source rocks of the Arikaree, Chadron, and Brule formations from eastern Montana and the Dakotas and similar analyses of sandstones from the underlying formation are shown in table 20.

The following publications on the uraniferous lignites of the Dakotas and eastern Montana were released during the period:

Denson, N. M., and Gill, J. R., 1956, Uranium-bearing lignite and its relation to volcanic tuffs in eastern Montana and the Dakotas, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 464-467: New York, United Nations.

Moore, G. W., Melin, R. E., and Kepferle, R. C., 1956, Preliminary geologic map of the Chalky Buttes area, Slope County, South Dakota: U. S. Geol. Survey Coal Investigations Map C-38.

Cave Hills, Harding County, South Dakota

By R. C. Kepferle and W. A. Chisholm

Riley Pass area

Results of core-drilling in the Riley Pass area indicate that the uranium-bearing E lignite bed is most strongly mineralized along structural troughs even though the local structural relief is only 10 feet. Inasmuch as the E bed is not present in much of the main structural basin of the North Cave Hills, perhaps other major deposits stratigraphically below the E bed may lie as much as 200 feet below the surface in the center of this basin.

The results of uranium and ash analyses for about 300 channel samples of the E lignite bed are shown in part in figure 45. In these samples, the uranium content of the lignite has no apparent relation to the ash content. Elements which tend to increase with an increase in uranium content include molybdenum, arsenic, scandium, and zirconium, phosphorus and sulfur. Selenium

Table 20.—Chemical analyses of representative samples from Paleocene, Oligocene, and Miocene rocks from eastern Montana and the Dakotas

Epoch	Formation	Sample	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	H_2O	CO_2
MIOCENE	Arikaree formation	Tuffaceous sandstone 375 feet above base Long Pine Hills Carter Co., Mont.	73.5	11.5	2.0	0.30	1.3	2.2	1.8	3.2	0.40	0.10	0.04	4.2	0.08
MIOCENE	Arikaree formation	Tuffaceous sandstone 276 feet above base Chalk Buttes Carter Co., Mont.	60.6	9.2	1.1	0.12	0.83	13.9	2.1	2.0	0.18	0.10	0.06	1.2	9.5
MIOCENE	Arikaree formation	Tuffaceous sandstone 62 feet above base Slim Buttes Harding Co., S. Dak.	63.7	12.2	2.4	0.24	2.3	3.6	2.5	3.2	0.39	0.08	0.08	6.7	2.4
OLIGOCENE	Brule fm.	Tuffaceous siltstone Little Badlands Stark Co., N. Dak.	37.7	8.4	2.9	0.17	1.8	22.5	1.3	1.6	0.34	0.18	0.20	5.3	17.0
OLIGOCENE	Chadron formation	Silicified claystone Little Badlands Stark Co., N. Dak.	79.2	8.6	2.9	0.13	0.40	0.58	0.09	0.36	0.64	0.03	0.01	6.8	0.06
OLIGOCENE	Chadron formation	Bentonite Slim Buttes Harding Co., S. Dak.	56.6	15.7	5.7	0.15	3.0	1.5	1.1	2.7	0.50	0.06	0.01	12.2	0.82
OLIGOCENE	Chadron formation	Basal arkosic sandstone, Slim Buttes Harding Co., S. Dak.	75.2	10.1	0.77	0.04	1.7	2.0	1.7	3.2	0.24	0.05	0.02	3.0	2.1
PALEOCENE	Ft. Union fm.	Sandstone Sentinel Butte, Golden Valley Co., N.Dak.	73.1	12.5	0.61	0.10	0.22	1.6	4.1	3.0	0.42	0.06	0.01	3.6	1.2
PALEOCENE	Ft. Union fm.	Sandstone Slim Buttes Harding Co., S. Dak.	76.5	11.8	2.0	0.20	0.86	0.48	1.5	3.1	0.44	0.12	0.02	3.1	<0.05

Analysts: Samuel D. Botts, Paul L. D. Elmore, and Katrine E. White, U. S. Geol. Survey Laboratory, Beltsville, Maryland.

Laboratory Nos.: 147, 773; 147, 765; 144, 501; 147, 761; 147, 762; 147, 769; 147, 770; 147, 763; 144, 508; respectively.

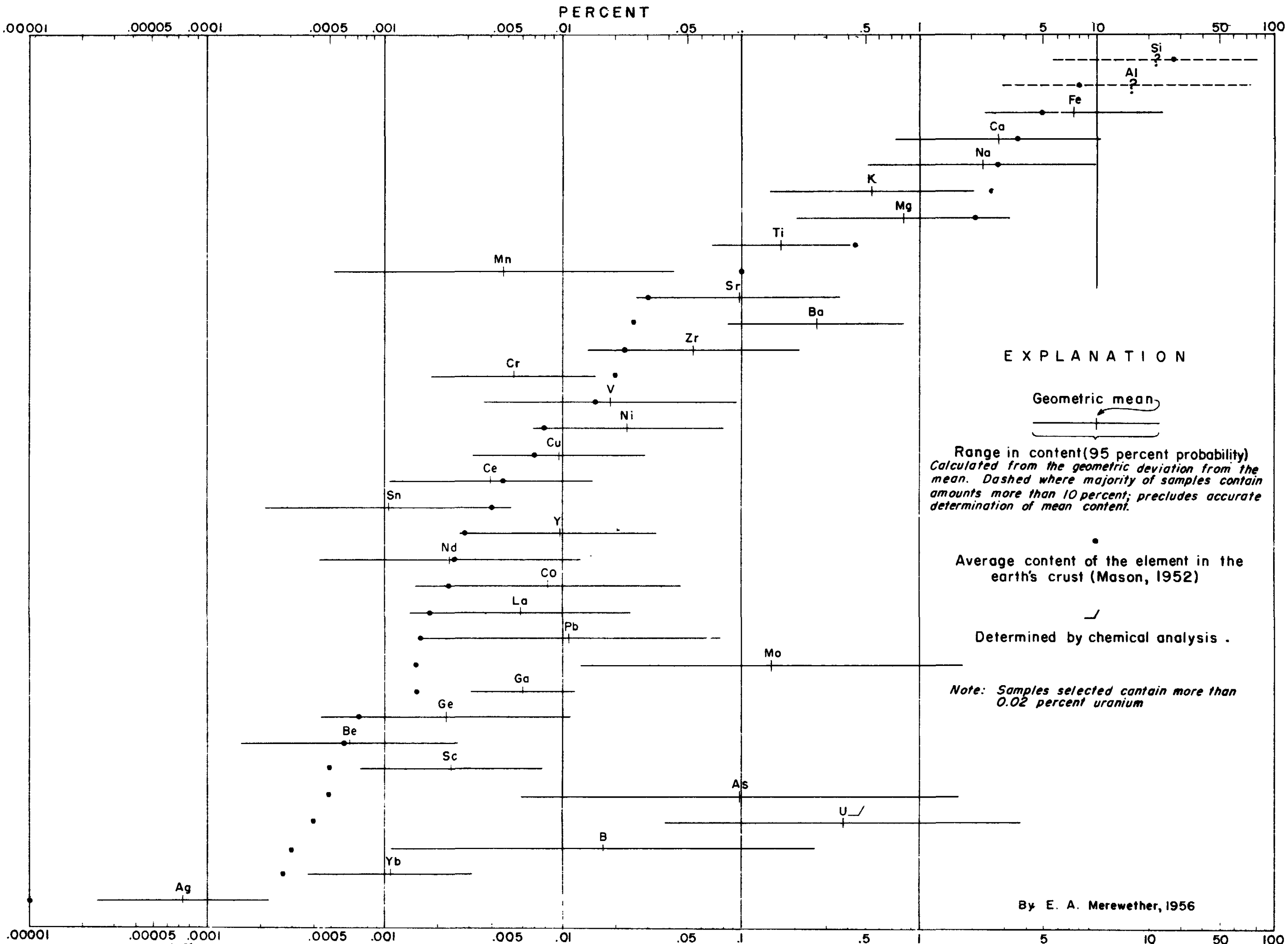


FIGURE 45-DIAGRAM SHOWING CONCENTRATION RANGE AND MEAN OF ELEMENTS DETECTED BY SEMIQUANTITATIVE SPECTROGRAPHIC ANALYSIS OF 96 SAMPLES OF LIGNITE ASH, NORTH CAVE HILLS, HARDING COUNTY, SOUTH DAKOTA

shows a tendency to decrease with an increase in uranium content as shown by the following analyses of a channel through the E lignite bed on the Relf claims in the Riley Pass area (analysts: Angelo, Cox, Wahlberg, Wilson, Schuch, Goss, and Burrow).

Laboratory number	Feet above base	% eU	% U	% Ash	% P_2O_5	% S	% As	ppm Se
237048	0.8-1.0	0.8	2.76	52.1	1.11	1.09	1.32	50
237049	0.5-0.8	0.54	0.67	34.5	0.26	0.59	0.34	250
237050	0.25-0.5	0.12	0.22	32.1	0.076	0.31	0.031	500
237051	base-0.25	0.037	0.046	36.6	0.092	0.26	0.071	500

The U/eU ratio of most of the samples collected from the Riley Pass area averages between 1.5:1 and 2:1, 3:1 generally being the maximum.

The secondary uranium minerals metanovacekite (Mg-U-arsenate) and saleeite, metazeunterite, metatorbernite, and meta-autunite (Mg-U-phosphate) have been identified from the lignite in the Cave Hills-Slim Buttes area. The weathered near-surface state of most of the samples probably precludes the preservation of any primary uranium minerals, though uraninite was recently identified by J. W. Gruner (written communication, 1956) from a core of lignite.

An autoradiograph of a sample of the E lignite containing no visible uranium mineral shows a concentration of radioactivity as a rim around a marcasite-pyrite concretion. This rim appears denser than the previtrain in the lignite and is jet black with a vitreous luster, in contrast to the dull grayish- to brownish-black, more porous nature of the less radioactive part.

Carbonate prospect

Cross-sections of the sampled faces of two pits at the Carbonate prospect in the South Cave Hills show that the uranium is closely related to clastic dikes which transect the carbonaceous mudstone (see fig. 46). The uranium content within two pits ranges from 0.002 to 0.9 percent, and averages about 0.02 percent. A visible secondary fluorescent uranium mineral, probably

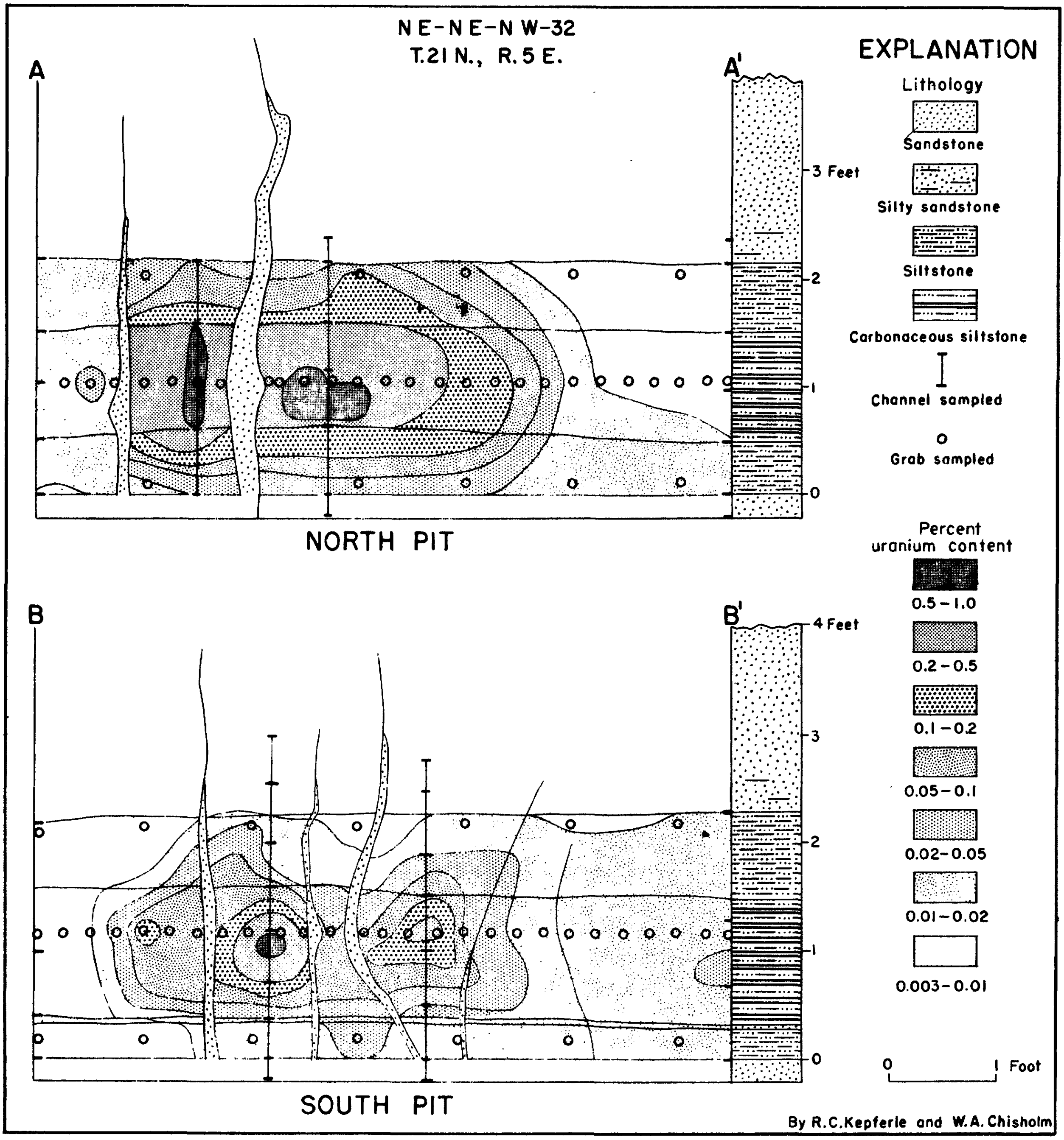


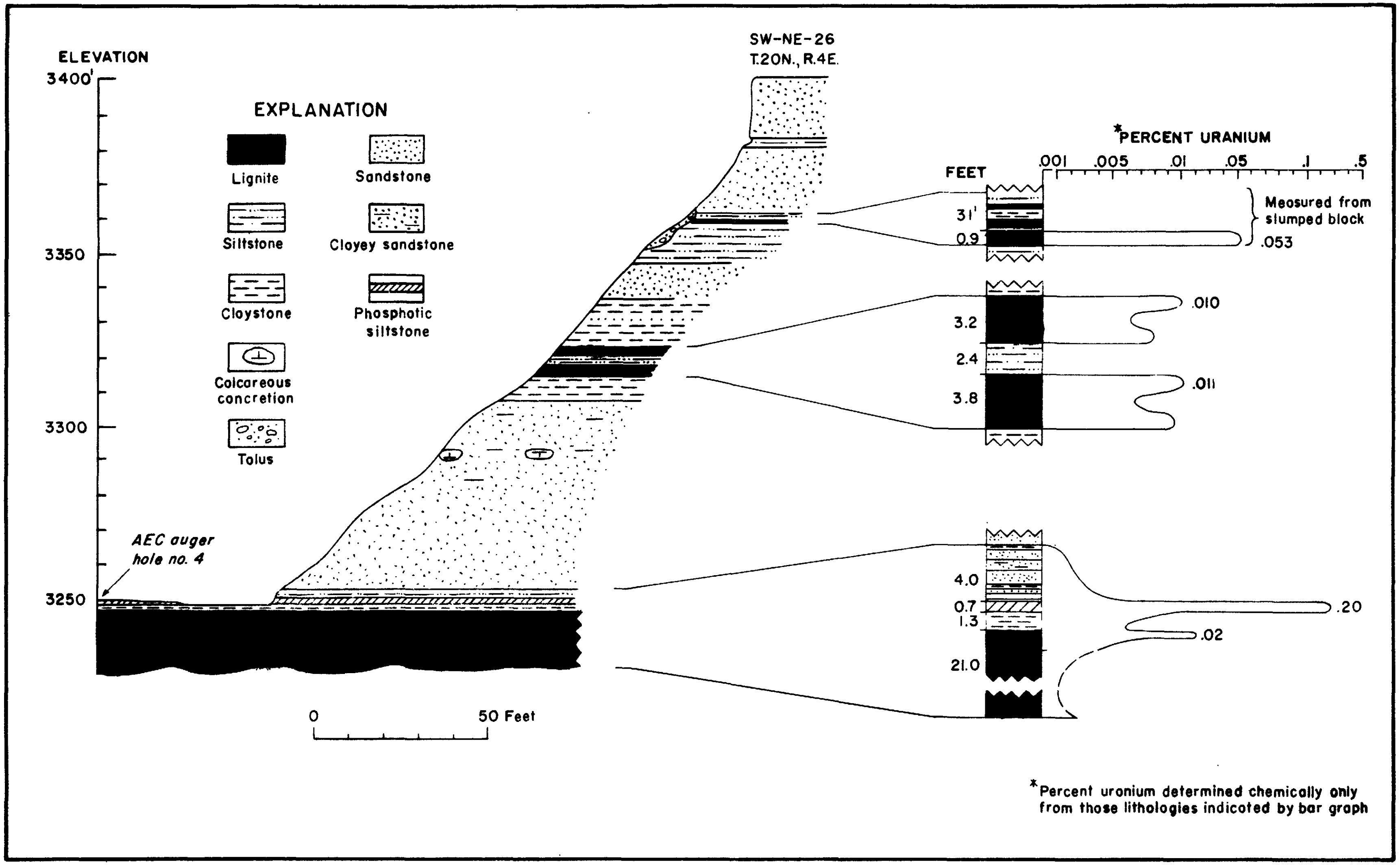
FIGURE 46.—SECTIONS SHOWING RELATION BETWEEN CLASTIC DIKES AND URANIUM CONTENT AT THE CARBONATE PROSPECT, SOUTH CAVE HILLS, HARDING COUNTY, SOUTH DAKOTA

metazeunerite or metatorbernite, occurs in the areas of highest uranium content. A positive correlation between uranium and molybdenum, arsenic, iron, and, to a lesser degree, vanadium is indicated. A pattern unrelated to uranium is shown by selenium. The ash content of the carbonaceous mudstone in the two pits ranges from about 65 to 95 percent and averages about 85 percent. The areas of lowest ash and highest carbon content coincide with the areas of highest uranium content. The proximity of these areas to the major dikes indicates that these areas were zones of weakness which parted during stresses created by loss of water and differential compaction after deposition. The resulting fractures were intruded by sand and subsequently served as avenues for laterally migrating uranium-bearing water.

Lonesome Pete mine

The ore in the Lonesome Pete mine in the South Cave Hills contains as much as 0.6 percent uranium and 16 percent P_2O_5, and averages about 0.1 percent uranium and 1.4 percent P_2O_5. The bed is gray to brownish-black and ranges from 0.3 to 1.0 feet thick. Darker samples generally contain the most uranium. The U/eU ratio in the phosphatic mudstone is about 1:1. The stratigraphic position of this mudstone is shown in a cross-section (fig. 47). Seventy chemical analyses show a strong parallel between the contents of U and P_2O_5 (fig. 48), the correlation coefficient between the two being about +0.93.

The correlation coefficient, a measure of geochemical coherence between two elements in a rock (Rankama and Sahama, 1949, p. 48), is expressed as +1 when there is a direct proportion between the occurrence of two elements and as a -1 when there is an inverse proportion. A value near zero indicates little or no relation between the abundance of two elements.



by W. A. Chisholm and R. C. Kepferle, 1956

FIGURE 47—COMPOSITE CROSS SECTION SHOWING RELATIONSHIP BETWEEN URANIUM CONTENT OF PHOSPHATIC MUDSTONE AND LIGNITE BEDS, LONESOME PETE MINE, HARDING COUNTY, SOUTH DAKOTA

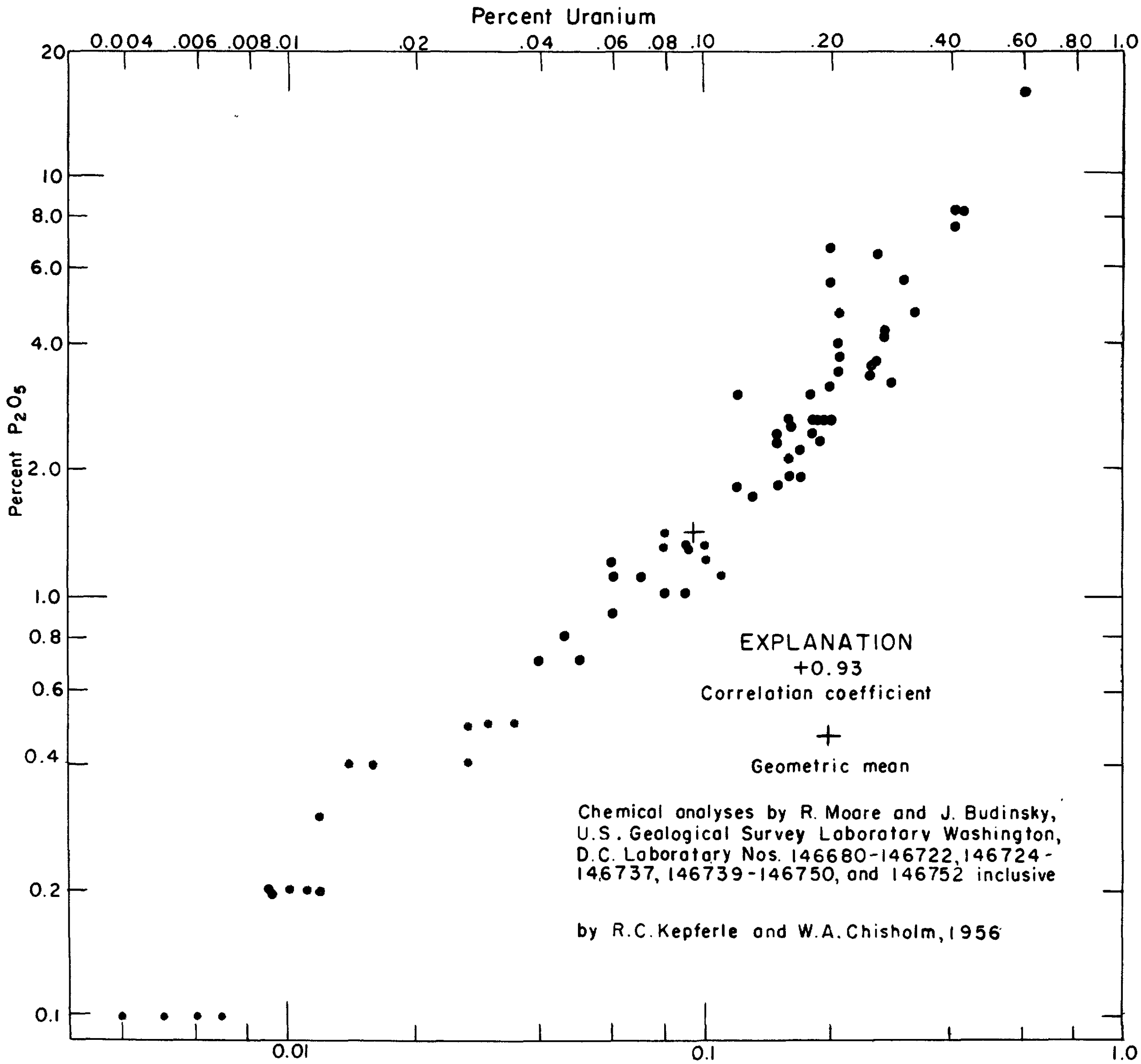


FIGURE 48-DIAGRAM SHOWING CORRELATION BETWEEN URANIUM AND PHOSPHATE CONTENT IN 70 SAMPLES OF MUDSTONE, LONESOME PETE MINE SOUTH CAVE HILLS, SOUTH DAKOTA.

The results of 50 semiquantitative spectrographic analyses of channel samples taken on 25 foot centers are shown in figure 49. Statistical study of these samples shows that the uranium has a strong correlation with calcium ($r = +0.75$), strontium ($r = +0.78$), and molybdenum ($r = +0.56$), and a weak negative correlation with iron ($r = -0.25$).

Chemical studies show that the major part of the uranium is held in the carbonate fluorapatite which contains calcium, fluorine, carbonate, and phosphate. The fact that phosphate increases with uranium in a ratio generally between 30:1 and 10:1 leads to the suggestion that in this particular bed the carbonate fluorapatite locally has adsorbed nearly the maximum uranium permitted by its molecular structure where, according to Neuman and others (1949) UO_2^{+2} replaces a Ca^{+2} ion. Other mineral constituents of the mudstone include quartz, dolomite, muscovite, and mixed layer clays composed of montmorillonite and illite.

The occurrence of dolomite and apatite in the phosphatic mudstone, with shark teeth and a vertebra in associated rocks, indicates that the mudstone was deposited in marine or coastal brackish water. This unit probably represents a westward-reaching tongue of the marine Cannonball formation.

At least three other occurrences of uranium in a phosphatic unit believed to be the stratigraphic equivalent to the one at the Lonesome Pete mine have been reported from widely separated points around the South Cave Hills, indicating that this or similar beds may be fairly widespread, and may constitute an extensive potential host rock for uranium.

Petrographic studies

In an attempt to relate various ore-bearing horizons, five lithologic sections were measured in the North and South Cave Hills. Heavy mineral separates of sandstone samples from these sections, several core holes, and

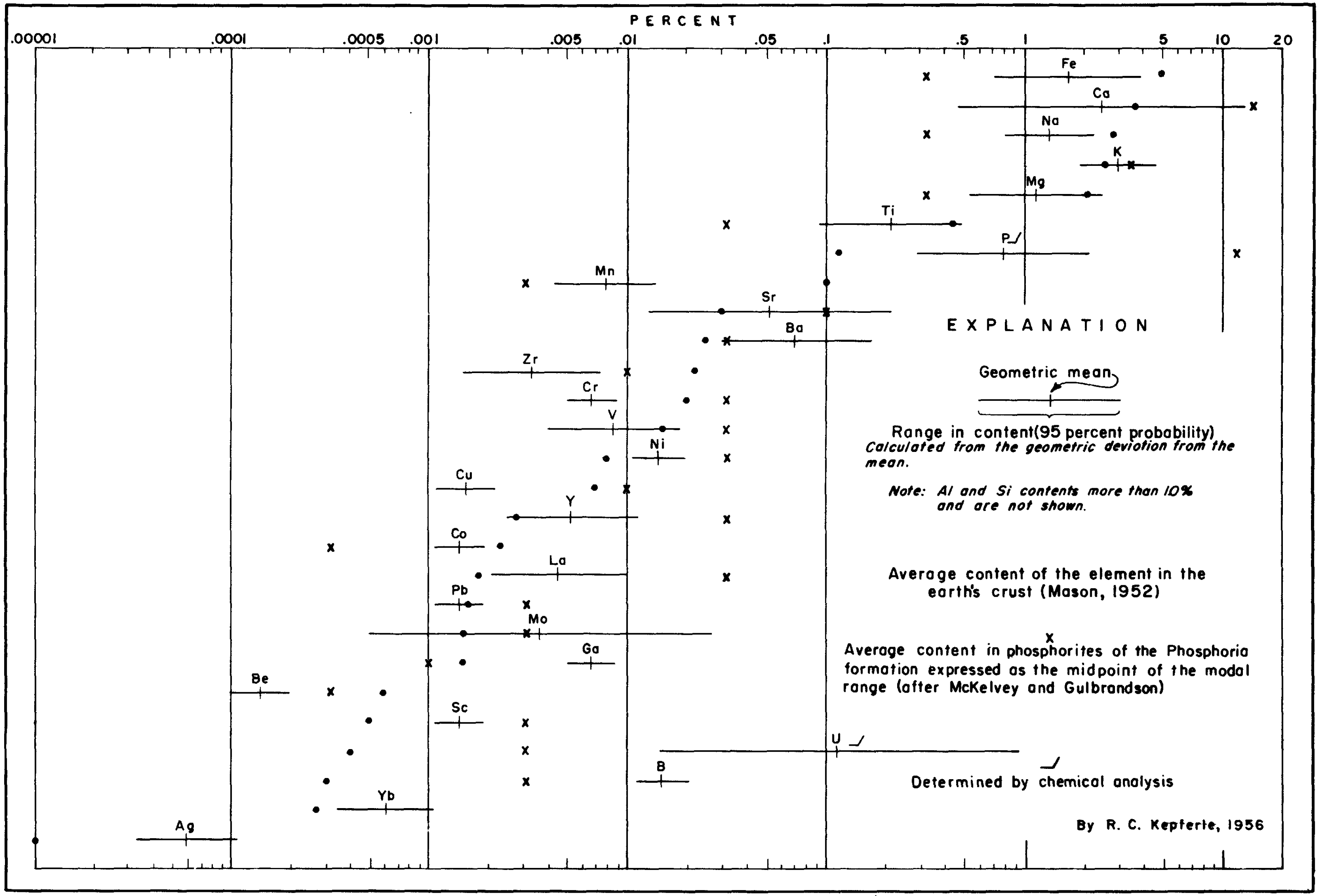


FIGURE 49 -DIAGRAM SHOWING CONCENTRATION RANGE AND MEAN OF ELEMENTS DETECTED BY SEMIQUANTITATIVE SPECTROGRAPHIC ANALYSIS OF 50 SAMPLES OF PHOSPHATIC MUDSTONE, LONESOME PETE MINE, SOUTH CAVE HILLS, HARDING COUNTY, SOUTH DAKOTA

a few additional surface outcrops were studied petrographically. The results of this preliminary study, shown in table 21, indicate that the heavy mineral assemblages change from one formation to another. A particular change occurs at the base of the Tongue River member where an increase in the amount of andalusite, staurolite, and kyanite indicates a change in the source of the sediments. The study also indicates that in the Cave Hills area the White River basal conglomerate is not derived from local reworking of the Fort Union sediments.

Origin of uranium

The immediate source of uranium in all the deposits studied appears to be from laterally migrating ground water. From overall field evidence, especially the higher uranium content of the uppermost receptor beds than of those farther down, the ultimate source of uranium is believed to be the devitrification of tuffaceous rocks in the overlying Oligocene and Miocene rocks, small remnants of which are present in the area. Uppermost receptor beds which do not contain higher amounts of uranium than those farther down generally are enclosed by less permeable rocks.

References

Neuman, W. F., Neuman, E. R., Main, E. R., and Mulryan, B. J., 1949, The deposits of uranium in bone V--Ion exchange studies: Jour. Biol. Chemistry, v. 179, p. 335-340.

Rankama, Kalervo, and Sahama, Th. G., 1949, Geochemistry: New York, John Wiley and Sons.

Table 21. --Percentages of heavy minerals in rocks exposed in the Cave Hills area, Harding County, South Dakota.

System	Series	Formation and Member	Thickness in feet	Interval studied	Garnet	Zircon	Hornblende	Corundum	Tourmaline	Sphene	Rutile	Sillimanite	Biotite	Staurolite	Kyanite	Chlorite	Epidote	Clinozoisite	Zoisite	Andalusite	Brookite	Anatase	Apatite	No. of samples averaged
TERTIARY	Oligocene	Chadron formation	60+	Conglomerate in basal 10 feet	5	16	*	-	13	1	3	-	1	28	14	*	6	1	*	11	-	-	-	9
			unconformity																					
	Paleocene	Fort Union formation, Tongue River member	200+	135-190 feet above base	24	33	*	-	17	2	2	-	1	5	1	-	4	1	*	8	-	-	-	12
				100-116 feet above base	45	11	*	*	8	3	*	-	9	5	1	*	4	2	*	11	-	-	-	12
				90-100 feet above base	46	10	*	-	8	3	1	-	6	2	*	*	10	2	1	10	*	-	*	5
				Basal 40 feet	48	12	-	-	4	-	1	-	2	1	*	1	21	4	1	4	-	-	-	6
		Fort Union formation, Ludlow member	350	10-330 feet below top	60	4	1	-	6	2	*	-	9	*	-	5	8	2	1	1	-	-	-	12
CRETACEOUS	Upper Cretaceous	Hell Creek formation	425	Upper 150 feet	13	8	5	-	10	1	2	*	3	*	-	3	46	5	1	2	*	-	-	2

* less than 1 percent
\- not detected

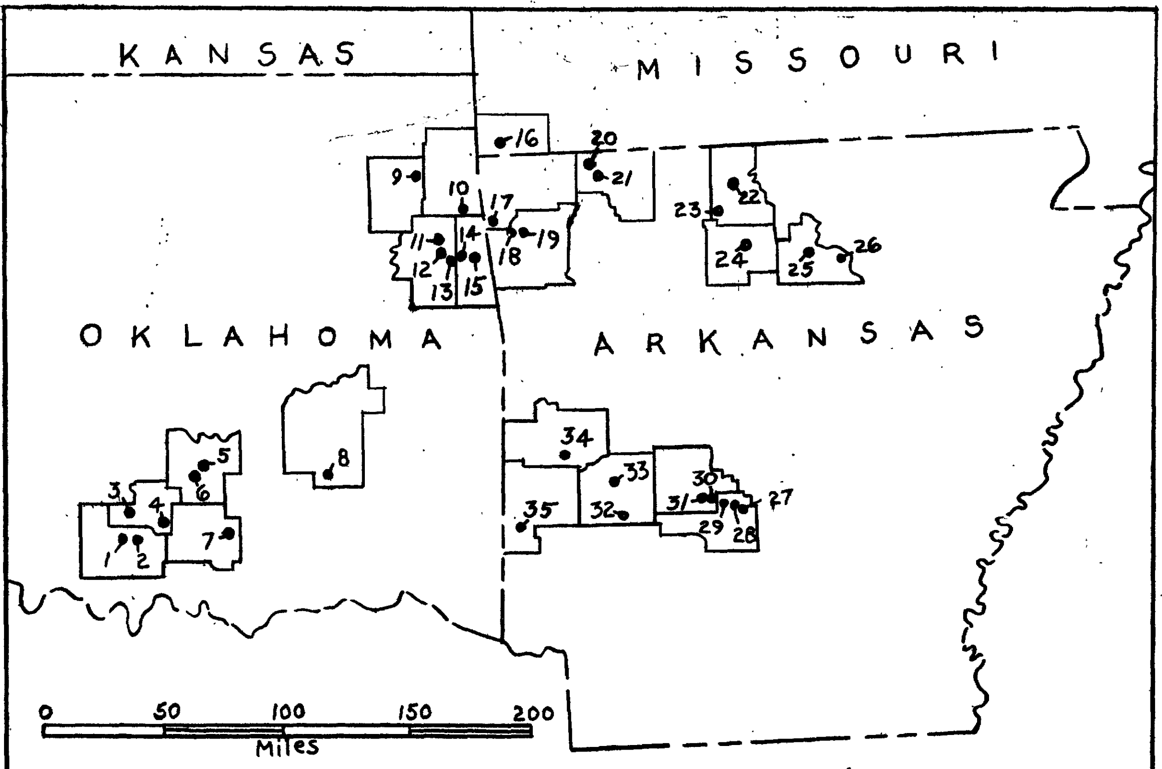
By Wayne Chisholm, 1956

Carbonaceous rock investigations

Midcontinent Devonian and Mississippian shales
By E. R. Landis

During the report period analyses of 204 samples collected from outcrops of black shale of Devonian and Early Mississippian age in eastern Oklahoma and northern and western Arkansas were evaluated.

Figure 50 shows the localities at which samples were collected. Rock units sampled are shale and chert of the Woodford, and the Sycamore limestone in southern Oklahoma; the Chattanooga and Fayetteville shales of northeastern Oklahoma and northern Arkansas; and the Arkansas novaculite, Stanley shale and Caney shale of west-central Arkansas. The Woodford, which ranges from 65 to more than 500 feet in thickness, is mainly of Late Devonian age but the uppermost part in the outcrop area is of Early Mississippian (Kinderhook) age. It consists mainly of black to dark gray shale with varying amounts of black to gray chert and gray phosphatic nodules. The Sycamore limestone of Mississippian age overlies the Woodford and at locality 4 (fig. 50), is only about 6 feet thick and consists of silty light gray limestone and soft, glauconitic, light gray clay shale containing gray phosphatic nodules. The Chattanooga shale, which is composed of fissile black to dark gray shale, is of Late Devonian and Early Mississippian age and ranges up to 60 feet in thickness but is absent in some areas due to nondeposition or post-depositional erosion. The Sylamore sandstone member of the Chattanooga shale is the basal unit of the Chattanooga in most places in the report area but is the only part of the Chattanooga present in parts of northern Arkansas. It is a light gray to tan, fine to medium grained, in places bituminous, sandstone that commonly contains black, rounded, phosphatic nodules from fine sand to pebble size. At



Maximum uranium content, in percent, of black shale and of phosphatic materials (shown in parentheses)

Woodford shale

Loc. 1-.003 (.008)
2-.008 (.0069)
3-.008
5-.002
6-.008
7-(.0127)
8-(.007)

Sycamore limestone

Loc. 4-(.0058)

Caney shale

Loc. 34- .004

Chattanooga shale

Loc. 9-.002
10-.004
11-.007(.013)*
12-.006
13-.001(<.001)
14-.003
15-.002
16-.002
17-.004
18-.001
19-.003 (.004)*
20-.004
21-.001
22-.55*
-.006*
23-.009*
25-.004*(.007)*
26-.007
*Sylamore ss. member

Arkansas novaculite

Loc. 27-.002
28-.002
30-<.001
31-.027
32-.004
33-.001
35-.001

Stanley shale

Loc. 29-.001
30-<.001

Fayetteville shale

Loc. 24-.001

Figure 50. Map of Midcontinent sample localities, Devonian and Mississippian black shales, indicating maximum uranium content at each.

a few localities in northern Arkansas (loc. 22, 23, and 25, fig. 50) thin black shale lenses are present in the Sylamore. The Arkansas novaculite, of Late Devonian and Early Mississippian age, is generally separable into three well-defined units; the upper and lower divisions composed predominantly of light gray to dark gray novaculite with some very thin shale beds, and the middle division composed predominantly of black to gray shales with subordinate amounts of novaculite. The Devonian-Mississippian time boundary falls within the middle division. The Fayetteville and Caney shales of Mississippian age, and the Stanley shale of Mississippian and Pennsylvanian age, all composed of black to dark gray shale, were examined and sampled at only a few localities.

A summarization of analyses giving the maximum uranium content of samples collected at the localities is shown on figure 50. At locality 22 in Marion County, Arkansas, a black shale bed 1.3 feet thick contains 0.006 percent uranium but a selected sample 1 inch thick contains 0.55 percent uranium. The uranium is intimately associated with organic material that resembles opaque attritus of coal (J. M. Schopf, personal communication). No uranium minerals are discernible megascopically or in polished or thin-section, and the presence of pyrite negates X-ray identification. The uranium content of this material is several times that found in other black shales in the United States, but, like them, is probably concentrated in the organic material in colloidal form or as unrecognizable metallo-organic compounds. At locality 31 a metamorphosed novaculite bed 4 inches thick in the Arkansas novaculite contains 0.027 percent uranium. The novaculite is associated with the Potash Sulphur Springs intrusive body at this locality.

The shale and chert of the Woodford and the Chattanooga shale both contain phosphatic materials, mainly in the form of nodules of fine sand to pebble size. As shown in figure 50, the phosphate-bearing parts of these formations generally contain more uranium than the shale. Analysis of a selected suite of nodules of various physical aspects indicates that apatite is the chief mineral in all, with quartz the most common accessory. The uranium content of the phosphatic material ranges from less than 0.001 percent uranium to 0.013 percent uranium and is generally about 0.004 percent uranium or less. Phosphatic nodules in the Chattanooga shale of the southeastern part of the United States also generally contain about 0.004 percent uranium or less (V. E. Swanson, personal communication). However, phosphatic nodules from shales of Pennsylvanian age in northern Oklahoma and eastern Kansas that have a phosphate content in the same range as the phosphatic material from Devonian and Early Mississippian rocks generally contain more than 0.01 percent uranium (W. Danilchik and H. Hyden, personal communication). This suggests either a difference in the amount of uranium available for concentration in the phosphatic materials, or a difference in depositional environment.

Conclusions from the available analyses are: (1) with one exception (locality 22) the black shales of Devonian and Early Mississippian age in eastern Oklahoma and northern and western Arkansas contain no more than 0.009 percent uranium and generally contain about 0.004 percent uranium or less; (2) phosphatic material of the apatite group, present as nodules in the shale or as disseminated material in sandstone, is generally slightly more uraniferous than the enclosing black shale.

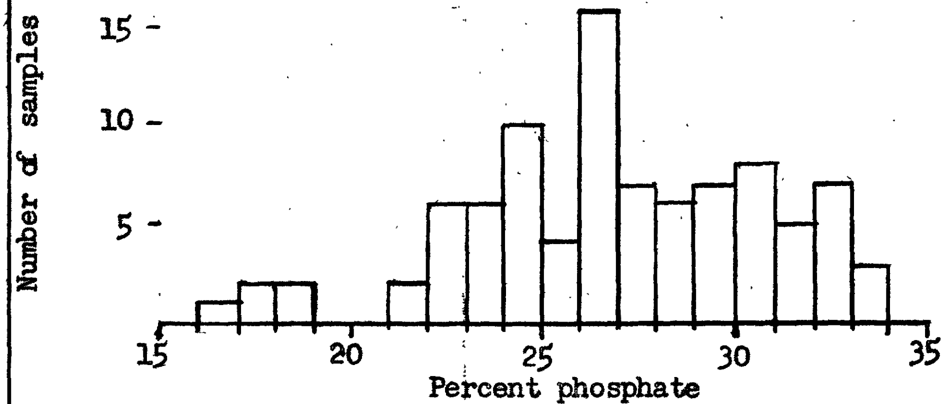
Midcontinent Pennsylvanian rocks
by W. Danilchik and H. J. Hyden

The rocks of the Des Moines series of Pennsylvanian age in the central Midcontinent are included in three groups. These are, in ascending order, the Krebs, Cabaniss, and Marmaton groups. Each of the groups contains numerous beds of sandstone, gray shale, limestone, coal, and black shale. The only appreciable radioactivity and uranium content are in the black shale units.

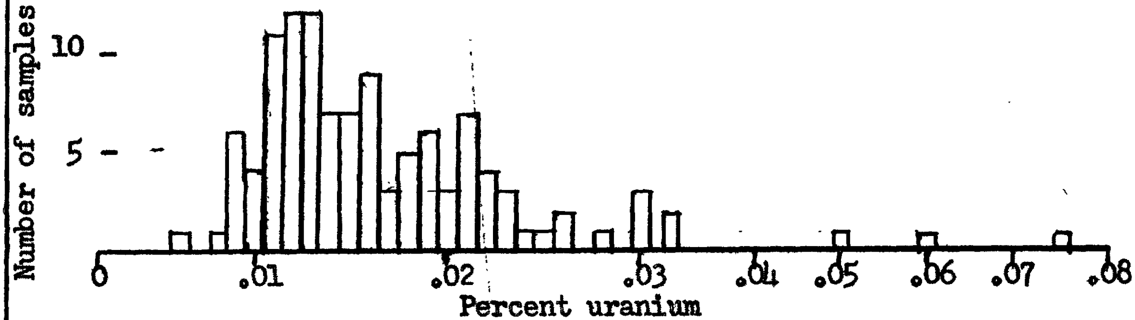
The black shale units are thin (2 to 9 feet), persistent, and are commonly associated with limestone or coal. The black shales are all rich in organic matter, but some units consist of soft, coaly shale that commonly contains ironstone or limestone nodules and lenses; others consist of hard bituminous shale that characteristically contains uraniferous phosphatic nodules. The nodules occupy 1 to 5 percent of these shales and range from one quarter of an inch to as much as three inches in diameter. The phosphatic nodule-bearing shale units are typically overlain by marine limestone and commonly overlie coal beds; the coaly shales commonly overlie coal and are overlain by gray shale.

The Krebs group contains four black shale units, only one of which contains phosphatic nodules locally. The Cabaniss group contains at least six black shale units, four of which are bituminous, phosphatic nodule-bearing. The Marmaton group contains four beds of black shale, all of which contain phosphatic nodules.

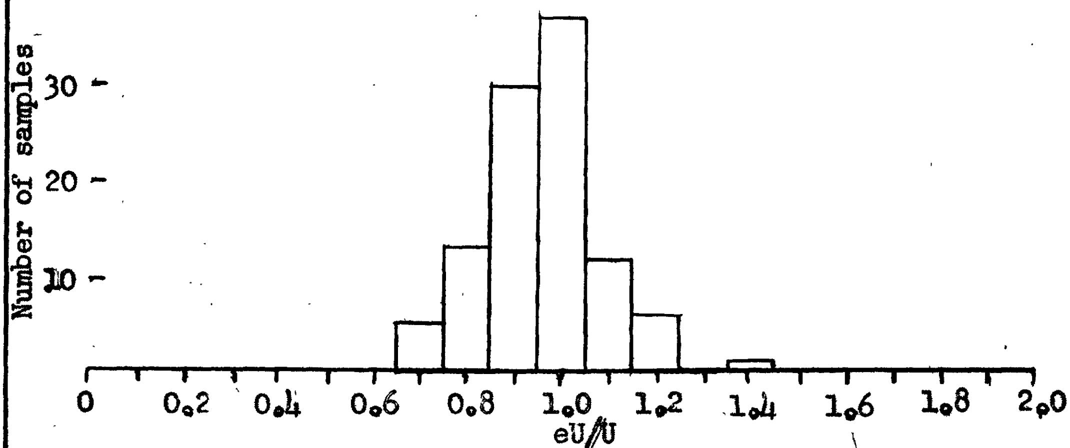
The uranium content of 147 channel samples of the shales, nodules excluded, ranges from less than 0.001 percent to 0.010 percent, but most of the samples contain less than 0.003 percent. The distribution of shale samples from the Krebs, Cabaniss, and Marmaton groups arranged according to uranium



A. Histogram showing phosphate content of 108 samples of phosphatic nodules.



B. Histogram showing uranium content of 108 samples of phosphatic nodules.



C. Histogram showing ratio of equivalent uranium to uranium in 104 samples of phosphatic nodules.

Fig. 51 Phosphate content, uranium content, and ratio of eU to U in phosphatic nodules from Pennsylvanian black shales of Okla., Kan., and Mo.

contents is given in table 22.

Table 22.—Uranium content of shales of the Des Moines series

Stratigraphic unit	Number of samples	Percent of samples containing indicated %U						
		0.001%U or less	0.002%U	0.003%U	0.004%U	0.005%U	0.006%U	0.006%U
Black shales in Marmaton group	45	22%	34%	13%	13%	11%	5%	2%
Black shales in Cabaniss group	82	34%	23%	21%	6%	10%	1%	5%
Black shales in Krebs group	20	70%	15%	5%	10%	—	—	—

Phosphate and uranium contents in phosphatic nodules were determined for 108 samples. Summaries of the results are shown in figure 51, parts A and B.

The determinations for uranium and phosphate in the phosphatic nodules, plotted on a scatter diagram, show no obvious relationship between the two constituents. Also, the relation between the amount of uranium in the nodules and their size, shape, internal color, and the presence of visible pyrite and calcite is random in a statistical evaluation of these attributes.

The eU and U ratios for 104 samples of phosphatic nodules range from 0.65 to 1.45 as is shown in figure 51, part C. Forty-eight samples have eU to U ratios of less than 1; 19 samples have eU to U ratios of more than 1.

Stratigraphic distribution of the uranium in northern Texas and southern Oklahoma
By D. H. Eargle and E. J. McKay

The study of the uranium distribution in the red beds of the lower Permian Wichita formation in the Red River Valley area was continued. Results of tracing mappable beds in this formation show (fig. 52) that about three quarters of the known uranium localities in the area are in sandstones between

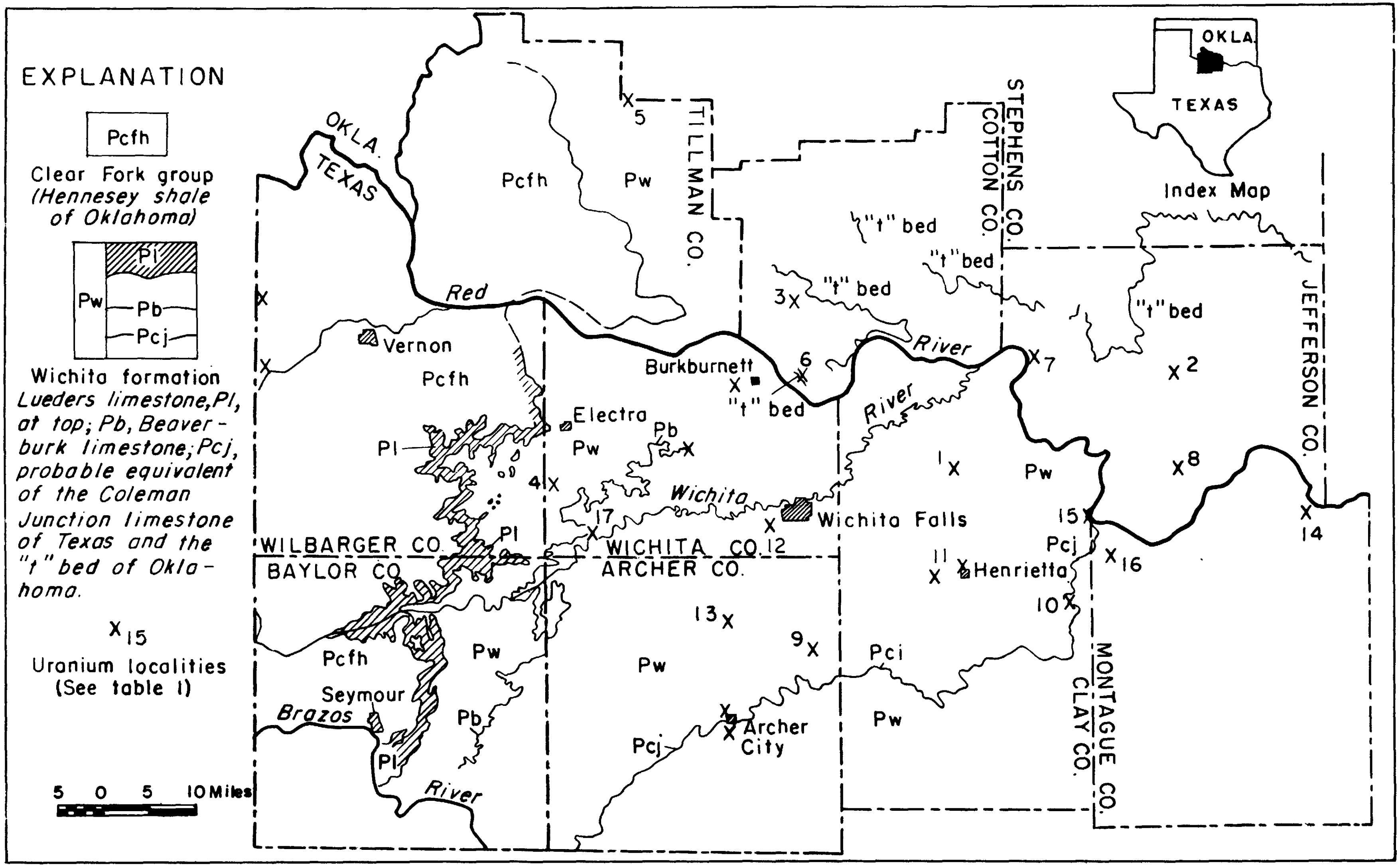


FIGURE 52 -MAP OF WICHITA FORMATION, PERMIAN, IN THE RED RIVER VALLEY SHOWING URANIUM LOCALITIES

the levels of the Lueders limestone at the top, and the Coleman Junction limestone member of the Putnam formation near the middle, of the Wichita group as developed in central Texas.

These limestone units of the Wichita group in Texas grade laterally northward into red-bed facies. The Lueders limestone is absent in the vicinity of Red River but its stratigraphic position is thought to be represented by the contact separating the chocolate red shales of the Hennessey shale of Clear Fork age and brick red sandstones and shales of the Wichita formation in Oklahoma. The Coleman Junction limestone member grades into red beds in southwestern Archer County, Texas and it stratigraphic position has been traced northward on a relatively persistent sandstone zone by Bunn (1930) and Sellards (1932). This sandstone zone is believed to be the equivalent in Oklahoma of a sandstone zone named the t bed (Miser, 1954).

The distribution of uranium, the easterly change in strike of the Coleman Junction limestone member and its equivalents, and the seemingly erratic strike of the t bed are interrelated features in a red-bed facies that is genetically related to the burial of the Wichita Mountain and Red River Uplifts (TEI-590, p. 257-262) by early Permian sediments. Though the distribution of uranium is known to be confined regionally to the red-bed facies, the relative areal density of potentially favorable sandstone lenses within the facies has not been determined. Evidence to date suggests (1) that the sandstone lenses increase in number and thickness northward within the red-bed facies, and (2) that the number of sandstone lenses increases in areas near the less deeply buried topographic or structural features of the local uplifts that existed in the region during Permian time.

Table 23 shows analyses of samples from the Wichita formation of the Red River Valley.

References

Bunn, J. R., 1930, Oil and gas in Oklahoma: Oklahoma Geological Survey Bull. 40, v. 11, p. 349.

Sellards, E. H., 1932, The geology of Texas: University of Texas Bull. 3232, v. 1, p. 141-143.

Miser, H. D., 1954, Geologic map of Oklahoma, scale 1:500,000: U. S. Geol. Survey.

Geochemistry of uranium-bearing shales

By Maurice Deul and I. A. Breger

Very thin sections of Chattanooga shale, about 10 µ thick, covered with stripping film were exposed for three months. These sections permit examination of the organic matter by transmitted light whereas in thin sections previously examined only spore coats were generally translucent. Study of the stripping film and the thin sections showed that: (1) almost all of the alpha tracks were single tracks, (2) the tracks originated from the organic matter, and (3) no concentrations of tracks were associated with pyrite in the organic matter. These observations indicate that most of the uranium is present in extremely fine disseminations in the organic matter, and that pyrite in the organic matter exerted no direct control on the concentration of the uranium. These disseminations are of such a small size that few, if any, double tracks were produced in three months. These observations and conclusions agree with data summarized in the last semiannual report (TEI-590, p. 264).

To test the hypothesis that the uranium in the Chattanooga shale is present as a separate colloidal phase disseminated through the organic matter, a sample was ground in water to an extremely fine size. The pulverized product was mixed with water and allowed to settle in a tall cylinder for about

Table 23.--Uranium content of samples from the Wichita formation, of Permian age, of the Red River Valley

Locality (See fig. 52)	Type of material		eU%	U%
1	Sandstone with copper minerals		0.021	-
			0.007	-
			0.057	0.062
2	Arkosic conglomerate with copper minerals		0.022	-
			0.008	-
3	Carbonaceous clay with copper-bearing nodules		0.075	0.062
			0.028	-
4	Carbonaceous sandstone		0.004	-
			0.015	-
			0.011	-
5	Arkosic conglomerate	(Maximum	0.14	0.13
		(Aver. 8 samples	0.069	0.070
6	Carbonaceous sandstone with copper minerals	(Maximum	0.64	0.82
		(Aver. 40 chip samples	0.0136	-
		(Aver. 4 samples	0.018	-
7	Ferruginous sandstone		0.052	0.070
8	Carbonaceous sandstone		0.004	-
			0.029	-
9	Carbonaceous sandstone		0.054	-
10	Ferruginous sandstone		0.021	-
11	Sandstone		0.001	-
			0.039	-
12	Ferruginous sandstone		0.010	-
13	Ferruginous and manganiferous sandstone with uranium minerals		0.28	0.36
			0.081	0.025
14	Sandstone		0.029	-
15	Sandstone with ferruginous concretions		0.019	-
16	Ferruginous and carbonaceous sandstone		0.39	-
17	Ferruginous sandstone		0.039	0.045
			0.002	-

100 hours. The supernatant liquid was siphoned off and the colloidal matter in the liquid was separated from ionic material by dialysis and then evaporated to dryness. Starting with shale containing 0.009 percent U, the colloidal matter contained 0.08 percent U, which is the highest concentration of uranium yet obtained from Chattanooga shale by mechanical means.

The concentrates of carbonaceous matter obtained from the Chattanooga shale by the colloidal method were lower in uranium content than the original shale. To eliminate the possibility that these concentrates of organic matter might be segregations of one particular nonuraniferous type, comparisons were made of colloidally concentrated carbonaceous matter and of carbonaceous matter collected by an acid leach of a sample of the shale. Infrared spectrum absorption curves for both samples of carbonaceous materials were essentially the same.

Using Van Krevelen's (1954) graphical-statistical approach for determining possible chemical changes in a series of samples plotted with atomic oxygen-to-carbon ratio on the abscissa and atomic hydrogen-to-carbon ratio on the ordinate, the analysis for the organic material present in unfractionated Chattanooga shale fell outside the zone in which the separates obtained colloidally fell. According to Van Krevelen's scheme the deviation could best be explained by dehydration of the original shale. A correction could be made by adjusting the analysis for hydrogen and the figure for oxygen based on the water content of the hydromica fraction of the total shale.

The following reports on the geochemistry of carbonaceous shales were published during the period:

Deul, Maurice, 1956, Colloidal method for concentration of carbonaceous matter from rocks: Bull. Am. Assoc. Petroleum Geologists, v. 40, no. 5, p. 909-917.

Deul, Maurice, 1955, Mode of occurrence of uranium in the Chattanooga shale (abs.): Bull. Geol. Soc. America, v. 66, no. 12, p. 1549.

Reference

Van Krevelen, F. W., 1954, Coal: London, Edward Arnold, p. 364.

Uranium in asphaltite and petroleum
By A. T. Myers

A total of 259 chemical determinations were completed on 108 samples during the period and semiquantitative spectrographic determinations were made on 63 of these samples. Distribution of samples and chemical determinations by types are:

Sample type	No. of samples
Crude oil	69
Petroliferous rock	33
Asphaltite	6
Total	108

Constituent	No. of determinations
Oil 1/	28
Ash	90
U in ash	80
U 2/	8
eU	32
Other 3/	21
Total	259

1/ Material extracted with a hot mixture of 75 percent benzene, 15 percent acetone, 10 percent methanol.
2/ Unashed material.
3/ Includes P, S, As, Se, asphaltite.

A study was made, in cooperation with the U. S. Bureau of Mines at Laramie, Wyoming, of a sample of Wilmington (California) crude oil and several fractions such as the asphaltenes, asphaltene free oil, the asphaltene free hydrocarbon eluate, and the nitrogen rich asphaltene free oil. The uranium found was 0.9 ppb in the crude oil, 8.3 ppb in the asphaltenes, 1 ppb in the asphaltene free oil, 0.2 ppb in the hydrocarbon eluate, and 50 ppb in the nitrogen rich fraction of the asphaltene free oil. A good correlation was found between nitrogen and uranium. Nitrogen also gave good correlation with copper, cobalt, nickel, and vanadium.

The sodium peroxide bomb was used successfully for the decomposition of organic samples in the determination of selenium. The use of the bomb eliminates the tedious wet decomposition of such samples and the possible loss of selenium during this step. After decomposition the fusion mixture is dissolved in sulfuric acid and the selenium distilled as the selenium tetrabromide.

A colorimetric method was developed for the determination of mercury in crude oil based on the reaction of mercury with di - B - naphthylthiocarbazone.

The following paper on uranium in asphalt-bearing rocks was published during the period:

Hail, W. J., Myers, A. T., and Horr, C. A., 1956, Uranium in asphalt-bearing rocks, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 489-493: New York, United Nations.

References

Dunning, H. N., Moore, J. W., and Myers, A. T., 1954, Properties of porphyrins in petroleum: Indus, and Eng. Chemistry, v. 46, p. 2000-2007.

Erickson, R. L., Myers, A. T., and Horr, C. A., 1954, Association of uranium and other metals with crude oil, asphalt, and petroliferous rock: Am. Assoc. Petroleum Geologist Bull., v. 38, p. 2200-2218.

URANIUM IN PHOSPHATES

Northwest phosphate
By V. E. McKelvey

Work during the period was concentrated on preparation of final reports on the geology of the western phosphate deposits. A draft of one of these reports on the nomenclature of Permian rocks in the western field was completed and submitted to Washington during the period. Reports on various phases of the western phosphate investigations that were published during the period are:

Cheney, T. M., 1955, Facies and oil possibilities of the Phosphoria formation and equivalent strata in eastern Utah and southwestern Wyoming: Wyo. Geol. Assoc. Guidebook, Tenth Annual Field Conference, p. 65-67: (abs.), Geol. Soc. America Bull., v. 66, no. 12, pt. 2, p. 1646.

Cressman, E. R., Physical stratigraphy of the Phosphoria formation in part of southwestern Montana: U. S. Geol. Survey Bull. 1027-A, p. 1-31.

Cressman, E. R., and Gulbrandsen, R. A., 1955, Geology of the Dry Valley quadrangle, Idaho: U. S. Geol. Survey Bull. 1015-I, p. 257-270.

McKelvey, V. E., 1955, Preliminary geologic maps of the Paris-Bloomington vanadium area, near Bear Lake, Idaho: U. S. Geol. Survey Mineral Invs. Field Studies Map, MF-41

______________, 1956, Uranium in phosphate rock, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 499-502: New York, United Nations.

McKelvey, V. E., and Carswell, L. D., 1956, Uranium in the Phosphoria formation, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 503-506: New York, United Nations.

Sheldon, R. P., 1955, Stratigraphy of the Phosphoria formation in the Wyoming and Wind River Ranges: Wyo. Geol. Assoc. Guidebook, Tenth Annual Field Conference, p. 64.

Swanson, R. W., Carswell, L. D., Sheldon, R. P., and Cheney, T. M., 1956, Stratigraphic sections of the Phosphoria formation: U. S. Geol. Survey Circ. 375.

Southeast phosphate

Geologic studies
By W. L. Emerick

A total of 40 holes aggregating 7,664 feet were logged by the gamma-ray unit during the period. Six holes were prospect holes drilled on private land by one of the phosphate mining companies, and 34 holes were water wells in Hillsborough and Polk Counties logged through the phosphate-bearing Hawthorn formation for geologic information. Cumulative totals for the gamma-ray unit given in this report are 3,690 holes totalling 141,239 feet, and conclude the radioactivity logging under the present program in the Florida land-pebble phosphate district.

Studies of the aluminum phosphate zone in the new mine of the Armour Fertilizer Works indicate that the aluminum phosphate zone is similar in stratigraphic position and appearance to exposures of the zone in mines to the southeast. The physical characteristics of the aluminum phosphate zone at the Armour mine probably persist southward into the aluminum phosphate zone of the unmined Clark James-South Ridgewood tracts.

The following reports on the Florida phosphate deposits were published during the period:

Altschuler, Z. S., Jaffe, E. B., and Cuttitta, Frank, 1956, The aluminum phosphate zone of the Bone Valley formation and its uranium deposits, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 507-513: New York, United Nations.

Cathcart, J. B, 1956, Distribution and occurrence of uranium in the calcium phosphate zone of the land-pebble phosphate district of Florida, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 514-419: New York, United Nations.

___________, 1956, Economic geology of the phosphate deposits of Florida (abs.): Econ. Geology, v. 51, p. 111-112.

Ketner, K. B., 1955, A bibliography of phosphate deposits in southeastern United States: U. S. Geol. Survey open-file report.

Petersen, R. G., 1956, Origin of the land-pebble phosphate deposits of Florida determined from their clay-mineral content (abs.): Geol. Soc. America Bull., v. 66, no. 12, pt. 2, p. 1696.

Phosphate deposits and their "leached zones" in the northern part of Florida

By G. H. Espenshade and C. W. Spencer

Field studies in the hardrock phosphate district were essentially completed. The evidence continues to support the theory that these secondary phosphate deposits were formed by the weathering of Miocene phosphorite.

Stratigraphic sections were measured and samples taken at a number of natural exposures of the Hawthorn formation in northern Florida. Additional stratigraphic data on the Hawthorn beds were obtained by means of core drilling at 15 localities (figs. 53-57). A total of 2,271 feet was drilled by May 25, 1956; one more hole (D. H. 46), to be drilled near Worthington Springs, Union County, will complete the program. The drill holes were logged with a scintillation gamma-ray logger and samples were taken for chemical analysis and petrographic and paleontologic study.

Good sections through the Hawthorn formation and younger sediments were cut in 12 of the drill holes (figs. 54-57). The stratigraphy and lithology of these holes are rather similar, and resemble that of the Bone Valley and Hawthorn formations of the land-pebble district (table 24). This apparent correlation between the drill hole sections and the land-pebble district is tentative and is based solely upon the similar lithology of the stratigraphic sequence of the two areas; paleontologic studies have not yet been made of the drill hole samples.

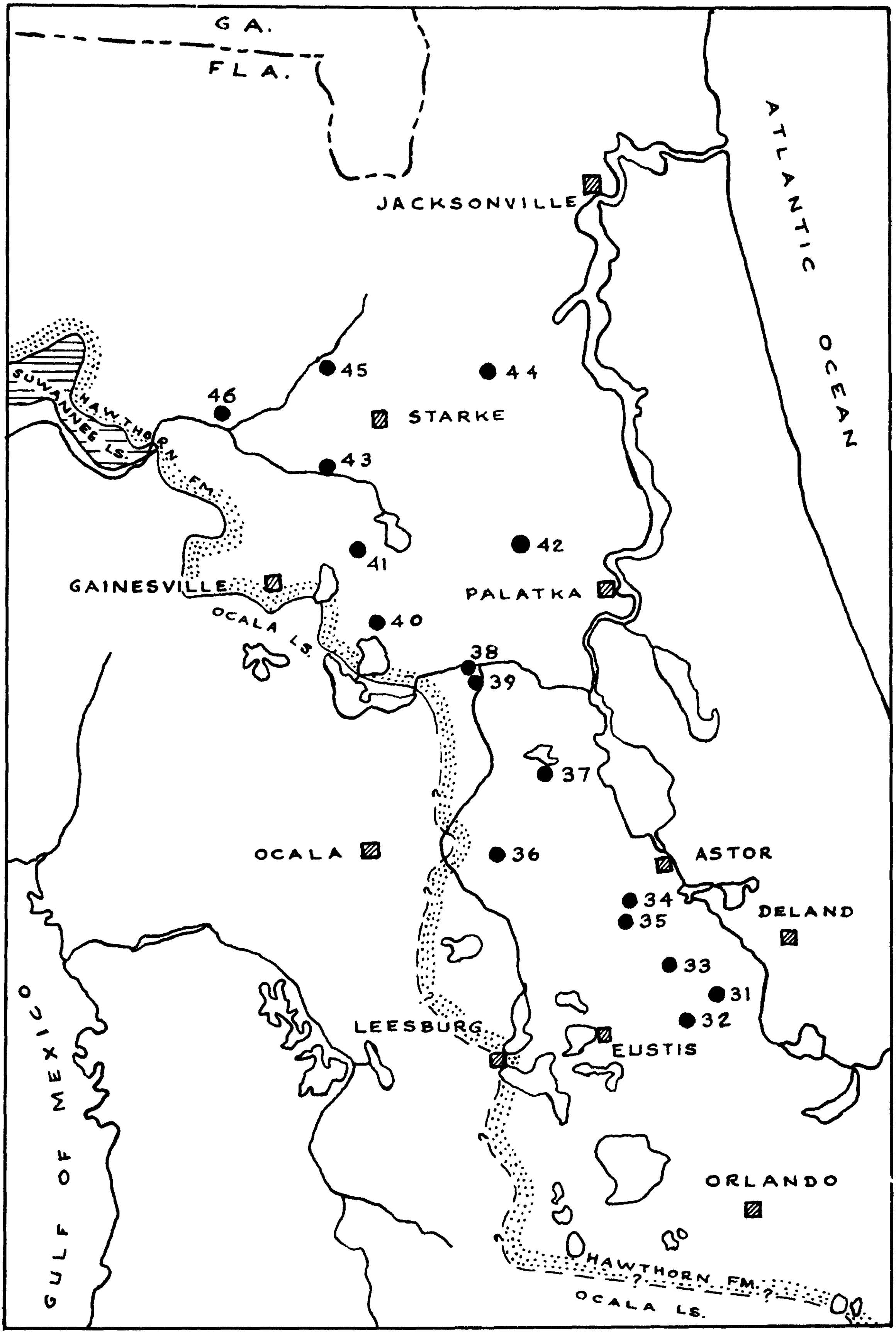


FIG. 53 LOCATION OF DRILL HOLES, FLORIDA PHOSPHATE STUDIES, 1956

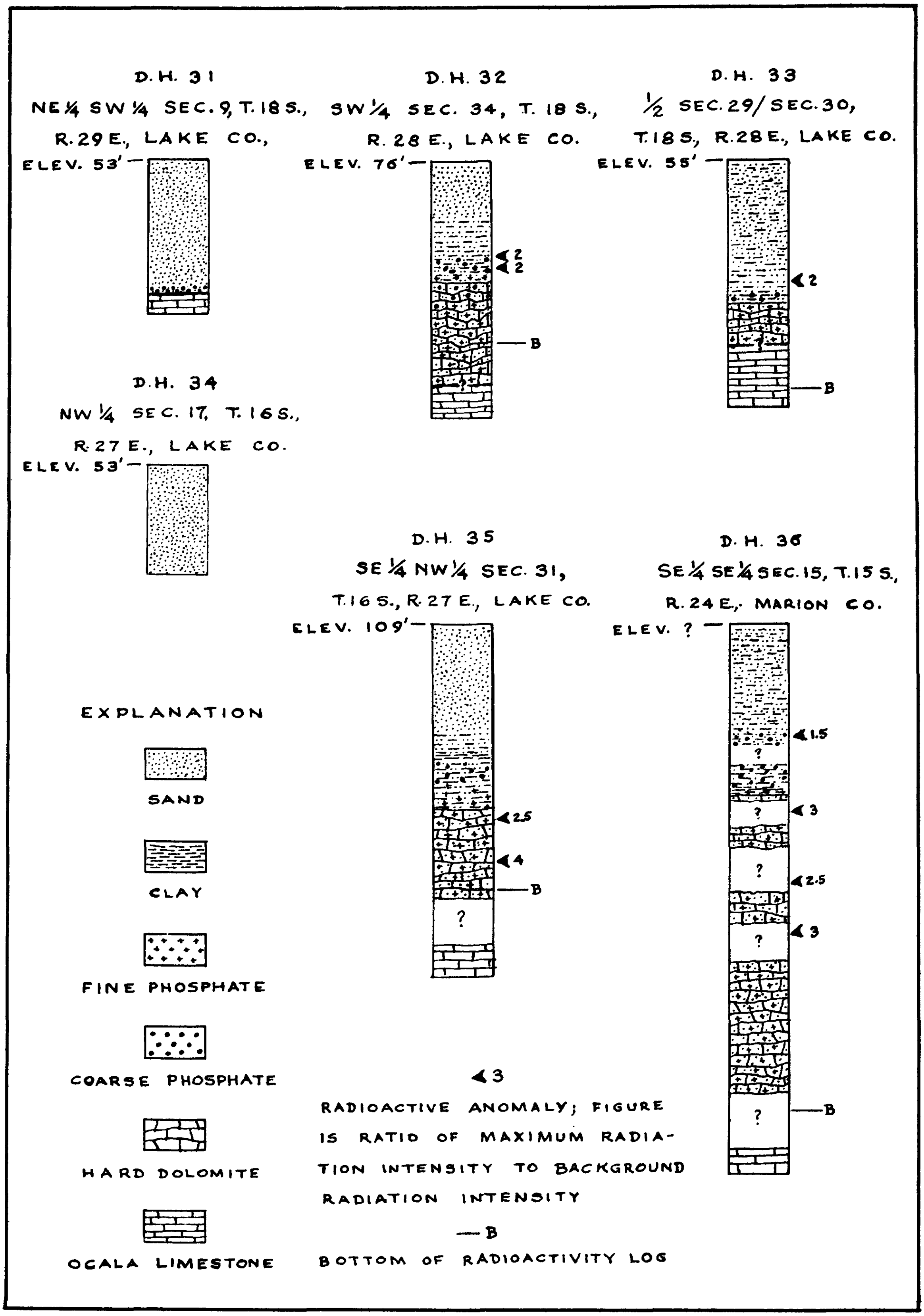


FIG. 54 LOGS OF DRILL HOLES 31 TO 36, FLORIDA PHOSPHATE STUDIES, 1956

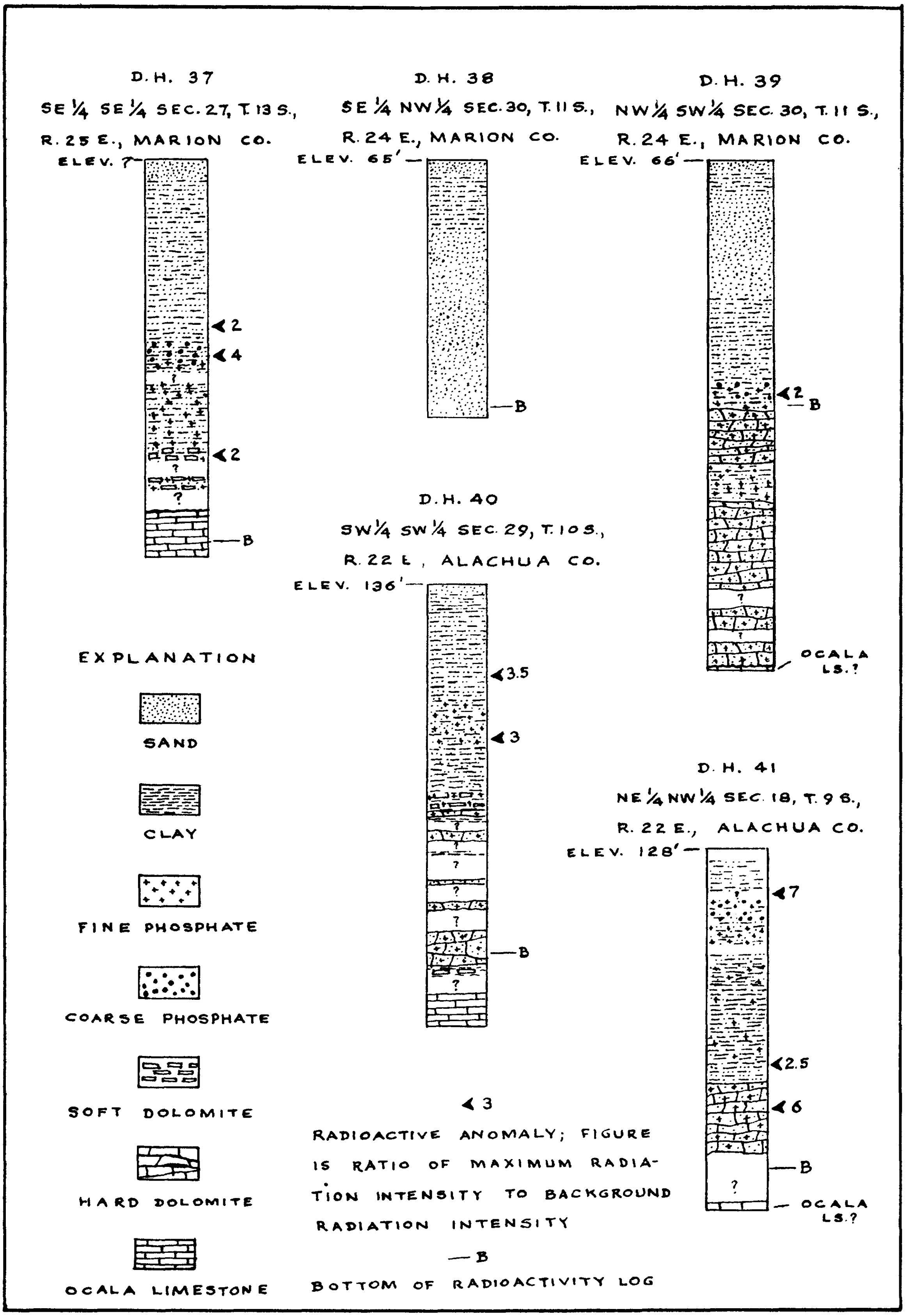


FIG. 55 LOGS OF DRILL HOLES 37 TO 41, FLORIDA PHOSPHATE STUDIES, 1956

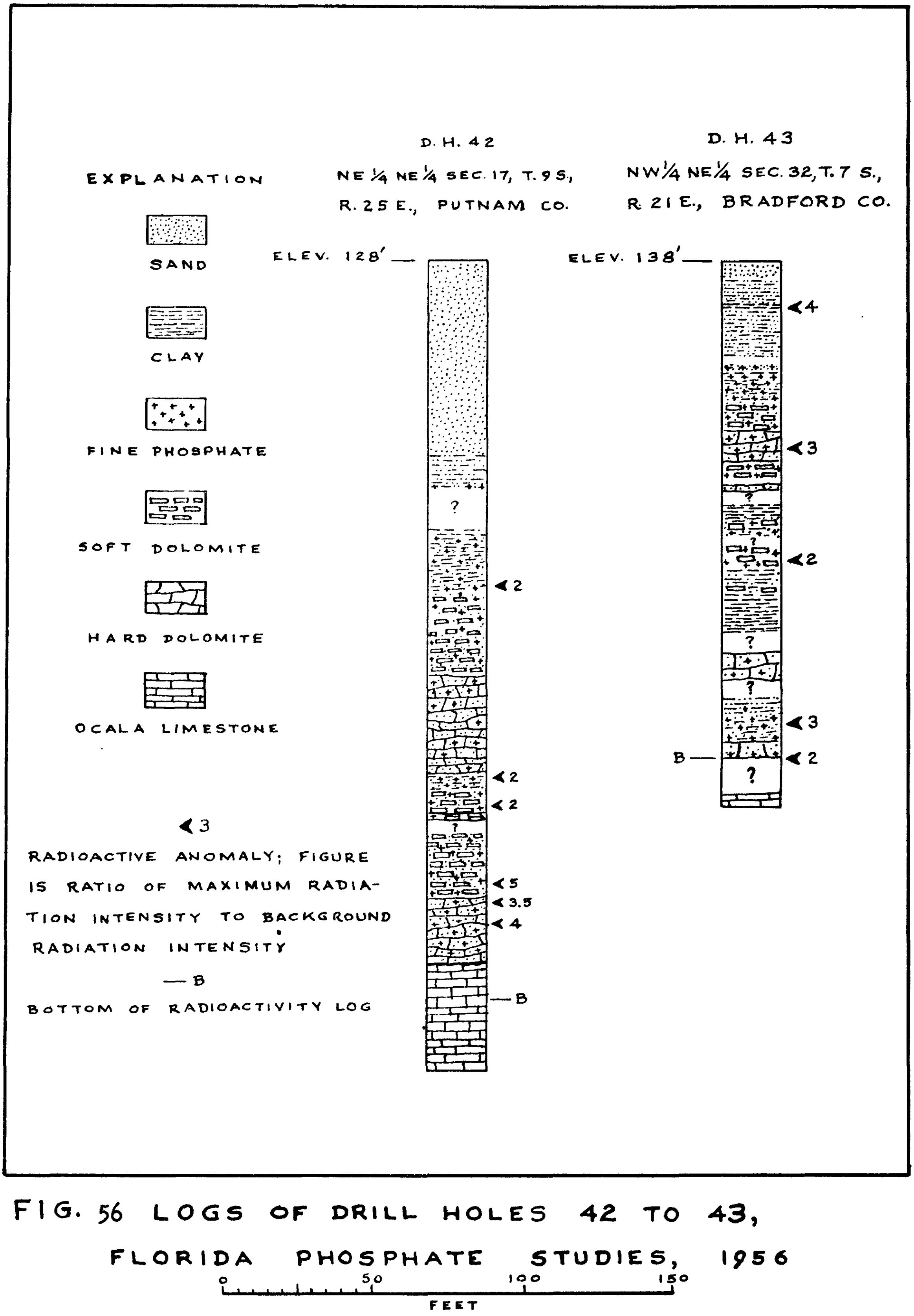


FIG. 56 LOGS OF DRILL HOLES 42 TO 43, FLORIDA PHOSPHATE STUDIES, 1956

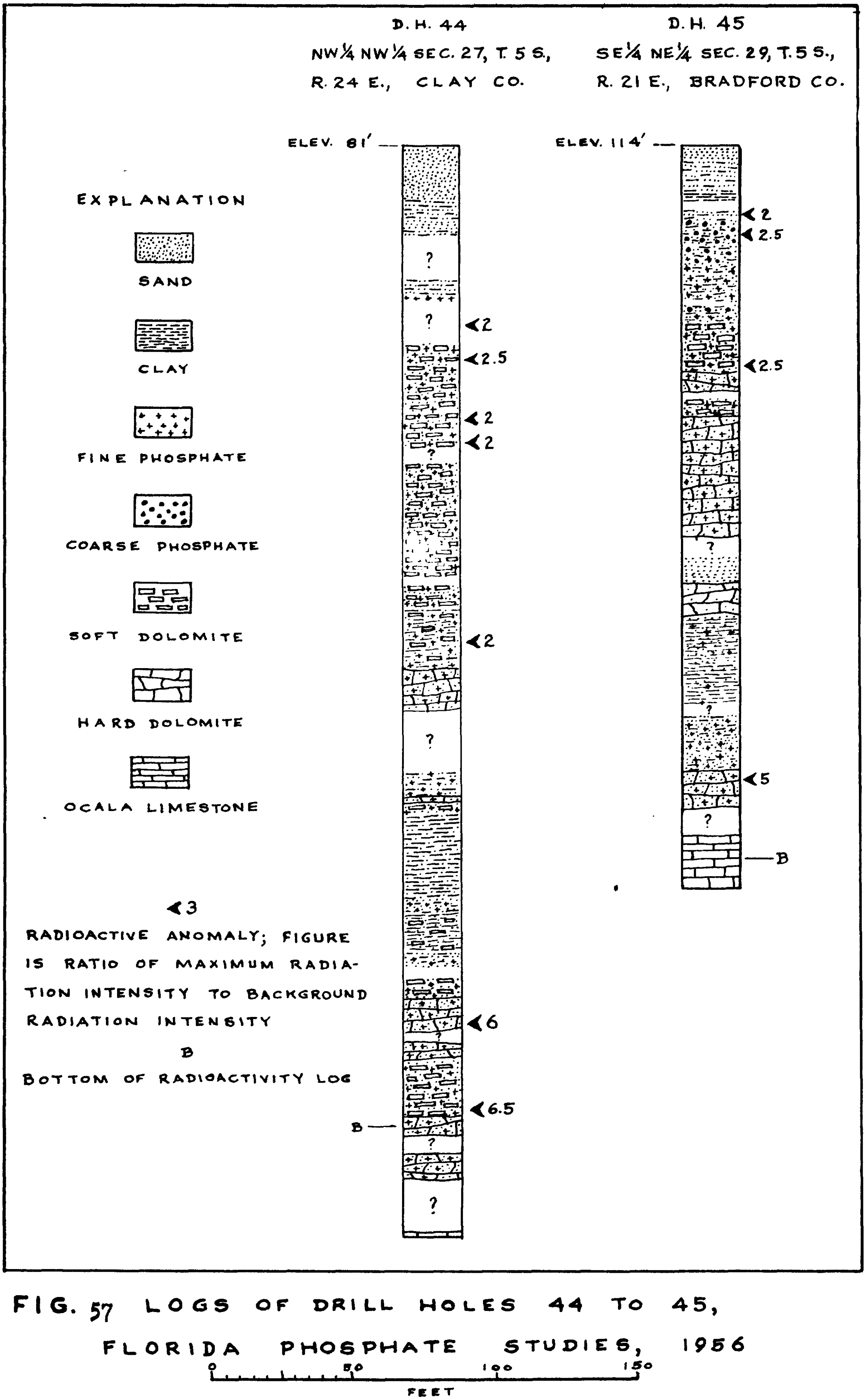


FIG. 57 LOGS OF DRILL HOLES 44 TO 45, FLORIDA PHOSPHATE STUDIES, 1956

Table 24.—Comparison of stratigraphy of drill holes in northern Florida with stratigraphy of land-pebble district

Stratigraphy of drill holes		Stratigraphy of land-pebble district	
Pleistocene?)	Loose sand	(Pleistocene?)	Loose sand
Hawthorn fm. (Middle Miocene)	Clayey sand ?	Bone Valley fm. (Pliocene?)	Clayey sand
	Clayey sand with coarse or fine phosphate		Clayey sand with coarse or fine phosphate
	Sandy phosphatic dolomite; mostly dense and hard in southern holes, soft and claylike in northern holes.	Hawthorn fm. (Middle Miocene)	Sandy phosphatic dolomite or limestone
		Tampa limestone (Lower Miocene)	Sandy limestone
	———unconformity———		
Ocala ls. (Eocene)	Soft limestone		

The greatest thickness of Miocene and younger beds was found in D. H. 44, where phosphate occurs intermittently throughout a thickness of over 300 feet. Water well records show that the Miocene beds become thicker to the northeast toward Jacksonville (Vernon, 1951, fig. 33).

Sandy phosphatic dolomite makes up most of the lower part of the Hawthorn formation in the drill hole sections. In the southern holes the dolomite is tan to gray, very hard and dense, and contains many irregular tabular cavities (mollusc borings?) that are filled with fine quartz sand and phosphate. In contrast, much of the dolomite in the northern holes is soft and claylike, and is composed of minute dolomite rhombohedra that are largely unconsolidated; fine quartz sand and phosphate are also present.

The position of the contact between the phosphatic dolomite beds and the Ocala limestone could not be closely determined in some drill holes because the upper beds of the Ocala limestone are cavernous and very soft, and core recovery at this horizon was usually poor. However, this contact was determined quite closely by the scintillation logger in those drill holes where conditions allowed the logging probe to descend below the contact; radioactivity decreases abruptly in passing from the Hawthorn beds to the Ocala limestone.

Certain beds of phosphorite or clayey sands in the Hawthorn formation, usually only several feet thick, are somewhat more radioactive than is normal for the Hawthorn beds. Radioactivity anomalies were found at the top of the phosphorite or at the base of the overlying clayey sands in nine out of 12 drill holes (figs. 54-57). The position of this radioactive zone corresponds to that of the "leached zone", or aluminum phosphate zone, of the land-pebble district. Radioactive anomalies also occur in unweathered phosphatic clayey sands and dolomite beds below this zone. In the four northern holes (D. H. 42 to 45) some of the most radioactive zones are in the phosphatic dolomite near the base of the Hawthorn formation.

<u>Reference</u>

Vernon, R. O., 1951, Geology of Citrus and Levy Counties, Florida: Florida Geol. Survey Bull. 33.

URANIUM IN NATURAL WATERS
By P. F. Fix

Substantial progress was made in developing criteria for discriminating hydrogeochemically between uranium ore deposits and mineralized ground, especially in tuffaceous terranes, and for sorting out and appraising the relative effect of artificial hydrodispersion haloes of uranium, caused by test drilling or mining in uraniferous ground. Artificial concentrations, commonly 25 to 100 times the natural uranium concentrations in the waters prior to drilling or mining, can distort the natural pattern badly, and their effects must be recognized in hydrogeochemical appraisals.

A measure of the beneficiation that may result from test drilling alone in a dry region was obtained in Karnes County, Texas, where the streams have increased about 3 times in average uranium content in the first year of test drilling. As drought has reduced or eliminated direct surface runoff in most streams, this increase is evidently caused chiefly by the effect of drill cuttings on ground water. Drill-hole waters range from 3,500 to 210,000 ppb U. Selective leaching of the margins of some deposits seems to occur with pH the chief known control.

Shallow well waters downdip southeast of Tordilla Hill are relatively high in uranium and vanadium, but in uranium alone at somewhat greater depth. This suggests a stratigraphic zoning with respect to vanadium. Deeper artesian aquifers beneath contain only about 3 times the regional background of uranium. The geochemical relationships of several other constituents, compared with those in the area of developed ore northeast of Tordilla Hill, lead to a good understanding of criteria for determining hydrogeochemically the approximate boundaries of secondary deposits of this type.

The following papers on the use of ground waters in uranium prospecting were published during the period:

Denson, N. M., Zeller, H. D., and Stephens, J. G., 1956, Water sampling as a guide in the search for uranium deposits and its use in evaluating widespread volcanic units as potential source beds for uranium, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 794-800: New York, United Nations.

Fix, P. F., 1956, Geochemical prospecting for uranium by sampling ground and surface waters, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 788-791: New York, United Nations.

Tourtelot, H. A., 1955, Uranium content of water in the Great Plains region of Nebraska and in adjacent states: Geol. Soc. America Bull., v. 66, no. 12, pt. 2, p. 1627-1628.

URANIUM IN PLACER DEPOSITS

Central Idaho placers

By D. L. Schmidt

The preliminary report on the uranothorite placers of Blaine and Camas Counties near Hailey, Idaho, is nearly finished. Mineralogical analyses of 2,100 pan samples collected since 1953 from the Cascade, Bear Valley, and Hailey districts have been essentially completed. A majority of the samples now await final synthesis regarding details of the genesis, distribution, and concentration of the contained heavy accessory minerals. A final report on the Cascade-Bear Valley placers, now in preparation, will include these data.

During the period the following report on uranium in placer deposits was published:

Mackin, J. H., and Schmidt, D. L., 1956, Uranium- and thorium-bearing minerals in placer deposits in Idaho, *in* Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 587-592: New York, United Nations.

CORRELATION OF AIRBORNE RADIOACTIVITY DATA AND AREAL GEOLOGY

By W. J. Dempsey, R. B. Guillou, R. M. Moxham and Robert Bates

Texas Coastal Plain

Approximately 2,500 traverse miles were flown in this area in October and November 1955. During May 1956 approximately 10,000 traverse miles were flown including a resurvey of the area previously flown. These surveys are at 1-mile spacing extending northwest from the top of the Goliad sand (Pliocene) to the Upper Cretaceous rocks northwest of the Balcones Fault Zone. Southeast of the Goliad sand to the Gulf Coast 6-mile spacing was flown. Detailed surveys at one-quarter mile spacing will be flown to fill in areas of particular interest.

Preliminary examination of the data available to date indicates that, in addition to the anticipated abnormal radioactivity in the known mineralized areas in the Jackson formation (Eocene), the following generalizations may be drawn: (1) there are small but distinct differences in the total gamma radioactivity emitted from the several formations. Such differences are apparently regional in most instances; (2) strike-oriented zones of abnormal radioactivity within formations may be a reflection of facies changes; (3) at least one area of abnormal radioactivity (parallel and slightly southwest of the San Antonio River) cuts across the regional strike of the formations, and perhaps is the result of some extrinsic radioactive material; (4) local radiation anomalies have resulted from concentrations of heavy minerals in the Reklaw and Queen City members of the Mount Selman formation (middle Eocene).

Perhaps the most interesting feature of the preliminary survey is the apparent existence of a regional northwestward radioactive gradient. The general radiation level increases from a very low value over the Pleistocene on the southeast and increases in a northwestward direction to a maximum over the locally uranium-bearing Jackson formation. In general a typical radiation profile extending northwestward from the Gulf from Aransas County to Bexar County would show a relatively low, level intensity over the Pleistocene with an almost imperceptible increase over the Goliad sand (Pliocene). The first distinct break occurs over the Catahoula tuff (lower Miocene?) where the radiation intensity increases by a factor or two, with respect to Pleistocene. The intensity reaches a maximum increase of a factor of about 10 over the Jackson, dropping abruptly over the underlying Yegua formation at the top of the Claiborne group (middle Eocene). There is a general decrease in intensity from the top to the bottom of the Claiborne group with the Cook Mountain and Sparta formations and the middle of the Mount Selman formation appearing as plateaus. Perhaps the most persistent stratigraphic feature of the radiation profiles examined to date is the marked low over the Carrizo sand immediately below the base of the Mount Selman formation. The low is of approximately the same level as that over the Pleistocene and is flanked on the northwest and southeast by sharp increases over the Wilcox and the overlying part of the Mount Selman respectively. From the Wilcox downward in the section the same general radiation intensity is recorded with perhaps a slight increase over the Upper Cretaceous rocks. The airborne surveys will be used as the basis for the Southeast Texas geophysical and geologic studies to be started in the fall of 1956.

Northern Michigan

Analysis of radioactivity data obtained from flights over Dickinson County, Michigan, in 1955 show the radioactivity pattern could not be used to differentiate between different rock types. Most of the area is covered by a thick mantle of glacial debris and outcrops are few and scattered. It was found that the intensity of the radiation varied directly with size and number of outcrops along the flight lines. To differentiate the various rock types in this and similar areas it will be necessary to reduce the cone of response of the scintillation equipment, either by flying at a lower altitude or by shielding the detecting elements.

East Pine Ridge escarpment, Wyoming

The rocks exposed in the East Pine Ridge escarpment, or Lance Creek area, in the northern part of Niobrara County, east-central Wyoming, are sediments of Upper Jurassic to Oligocene ages. In the area several radioactivity anomalies have been discovered in the White River formation of Oligocene age, where they appear to be confined to a lensing conglomeratic sandstone. Anomalous radioactivity also has been detected in the lignitic coals of the Fort Union formation south of the Lance Creek area and in the Fox Hills sandstone immediately northwest of the Lance Creek dome. In an effort to determine significant geologic relationships on the basis of radioactivity, 1,700 traverse miles were flown on one-quarter mile spacings over an area of 425 square miles.

The stratigraphic sequence in the Lance Creek area is somewhat similar to that in the coastal plain of Texas, but the topographic relief is much greater. In areas of sharp relief it is impossible to maintain the plane at a constant elevation above the ground, and for that reason varying amounts of "terrane effect" are incorporated into the radioactivity data. At present, the amount of "terrane effect" in the Lance Creek data is difficult to determine because of the lack of topographic maps. However, radioactivity data corrected to a common altitude by means of a radio altimeter is available and is being rectified and plotted. It is hoped that by removing most of the "terrane effect" the various levels of radiation associated with the geologic units will be more readily apparent and that the formational boundaries can be plotted with some degree of accuracy. In this way it should be possible to determine the formational distribution of radioactive materials fairly accurately.

Galax, Virginia

An airborne radiometric survey of about two quadrangles over the igneous-metamorphic complex in the vicinity of Galax, Virginia, was partially completed. Adverse weather conditions and equipment failure prevent finishing the work. Preliminary examination of the records indicate that airborne radioactivity data would be useful in the delineation of rock units. This survey will be completed in the coming field season and a study of the results made.

Cross-country radioactivity surveys

Cross-country airborne radioactivity surveys were flown in the spring of 1955 in order to determine an average background in various parts of the country. Except in a few areas of rough topography, a 500-foot elevation above the ground was maintained. Background in the Atlantic Coastal Plain from Norfolk, Virginia, to Charleston, South Carolina, varied from 200 cps to more than 380 cps, while from Tifton, Georgia, to Jacksonville, Florida, the variation was from 200 cps to 300 cps. Between New Orleans, Louisiana, and Moline, Illinois, in the Mississippi Valley, background varied from 350 cps at La Place, Louisiana, to more than 700 cps over the St. Francois Mountains in southeast Missouri; the latter value was undoubtedly influenced by topography. From Wichita, Kansas, to the Pecos River, Texas, by way of San Antonio, Texas, background varied from 400 cps to over 500 cps, and variation from 450 cps to 850 cps was noted between El Paso, Texas and Egnar, Colorado.

Preliminary study of the records indicates a possible gross correlation between areal geology and radioactivity features in some areas.

Equipment drift

Data from four projects flown in 1955 was analyzed to determine the character and extent of drift in the radiation equipment of the Geological Survey's aircraft. Results as far are inconclusive. Differing drift rates are indicated while using caesium and radium standards. Duplication of a base line several times during the course of a flight is not a satisfactory method of determining instrument drift probably because the radon content of the air varies.

RECONNAISSANCE FOR URANIUM IN ALASKA

By V. L. Freeman and J. J. Matzko

Field work by the Geological Survey and prospecting by private parties have for the most part been recessed during the report period. However, in southeastern Alaska weather conditions permitted a limited amount of prospecting. Prospecting continued on southern Prince of Wales Island, Gravina Island, and in the Skagway area and claims were staked on promising radioactivity anomalies in each of these regions. Samples received at the Survey's College radioactivity testing laboratory from near Skagway include some ore grade material. About 50 claims have been reported staked in the Skagway area. (See index map, fig. 58, locality A.)

A radioactive area detected by airborne radiometric equipment flown by prospectors was found in the William Henry Bay area, about 50 miles northwest of Juneau. (See fig. 58, locality B.) Small areas of minimum ore-grade material have been outlined. The only identified radioactive mineral is thorianite that occurs in small reddish patches in the bedrock. The bedrock appears to be a highly metamorphosed rock probably intruded by diorite.

Development work on the Ross-Adams Lode near Bokan Mountain on Prince of Wales Island was recessed for the winter. (See fig. 58, locality C.) Laboratory work by the Geological Survey laboratories on samples from this deposit shows that primary uranium-bearing minerals are thorianite, uranothorianite, and thorite. Secondary radioactive minerals identified are bassetite, novacekite, sklodowskite, beta-uranophane, and gummite. An analysis of trace elements in the ore from the Ross-Adams Lode shows no correlation of the uranium present with titanium, niobium, or tantalum as is the case in the nearby I and L group. The deposit on the I and L

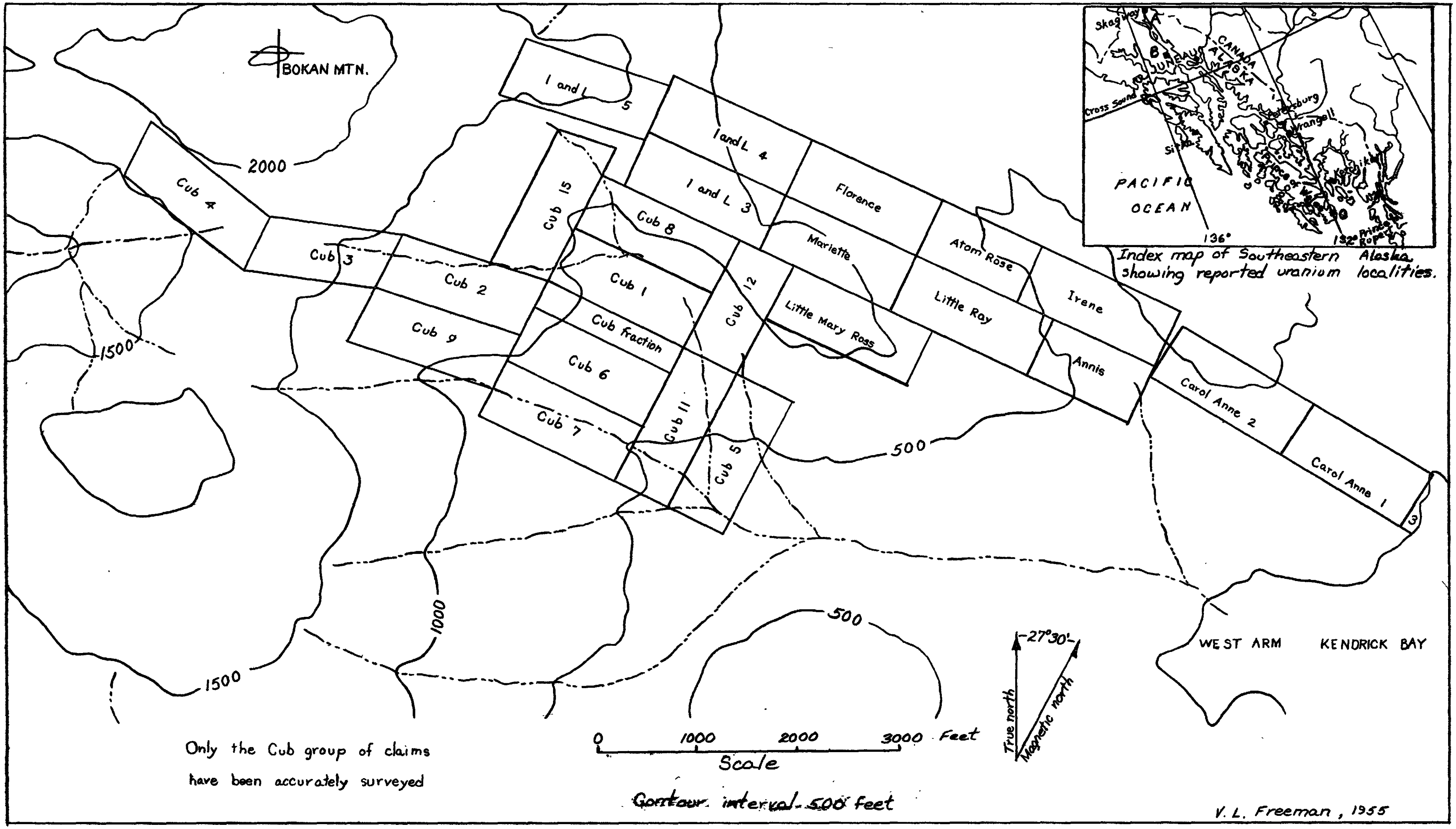


Figure 58. -- Claim map of the Kendrick Bay - Bokan Mountain area.
(Claim boundaries are approximate only)

group is easily classified as a pegmatite deposit but the Ross-Adams Lode, although clearly hydrothermal, is not easily classified because a relationship between the ore and any structural feature has not been established. The distribution of trace elements strongly suggests that the Ross-Adams Lode deposits are unrelated in origin to pegmatites.

An area of about 60 square miles in the Bokan Mountain-Kendrick Bay area, including the Ross-Adams Lode, will be mapped by the Geological Survey starting in June 1956. A photogeologic map of the area will be available to the field geologist.

The following reports on reconnaissance in Alaska were published during the period:

Matzko, J. J., 1955, Reconnaissance for uranium and thorium in Alaska (abs.): Geol. Soc. America Bull., v. 66, no. 12, pt. 2, p. 1704-1705.

__________, 1955, Phosphate rock from the Brooks Range, northern Alaska (abs.): Geol. Soc. America Bull., v. 66, no. 12, pt. 2, p. 1705.

ANALYTICAL SERVICE AND RESEARCH ON METHODS

Sample control and processing
By J. J. Rowe

The number of samples received by the laboratories decreased as compared to the preceding report period, due in part to the seasonal variation in field activities. The backlog was reduced from 8,800 to 6,900 samples.

The types of analyses requested have changed considerably within the past year. During the present report period requests for radioactivity determinations dropped sharply as did, to a lesser degree, requests for spectrographic analyses. The number of X-ray determinations requested increased from 1,154 in the preceding period to 1,347 in the present period, or about 17 percent. The total number of chemical determinations increased from 17,544 to 18,596, or about 6 percent; but within that category the number of determinations for uranium decreased from 7,621 to 6,583, or about 14 percent, while analyses for elements other than uranium increased from 9,923 to 12,013, or about 21 percent.

A summary of analytical services and sample inventory for the report period is given in table 25.

Radioactivity

Services
By F. J. Flanagan and J. N. Rosholt

In addition to routine radioactivity analyses reported in table 25, a total of 251 radiochemical determinations were made during the period, including analyses for Pa^{231}, Th^{232}, Th^{230}, Th^{228}, Ra^{228}, Ra^{226}, Ra^{224}, Ra^{223}, Ra^{222}, Bi^{212}, and Pb^{210}.

Table 25.—Semiannual summary of analytical services and sample inventory, December 1, 1955–May 31, 1956

Project or source	Chem. Detns.		Radio-activity	Spec. (Samples)	X-ray (Samples)	On Hand Dec. 1	Rec'd Dec.–June	Completed Dec.–June	On Hand 6/1/56
	U	Others							
Washington Laboratory									
AEC	67	10	83	11	41	56	103	146	13
Colorado Plateau sandstones	7	278	22	—	49	531	75	95	511
Sandstones–Other than Plat.	515	569	397	105	4	323	145	432	36
Carbonaceous rocks	1,095	1,061	1,094	256	19	124	1,274	1,082	316
Southeast phosphates	26	—	159	6	38	178	30	194	14
Northwest phosphates	—	13	—	125	—	120	189	129	180
Alaskan	40	13	19	18	5	16	82	81	17
Public samples	173	—	205	19	65	152	1,261	1,234	179
Mineralogical projects	455	610	44	225	392	364	1,211	1,080	495
Geochemistry of uranium	622	394	91	82	248	389	1,030	858	561
Miscellaneous	92	2,976	33	303	70	225	594	726	93
Total	3,092	5,924	2,147	1,150	931	2,478	5,994	6,057	2,415
Denver Laboratory									
AEC	1,058	746	1,333	279	146	305	2,386	2,027	664
Plants and soils	558	1,142	104	1	—	2,203	535	2,552	186
Colorado Plateau sandstones	639	1,813	536	280	44	1,765	1,520	1,547	1,738
Sandstones–Other than Plat.	274	570	255	135	62	472	928	783	617
Veins, igneous rocks	73	136	79	159	21	212	444	503	153
Carbonaceous rocks	176	309	85	90	45	397	207	402	202
Phosphates	2	4	2	—	—	13	17	13	17
Waters	365	533	2	32	—	214	68	245	37
Public samples	58	5	55	8	2	50	65	88	27
Geochemistry of uranium	43	223	2	13	5	56	68	53	71
Miscellaneous	245	608	360	80	91	611	1,579	1,409	781
Total	3,491	6,089	2,813	1,077	416	6,298	7,817	9,608	4,493
Grand Total	6,583	12,013	4,960	2,227	1,347	8,776	13,781	15,665	6,908

Experiments designed to ascertain the best method of counting samples of lignite were undertaken during the period. Using both a lignite sample and a counting standard, samples were formed by filling containers differing only in height, or by forming pellets at a pressure of 10,000 pounds per square inch corresponding to the same heights. Preliminary results, expressed in table 26, show that pelleting is not only more stable, but in general yields higher results as might be expected from greater sample weights contained in the pellets for identical heights.

Table 26.--Results of two methods of sample preparation for radioactivity counting (as percent eU)

Method	Sample height in inches				
	1/8	1/4	3/8	1/2	5/8
Filling and leveling	.69	.77	.85	.74	.80
Pelleting	.85	.88	.82	.85	.91

Consideration of the entire operation of sample splitting leads to the following enumeration of qualities desirable in a splitter:

1. Size of sample to be split should have a wide range.
2. The splitter should be capable of sampling a wide variety of grain sizes.
3. The time required for the operation should approach a minimum.
4. All particles in the mass to be sampled should have an equal chance of being sampled.
5. The sampler should be of simple design, easily cleaned, and require a minimum of maintenance.

Consideration of these qualities in addition to the efficient operation of the multiple cone sample splitter and the recommendation above that the amount of sample split off should be small, have led to the design of an inverted cone splitter which may be used for either powders or grains. The splitter is a 60° cone on its base with four slits, at 90°, cut radially into the surface. Tests with a -100 mesh sample of crushed monzonite indicate that the device takes a 13.22 ± percent split of the sample.

The following report was published during the period:

Smith, W. L., and Flanagan, F. J., 1956, Use of statistical methods to detect radioactivity change due to weathering of a granite: Am. Jour. Science, v. 254, p. 316-324.

Research
By F. E. Sentfle and J. N. Rosholt

Emphasis on radioactivity research at the Washington laboratory during the report period has been directed toward studies of equilibrium and the measurement of daughter products in ores and minerals by gamma-ray spectroscopy. A substantial amount of instrumental research has been done, and two three-channel gamma-ray spectrometers have been built. Studies of ways to increase the sensitivity and resolution of the spectrometers were also made, and various phosphors and phosphor cells were experimented with in order to enhance the resolution.

It is planned to construct a scintillation ratemeter for fast assay work. One of the objectives is development of a composite crystal for the instrument; a number of small composite crystals have already been constructed and appear to be satisfactory.

Fundamental studies of the gamma-ray spectrum of the uranium series were made during the period. From preliminary investigations, using samples from the Wind River Basin, Wyoming, it appears that one of the major causes of disequilibrium is the movement of thorium as well as radium by a leaching process.

At the Denver laboratories results of all of the complete radiochemical analyses of disequilibrium samples performed to April 1956 were tabulated and classified according to type of disequilibrium, irrespective of location. The results of 97 widely distributed samples exhibiting uranium series disequilibrium representing most of the western part of the United States are shown in figure 59. By the use of analyses of the key isotopes $U^{238}+U^{235}$, Pa^{231}, Th^{230}, and Ra^{226}, these samples are tentatively classified according to six basic types of disequilibrium.

The first column in figure 59 shows the tentative name for the type of disequilibrium. The second column gives the number of samples analyzed and found to represent the appropriate type. The equivalent abundance ratios are the average value for this number of samples. In the columns under the title of equivalent abundance ratios, the first four rows show the comparison of equivalent daughter content to uranium content, the U/U ratio being 1; the first row represents the hypothetical sample of perfect equilibrium. The second, third, and fourth rows represent samples which are primarily deficient in daughter products of uranium. The fifth, sixth, and seventh rows represent disequilibrium samples which are the complement of the former three, all being deficient in uranium. In the last three rows uranium and all of the equivalent daughter product abundances are compared to equivalent Ra^{226}, the eRa^{226}/eRa^{226} ratio being 1.

The six types of disequilibrium are described below:

Type 1 - Daughter product deficiency is represented by samples where uranium is greater than equivalent Pa^{231} which is greater than equivalent Th^{230} which is greater than equivalent Ra^{226}. Here the most common cause of disequilibrium is usually the preferentially greater leaching of or removal of daughters compared to uranium removal.

Type 2 - The related daughter product deficiency is a special type of disequilibrium where each of these daughter abundances must retain specific relations with the others. This relation must be such that the ratio of

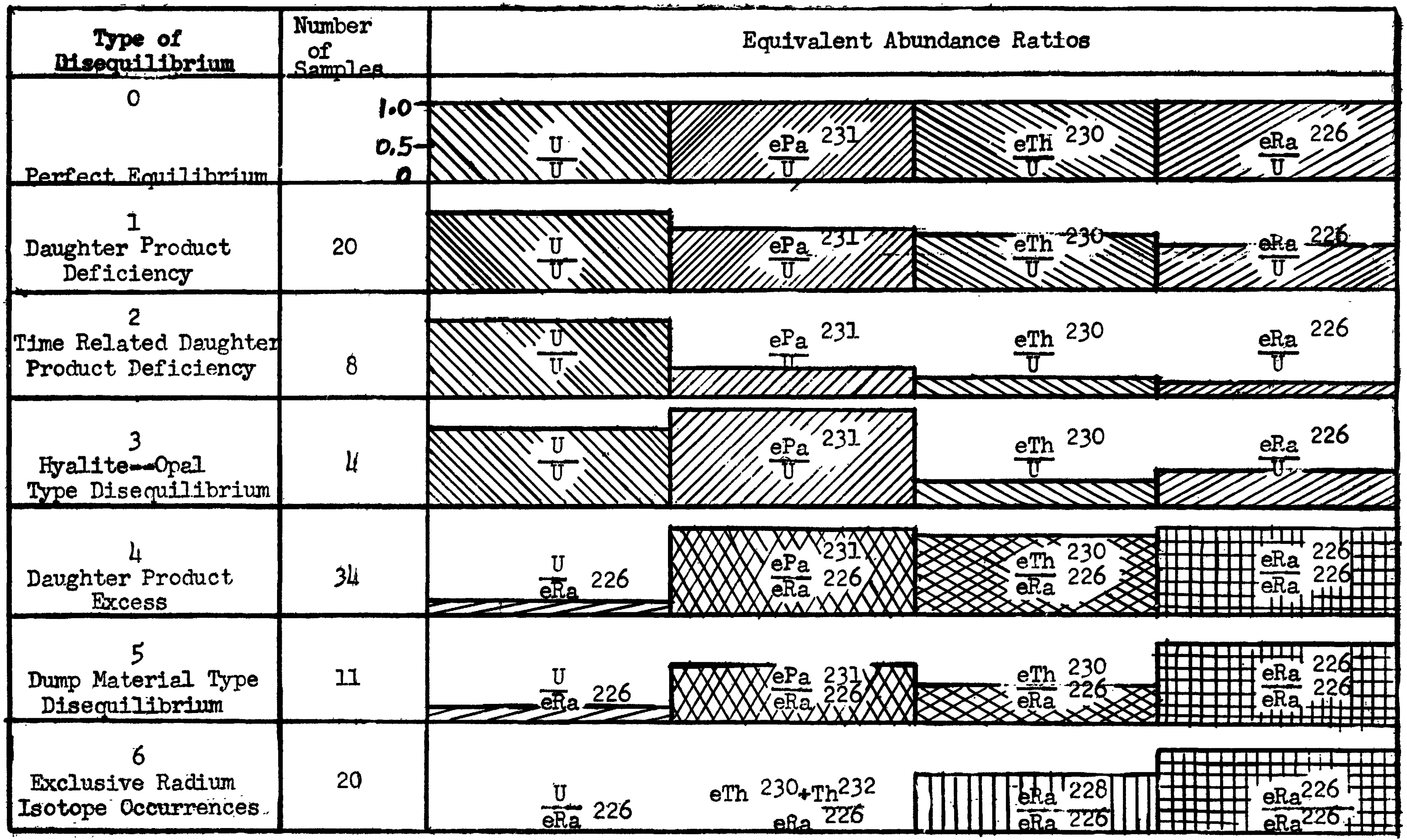


Figure 59.—Disequilibrium Classification

ePa^{231}/U, eTh^{230}/U and eRa^{226}/U will each represent the amount of daughter products which would build up under pure uranium in the same interval of time, for example 20,000 years. Many of the samples which fall into this category are believed to be the result of deposition of radioactively pure uranium with little or no subsequent leaching prior to the time of sample collection.

Type 3 - Hyalite-opal type disequilibrium is represented by samples in which equivalent Pa^{231} is greater than uranium which is greater than equivalent Ra^{226} which is usually much greater than equivalent Th^{230}, the key isotope being the anomalously low Th^{230}. Samples of this type are believed to be the result of rather recent deposition of uranium contaminated with significant amounts of daughter products. It was named after a sample which was known to be of relatively recent deposition with the formation of hyalite opal.

Type 4 - Daughter product excess is represented by low uranium content while the remaining longer-lived daughters are present in approximately equilibrium amounts with respect to each other. A great number of the anomalously high activity samples fall into this category. At this stage in the study of disequilibrium, it usually is not possible to tell with any degree of assurance whether the uranium was leached or the daughter products were added on this type of sample.

Type 5 - Dump material type disequilibrium is a special case of daughter product excess where equivalent Ra^{226} is greater than equivalent Pa^{231} which is greater than equivalent Th^{230} which is usually much greater than uranium. All of the samples represented by this type of disequilibrium are known to come from pyritic mines or mine dumps and are the result of differential leaching of all components. The sulfuric acid solutions which are produced in these materials will have a great tendency to retain the radium even though it may migrate somewhat; also the acid will enhance the leaching of uranium.

Type 6 - Exclusive radium isotope occurrence is a peculiar and not too uncommon deposition type in certain localities. Here a radium isotope in the Th^{232} series is introduced; Ra^{228}, since its occurrence is nearly as common as Ra^{226}. The radioactive components are radium isotopes with very little or no uranium, Th^{230}, Pa^{231}, or Th^{232}, and are often closely associated with oil field brines. Some highly radioactive deposits are definitely believed to be the result of coprecipitation of radium with barium sulfate, strontium sulfate, and occasionally iron hydroxide from large volumes of water. This type is also found in hot springs deposits. It is also believed that the reason for the prevalence of deposition of radioactively pure radium isotopes is that the large volume of water contains only radium as a significant radioactive component at this stage. It should also be noted that samples containing significant Ra^{228} must be of very recent origin; that is, less than 30 or 35 years old.

The following paper was published during the period:

Sentfle, F. E., and Farley, T. A., 1956, Use of argon as a counting gas at -183°C: Rev. Sci. Inst., v. 27, no. 4, p. 238.

References

Faul, Henry, Ed., 1954, Nuclear Geology, New York, John Wiley & Sons, p. 12.

Friedlander, G., and Kennedy, J. W., 1949, Introduction to radiochemistry: New York, John Wiley & Sons, p. 12, 14.

Spectrography

Services
By C. L. Waring and A. T. Myers

During the report period, 138,596 spectrographic determinations were made on 2,227 samples at the Washington and Denver laboratories. A wide variety of geologic materials were analyzed by semiquantitative methods, including igneous rocks of many types, vein material, uranium and other ore pulps, sediments including shales, lignites and phosphates, crude oil ashes and asphalts, and water residues. Interest continued in the mineral types of samples, particularly uranium, multiple oxides, and species containing rare earths. Some samples are suspected to contain new minerals such as santafeite (a vanadium-manganese mineral), vesignieite (a vanadium-copper-barium mineral), and a vanadium calcite mineral.

Powder standards for semiquantitative spectrographic methods were prepared and checked during the period. These standards will be used for standardizing procedures and will result in the laboratories' reporting to one-half of the decimal magnitude.

Research and methods development
By A. T. Myers and C. L. Waring

Minor elements in low-rank coal

The distribution of 27 minor elements was studied in the ashes of 319 samples of low-rank coals from Texas, Colorado, North Dakota, and South Dakota. Semiquantitative spectrographic and chemical procedures were applied to the ashes of these coals to learn what elements if any were correlated with uranium, and also to determine any element present at concentrations which might be commercially exploitable. The studies show that boron, barium and strontium are enriched in all of the ashes analyzed. A possible correlation between uranium and molybdenum was indicated for the Dakota coals. The coals from Milam County, Texas, showed high concentrations of tin, copper, and zirconium.

Selenium

Investigations of the minor element content of sulfides associated with uranium ore from sandstone-type deposits show that selenium commonly substitutes for sulfur. Many sulfide concentrations represent a primary deposit of selenium and such concentrations associated with uranium ore deposits might furnish an economic source of selenium.

Selenium normally is not a very sensitive element spectrographically, requiring about 5 percent for detection. As a result of recent spectrographic experiments, this element can now be detected at 0.0015 percent, which will cover most of the samples received for selenium determinations with the exception of sulfides from the Chinle and Shinarump formations of the Triassic age; some of these sulfides contain less than 3 ppm selenium.

Rapid scanning microphotometry

A direct reading microphotometer, the construction of which was described in the last semiannual report (TEI-590, p. 302) was applied to semiquantitative spectrographic analysis. Standard plates for 60 elements were prepared and recordings made. Percentages of the elements in the standards decrease or increase in 18 concentration steps per element. A spectrum line study is in progress using the recordings.

The following papers were published during the period:

Canney, F. C., Myers, A. T., and Ward, F. N., 1955, A truck-mounted spectrographic laboratory for use in geochemical exploration-a preliminary report (abs.): Econ. Geology, v. 50, no. 7, p. 768-769.

Waring, C. L., and Worthing, H. W., 1956, A spectrographic method for determining the hafnium-zirconium ratio in zircon: U. S. Geol. Survey Bull. 1036-F.

Infrared spectroscopy
By R. G. Milkey

The work of the project was generally along lines of activity defined in previous reports (TEI-540, p. 223-224; TEI-590, p. 302-304), and comprised services, research, and accumulation of infrared standard spectra and other reference data.

Organic samples analyzed were generally the organic extracts of various carbonaceous rocks, coals, oils, shales, and asphaltic sandstones. They were usually obtained by solvent extraction, or by mechanical separation of organic from mineral matter, and contained a complexity of materials. The infrared spectra were useful for comparing differences in composition, and for defining the various unit structures present, such as hydroxyl, methyl, and methylene, carbonyl, and aliphatic and/or aromatic groups. The more recent use of chromatographic columns to obtain elution fractions promises to be useful in identifying these materials. The spectra of one such elution fraction obtained from an oil indicated an extract of phthallic acid, most probably a long-chained ester.

Synthetic carnotite was analyzed as well as its sodium, lithium, cesium, rubidium, and thallium analogs, and the general similarity of spectra indicated that their overall structures are similar. Their anionic layers remained substantially unaffected by the cationic substitutions.

Process control by means of infrared absorption was provided for samples from an industrial liquid-liquid extraction process conducted by the AEC.

Several research studies were continued, as follows: (1) the work on tectosilicates continued, bringing the total studied to date to 50; (2) investigation was made of variables which affect the sampling of solid materials by use of finely-divided potassium bromide as an imbedding medium;

and (3) a total of 48 vanadate compounds were analyzed, and correlations will be made between the absorption features of these spectra.

Chemistry

Services
By Irving May and L. F. Rader, Jr.

During the period, 13,996 chemical determinations on 7,587 samples were made at the Washington and Denver laboratories. A breakdown of the analyses by types is given in table 27.

A direct-dilution fluorimetric method for the rapid determination of uranium in the field was set up for use of the Spokane, Washington, AEC sub-office. A weighed portion of sample pulp is fused with a scoop of carbonate-fluoride flux, a small center portion from the flux pad is punched out and refused with additional flux. The fluorescence intensity of the final melt is observed visually. About 50 samples per man-day can be analyzed with a precision of ± 0.01 percent U_3O_8 in the range 0.01 to 1.0 percent U_3O_8. The equivalent of 1.0 to 5.0 milligrams of pulp in the final fusion is used depending on the concentrations and kinds of quenching elements present in the sample.

The application of radioactive tracers to the study of the efficiency of various separation procedures was begun. Cobalt 60 was used in connection with cobalt and nickel, and antimony 124 for studies of procedures for the determination of antimony. The tracer method shows that from 10 to 50 percent of the antimony is not dissolved after fusion according to a recommended procedure.

Table 27.—Completed chemical determinations
December 1, 1955-May 31, 1955

Determination	Completed the past six months	Determination	Completed the past six months
Uranium	5,742	Vanadium	448
Thorium	67	Calcium carbonate	175
Silicon	61	Gold	37
Iron	139	Silver	37
Rare earths	17	Copper	668
Magnesium	207	Zinc	13
Calcium	376	Lead	6
Strontium	104	Titanium	15
Sodium	128	Molybdenum	87
Potassium	128	Manganese	127
Hydrogen	37	Cobalt	25
Water	18	Nickel	25
Carbon	100	Platinum	2
Carbon dioxide	37	Barium	18
Bicarbonate	197	Lithium	18
Phosphorus	728	Carbonate	111
Sulfur	230	Fluorine	50
Selenium	1,467	Antimony	26
Arsenic	561	Nitrogen	28
Chlorine	119	Aluminum	11
Ash	782	Acid. insol.	17
Carbon isolation	36	pH	316
Boron	86	Sulfate	11
Miscellaneous	358	Total	13,996

Totals given in this table will not necessarily agree with those of table 25, Analytical service and sample inventory, because of time lag between laboratory completion and summary compilations in Sample Control audits.

A method was developed for greatly reducing the interference of chromium in the colorimetric determination of phosphorus as the molybdivanadophosphate.

A semi-micro carbon and hydrogen train was set up and is being used for routine carbon and hydrogen determinations where an adequate sample is available.

Research

The analytical chemistry of thorium, by M. H. Fletcher and F. S. Grimaldi

Studies on the precipitation of thorium iodate from nitric acid medium containing tartaric acid, hydrogen peroxide, and 8-hydroxyquinoline were completed. By this means one microgram or more of ThO_2 is separated in one step from up to 30,000 times that amount of rare earths, Ti, Nb, Ta, Zr, Fe, and Sc. This separation procedure combined with the spectrophotometric determination of thorium according to the thoron-mesotartaric acid method developed by the writers was successfully applied to the rapid determination of 0.001 percent ThO_2 or more in silicate rock, and 0.01 percent ThO_2 or more in a wide variety of thorium ores.

The application of the thoron-mesotartaric acid spectrophotometric procedure was extended to the direct determination of thorium in zircon.

Work is in progress to attain the final objective—the determination of 0.0001 percent ThO_2 (and possibly less) in rocks.

The determination of lead in standard granite sample G-1, by R. A. Powell and J. J. Warr

Preliminary work was completed on the cooperative investigation of the lead content of standard granite sample G-1.

One gram samples were taken with a spatula from five bottles of sample G-1, chosen at random, and lead determinations were made with results as follows:

Sample No.	Lead found (ppm)	Average
G1-A	47,49,51,51,46,50	49
G1-B	47,46	46.5
G1-C	48,48	48
G1-D	49,46	47.5
G1-E	44,46	45

Further lead determinations will be made on special sample splits of G-1 which will be submitted to this and other cooperating laboratories.

The determination of calcium and magnesium in phosphate rock, by C. A. Kinser and R. A. Powell

The automatic titration apparatus was applied to the versene titration of calcium and magnesium. Good repeatability and accuracy were obtained on standard calcium and magnesium solutions and on NBS standard dolomite. Studies are in progress on the application of this method to the determination of calcium and magnesium in phosphate rock. Preliminary studies were made to determine the amounts of phosphorus, iron, and aluminum that can be tolerated in a direct titration method without incurring an error greater than one percent. The data indicated that for a generally applicable procedure the above elements must be separated.

The determination of uranium by spectrophotometric methods, by H. I. Feinstein

A new reagent for the spectrophotometric determination of uranium, thenoyltrifluoracetone (TTA), is now being investigated. The reaction is between 5 and 6 times as sensitive and the product more stable than thiocyanate. Optimum cenditions were established for the reaction with pure uranium solutions. The reagent is being evaluated for use in the determination of uranium in rocks and ores.

The following papers on research on methods of chemical analyses were published during the period:

Grimaldi, F. S., Ingram, Blanche, and Cuttitta, Frank, 1955, The determination of large and small amounts of fluorine in rocks: Anal. Chemistry, v. 27, p. 918-921.

Grimaldi, F. S., and Fletcher, M. H., 1956, The thoron-tartaric acid systems for the spectrophotometric determination of thorium: Anal. Chemistry, v. 28, 812-816.

Parshall, E. E., and Rader, L. F., Jr., 1955, Diagrams for construction of Model 1954 transmission and reflection fluorimeter: U. S. Geol. Survey Open File Report.

GEOCHEMICAL AND PETROLOGIC RESEARCH ON BASIC PRINCIPLES

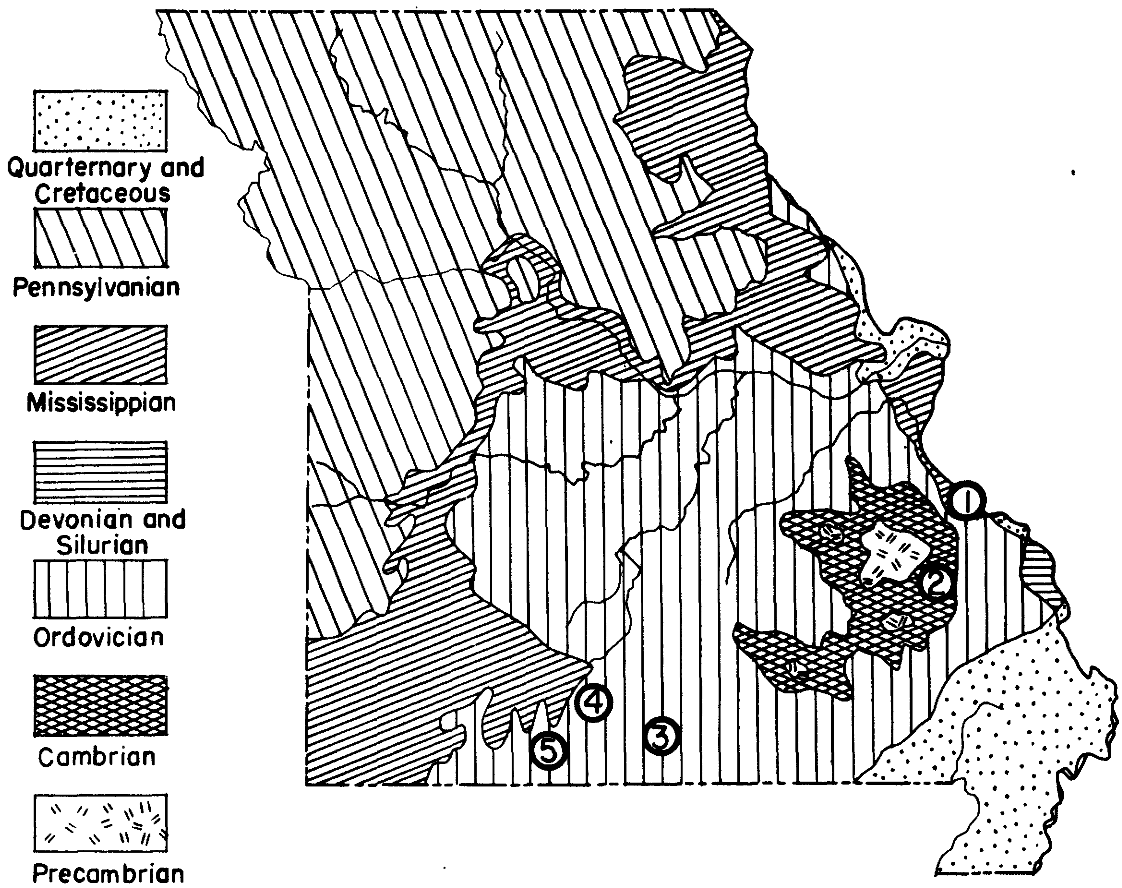
Radon and helium studies

By A. P. Pierce

Field and laboratory studies of the occurrence and distribution of uranium, thorium and their decay products in oil and gas bearing rocks during the period included visits to several asphaltite occurrences on the flanks of the Ozark Uplift in southern Missouri, on the west flank of the Delaware Basin near Carlsbad, New Mexico, and in the San Rafael Swell, Utah.

Uraniferous asphaltite occurrences that have been noted in marine sediments occur typically in thin bedded dolomites and sandstones that were deposited in shelf environments in some areas have an associated evaporite facies. Widespread occurrences of uraniferous asphaltite have been found in marine carbonate-evaporite facies of Wolfcamp and Leonard age along the Amarillo-Wichita uplift of Texas and Oklahoma; in the marine carbonate-evaporite facies of Leonard and Guadalupe age on the east flank of the Big Horn Basin, Wyoming; and throughout the Guadalupe marine carbonate-evaporite facies in the back reef sediments of the Delaware Basin, New Mexico. Although the asphaltite nodules in these occurrences are clearly of epigenetic origin, their extensive association with Permian carbonate-evaporite facies suggests that uranium is frequently mobilized and redistributed along with petroleum and natural gas during diagenesis of these kinds of rocks.

A similar history is indicated for a number of uraniferous asphaltite occurrences in formations of Paleozoic age of southern Missouri, which are shown in figure 60. At Mine la Motte, Missouri nodules of uraniferous asphaltite associated with galena occur in basal sandstones of the Cambrian Bonneterre dolomite. Near Ava, Dora and Forsyth, Missouri, nodules of



1. Bussen's Quarry, St. Genevieve County. Asphaltite seams in Mississippian Spergen.
2. Mine La Motte, near Fredericktown, Madison County. Asphaltite nodules in Cambrian Bonneterre-Lamotte.
3. Ozark County, near town of Dora. Asphaltite nodules and pellets in Ordovician Ronbidoux.
4. Douglas County, near town of Ava. Asphaltite nodules and pellets in Ordovician Ronbidoux.
5. Forsyth, Taney County. Asphaltite pellets in Ordovician Jefferson City.

FIGURE 60 GENERALIZED GEOLOGIC MAP OF MISSOURI SHOWING LOCALITIES AT WHICH URANIUM-BEARING ASPHALTITE WAS EXAMINED.

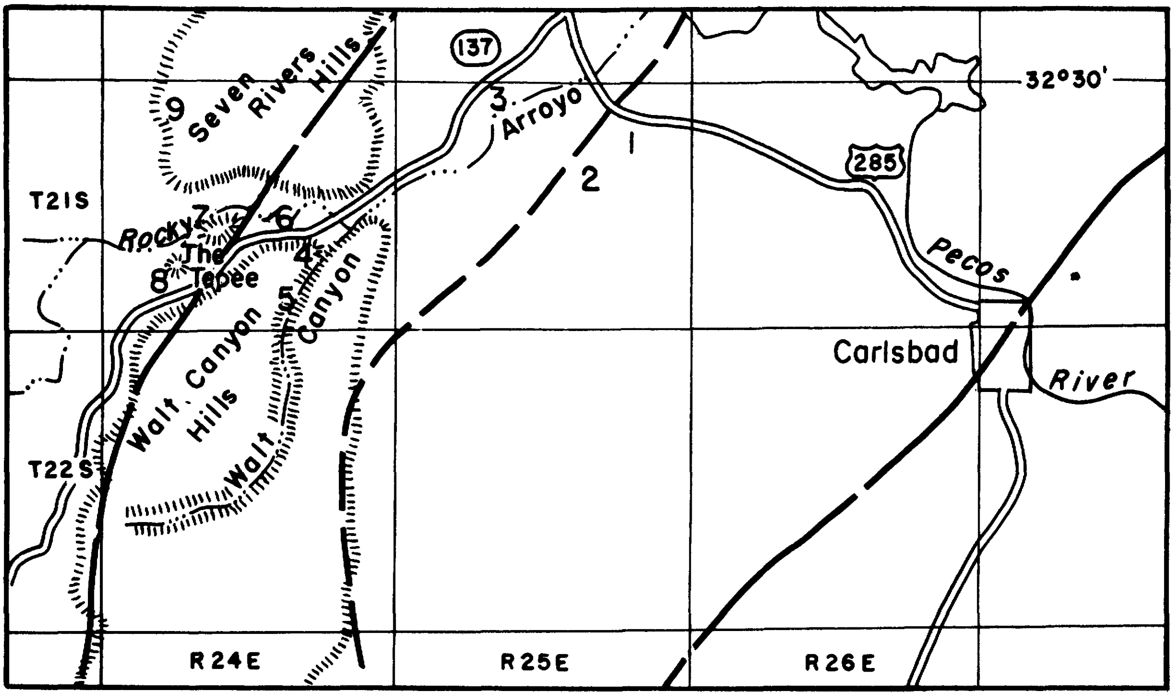
70 35 0 70 Miles

Approximate scale

uraniferous asphaltite are associated with chert and clay in thin-bedded dolomites of the Roubidoux and Jefferson City formations of Ordovician age. Uraniferous carbonaceous stylolitic fillings occur in the Spergen limestone of Mississippian age at Bussen's Quarry near St. Genevieve, Missouri.

A detailed study was made of uraniferous asphaltite occurrences in the back reef sediments of the Delaware Basin shown in figure 61. Asphaltite mineralization of dolomites in this area has been controlled by bedding planes, stylolites, fractures, fossil molds, and intracrystalline porosity. Petroleum extracted from the rock contains 150 ppm of uranium, as against 2.8 percent uranium in the solid asphaltite nodules and about 10 ppm uranium in their host rocks. Gastropod molds filled with uraniferous petroleum are coated with a more intensely uraniferous asphaltite that is evidently in the process of being precipitated from the petroleum filling the molds.

The most striking geologic feature in the formations of Guadalupe age of this area are the abrupt lateral changes in lithology between predominantly sulfate deposits to the west and carbonate deposits to the east. The carbonate-sulfate facies changes, which are only several miles wide, have moved progressively eastward in the younger formations as is shown in figure 61. These facies changes appear to have been an important geochemical control during mineralization of the rocks by the uraniferous asphaltites and associated minerals. Asphaltite nodules occurring in dolomites nearest to the carbonate-sulfate contacts are associated with galena, malachite, and azurite, and are encased or "armored" by shells of pyrite that has apparently been reduced against the asphaltite from associated sulfate solutions, whereas asphaltite nodules occurring at greater distances from the carbonate-sulfate contacts are not associated with sulfide minerals.



EXPLANATION

Yates } Carbonate-Sulphate contacts
Seven Rivers } Carbonate-Sulphate contacts
Capitan Reef front

1. Road cut in Yates formation. Asphaltite nodules (some associated with galena) in dolomite.
2. Copper prospect in Yates formation. Asphatite nodules (some associated with pyrite) in dolomite.
3. Ratcliff-Black Simmons # 1 (dry hole). Asphaltite in sandstone in Yates and Seven Rivers (or Queens) formations.
4. Pitt's adit in Seven Rivers formation. Asphaltite nodules and seams in dolomite.
5. Asphaltite nodules associated with uraniferous oil in fossil molds in dolomite beds in Seven Rivers formation.
6. Interstitial asphaltite associated with petroliferous sandstone in Seven Rivers formation.
7. Asphaltite nodules in dolomite in Seven Rivers formation.
8. Asphaltite nodules (many associated with pyrite) in dolomite in Seven Rivers formation.
9. Malco-Resler #1 Riggs Federal well (dry hole). Asphaltite in sandstone in Seven Rivers (or Queens) formations.

FIGURE 61-MAP SHOWING LOCATION OF KNOWN OCCURRENCE OF URANIUM-BEARING ASPHALTITE NEAR CARLSBAD, NEW MEXICO AND CARBONATE-SULPHATE CONTACTS OF YATES AND SEVEN RIVERS FORMATIONS.

4 0 4 Miles

A study of organic analyses that have been obtained upon a suite of uranium and thorium bearing asphaltite nodules from twelve separate geologic occurrences indicate a progressive loss of hydrogen with increasing age and uranium and thorium content. The carbon:hydrogen ratios of the asphaltites appear to increase as a function of the total radiation flux to which the samples have been exposed since the time of mineralization. Altogether, the data suggest that the asphaltites in common have been derived from organic source materials containing saturated carbon bonds, such as natural asphalt of petroleum.

The isotopic composition of radium was determined in brines collected from the Panhandle Field, Texas, the Augusta Field, Kansas, and from a brine well near Avant, Oklahoma. Analyses were obtained of the Ra^{223}, Ra^{226}, Ra^{224}, and Ra^{228} contents of the brines. The relative amounts of these isotopes present in each of the brines were such that the radium must have been in equilibrium with its parent radio-elements in the rock only several days prior to collection of the samples. Because of the short time available for radium migration, the radium parents must be located in the immediate pores of the rocks from which the waters are produced. The results suggest that the magnitude of radium concentrations in such waters reflects the extent to which uranium and thorium are enriched in permeable rock openings.

Distribution of uranium in igneous complexes

By George Phair

Precambrian granites of the Colorado Front Range

Results of uranium analyses on samples collected during the 1955 field season permit a preliminary comparison to be made among some of the major bodies of "Silver Plume" granite in the Front Range. These data are summarized in figure 62. As might be expected, the larger the intrusion the greater the variability in uranium contents. All bodies regardless of size that have been sufficiently sampled show approximately the same lower cut off in uranium content (about 3 ppm), but the upward range of variation and the proportion of "highs" increases with size of the intrusion sampled. There thus appears to be a rather uniform base level below which the uranium content can not readily drop, but above which the original uranium content can be supplemented by a variety of igneous processes operating locally. The base level itself is probably fixed by processes of magmatic differentiation, but the reasons for the upward variations are not yet clear.

Data on four widely separated "Silver Plume" granite dikes that cut the Boulder Creek batholith are also included in figure 62. Although all of these dikes contain more uranium than the adjacent Boulder Creek rocks, they follow the pattern of uranium distribution observed throughout the batholith. The two dikes from the uranium-poor western and northern border zones of the batholith approach the 3 ppm uranium cut off. A third dike from the northern half of the interior, like its batholithic wall rocks, has an intermediate uranium content. A fourth dike from the southern half of the interior like its igneous country rocks, contains relatively high quantities of uranium.

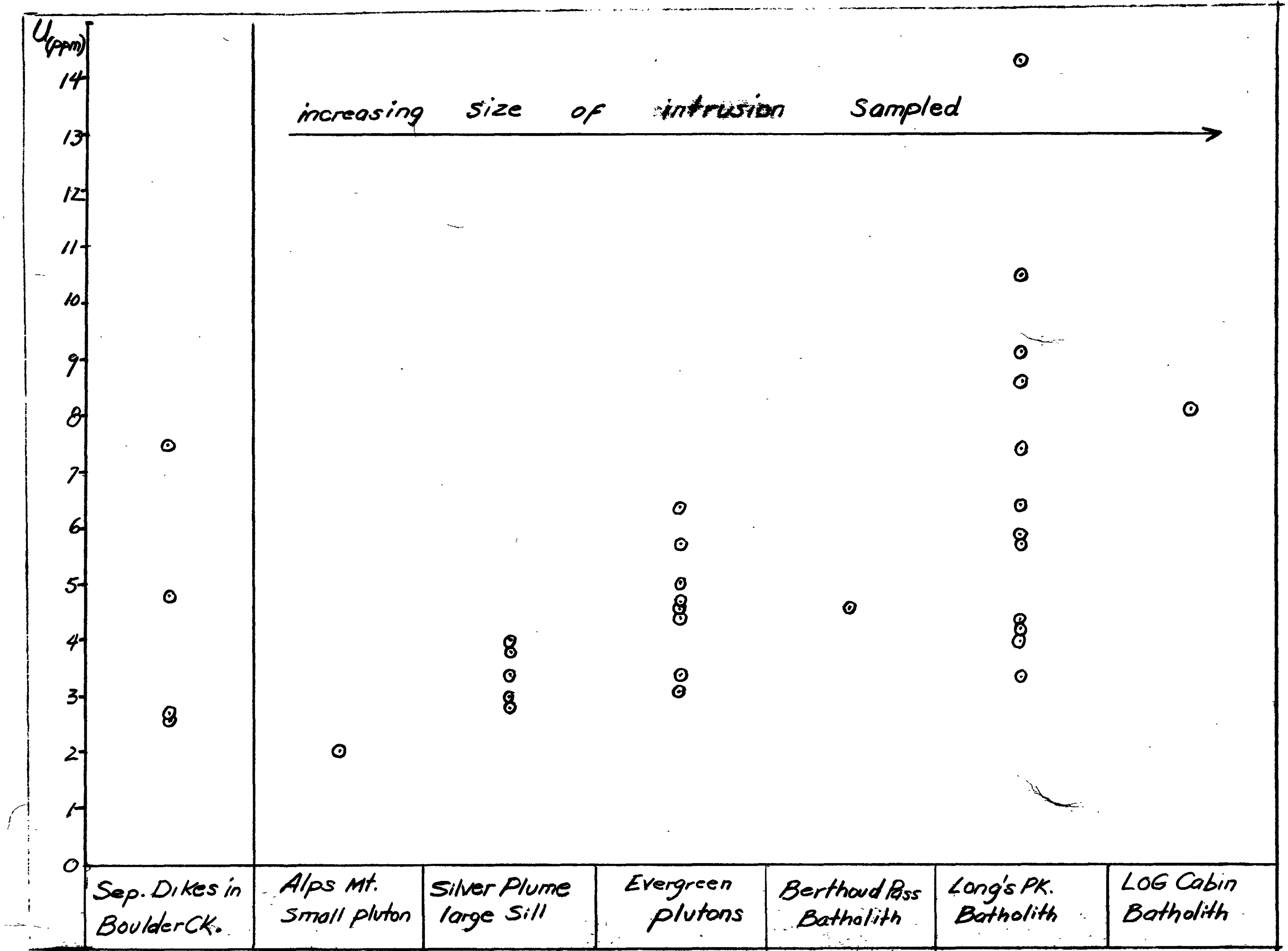


Fig. 62. Uranium Contents of 'Silver Plume' Intrusives.

Heretofore, in the absence of adequate data on trace element variation in a rock type within a single intrusive or between separate intrusions of the same rock type, the assumption commonly has been made that the variations were completely unsystematic. One of the results of studies of the Front Range rocks has been the demonstration of the fact that regional uranium patterns do exist within a particular rock type.

The Boulder Creek Batholith

The distribution of uranium in eighty 25-pound samples of the calc-alkalic rocks of the Boulder Creek Batholith is shown graphically on figure 63. As in the "Silver Plume" granites, a regional variation is evident. For each of the four major rock types recognized the average uranium content varies with geographic location within the batholith approximately as follows: interior southern half > interior northern half > northern border > western border. Although a variety of rock types is present in each of the areas, the uranium content of all rocks in a particular area is roughly determined by that of the predominant rock type. For example, quartz monzonites in an area of predominant granodiorite average distinctly lower in uranium content than do the quartz monzonites in an area of predominant granite. Nevertheless for any one area systematic differences are preserved and the order of increasing average uranium content is nearly always the same: quartz diorite < granodiorite < quartz monzonite < granite. Apparently the fractionation of uranium, like the magmatic differentiation of the major rock types, has proceeded in the same direction in all areas but to varying degrees in different areas.

Data on the alpha activity of zircon and on the uranium content of apatite in the different rock types of the Boulder Creek Batholith are summarized in

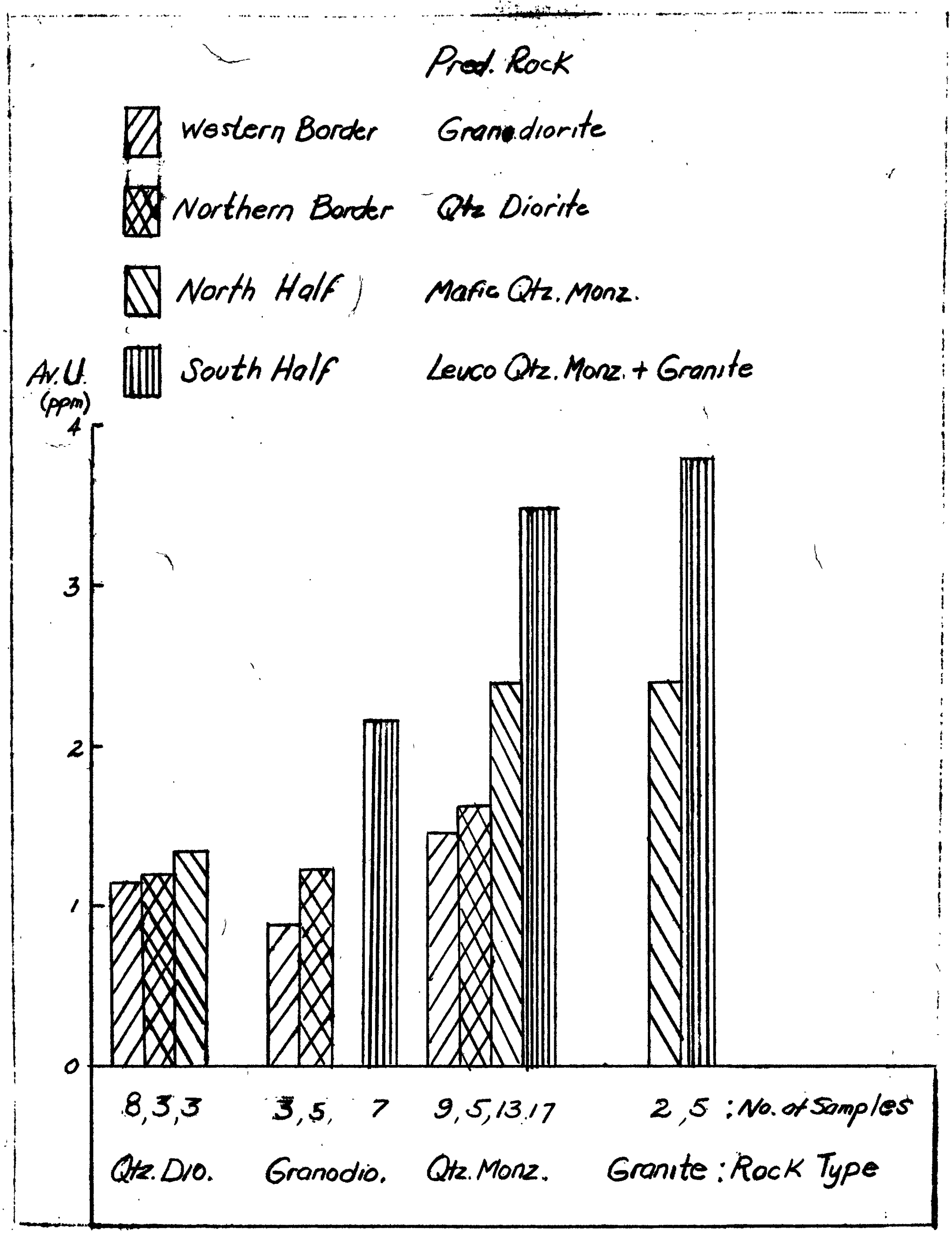


Fig. 63. Geographical Distribution of Uranium in the Rocks of the Boulder Creek Batholith, Colorado.

table 28. Although the individual results show a rather wide scatter

Table 28.—Alpha activity of zircon[1] from rocks of the Boulder Creek Batholith

Rock type[2]	No. of samples	Range (α's/mg/hr)	Average (α's/mg/hr)
quartz diorite	2	162-283	233
granodiorites	4	225-353	286
bio-qtz monzonite	7	285-416	359
hbl-bio qtz monzonite	9	224-833	383
hbl-bio granite	1	—	292
bio granite	2	538-860	699

II Uranium content of apatite (analyst: R. Clarke)

		U (ppm)	Average U (ppm)
quartz diorite	1	—	49
granodiorite	2	11-69	40
bio-qtz monzonite	2	44-48	46
hbl brg bio qtz monzonite	1	—	53
hbl-bio granite	1	—	23

1/ 100-200 mesh fractions of zircon
2/ field names

the average alpha activity of the zircon increases progressively with magmatic differentiation in the order: quartz diorite < granodiorite < quartz monzonite < granite. When the alpha activities of the individual zircon samples are plotted against the uranium contents of the containing rocks the points fall within a broad, but generally rising, belt. The individual uranium contents of the apatite samples, when plotted against the uranium contents of the containing rocks, fall with one exception on, or close to, a smooth curve. The one exception is an apatite from a granite containing an unusually large amount of uranium (5.3 ppm). Since the uranium content of the apatite increases systematically with uranium content of the bulk rock even though the apatite itself contributes less than 3 percent of the total uranium in the rock, a magmatic or late magmatic origin for the uranium in the rock is strongly indicated.

This reduces the possibility that the variability in uranium content shown by any one rock type can be explained on the basis of introduction of foreign uranium, or of leaching of "labile" uranium brought about by pervasive weathering or hydrothermal solutions. It is possible that such "wandering uranium" may account for the high uranium contents of some rocks containing more than 5 ppm uranium.

The study of the distribution of uranium in the rocks and accessory minerals of the Boulder Creek Batholith has been closely tied to the geology. Distribution of the several rock types has been plotted on an outline map, and zones of metamorphism and of assimilation have been delineated. The complex Boulder Creek Batholith thus provides a convenient testing ground for finding out just what the alpha/lead ages of zircons mean under specified conditions of differentiation, assimilation, regional metamorphism, and local cataclastic metamorphism.

Alpha/lead ages of zircon samples from 24 rocks of the Boulder Creek Batholith, calculated according to the simplified age equation, $Age_{my} \doteq \frac{2400\ Pb}{\alpha/mg/hr}$, and therefore approximate, are plotted in figure 64. From this plot these conclusions seem warranted at this time:

(1) Regardless of rock type, the strongly crushed rocks–augen gneisses, flaser gneisses, etc.—give the youngest ages.

(2) Zircon samples from the crushed rocks contain less than 100 ppm Pb whereas the zircon samples from their uncrushed analogues with one exception contain more than 100 ppm Pb. Hence the logical explanation for the low ages lies in the loss of lead during cataclastic deformation rather than in the addition of radioactive constituents.

(3) No significant age differences are shown by zircon from massive rocks and those from foliated but uncrushed rocks. In part such foliation

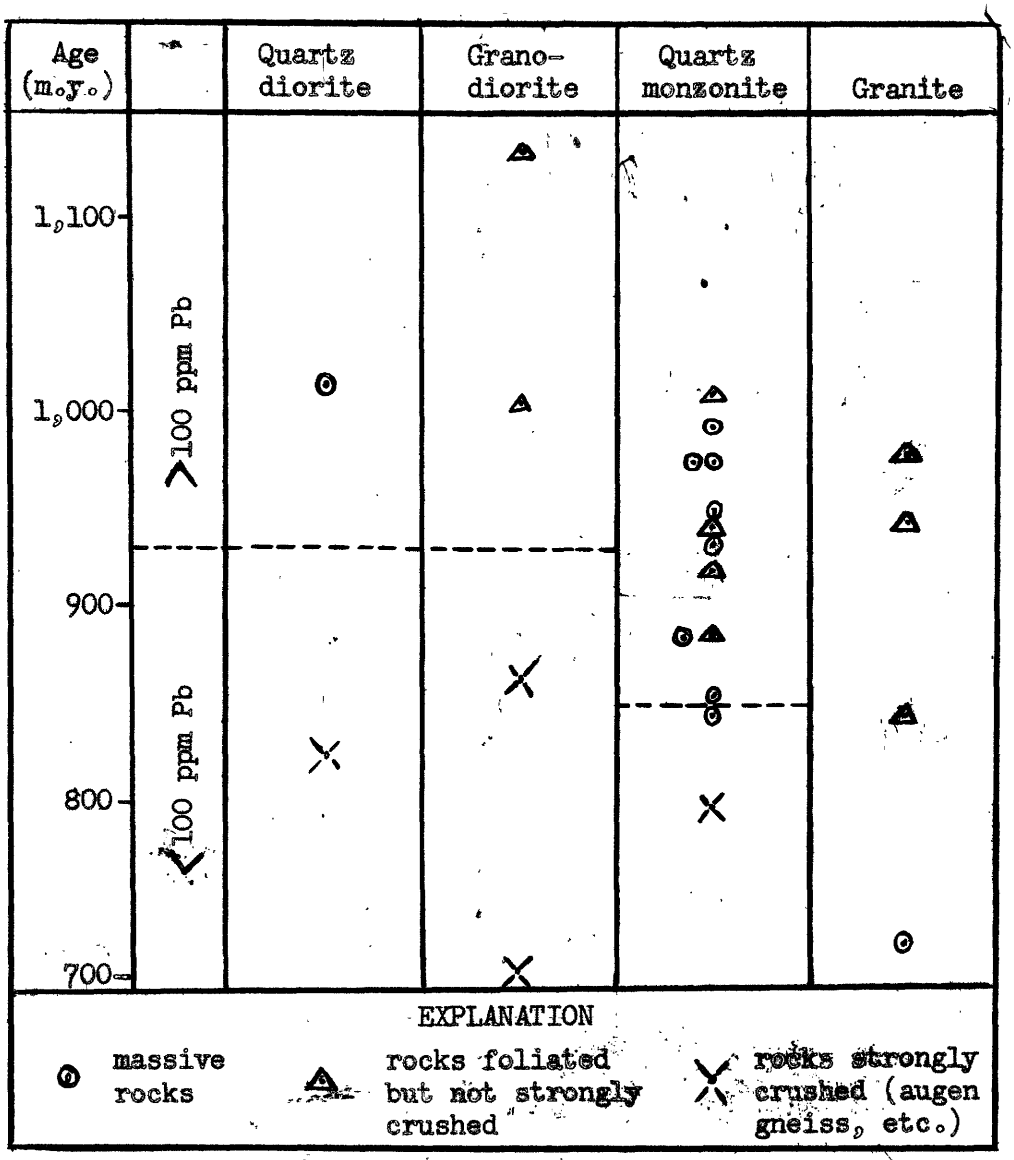


Fig. 64.—Alpha/lead ages of zircon samples from the rocks of the Boulder Creek Batholith, California.

has been interpreted as primary.

So far it does not appear that significant differences are introduced by low grade retrograde metamorphism independent of crushing. Such retrograde metamorphism is indicated by the nearly complete replacement of original hornblende by biotite throughout the border phases of the complex. As yet it is not possible to say whether the differences in age between the different rock types in the batholith as suggested in figure 64 are real. The quartz monzonites greatly predominate over all other rocks in this complex, and hence are represented by a relatively large number of analyses (12). Eliminating the one crushed rock, all 11 ages on the quartz monzonites fall in the range 845-1010 million years and average 927 million years, the maximum deviation from the mean being ± 9 percent; well within the 10 percent precision claimed for the method. This level of precision holds in spite of differences in radioactivity of as much as three-fold among the separate samples of zircon. It follows that the contaminating common lead in these samples, if present at all, must be very low, or the unlikely assumption must be made that common lead was introduced into each zircon in an amount proportional to its alpha activity.

White Mountain magma series, New Hampshire

Preliminary study of uranium analyses of samples of granites in the White Mountain magma series, New Hampshire, indicates (1) that biotite granite is about twice as rich in uranium as amphibole granite; (2) that biotite and amphibole granite of the main batholithic mass contain a larger proportion of uranium than corresponding granites of the outlying masses; and (3) that there is no obvious relation between position within the main batholithic mass and concentration of uranium (the mean uranium content of of 14 samples from points less than one mile from the border is 13.0 ppm as compared to 12.5 ppm in 17 samples from the interior of the mass). The data are summarized in table 29.

Table 29.—Uranium contents of granites in the White Mountain magma series, New Hampshire

	Biotite granite		Amphibole granite	
Rock mass	No. of samples	Uranium (mean ppm)	No. of samples	Uranium (mean ppm)
Main batholithic mass	31	12.7	8	6.9
Outlying masses				
Cannon Mtn. stock	2	10.9		
Mad River stock	2	7.4		
Percy Peaks-Pilot Range masses	5	10.6	4	3.0
Other outlying stocks	5	4.5		
Totals and means	45	11.2	12	5.6

The following reports were published during the period:

Gottfried, David, Sentfle, F. E., and Jaffe, Howard, 1955, Further evaluation of the Larsen method of age determination (abs.): Geol. Soc. America Bull., v. 66, p. 1565.

Gottfried, David, Sentfle, F. E., and Waring, C. L., 1956, Age determination of zircon crystals from Ceylon: Am. Mineralogist, v. 41, p. 157-161.

Holland, H., and Gottfried, David, 1955, The effect of nuclear radiation on the structure of zircon: Acta Crystallographica, v. 8, p. 291-300.

Hurley, P. M., and Fairbairn, H. W., 1955, Ratio of thorium to uranium in zircon, sphene, and apatite (abs.): Geol. Soc. America Bull., v. 66, p. 1578.

Hurley, P. M., Larsen, E. S., Jr., and Gottfried, David, 1956, Comparison of radiogenic helium and lead in zircon: Geochimica et Cosmochimica Acta, v. 9, p. 98-102.

Hurley, P. M., 1956, Direct radiometric measurement by gamma-ray scintillation spectrometer: Geol. Soc. America Bull., v. 67, p. 395-411.

Jaffe, Howard, Gottfried, David, and Waring, C. L., 1955, Age determinations of Precambrian through Tertiary igneous rocks by the Larsen method (abs.): Geol. Soc. America Bull., v. 66, p. 1580.

Phair, George, 1956, Notes on the geological cycle of uranium; summary in Chemical and Engineering News, v. 34, p. 326.

Smith, W. L., and Cisney, E. A., 1956, Bastnaesite, an accessory mineral in the Redstone granite from Westerly, Rhode Island: Am. Mineralogist, v. 41, p. 77-81.

Solution chemistry of uranium-bearing minerals

Transportation and deposition of uranium ore-forming minerals

By A. M. Pommer

The ore forming solutions in the Colorado Plateau must have been at equilibrium with the rocks, because the fluids traveled for long distances through the sediments without interaction. Under these conditions the fluids are likely to be alkaline. But thermodynamic considerations indicate that V(III) ions can be transported only under rather acid conditions. This does not rule out a hypogene origin of the vanadium. The reaction

$$V^{+++} + H_2O \rightleftharpoons VO^{++} + H^{+} + 1/2\ H_2$$

proceeds from left to right at elevated temperatures, and hypogene solutions which originally may have contained vanadium(III) and which reached such a temperature at any time during their ascent may be expected to contain V(IV), which can be transported in alkaline solution. If the system is cooled, the reverse reaction cannot take place because the hydrogen gas diffuses out of the system. Similarly, at elevated temperature

$$U^{++++} + 2\ H_2O \rightleftharpoons UO_2^{++} + 2\ H^{+} + H_2$$

and hypogene solutions originally containing U(IV) which at one time reached a temperature of about 1000°C may be expected to contain U(VI). The UO_2^{++} ion can be transported over a wide pH range as uranyl carbonate complex if CO_2 is present. On the basis of these considerations it is postulated that the transportation of vanadium(III) and uranium(IV) is not very likely, and that an alkaline solution containing $HV_2O_5^+$ and $UO_2(CO_3)_2(H_2O)_2^{--}$ ions is a likely ore-forming fluid for uranium-vanadium deposits.

The concepts concerning possible compositions of ore-forming fluids were tested by attempts to prepare minerals typical of the Colorado Plateau ore deposits from V(IV), V(V) and uranyl carbonate solutions. While no known minerals were prepared, solids having X-ray patterns close to duttonite, corvusite, carnotite, and metatyuyamunite were obtained.

A possible fluid capable of depositing copper-uranium ore minerals may contain a carbonate complex of copper and uranium. In this connection, the following solubility data on copper carbonate complexes were obtained (G. B. Magin, Jr., analyst):

Solution	pH	mg Cu/ml solution	mg Na_2CO_3/ml solution
Cu-1	9.1	0.39, 0.40	98.58, 98.57
Cu-2	9.5	0.33, 0.35	107.6, 107.6

Oxidation potential studies on some vanadium clays indicate that the ore-forming fluid in the Morrison formation may have contained vanadium(IV).

Studies on the vanadate systems
By R. F. Marvin

The X-ray powder diffraction patterns of six synthetic potassium vanadates and one calcium vanadate were indexed to check purity using available crystallographic data.

Two samples of turanite, as identified by X-ray powder diffraction patterns, were prepared for chemical analysis to check their composition.

The solubilities of synthetic rossite ($CaV_2O_6 \cdot 4H_2O$), hewettite ($CaV_6O_{16} \cdot 9H_2O$), and $V_2O_5 \cdot 2H_2O$ were determined at 30°C and are: rossite 4.5 g/l; hewettite 0.03 g/l; $V_2O_5 \cdot 2H_2O$, 0.03 g/l. As pascoite ($Ca_3V_{10}O_{28} \cdot 16H_2O$) dissolved and subsequently precipitated as hewettite during the solubility run, its solubility could not be determined, but is estimated to be approximately 20 g/l at 30°C.

A cursory examination of the systems $NH_4OH-V_2O_5-H_2O$, $Na_2O-V_2O_5-H_2O$, $BaO-V_2O_5-H_2O$, $MgO-V_2O_5-H_2O$, and $ZnO-V_2O_5-H_2O$ showed that these systems yielded phases comparable to those of the $K_2O-V_2O_5-H_2O$ and $CaO-V_2O_5-H_2O$ systems. The metavanadate and hexavanadate (the stable polyvanadate) phase boundary remained in the pH region 7 to 6 for the $Na_2O-V_2O_5-H_2O$, $NH_4OH-V_2O_5-H_2O$, and $MgO-V_2O_5-H_2O$ systems, but was in the pH region 6 to 5 for the $ZnO-V_2O_5-H_2O$ system and 5 to 4 for the $BaO-V_2O_5-H_2O$ system. The anhydrous hexavanadate $[R^+]_2\ V_2O_{16}$ formed in only one system, $NH_4OH-V_2O_5-H_2O$, which shows a great similarity to the $K_2O-V_2O_5-H_2O$ system.

In the pH region of 5.5 to 3, Co, Zn, and Mg ions form double salts of the form $[R^+]_2[R^{++}]_2\ V_{10}O_{28}\ x\ H_2O$ with potassium- and ammonium-vanadate solutions; Ba and Cu ions do not form any double salts.

Approximately 100 solutions of potassium-vanadate in the pH range of 10 to 1 were evaporated at 30°, 50°, 90°C. The pH was adjusted with nitric acid. The resulting products were quite similar to the phases obtained from previous solutions in which acetic acid was used except that no $KVO_3 \cdot H_2O$ was formed. A slight precipitation of fibrous, brown $K_2V_6O_{16} \cdot 2H_2O$ often preceded the crystallization of $K_2V_6O_{16}$. In the pH range 3 to 2, the solid phase changed to a variant having a composition close to $K_4(VO_2)_2(V_6O_{16})_3\ x\ H_2O$.

The following papers were published during the period:

McKelvey, V. E., Everhart, D. L., and Garrels, R. M., 1956, Summary of hypotheses of genesis of uranium deposits, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 551-561: New York, United Nations.

McKelvey, V. E., Everhart, D. L., and Garrels, R. M., 1955, Origin of uranium deposits: Econ. Geology, Fiftieth Anniversary Volume, p. 464-553.

Garrels, R. M., Some thermodynamic relations among the uranium oxides and their relation to the oxidation states of the uranium ores of the Colorado Plateaus: Am. Mineralogist, v. 40, p. 1004-1021.

Isotope geology and nuclear research

Geochronology
By L. R. Stieff

Preliminary zircon age data were obtained from a suite of four igneous rocks from the San Pedro Martir and related intrusives in Baja California. These are the first samples to be collected and analyzed as part of a long range program to establish reliable isotopic ages at key points in the geologic time scale. Earlier field investigations in the area, confirmed by the identification of fossils, indicate that the igneous rocks intrude sediments at least upper Lower Cretaceous in age and are in turn overlain by sediments of approximately middle Upper Cretaceous age. The Larsen ages on the accessory minerals separated by D. Gottfried are as follows:

Table 30.--Larsen ages of minerals from intrusives in Baja California

Sample No.	Mineral	/mg/hr	ppm Pb	Age
BC-1-5	Zircon	43 1/	2.0, 1.8 2/	109 m.y.
SV-1	Zircon	123	5.1, 5.0	98 m.y.
BC-1-4	Zircon	156	6.3, 6.0	95 m.y.
B-1-2	Monazite	3,430	165, 170	98 m.y.

1/ Alpha counts by H. Jaffe
2/ Quantitative spectrographic Pb analyses by C. Waring

The ages of the Baja California accessory minerals agree reasonably well with the average age of 105 $\pm$ 10 million years obtained earlier on 25 Southern California batholith zircons. These reconnaissance results indicate that, although the lead content of the zircons is low, the area is well suited for age studies.

A preliminary report on the age of the Blind River uranium ores in the Mississagi conglomerate of lower Huronian age is essentially complete. This study was undertaken in an effort to test in a new area the age interpretations developed from the detailed study of the isotopic data on the uranium ores and lead minerals of the Colorado Plateau. The isotopic data obtained are given in table 31.

Table 31.—Pb^{206}/Pb^{204}, Pb^{207}/Pb^{204}, Pb^{208}/Pb^{204}, Pb^{206}/Pb^{207} ratios of Blind River samples 1/

Sample No.	Pb^{206}/Pb^{204}	Pb^{207}/Pb^{204}	Pb^{208}/Pb^{204}	Pb^{207}/Pb^{208}
GS/461D/55	8813.0	791.4	394.6	0.0898
GS/461E/55	7370.0	616.6	345.8	0.0837
GS/463A/55	1155.8	172.0	99.74	0.1488
GS/464/55	2485.1	228.9	142.3	0.0921
GS/467/55	215.1	67.38	61.31	0.3132
GS/477/55	5109.0	735.9	36.18	0.1440
GS/476/55	337.5	62.77	53.23	0.1859

1/ Isotopic analyses, C. Ciallela

The isotopic composition of the lead in sample GS/477/55 is of considerable interest. It contains essentially pure radiogenic lead as indicated by its very high Pb^{206}/Pb^{204} and Pb^{207}/Pb^{204} ratios, 5109.0 and 735.9 respectively. Because of the very small amount of Pb^{204} present, the Pb^{207}/Pb^{206} ratio of the radiogenic lead will be virtually unaffected by the choice of "common lead" used in making the correction for the nonradiogenic lead present. The Pb^{207}/Pb^{206} ratio of this lead is approximately 0.14 and is equivalent to a maximum age of approximately 2,200 million years. Similar or older radiogenic lead was found in the other pyrite and galena samples analyzed by the Geological Survey and the Geological Survey of Canada.

The calculated ages of the four Blind River ores are given in table 32.

Table 32.—Calculated ages in millions of years of Blind River uraninite samples

Sample No.	Pb^{206}/U^{238}	Pb^{208}/Th^{232}	Pb^{207}/Pb^{206}
GS/461D/55	340	345	1,400
GS/461E/55	440	380	1,250
GS/463A/55	1,850	3,100	2,250
GS/464/55	400	410	1,350

The first three samples listed are high-grade uraninite specimens while the last sample is somewhat higher than average grade ore. The extreme ages of sample GS/463A/55 can be attributed to the presence of abundant microscopic particles of galena which could not be removed during the sample preparation. The Pb^{207}/Pb^{206} ratio of this sample also suggests that it contains radiogenic lead similar to that found in the galena and pyrite from this area.

The age sequences listed can be interpreted as reflecting the presence of different amounts of an older generation of radiogenic lead in the ore; GS/463A/55 containing excessive amounts of old lead while GS/461D/55, 461E/55 and 464/55 contain relatively smaller amounts. In the case of the latter three samples, the appreciably older Pb^{207}/Pb^{206} ages would be a consequence of the extreme sensitivity of the Pb^{207}/Pb^{206} method to the addition of relatively small amounts of older lead. The Pb^{206}/U^{238} ages, in contrast, are much less sensitive to the presence of small amounts of old radiogenic lead and an age less then the Pb^{206}/U^{238} age would be expected to approximate more closely the actual age of the ore. If this interpretation, which is similar to that proposed for the Colorado Plateau age data, is correct, the very limited information now available would suggest that the present Blind River uranium ores are not older than Paleozoic. This tentative conclusion finds some support in the good agreement between the Pb^{206}/U^{238} and Pb^{208}/Th^{232} age obtained for three of the four samples.

Publications during the report period were:

Stieff, L. R., and Stern, T. W., 1955, Interpretation of the Pb^{206}/U^{238} Pb^{207}/U^{235} Pb^{207}/Pb^{206} age sequence of uranium ores (abs.): Geol. Soc. America Bull., v. 66, no. 12, pt. 2, p. 1621-1622.

__________________________, 1956, Interpretation of the Pb^{206}/U^{238} Pb^{207}/U^{235} Pb^{207}/Pb^{206} age sequence of uranium ores, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 540-546: New York, United Nations.

Stable isotopes

By Irving Friedman

Additional deuterium analyses of water dissolved in glassy rhyolitic rock confirm the previous opinion that the water in high water glasses, (over 0.4% H_2O) is of secondary origin. The narrow range of deuterium concentration in the low water content glasses (0.09 to 0.4% H_2O) suggests either a common surficial water source (the oceans?) or the presence of juvenile water in these rocks. If it is assumed that these rocks represent remelted sediments that were laid down in a geosynclinal basin connected to the oceans, the deuterium content of the glasses would indicate either that the ancient oceans contained much less deuterium than those of today, or that a large fractionation takes place during the dissolving of water in rhyolite magma.

A study of deuterium fractionation during the freezing of sea water was carried out in cooperation with Woods Hole Oceanographic Institution. Samples were obtained of sea water and sea ice forming near Woods Hole, Massachusetts, plus samples obtained from Hopedale Bay, Labrador. A fractionation of 1.3% to 1.8% was obtained from Woods Hole samples, while a larger fractionation 1.9% to 2.2% was obtained at Hopedale Bay. In both cases the ice was enriched in the heavier isotope by the above factor.

The analysis of a series of rain samples from Lake Maracaibo, Venezuela was completed and will permit completion of the study of the deuterium balance of the lake basin.

Isotope geology of lead
By R. S. Cannon, Jr.

Accumulating information on the lead-isotope geology of the Coeur d'Alene district of Idaho stands out as the most intriguing development of this report period. Progress on this topic is particularly gratifying because this project literally was born of a desire to solve the mystery posed by a seemingly anomalous isotopic analysis of lead reported by Nier (1938) from a single sample of cerussite from Wallace, Idaho. This sample contained a primitive type of lead that seemed out of step with Nier's other analyses and suggested a possibility of some flaw in the orthodox geologic interpretation that Coeur d'Alene lead ores--along with the Idaho batholith--were formed in Cretaceous time. Cannon (1950) focused attention on this anomaly and tried to analyze alternative interpretations in a talk presented before the Geological Society of America:

> "Perhaps this analysis means that Coeur d'Alene lead evolved more slowly than lead elsewhere--that it originated in an environment where uranium and thorium were abnormally scarce. This could be interpreted to mean that Coeur d'Alene lead might be an unusual lead that arose from a deep source below the sima (along the Osburn fault) in Laramide time. Or perhaps in Laramide time Precambrian lead was leached from Precambrian rocks or ores and redeposited in the Coeur d'Alene veins. Or, as a third possibility, perhaps the Coeur d'Alene ores are not of Laramide age, but are old deposits, formed in Precambrian time."

Since then three lines of isotopic evidence have been developed to provide a better foundation for interpretation, but the new evidence is controversial within itself. An isotopic lead-uranium age determination of uraninite reported by Kerr and Kulp (1952) implies that uranium veins in the Sunshine mine of the

Coeur d'Alene district were formed in Precambrian time. On the other hand the Gem stocks of monzonite, according to lead-alpha age determinations on accessory zircon and thorite by Larsen and Gottfried, reported by Faul (1954), were intruded into sedimentary rocks of the Belt series about the same time as the Idaho batholith, most likely in Cretaceous time. The implications of this evidence are uncertain, for no one seems to have reported any kind of definitive evidence to show whether the deposition of lead-zinc veins was earlier, contemporaneous with, or later than intrusion of monzonite. In this dilemma the evidence from isotopic composition of lead in lead minerals might serve in the role of umpire, so for this purpose we have compiled from all available sources more than 30 isotope analyses of lead from the Coeur d'Alene district and surrounding region. Besides two analyses published by Nier (1938) the rest are from published and unpublished reports of analytical work done in the past few years at the University of Toronto, Columbia University, and at Oak Ridge for the U. S. Geological Survey.

Three analyses newly made for this project are reported here for the first time. Two of them are analyses of galena from two mines in the Pine Creek district at the west end of the Coeur d'Alene lead belt where the Prichard formation of the Belt series is the host rock; the third is of a trace occurrence of galena found by chance in a calcite veinlet cutting lithographic manganiferous dolomite of the Piegan group of the Belt series in a roadcut of U. S. Highway 93 on the west shore of Flathead Lake in Montana, about 100 miles east of the Coeur d'Alene district.

Lab. No.	Sample and locality	204	206	207	208	Sum
GS/484	Galena from adit level, Highland Surprise mine; Prichard fm. Belt series; west end of Coeur d'Alene region.	1.00 1.46	16.25 23.71	15.40 22.47	35.88 52.36	68.53 100.00
GS/483	Galena from stope above 500' level, Sidney mine; Prichard fm., Belt series; west end of Coeur d'Alene region.	1.00 1.48	16.01 23.70	15.23 22.55	35.31 52.27	67.56 100.00
GS/482	Galena, lone crystal in calcite veinlet in dolomite in Piegan group, Belt series; Flathead Lake, Montana	1.00 1.46	16.45 23.99	15.37 22.41	35.75 52.14	68.57 100.00

In isotopic composition the two samples from the Pine Creek district are virtually identical with one another and with other analyses of Coeur d'Alene ore-lead. The sample from Montana is closely similar. This similarity evidently is fundamental, for we observe that the ten available isotopic analyses of Coeur d'Alene ore-lead are identical (within limits of experimental error) with eight analyses of galena-lead from other localities, in Montana and in British Columbia, where host rocks likewise are sediments belonging to or correlative with the Belt series of Precambrian age. Figure 65 shows this remarkable uniformity and shows too the noteworthy difference in composition of 14 samples of galena-lead from other localities in Idaho, Washington, and British Columbia, where host rocks are younger sedimentary, volcanic, or batholithic rocks of Paleozoic or Mesozoic age. Only one sample, analyzed at one of the other laboratories, falls apart from and more or less intermediate between these two fairly compact groups of data: galena-lead from a mine in British Columbia where the country rock is reported to belong to the Windermere series. Further attempt to evaluate this particular sample would require closer geologic control, for work by Park and Cannon (1943) south of the border implies that the Windermere series is likely to embrace sedimentary rocks of Ordovician, Cambrian,

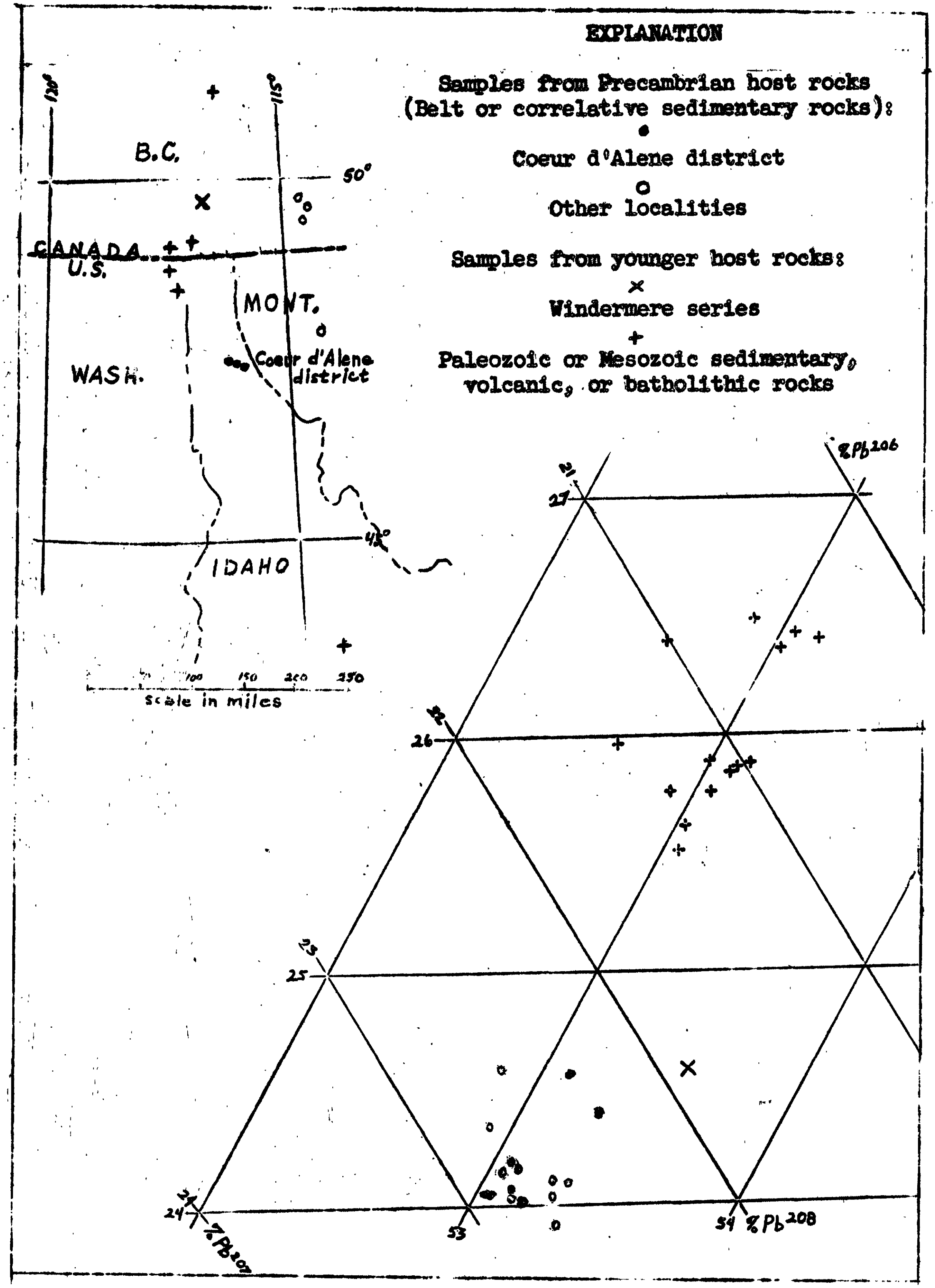


Figure 65 Sample localities and isotopic composition of some galena leads from Washington, Idaho, Montana and British Columbia.

and probably Precambrian age. Variations among the three groups of lead-isotope analyses are summarized below:

Host rocks	No. of samples averaged	204	206	207	208	Sum
Belt series; Coeur d'Alene district	10	1.00	16.52	15.55	36.36	69.43
Belt or equivalent; other localities	8	1.00	16.74	15.71	36.79	70.24
Paleozoic-Mesozoic rocks	14	1.00	19.94	16.09	40.60	77.63

These isotopic data are not decisive, probably only because our understanding of lead-isotope geology is still in an embryonic stage of development. Even so, the data seem to justify the speculation that the actual history of Coeur d'Alene ore deposits is to be sought among the following possibilities. (1) The veins are old (Precambrian); depositional process not defined. (2) The veins are young (i.e. Cretaceous), in which case we must postulate an ore-forming process that remobilized old or primitive-type lead from some ancient environment relatively rich in lead but poor in uranium and thorium, such as: (a) Precambrian lead-ore deposits, (b) Precambrian rocks (e.g. Belt sediments rich in lead, poor in radioelements), or (c) the earth's mantle or other deep source tapped by the Osburn fault. (3) An ore-forming process that concentrated traces of lead originally deposited with Belt sediments, a process that might have concentrated lead at any time since the Precambrian sedimentation. The weight of the data tends to discredit hypotheses that would derive lead from preexisting ore deposits (2a) or from the depths of the earth along unique fault-channels (2c). Rather, the data appear to favor the other alternatives that all occurrences of lead in Belt rocks so far tested were concentrated either in Precambrian time (1), or from traces extracted from Belt host rocks (3), or both. In any case the fact is impressive that the analyzed lead minerals from this region of nearly 100,000 square miles contain a primitive type of lead if they were collected from a Precambrian sedimentary environment, but a much more evolute (i.e. rich in radiogenic isotopes) kind of lead if collected from younger host rocks. The apparent isotopic uniformity of lead in Belt terrane, regardless of other variables like geographic location, size, and grade of the lead deposit, or lithology, grade of metamorphism, igneous activity, or structural setting within its environment, appears to harmonize best with some concept akin to the hypothesis entertained by Hershey (1916) that Coeur d'Alene ore-lead was derived from material minutely disseminated in the sedimentary rocks. Additional and more diagnostic evidence is expected from our continuing studies of a suite of lead and uranium samples selected for this purpose.

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Nuclear geology
By F. E. Sentfle

Work continued on investigations of the Cu^{63}/Cu^{65} ratios across a "roll" structure in the Colorado Plateau. A small enrichment of the heavy isotope was found in the center of the roll. A plot of the results is shown in figure 66. The enrichment of Cu^{65} within the roll is nearly three times the experimental error. While this is not a large enrichment it probably is significant. Two explanations of such a pattern can be made. First, the copper may have undergone an exchange reaction with some material within the roll, or normal copper may have been laid down within the roll and subsequently redissolved, diffusing into the host rock. If the latter explanation is correct, the copper just outside the roll would be enriched in Cu^{63} which preferentially diffused out of the roll. This appears to be the case, but as the results are within the experimental error, they are not as yet definitive.

Other isolated samples have also been run for the Cu^{63}/Cu^{65} ratio but with one exception all have been about normal. A radioactive niccolite sample from Iran was shown to have slight enrichment of the heavy isotope. A preliminary measurement of the Cu^{63}/Cu^{65} ratio is 2.218 compared with a standard ratio of 2.223. This sample is being investigated further.

The analyses of the U^{235}/U^{238} ratio of samples from the Colorado Plateau were completed at the Mass Assay Laboratory at Oak Ridge. The results (table 33) indicate a constant ratio.

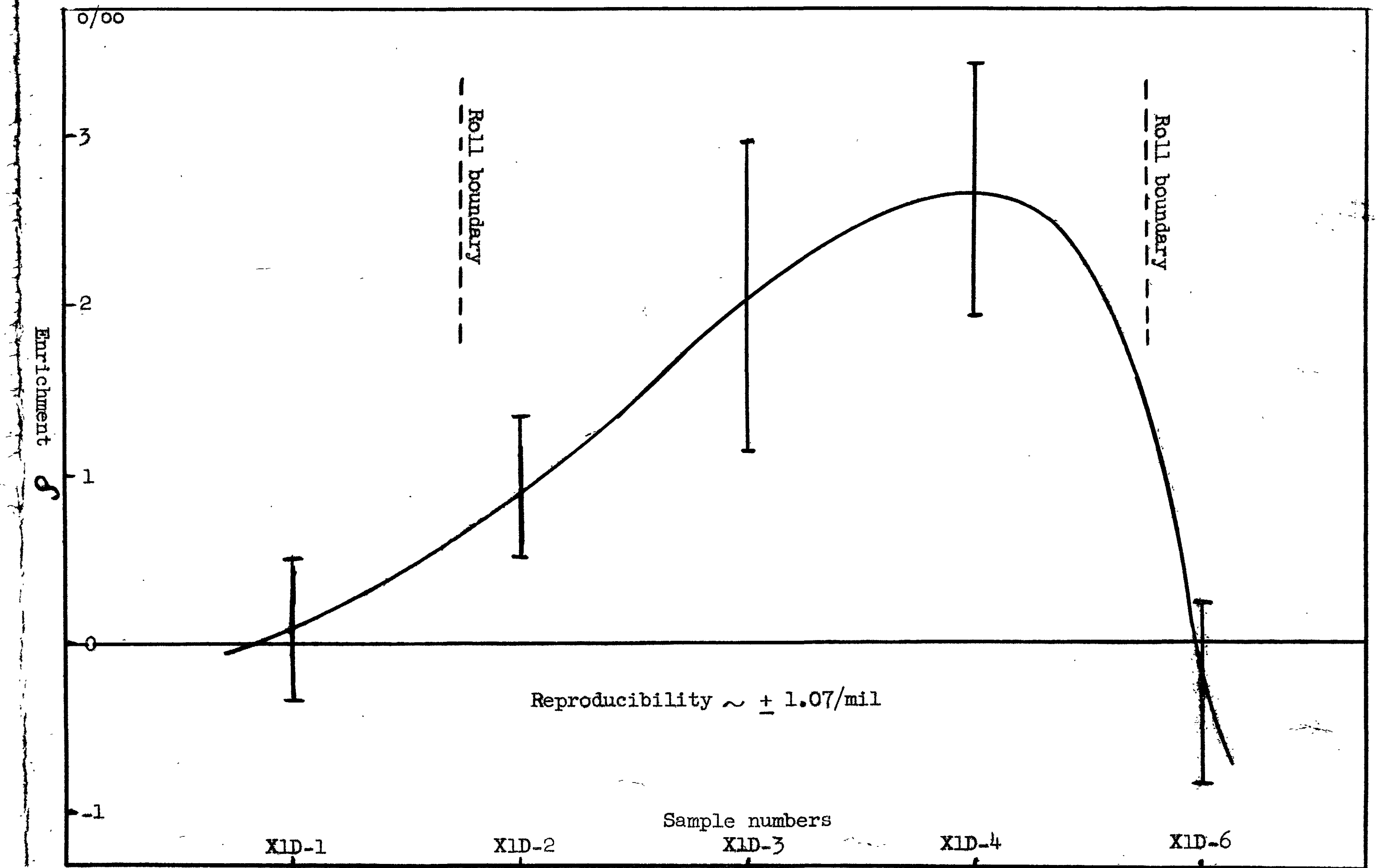

Figure 66.—Cu^{63}/Cu^{65} ratios across a "roll" structure on the Colorado Plateau

Table 33.—U^{235}/U^{238} ratios of samples from the Colorado Plateau

Sample No.	Location and description	N_U238/N_U235
G	Heavily oxidized uranium ore, Mineral Joe mine, Colorado	137.1 ± 0.35
S	Oxidized ore, composite sample, Mineral Joe mine, Colorado	137.7 ± 0.64
J	Oxidized ore, Mineral Joe mine, Colorado	137.8 ± 0.31
N	Partially oxidized uranium ore, Mineral Joe mine, Colorado	137.7 ± 0.31
GS-64	Fresh uraninite, Happy Jack mine, Utah	137.8 ± 0.26
GS-87	Oxidized ore, Happy Jack mine, Utah	137.8 ± 0.31
PK-18	Carbonaceous ore, Temple Mountain, Utah	137.8 ± 0.31
AE-1165	Fresh unaltered uraninite, Mi Vida mine, Utah	137.7 ± 0.31
AE-1260	Coffinite, Woodrow Pipe mine, New Mexico	137.6 ± 0.24
AE-1271	Coffinite, Poison Canyon mine, New Mexico	137.8 ± 0.31
AE-1288	Oxidized ore, black, J. J. mine, Paradox Valley, Colorado	137.8 ± 0.31
PK-2	Apparently altered uraninite, Joachimsthal	137.8 ± 0.28
PK-5	Uraninite, Great Bear Lake	137.8 ± 0.25

Geochemistry of uranium-bearing carbonaceous rocks

By I. A. Breger and Maurice Deul

Analyses of logs from various parts of the Colorado Plateau show that the wood is coalified and ranges in rank from lignite to subbituminous. The coalified wood contains from 45 to 84 percent carbon, and 3.3 to 7.5 percent hydrogen. The following observations were noted:

(1) There is no correlation between organic carbon and uranium.

(2) For coalified wood containing approximately 0.1 to 7.5 percent uranium, organic hydrogen varies inversely with uranium. This is thought to result from a radiochemical dehydrogenation of the coal by the alpha particles from uranium and its daughter products. For uranium contents of 0.001 to 0.1 percent, changes in hydrogen are too small to detect. Volatile matter, which is related to some extent to hydrogen, varies with uranium as does hydrogen,

(3) Total sulfur increases abruptly as uranium content rises above about 2 percent. Organic sulfur may or may not increase above this uranium value. It appears that sulfur in some form was introduced with the mineralizing fluid and, under the proper conditions, reacted with the coalified wood.

(4) Several samples of coalified wood, mineralized and unmineralized, have lost all vestiges of cellular structure (Schopf, personal communication).

Samples of carbonaceous sandstones ("uraniferous asphaltites") were fractionated by ball-mill grinding to obtain low-ash organic isolates suitable for ultimate analysis. Analyses of fractions from a sample from the old adit, northwest corner of Temple Mountain, Emery County, Utah, are shown in table 34. The organic isolate accounts for 43.6 percent of the starting sample but contains 70.0 percent of the uranium in the starting sample; X-ray analysis indicates the presence of uraninite.

Similar data for an impregnated sandstone from the Black King mine, Placerville, Colorado, are given in table 35.

The composition of the organic isolate from Temple Mountain corresponds to that for a subbituminous coal. The following observations were made for the sample from Placerville:

(1) The finest ground material (middlings) contains a large concentration of uranium indicating that uranium can be separated from the organic material. X-ray analysis of the organic isolate (1.0 percent uranium) shows a weak cubic pattern with $a_0 \pm 5.44$ Å indicating uraninite.

(2) Association of uranium with organic matter is evident from the fact that the organic isolate, which constitutes only 28.7 percent of the sample, contains 72.4 percent of the uranium in the total sample. The inorganic isolate is not pure (85.3 percent ash) and undoubtedly contains organic matter with associated uranium.

Table 34.—Data for impregnated sandstone from old adit, northwest corner of Temple Mountain, Utah

	Original	Organic isolate	Inorganic isolate	Middlings
C, percent (dry basis)	32.12	68.86	1.79	72.56
H, percent (dry basis)	2.13	4.21	0.48	7.05
Ash, percent (dry basis)	57.51	12.85	95.08	5.26
N, percent (dry basis)	0.10	0.24	—	0.43
S, percent (dry basis)	2.92	5.60	—	6.68
U, percent (dry basis)	1.84	2.95	0.95	0.32
C, percent (MAF)*	75.56	79.01	36.3	76.59
H, percent (MAF)	5.00	4.90	9.74	7.39
N, percent (MAF)	0.22	0.28	—	0.46
S, percent (MAF)	6.86	6.43	—	7.07
Weight, g.	200.0	87.1	95.5	0.32

* Moisture- and ash-free

Table 35.—Data for impregnated sandstone from Black King mine, Placerville, Colorado

	Original	Organic isolate	Inorganic isolate	Middlings
C, percent (dry basis)	28.94	87.34	—	—
H, percent (dry basis)	1.47	4.28	—	—
Ash, percent (dry basis)	61.00	3.72	85.25	72.31
U, percent (dry basis)	0.65 1/	1.00 2/	0.13 1/	4.4 1/
C, percent (MAF) 3/	74.1	90.6	—	—
H, percent (MAF)	3.77	4.45	—	—
Weight, g.	200.0	57.3	136.0	0.6

1/ Uranium in ash
2/ Uranium in total sample
3/ Moisture- and ash-free

(3) The ultimate analysis of the organic material indicates it to be related to coal in the medium-volatile bituminous range.

The carbonaceous matter separated from a silty, highly feldspathic, member of the Dripping Spring quartzite of Gila County, Arizona, was analyzed by infrared spectroscopy. The spectrum showed a highly condensed aromatic structure and absence of aliphatic structure and was similar to spectra of organic concentrates from uraniferous sandstones and carbonaceous pellets from the Colorado

Plateau which have been shown to be related to coal and to coal-like substances derived from the degradation products of plants. On the ash-free basis this carbonaceous material contains 88 percent carbon, 4.5 percent hydrogen, and 7.5 percent oxygen + nitrogen + sulfur.

The following papers on uranium-bearing carbonaceous rocks were published during the period:

Breger, I. A., 1955, Radioactive equilibrium in ancient marine sediments: Geochimica et cosmochimica Acta, v. 8, p. 63-73.

__________, 1955, The association of uranium with a naturally occurring coal extract (abs.): Geol. Soc. America Bull., v. 66, no. 12, pt. 2, p. 1534; Econ. Geol., v. 50, no. 7, p. 767-768.

Breger, I. A., and Deul, Maurice, 1956, The organic geochemistry of uranium, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy—v. 6, Geology of uranium and thorium, p. 418-421: New York, United Nations.

Breger, I. A., Deul, Maurice, and Meyrowitz, Robert, 1955, Geochemistry and mineralogy of a uraniferous subbituminous coal: Econ. Geology, v. 50, no. 6, p. 610-624.

MINERALOGIC AND PETROGRAPHIC SERVICE AND RESEARCH

Mineralogical services

By R. C. Kellagher and L. B. Riley

Except for samples submitted by the public, which were considerably fewer in number than in the preceding six months, the work load of the mineralogic laboratories is comparable with that of former periods. The number and variety of minerals identified per sample were also comparable to previous periods. There was some increase in samples where all, or appreciable parts, of the uranium content is not contained in visible uranium minerals but is disseminated in such substances as limonite and carbonaceous material. The number of samples containing uraninite or coffinite and uraniferous samples containing sulfides, particularly pyrite or marcasite also increased, reflecting greater interest in unoxidized ores. There also was a marked increase in interest in the non-uranium mineral assemblages associated with uranium ores.

Nearly every sample submitted for mineralogical examination, and many of those for X-ray determinations, require separation into component parts. The use of autoradiographs has become a routine aid in determining the location of highly radioactive minerals in many types of samples. When this technique fails, the use of stripping films on thin sections has proved useful, and by counting alpha tracks in the film a rough estimate of the uranium content of a particular mineral may be made.

An ultrasonic unit, of one quart capacity designed for 20 KC with 200 watt input, was placed in operation this period. It already has proved valuable in separating friable minerals without crushing, and in cleaning various mineral coatings from sand grains for further study.

Electron microscopy and electron diffraction

Two new techniques were developed for making surface replicas. One method is to flood the specimen surface with polyvinyl alcohol-water solution, dry, and then mechanically strip the film from the specimen surface. The film is then placed in a high vacuum and shadowed first at a low angle with chromium and again at 90° with carbon. The film is then placed in water to dissolve the polyvinyl alcohol from the carbon-chromium layers.

The second method of making replicas is to flood the specimen surface with a 5:1 amyl acetate-collodion solution, dry, and flood again with a polyvinyl alcohol-water solution. After drying, the film is stripped from the surface, placed in a high vactum and shadowed at a low angle with chromium. The film is then placed in water to dissolve the polyvinyl alcohol from the collodion-chromium layers.

Crystal symmetry determinations were made of two new minerals, a manganese oxide from Cuba, and a corvusite-like mineral from the Colorado Plateau. A detailed examination has been made of sepiolite from Madagascar and laughlinite from Colorado.

The application of electron diffraction techniques to mineralogical studies, and the study of metamict minerals by electron diffraction techniques were continued.

The following papers on electron microscopy were published during the period:

Dwornik, E. J., and Ross, Malcolm, 1955, Application of the electron microscope to mineralogic studies: Am. Mineralogist, v. 40, p. 261-274.

Dwornik, E. J., and Tischler, M. S., 1955, Electron microscope and electron diffraction studies of vanadiferous clays from the Colorado Plateau (abs.): Jour. of Applied Physics, v. 26, p. 1391.

Ross, Malcolm, 1955, Interpretation of transmission electron diffraction spot patterns of certain monoclinic crystals (abs.): Jour. Applied Physics, v. 26, p. 1391.

X-ray services
By George Ashby

In this report period, 1,093 determinations were made on 829 samples representing about 30 percent increase in volume of service work over the previous report period.

An analogue computer, designed to evaluate the two-dimensional Fourier series $\rho(x,y) = \sum_h \sum_k |F_{hk0}| \cos[2\pi(hx-ky)-\alpha_{hk}]$ for crystal structure calculations, is nearing completion (see also Crystallography of uranium and associated minerals and Mineralogical services, this volume). Two motor-driven gear trains automatically turn the rotors of a set of synchros to generate the voltage analogue of each of the terms of the double summation as a function of x and y. Each p(x,y) is obtained as an average voltage and printed by a printing voltmeter.

In the computer a set of terms up to 21 x 11 can be handled; however, the machine is designed to permit the expansion to any number of terms. Electron density values can be determined at intervals of 1/50 or 1/100 of the unit-cell edge. The data for a two-dimensional electron density map can be determined (at 1/50 intervals) automatically in about 1-1/2 hours. This unit will aid considerably in the handling of X-ray data for structure analysis.

A high temperature sample mount was constructed for the X-ray diffractometer. Its design is essentially the same as that of the mount previously described but with a larger furnace to accommodate samples of large area.

Crystallography of uranium and associated minerals

By H. T. Evans, Jr.

Structure studies of vanadium minerals

The crystal chemical study of the vanadium oxide mineral from Carlile, Wyoming, referred to in the last semiannual report (TEI-590, p. 330-331) was pursued actively in this period, with the result that the mineralogy of vanadium(III) and vanadium(IV) is now fairly well defined. The crystals from Carlile give two X-ray lattices, indicating that they are made up of two phases intimately mixed in parallel orientation. Both phases, A and B, are monoclinic, with the (010) and (001) planes in common, and have the 3.0 A. b axis fibre spacing characteristic of montroseite. Phase A has a structure reported earlier, consisting of montroseite-like double VO_6 octahedron chains linked laterally into sheets parallel to (001). Phase B has been found to have a similar structure, but with single octahedron chains alternating with the double chains. The valence of vanadium in these oxides is determined by the number of hydrogen atoms that can be detected by X-ray methods only indirectly by measuring bond lengths. The structures are now sufficiently well refined to show that the two phases contain both vanadium(III) and (IV), A in ratio 1:1 and B in ratio 1:2.

It has further been found that another mineral of widespread occurrence on the Colorado Plateau, doloresite, has the same basic structure as Phase B. The constitution of this mineral has been a stubborn problem for over two years, in spite of most diligent efforts to solve its structure. It is now apparent that the orthorhombic symmetry which has been assumed until lately for doloresite is spurious, resulting from a repeated microscopic twinning of a monoclinic lattice analogous to that of Phase B. Although the vanadium and oxygen arrangement is the same for doloresite and Phase B, the number of hydrogen atoms is different, since refinement of the structure using doloresite data leads to different atomic coordinates than those found for Phase B. This process is not complete as yet, but it appears that vanadium in doloresite may be all vanadium(IV), or partly (IV) and partly (V).

Another vanadium oxide mineral, duttonite, found by previous crystal structure investigations to be $V_2O_4 \cdot 2H_2O$, was further studied with respect to its behavior on oxidation. It was found that duttonite changes color from pale brown to dark brown at temperatures up to 170°C, but its structure breaks down at an appreciable rate to give V_2O_5 only above 175°C. It is felt that duttonite loses part of its hydrogen at the lower temperatures to produce an oxidized duttonite with composition $V_2O_5 \cdot H_2O$. A mineral answering this discription was found on a specimen from Monument Valley, Arizona.

As a result of these and previous crystal chemical studies, the series of phases in the vanadium-oxygen-water system which occur in the weathering sequence from montroseite up to corvusite were identified and characterized as follows:

montroseite	$V_2O_3 \cdot H_2O$
Phase A	$V_2O_3 \cdot V_2O_4 \cdot 3H_2O$
Phase B	$V_2O_3 \cdot 2V_2O_4 \cdot 5H_2O$
paramontroseite	V_2O_4
duttonite	$V_2O_4 \cdot 2H_2O$
doloresite	$3V_2O_4 \cdot 4H_2O$?
oxidized duttonite	$V_2O_5 \cdot H_2O$

The first three minerals are primary and the last four are their weathering products. These are further altered to the corvusite and hewettite groups of minerals.

Structure studies of uranium minerals

The crystal structure of johannite, $Cu(UO_2)_2(SO_4)_2(OH)_2 \cdot 6H_2O$, was carried to the point where the essential framework is revealed. It consists of a layer structure in which uranyl groups are jointed in pairs by two hydroxyl groups, and these pairs linked into a sheet by sulfate groups. The coordination around the UO_2^{+2} group is apparently five-fold. The work on this mineral and on liebigite, $Ca_2UO_2(CO_3)_3 \cdot 10H_2O$, helped to explain why the tricarbonate complex ion, $UO_2(CO_3)_3^{-4}$, is the principal transporting agent in ground waters. The carbonate ions completely enclose the uranyl group, thus preventing the formation of hydroxyl bridges which lead to hydrolysis and precipitation of uranium in alkaline solutions in which carbonate is absent. Sulfate apparently cannot associate with UO_2^{+2} to the same degree (the predominant complex in sulfate solutions has a UO_2^{+2}/SO_4^{-2} ratio of 1:1), and consequently cannot prevent hydroxyl links from forming to produce layer compounds like johannite at pH ranges above 5.

The unit cell data for the synthetic alkali analogues of carnotite were completed and work on the crystal structure is in progress. Cell dimensions and β angle increase regularly with increasing ionic radius of the alkali from Na through Cs.

Limitations on the possible composition of ore forming solutions

The activity ratios of various important anions ($S^{=}$, $CO_3^{=}$, OH^-, F^- and $SO_4^{=}$) in hydrothermal solutions were evaluated using a simple thermodynamic technique. The mineralogy of primary ore deposits was interpreted in the light of the ratios, and limits were placed on the variability of each ratio in hydrothermal solutions. All of the calculations were made for 25°C, but cautious extrapolation to higher temperatures seems justified. The calculated partial pressure of CO_2 in the ore forming fluid is generally less than 1 atmosphere which suggests that a dense CO_2 phase cannot be considered the ore fluid for most hydrothermal deposits. The partial pressure of H_2S is usually less than 10^{-4} atmosphere which makes it difficult to defend the theory that metals other than those which complex with sulfur very readily (e.g. Hg, Sb, As and perhaps Ag and Au) are transported in quantity as complex sulfides or hydrosulfides.

The following papers relating to uranium crystallography were published during the report period:

Erd, R. C., and Evans, H. T., Jr., 1956, The compound Fe_3S_4 (Smythite) found in nature: Jour. American Chem. Soc., v. 78, p. 2017.

Evans, H. T., Jr., 1955, Vanadium mineral alteration sequences in relation to crystal chemistry and thermodynamics (abs.): Econ. Geology, v. 50, no. 7, p. 774.

Garrels, R. M., and Christ, C. L., 1955, Some aspects of the crystal chemistry of the oxidation of the Colorado Plateau uranium ores (abs.): Econ. Geology, v. 50, no. 7, p. 776: Geol. Soc. America Bull., v. 66, no. 12, pt. 2, p. 1564.

Properties of uranium-bearing minerals

By A. D. Weeks

Studies of the properties of uranium-bearing minerals will be combined on July 1, 1956 with those on the mineralogy of uranium deposits, which are reported on pages 123-128 of this volume.

Work is in progress on the poorly defined uranyl sulfate minerals related to zippeite and the uranyl arsenates, troegerite, and uranospinite. Clifford Frondel has obtained some of the type specimens of troegerite, and it is hoped that a satisfactory characterization can be made.

The rate of discovery of new uranium minerals and associated new vanadium and molybdenum minerals shows no tendency to decrease. Under investigation is a new calcium uranyl phosphate found in sufficient quantities for chemical analysis in Utah, Nevada, and Texas; also a new uranyl carbonate, a schoepite-like mineral, a possible uranyl molybdenate, and several vanadates.

The following reports were published during the period:

Frondel, Clifford, 1956, The mineralogy of thorium, in Proc. Internatl. Conf. on Peaceful Uses of Atomic Energy--v. 6, Geology of uranium and thorium, p. 568-577: New York, United Nations.

Frondel, J. W., and Fleischer, Michael, 1955, A glossary of uranium- and thorium-bearing minerals, third edition: U. S. Geol. Survey Bull. 1009-F.

GEOPHYSICAL SERVICES AND RESEARCH

Development and maintenance of radiation detection equipment
By E. E. Wilson

Tests were made on several newly designed types of shielded and unshielded scintillation detector probes to determine their response in a continuous medium (water). Two principal types of probes were involved; one consists essentially of a thin, unshielded wafer-shaped crystal, the other a cylindrical crystal covered by a slotted lead shield. In general it was found that the overall angular response of the thin crystal probe was superior to the slotted shield type. Both probes are now undergoing tests in simulated drill holes.

An experimental model of a prototype alpha probe was designed, fabricated, and field tested in the Grants area. The unit was used to measure the radon contamination in drill holes and responded satisfactorily to the very high alpha activity. With more elaborate instrumentation, an effort will be made to determine whether the decay processes of some of the short lived, naturally occurring radioisotopes may be studied.

A "Time Interval Differentiator" has been designed and is currently being tested. The device is to be used in an effort to identify certain alpha-emitting isotopes. Essentially it consists of an alpha scintillation counter that responds only to paired pulses occurring within a given time interval. The time interval between the accepted pulses may be varied in accordance with half life of the parent isotope of interest. Bench tests indicate the electronic circuitry is satisfactory and isotope tests are underway to determine its ultimate usefulness in the study of decay schemes.

Individual characteristics of phototube-crystal assemblies were studied with respect to temperature and source energy. The family of curves using a poly-energetic source showed a common plateau for different phototube-crystal combinations. The plateau length was increased by using a mono-energetic source and decreased when the temperature of the assembly was raised from 80° to 140°F.

An Oak Ridge Model DD-2 amplifier and pre-amplifier was constructed and tested using a precision mercury pulser and calibrated oscilloscope. This unit is now being used in the gamma-ray absorption experiments. Several special purpose mechanical and electro-mechanical assemblies have been constructed, including a rack and pinion drill assembly for a specimen drill attachment, a water reservoir core for an isodynamic separator, sample splitters, an electronic unit counter, and a light-measuring device for a microscope attachment.

A continuously recording radioactive fluid monitor was devised, tested with liquid samples and shipped to an AEC phosphate reduction plant in Florida. The equipment will be used to determine the uranium content of the solutions in the storage vats.

Service and calibration of all types of field and laboratory radiation detecting instruments continues.

Consulting services relating to the establishment of laboratory facilities to be used for the maintenance and calibration of field and laboratory instruments in Peru, Brazil, and Chile are being furnished.

Gamma-ray logging studies

By C. M. Bunker

Calibration of gamma-ray logging equipment, including two types of Geiger probes and a portable scintillation logging unit, used in the Florida phosphate district was completed. Data obtained from the work will make it possible to derive calibration data from similar relatively low grade, extended deposits in other areas.

Calibration of jeep-mounted scintillation logging equipment has been temporarily postponed pending delivery of a new ratemeter constructed to specifications obtained as a result of an extensive testing program undertaken during the past few months.

A simulated ore body 0.8 feet thick and inclined at 60 degrees from the horizontal was constructed and logged. A layer of the same thickness was constructed horizontally and logged with the same type of equipment. Interpreting the resultant logs by the same method results in an overestimation of actual thickness by a factor of 6 and an increase of 12 percent in the count rate in the inclined layer.

Construction of a scintillation-type core scanner was completed. The unit consists basically of 4 sodium iodide detectors placed at 90 degree intervals around the radius of a cylindrical space through which drill core is conveyed on an endless belt. The total count-rate response of the 4 crystals is recorded on an Esterline-Angus chart, plotting count rate versus sample length.

Data have been obtained from a great number of sodium iodide crystals and photomultiplier tubes to determine relative count rate response to various voltages and input sensitivities. The results indicate that photomultiplier tubes can be chosen for use which have essentially the same count rates when used with identical crystals; repeatable curves can be obtained from a plot of count rate versus specified tube voltages and input sensitivities.

Data pertaining to the relative count-rate response of commercial and government gamma-ray logging equipment and the interpretation of the gamma-ray logs are being accumulated. Such information will be of assistance to geologists who must make use of gamma-ray data from various commercial and government sources as an aid in geologic and other studies.

Physical behavior of radon

By. A. S. Rogers and A. B. Tanner

A detailed study of contours of radon concentrations in waters from about 325 wells in valley-fill in the North Ogden, Utah area was completed (see p. 338, TEI-590). The area investigated (about 25 square miles) roughly parallels an east-west trending projection of the Wasatch Mountains, called the Pleasant View Salient. The Salient consists of Cambrian quartzites and limestones which are cut by numerous faults. Hot spring waters containing 5,800 $\mu\mu c/l$ of radon and 44 $\mu\mu c/l$ of radium issue from a fault at the western end of the Salient. The traces of four other major faults are approximately perpendicular to the base of the Salient.

The contours of radon concentrations show:

(1) A narrow "high" extending from the area of the hot springs along and paralleling the base of Salient.

(2) Four narrow highs appear to extend from the four faults in the Salient which are perpendicular to the base of the Salient. This suggests that the faults may also extend into the valley-fill.

(3) Another zone of high radon concentration which is less regular, broader, and less in magnitude occurs in an area of "mixed waters", representing

a transition zone between $CaHCO_3$ waters and NaCl waters.

The radon concentrations in the ground waters vary from 100-2,800 $\mu\mu c/\ell$.

Several "piezometric wells" were sampled in some areas where producing wells were absent. These wells consist of a 3/8" pipe, 10 feet deep, and are used for measuring flucuations in the water table surface. Water samples from these "wells" compare favorably in radon content with nearby producing and deeper water wells.

Four wells were jetted (drilled by water under pressure and a constricted nozzle) in a line extending west from, and perpendicular to, the zone of hot spring activity. The radon content dropped from 5,800 $\mu\mu c/\ell$ at the hot spring to about 300 $\mu\mu c/\ell$ within 500 feet, although the ground water was still hot and saline. The radon content increased further west suggesting the existence of a fault in the unconsolidated valley-fill. The cuttings from the jetted wells were examined by John H. Feth of the Geological Survey and on the basis of microfossils and lithology a fault was also indicated in the same area.

Preliminary field tests were made of a newly designed instrument to provide continuous logging of alpha radiation drill holes. The logging unit is intended to be used from a truck or jeep and uses a scintillation technique. Attachments have been made for making either alpha or gamma-ray measurements. The alpha detector consists of a truncated cone of lucite, the smaller flat surface of which is coated with silver-activated zinc sulfide powder. The gamma-ray detector consists of a crystal of thallium-activated sodium iodide. Alpha logs that are made with the probe decending are quite different from those made with the probe ascending because of the buildup on the probe of alpha activity from the short-lived decay products of radon. The tests indicate that the alpha logs can be used to correct gamma-ray logs of drill holes in which the concentration of radon decay products is high enough to give misleadingly high counting rates.

The following paper was published during the period:

Rogers, A. S., 1955, Geological significance of radon in stream and well waters (abs.): Geol. Soc. America Bull., v. 66, no. 12, p. 1609.

Absorption and scattering of gamma-radiation
By A. Y. Sakakura

The Univac solution of the Bolzmann Equation (two media, plane geometry, with semi-infinite volume source) is now substantially complete. The analysis of the results and the presentation of data in more useful form, through the superposition of the data to form uranium, potassium and thorium spectrum and intensity calculations, are now in progress. Comparison of the build-up factor from one of the air scattering problems with that calculated from polynomial solutions show substantial agreement.

A paper on the results of a cooperative study with the Oak Ridge National Laboratory on asymptotic expansions of solutions of the heat conduction equation in internally bounded cylindrical geometry has been submitted for publication, and a report on air scattered gamma-rays from thick uranium sources has been completed.

Construction of a DD-2 linear amplifier and a water-tight pre-amplifier housing was completed for use in the water tank (cylindrical geometry, two media) experiment. A mercury relay pulser was constructed for use in testing the DD-2. The DD-2 was tested and calibrated, and all of the equipment for the experiment was installed. Preliminary measurements (circuit dead time, stability, accuracy, etc.) are completed and the collection of data from the experiment should be completed in the current fiscal year.

Construction and testing of directional probes of two different designs was accomplished and a short report was written. The testing of the directional probes and a standard gamma-ray probe for comparison consisted of determining the directional response of each detector in a simulated drill hole (comprised of a plexiglas pipe in a water tank) as a function of source position in the surrounding water.

Some experimentation was done with reflective backings for sodium iodide crystals and silicone-filled light pipes. A reflective paint (TiO_2 and vinyl cement) was found to give nearly as good a light collection efficiency as dry magnesium oxide powder.

RESEARCH AND RESOURCE STUDIES

Uranium in petroleum, natural petroleum derivatives, and other natural bitumens

By K. G. Bell

Conclusions derived from a study of the association of uranium with petroleum, natural petroleum derivatives, and other natural bitumens are summarized below:

Uranium is a minor trace element constituent of petroleum, its natural derivatives, and other naturally occurring bitumens. The amounts of uranium present in crude oils produced by primary recovery processes range from nil to a few tens of parts per billion. An average uranium content for all crude oil is estimated to be about one part per billion. A large portion of the uranium content of petroleum is associated with asphaltenes. Paraffin-base crude oils contain very minute quantities if any of uranium. Mixed-base and asphalt-base crude oils in general show a small positive correlation between specific gravity, asphaltene content, and uranium content. There is no correlation between uranium contents of crude oils and their geologic ages. Crude oils from one region are no more uraniferous than those from any other region except as a result of local predominance of heavy asphaltic constituents. Crude oils of the Colorado Plateau region, as a group, carry less than average quantities of uranium even though occurring in a uraniferous province, a condition which is attributed to predominance of paraffinic constituents. Crude oils produced by secondary recovery processes utilizing water flooding and detergents carry above average quantities of uranium, possibly because asphaltic residues are removed from pore walls of reservoir rocks. The chemical state of uranium in petroliferous materials and its source have not been determined.

The bituminous constituent of rock asphalts carries up to a few tens of parts per million uranium, the average being about one part per million. It is believed that the bitumen extracts uranium from the host rock under near surface conditions. There is a positive correlation between uranium contents of the bitumens and of the host rocks. So-called "asphaltite" uranium ores such as mined at Temple Mountain, Utah, may not be of petroliferous origin.

There is no evidence that petroleum acts as an ore-forming fluid for uranium. However, oil-field waters carrying soluble organic substances extracted from petroleum and hydrogen sulfide may provide a reducing environment in which uranium carried by ground waters or hydrothermal solutions may be precipitated at the interface.

Relation of uranium deposits to tectonic elements

By F. W. Osterwald and B. G. Dean

Study of the distribution of uranium deposits in the Cordilleran Foreland in relation to the regional tectonic pattern suggests that tectonic features may delineate new areas favorable for discovery of uranium deposits. Tectonic structures of the Foreland are divided into three groups, according to relative size or scale, namely: (1) large-scale structures, more than 100 miles in length and a few thousand feet in structural relief, such as major mountain ranges, basins, and fault zones; (2) intermediate-scale structures, several tens of miles in length and a few hundred to a thousand feet in structural relief, such as large folds and faults, generally superimposed on large-scale structures; (3) small-scale structures, not exceeding a few miles in length and a few hundred feet in structural relief, such as minor folds, faults, and joint systems.

Clusters of uranium deposits appear to be located preferentially in one or more particular structural environments. Large-scale structures provide apparently favorable conditions for uranium deposits in: (1) areas of intersecting structures, as shown by vein deposits near the intersection of the northeast-trending Hartville uplift and the northwest-trending Powder River basin; (2) areas near major basin axes, as shown by deposits in the Powder River, Wind River, and Great Divide basins; (3) areas in or near zones of small- to intermediate-scale en echelon structures superimposed on the flanks of large-scale structures, as shown by vein deposits in the Colorado Front Range, deposits in the Gas Hills, Crooks Gap, and Owl Creek Mountain areas of Wyoming; and (4) areas marginal to major structures in which intermediate- to small-scale faults and folds trend parallel to the major structures, as shown by deposits in the Pryor Mountains, Montana, Hartville uplift, Wyoming, and Old Woman anticline, Wyoming.

Uranium deposits associated with large-scale structural environments may be further localized by one or more smaller scale structures; areas on the margins of large-scale structures in which the smaller scale structures are arranged in an en echelon pattern are particularly favorable. However, many of the smaller scale structures are not obviously associated with any known large-scale structures. The following intermediate- and small-scale structures provide favorable conditions for uranium deposits in: (1) areas at the intersection of small- to intermediate-scale folds or faults, as shown by vein deposits in the Colorado Front Range and in the northern Black Hills, South Dakota, and by other deposits in Harding County, South Dakota, west of Craig, Colorado, in the Black Hills area, Wyoming, and in the Gas Hills area, Wyoming; (2) areas near the crest and along the flanks of small- to intermediate-scale anticlines, where more deposits are on the flanks than at the crests of the anticlines, as shown by deposits in Billings County, North Dakota, in the Black Hills area, Wyoming and South Dakota, in Rio Blanco County, Colorado, in Carter and Fallon Counties, Montana, and in Old Woman anticline, Wyoming; and (3) areas along or néar the troughs of small- to intermediate-scale synclines, such as deposits in Harding and Fall River Counties, South Dakota, in the Black Hills area, Wyoming, and in Carter County, Montana.

Uranium in coal and allied carbonaceous rock

By J. D. Vine and E. A. Merewether

To clarify the relationships between uranium and other elements in coal and allied carbonaceous rocks, the statistical treatment of semi-quantitative spectrographic data was applied to analyses of 111 ashed samples of lignite and lignitic shale from the Riley Pass area of the North Cave Hills, Harding County, South Dakota. The samples studies were collected by R. C. Kepferle, J. R. Gill, and W. A. Chisholm, in 1954 and 1955 from the "E" and "F" beds of the Tongue River member of the Fort Union formation of Paleocene age. The ash content of the samples ranges from 18 to 74 percent with a median value of about 40 percent.

The frequency distribution histogram representing the uranium content of the 111 ashed samples is given in figure 67. In order to test the hypothesis that the slight bimodality of this histogram might be due to a difference in the chemical behavior of uranium the samples were separated on the basis of uranium content into two suites, each with a symmetrical distribution curve centered on one mode and treated as a distinct population. One suite consists of 96 samples containing 0.02 to 16 percent uranium; the other suite consists of 27 samples containing 0.004 to 0.33 percent uranium.

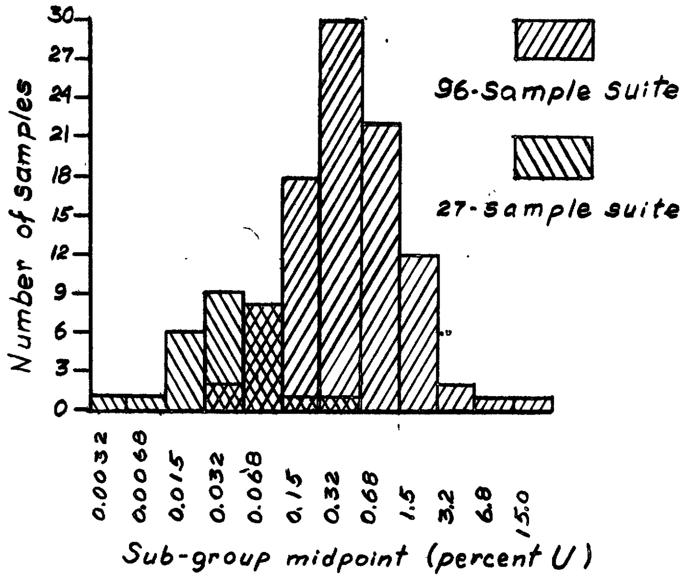

Fig. 67 Frequency distribution histogram of the percent uranium in 111 ashed samples of lignite and lignitic shale from the North Cave Hills area, Harding County, South Dakota.

Because the distribution curves overlap, 12 samples were included in both suites. Arbitrary selection of the 12 samples in the region of overlap was made on the basis of good radioactive equilibrium. A coefficient of linear correlation (fig. 68) was computed for uranium and 30 elements that had adequate distribution curves. Manganese, with a negative coefficient of correlation of 0.38 in the 27-sample suite and a positive coefficient of correlation of 0.16 in the 96-sample suite, is the only element that is appreciably different in the two suites. This difference is not adequate to demonstrate the validity of the original hypothesis.

In the 96-sample suite (0.02 to 16 percent uranium) Mo, As, Sc, and Zr have positive correlation with uranium that exceeds the 5 percent level of significance (95 percent confidence limit). In the 27-sample suite (0.004 to 0.33 percent uranium) Sc and As have positive correlation with uranium that exceeds the 5 percent level of significance, Mo and La have values slightly less than the 5 percent level, and Zr has an essentially random relation to uranium. The positive correlation of uranium with any other element may be due to similar physical or chemical behavior or chemical reaction in the environment of coal. The positive correlation of uranium with arsenic, for example, may be due to the presence of a uranyl arsenate, such as metazeunerite, whereas the positive correlation of uranium with molybdenum may be due to analogous physical or chemical

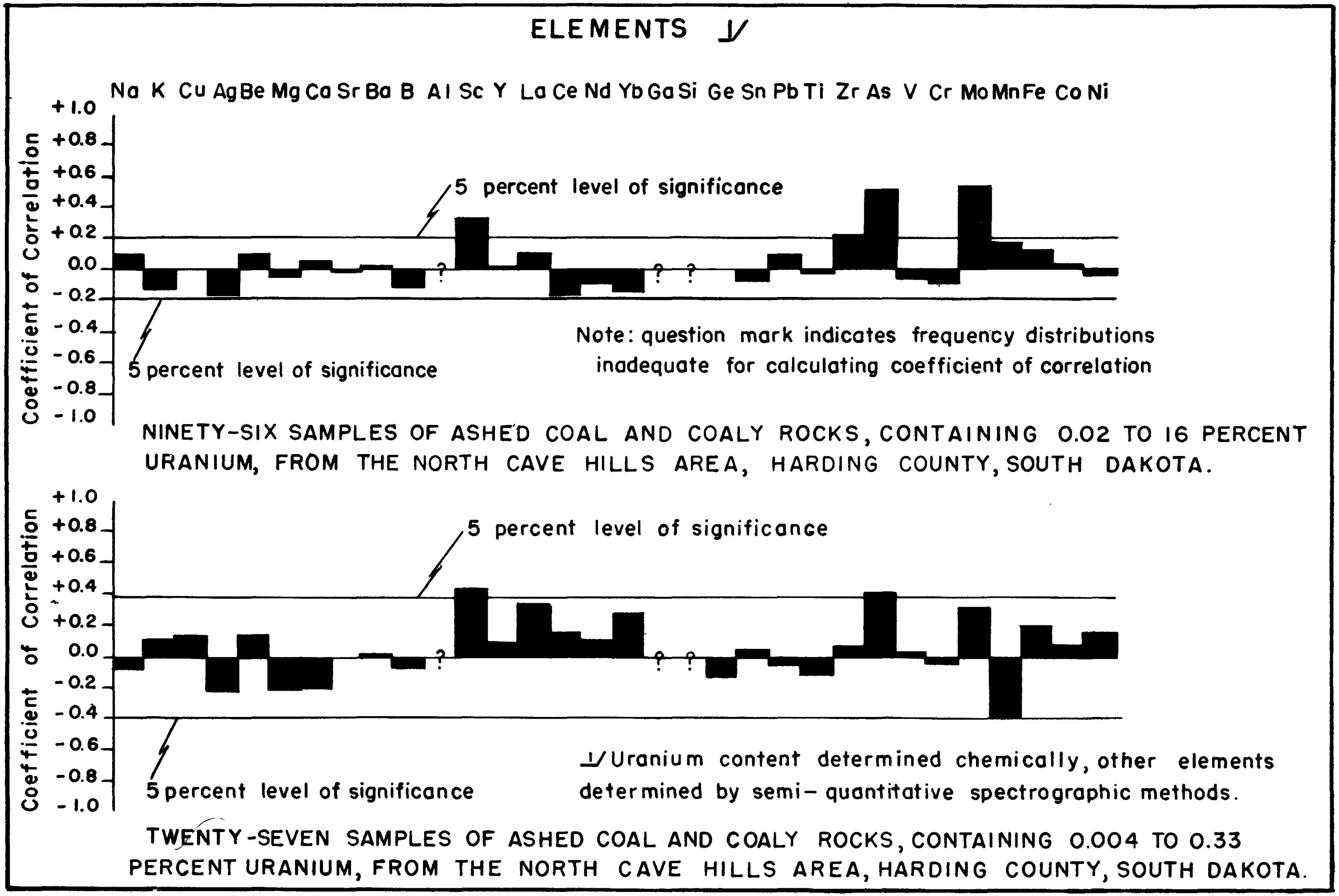

FIG. 68 —GRAPHS SHOWING COEFFICIENTS OF CORRELATION OF ELEMENTS WITH URANIUM.

behavior. The positive correlation of uranium with Sc and Zr is less readily explained.

Relationship between uranium-bearing veins and their host rocks

By G. W. Walker

A review of data regarding the relationship of uranium-bearing vein deposits to different kinds of host rocks has shown that (1) such veins are in rocks of nearly all textural, chemical, and mineralogical types, (2) they are most abundant in holocrystalline, commonly equigranular, igneous and metamorphic rocks characterized by a moderate to high silica content; these rocks have diverse chemical compositions but have similar physical characteristics in regard to deformation under stress, and (3) available data apparently are inadequate to demonstrate any widely applicable relationship between the presence or relative abundance of any element or suite of elements in the rocks and the concentration of uranium minerals in veins.

Locally, the chemical and/or mineralogic composition of the host rocks appears to aid in the deposition and localization of uranium in individual veins, as for example, those preferentially localized in hornblende gneiss in the Golden Gate Canyon area, Jefferson County, Colorado (Adams, J. W. and Stugard, Frederick, Jr., unpublished data, 1954) and those in garnet-quartz rock, Fall River area, Clear Creek County, Colorado (Moore, F. B., personal communication, 1955). For most vein deposits, however, no such chemical relationship can be established, possibly owing to (1) lack of adequate data, (2) inert chemical properties of ore solutions with respect to the host rocks, or (3) marked differences in chemical interaction between ore solutions and host rocks from one deposit to another.

Most uraniferous vein deposits are in silicate rocks that show an almost complete lack of any important plastic flow phenomena under relatively near surface conditions of pressure and temperature; the host rocks have a greater tendency to rupture under stress than do other kinds of rock. Conceivably this tendency to rupture and the detailed characteristics of the resultant fractures, shears, faults, and fragmentation, affecting the adsorptive properties of the host rocks, may have an important bearing on the apparent preferential deposition of uranium in holocrystalline rocks composed dominantly of silica and silicate minerals.

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