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National Uranium Resource Evaluation

NEWCASTLE QUADRANGLE WYOMING AND SOUTH DAKOTA

U.S. Geological Survey
Golden, Colorado

Issue Date
September 1982

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY
Assistant Secretary for Nuclear Energy
Grand Junction Area Office, Colorado

This report is a result of work performed by the U.S. Geological Survey, through an interagency agreement with the U.S. Department of Energy, as part of the National Uranium Resource Evaluation. NURE was a program of the U.S. Department of Energy's Grand Junction, Colorado, Office to acquire and compile geologic and other information with which to assess the magnitude and distribution of uranium resources and to determine areas favorable for the occurrence of uranium in the United States.

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NATIONAL URANIUM RESOURCE EVALUATION
NEWCASTLE QUADRANGLE
WYOMING AND SOUTH DAKOTA

Elmer S. Santos, Principal Investigator

With a section on Interpretation of U.S. Geological Survey
Stream-Sediment and Hydrogeochemical Data,
by Keith Robinson, K. A. Geer, and J. G. Blattspieler

U.S. GEOLOGICAL SURVEY
Golden, Colorado

September 1982

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY
GRAND JUNCTION AREA OFFICE
UNDER CONTRACT NO. DE-A113-78GJ01686

This report has not been edited for conformance with U.S. Geological Survey stratigraphic nomenclature or resource classification.

This is the final version of the subject-quadrangle evaluation report to be placed on open file. This report has not been edited. In some instances, reductions in the size of favorable areas on Plate 1 are not reflected in the text.

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ILLUSTRATIONS (Continued)

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* This map is published as U.S. Geological Survey Miscellaneous Field Studies Map MF-883 and is available from Branch of Distribution, U.S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225.

ABSTRACT

Uranium resources of the Newcastle $1^{\circ}x2^{\circ}$ Quadrangle, Wyoming and South Dakota were evaluated to a depth of 1,500 m (5000 ft) using available surface and subsurface geologic information. Many of the uranium occurrences reported in the literature and in reports of the U.S. Atomic Energy Commission were located, sampled and described. Areas of anomalous radioactivity, interpreted from an aerial radiometric survey, were outlined. Areas favorable for uranium deposits in the subsurface were evaluated using gamma-ray logs. Based on surface and subsurface data, two areas have been delineated which are underlain by rocks deemed favorable as hosts for uranium deposits. One of these is underlain by rocks that contain fluvial arkosic facies in the Wasatch and Fort Union Formations of Tertiary age; the other is underlain by rocks containing fluvial quartzose sandstone facies of the Inyan Kara Group of Early Cretaceous age. Unfavorable environments characterize all rock units of Tertiary age above the Wasatch Formation, all rock units of Cretaceous age above the Inyan Kara Group, and most rock units of Mesozoic and Paleozoic age below the Inyan Kara Group. Unfavorable environments characterize all rock units of Cretaceous age above the Inyan Kara Group, and all rock units of Mesozoic and Paleozoic age below the Inyan Kara Group.

INTRODUCTION

By Elmer S. Santos

PURPOSE AND SCOPE

The Newcastle $1^{\circ}x2^{\circ}$ Quadrangle, Wyoming and South Dakota was evaluated to identify and delineate volumes of rock that exhibit characteristics favorable for the occurrence of uranium deposits containing at least 100 mt of U_3O_8 with an average grade of no less than 0.01 U_3O_8. Each rock formation was categorized as favorable, unfavorable, or unevaluated as potential hosts for uranium deposits, based on recognition criteria obtained from the study of uranium districts world wide (Mickle and Mathews, 1978). All geologic environments to a depth of 1,500 m (5,000 ft) were evaluated using surface and subsurface data.

Evaluation of the Newcastle Quadrangle was conducted by the U.S. Geological Survey (USGS) for the National Uranium Resource Evaluation (NURE) program, managed by the Grand Junction Office of the U.S. Department of Energy (DOE). The evaluation program began June 1, 1978 and ended March 31, 1980. Time spent in literature search, field work, evaluation of data, and in preparation of the final report totaled approximately 2.5 man-years by the author and other USGS personnel.

ACKNOWLEDGEMENTS

A. C. Christiansen, L. W. McGrew, and J. D. Love, in addition to compiling the geologic map of the Newcastle Quadrangle, participated in the

compilation of the selected bibliography and the index to geologic maps. P. B. Mudgett investigated the land status and N. M. Denson participated in field reconnaissance related to this investigation. Thanks are also due to L. C. Craig and H. C. Granger of the USGS and to personnel of the Bendix Field Engineering Corporation for their suggestions and cooperation in this effort.

PROCEDURES

To evaluate the uranium resources of the Newcastle Quadrangle a study of the literature pertaining to the geology and uranium occurrences of this and adjacent areas was made. This study provided the basis for a preliminary evaluation of favorable and unfavorable environments existing within the quadrangle. To further evaluate those areas that contain environments which might be favorable, the following surface geologic investigations were made: (1) examination of many uranium occurrences previously reported in the literature and in the Preliminary Reconnaissance Reports (PRR) of the U.S. Atomic Energy Commission (USAEC), (2) location and examination of aerial radiometric anomalies indicated by data obtained from an airborne survey made by geoMetrics, Inc., and (3) a general reconnaissance of outcrops in areas that could contain favorable environments. Samples of rock, stream sediments, and water were collected and submitted for geochemical analysis to laboratories of the USGS and a contract laboratory. A portable scintillometer, the Mt. Sopris Model SC 131-H[1], was used to measure gross gamma counts at sampled horizons and to determine the characteristic background radiation of rock units that might serve as hosts for uranium deposits. Results of the Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) Program were not available at the time this report was written.

GEOLOGIC SETTING

The Newcastle Quadrangle, an area of 18,100 km^2, is located in northeastern Wyoming and in a small part of southwestern South Dakota between lat. 43°00′00"N and 44°00′00"N, and long 104°00′00"W and 106°00′00"W (Fig. 1 and Pl. 10). Located in the Great Plains physiographic province, most of the quadrangle lies in the unglaciated Missouri Plateau with a small part of the northeast corner in the Black Hills (Love and others, 1977).

The survey area is located within the stable platform tectonic province and occupies the southern part of the north-northwesterly trending intermontane Powder River Basin which is bounded on the west by the Big Horn Mountains and Casper Arch, on the south by the Laramie and Hartville uplifts, and on the east by the Black Hills uplift (Fig. 3). The Basin is asymmetrical with steeper dips on the west than on the east flank.

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[1] The use of brand names is for descriptive purposes only and does not necessarily constitute endorsement by the U.S. Geological Survey.

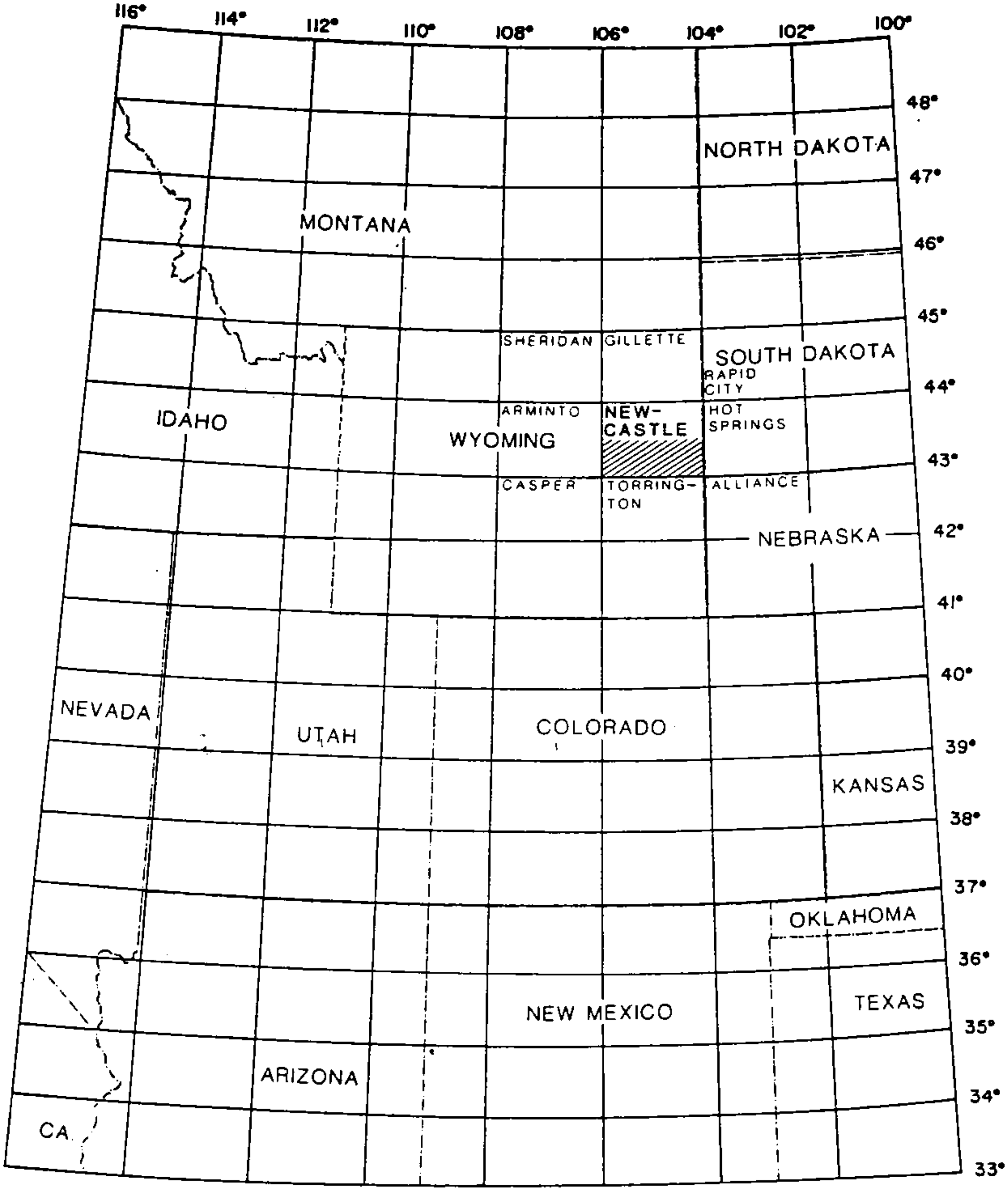


FIGURE 1.--Location of Newcastle Quadrangle

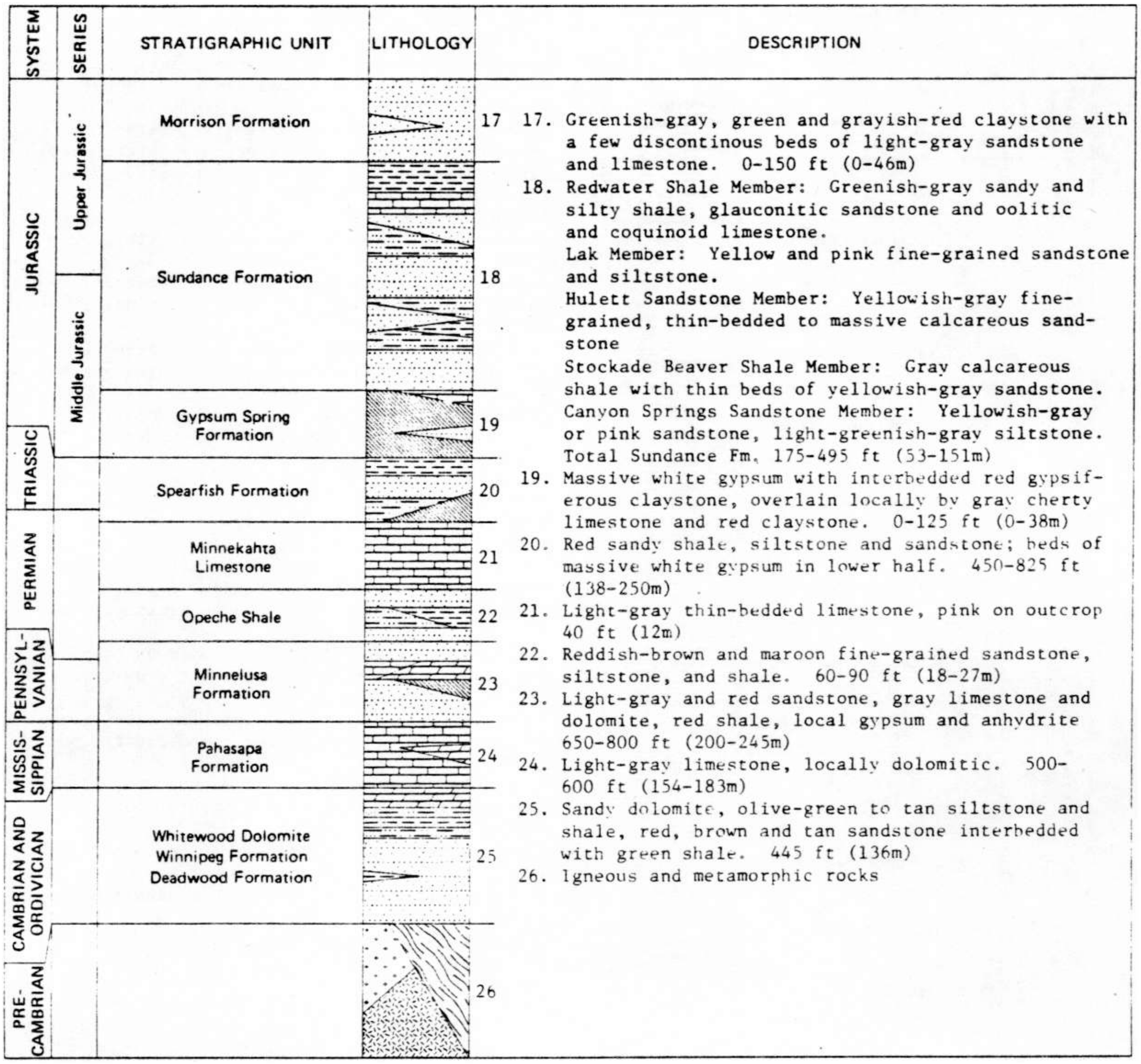
The sedimentary formations overlying the Precambrian crystalline basement have a total thickness of 4,900 m (16,000 ft). There are in descending order 1,230 to 1,830 m (4,000 to 6,000 ft) of Tertiary sediments, 2,140 m (7,000 ft) of Cretaceous rocks, 335 m (1,100 ft) of Jurassic and Triassic rocks, and 615 m (2,000 ft) of Paleozoic rocks. Stratigraphic nomenclature and generalized lithologic descriptions are summarized in Figure 2 and 2A. All pre-Cretaceous rock units except the Spearfish and Morrison Formations consist of marine and marginal-marine limestone, dolomite, gypsum, sandstone, siltstone, and shale. The Spearfish and Morrison Formations are of continental origin and consist of mudstone, shale, siltstone, and sandstone with minor limestone and gypsum. All Cretaceous rock units, except the Inyan Kara Group and Lance Formation consist of marine and marginal-marine shale, siltstone, sandstone, and limestone. The Inyan Kara Group, made up of the Lakota and Fall River Formations, consists of sandstone, siltstone, shale, claystone, and minor coal, all of continental origin. Also of continental origin are strata of the Lance Formation which consist of shale, sandstone, and thin coal beds. Post-Cretaceous formations ranging in age from Paleocene to Miocene are all of continental origin and consist of shale, siltstone, sandstone, and coal beds.

The base of Tertiary units is above a 1,500 m (5,000 ft) depth along the western margin of the quadrangle. Along the eastern margin, the top of Precambrian rocks is above a 1,500 m depth. From west to east successively older rock units of Mesozoic and Paleozoic age occupy the interval between the surface and a depth of 1,500 m.

ENVIRONMENTS FAVORABLE FOR URANIUM DEPOSITS

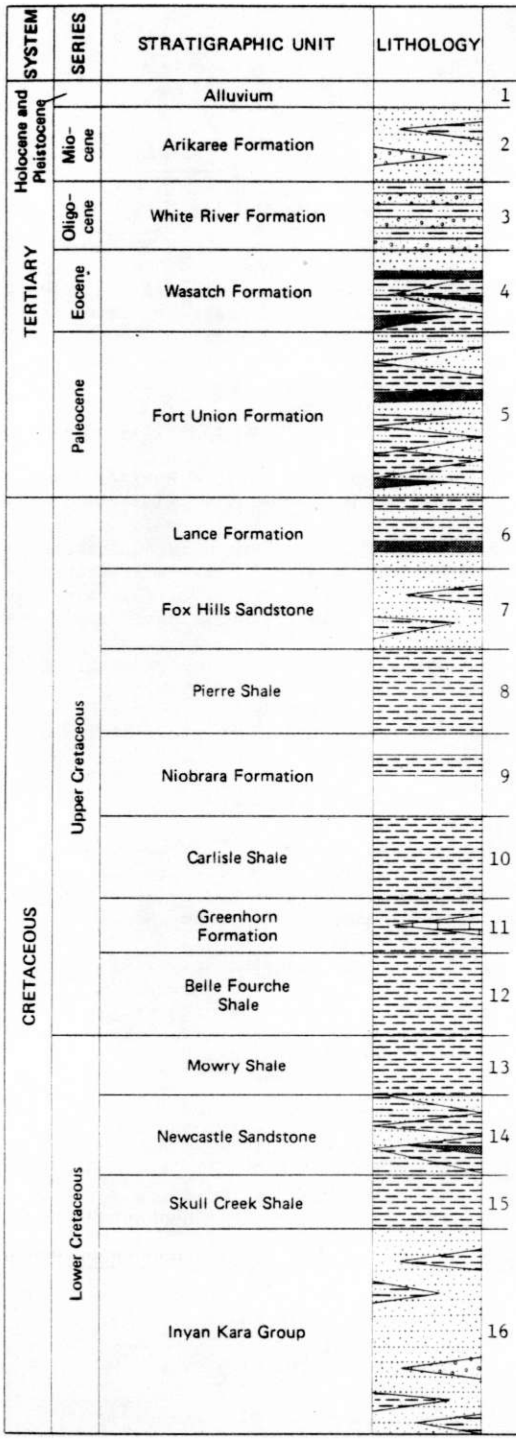
Two areas (Pl. 1) in the Newcastle Quadrangle have environments favorable for uranium deposits containing at least 100 mt of U_3O_8 with an average grade of no less than 0.01 percent uranium (U_3O_8). The host rocks in Area A contain sandstone-type deposits (Class 240) which are all "Wyoming" roll-type deposits of Subclass 241 (Austin and D'Andrea, 1978). The host rocks in Area B contain sandstone-type deposits (Class 240) which display characteristics of both channel-controlled and non-channel-controlled peneconcordant deposits (Subclasses 243 and 244). It is possible that roll-type deposits of Subclass 242 may occur in the subsurface in Area B. Host-rock units in Area A are the Wasatch and Fort Union Formations and, in Area B, the Inyan Kara Group.

Rock units considered favorable as hosts for uranium deposits in the Newcastle Quadrangle are the Wasatch and Fort Union Formations and the Inyan Kara Group. Since the early 1950's uranium in the Wasatch Formation has been mined from numerous small near-surface deposits and, more recently, from several large deposits at depths up to 245 m (804 ft). Two of these large mines are believed by some to be wholly or partly in the Fort Union Formation. Close-spaced exploration drilling by mining companies throughout the area indicate many more, as yet, undeveloped deposits have been found in both units.



17. Greenish-gray, green and grayish-red claystone with a few discontinous beds of light-gray sandstone and limestone. 0-150 ft (0-46m)
18. Redwater Shale Member: Greenish-gray sandy and silty shale, glauconitic sandstone and oolitic and coquinoid limestone.
    Lak Member: Yellow and pink fine-grained sandstone and siltstone.
    Hulett Sandstone Member: Yellowish-gray fine-grained, thin-bedded to massive calcareous sandstone
    Stockade Beaver Shale Member: Gray calcareous shale with thin beds of yellowish-gray sandstone.
    Canyon Springs Sandstone Member: Yellowish-gray or pink sandstone, light-greenish-gray siltstone.
    Total Sundance Fm. 175-495 ft (53-151m)
19. Massive white gypsum with interbedded red gypsiferous claystone, overlain locally by gray cherty limestone and red claystone. 0-125 ft (0-38m)
20. Red sandy shale, siltstone and sandstone; beds of massive white gypsum in lower half. 450-825 ft (138-250m)
21. Light-gray thin-bedded limestone, pink on outcrop 40 ft (12m)
22. Reddish-brown and maroon fine-grained sandstone, siltstone, and shale. 60-90 ft (18-27m)
23. Light-gray and red sandstone, gray limestone and dolomite, red shale, local gypsum and anhydrite 650-800 ft (200-245m)
24. Light-gray limestone, locally dolomitic. 500-600 ft (154-183m)
25. Sandy dolomite, olive-green to tan siltstone and shale, red, brown and tan sandstone interbedded with green shale. 445 ft (136m)
26. Igneous and metamorphic rocks

FIGURE 2. GENERALIZED STRATIGRAPHIC COLUMN FOR THE NEWCASTLE-GILLETTE 1°X2° QUADRANGLE



DESCRIPTION

1. Sand, silt, clay and gravel, 0-33 ft (0-10m)
2. Tan, very fine grained sandstone, some siltstone and conglomerate. Predominantly of eolian and volcanic origin. 0-600 ft (0-183m)
3. Pink, light- to medium-gray and green tuffaceous siltstone and conglomerate. 0-1100 ft (0-335m)
4. Interbedded sandstone, siltstone, shale, carbonaceous shale and coal beds. 0-1800 ft (0-549m)
5. Lebo Member: Light- to dark-gray, very fine grained to conglomeratic sandstone interbedded with siltstone, claystone, carbonaceous shale and coal beds. 1700-2800 ft (518-853m). Tullock Member: Interbedded sandstone, siltstone, shale, carbonaceous shale and thin coal beds. 1000-1500 ft (305-475m)
6. Thinly interbedded brown to gray sandstone, shale, carbonaceous shale, and coal beds. 1000-3000 ft (305-914m)
7. Gray to brownish-gray massive to thin-bedded sandstone interbedded with gray sandy shale and siltstone. 0-600 ft (0-183m)
8. Dark-gray shale, some sandy shale and siltstone and many beds of bentonite. 945-3500 ft (288-1067m)
9. Chalk marl and calcareous shale with numerous thin beds of bentonite, dark gray where fresh, weathers light yellow. 150-225 ft (46-68m)
10. Grayish-black to dark-gray shale, locally silty and sandy, contains numerous limestone concretions. 450-600 ft (137-183m)
11. Gray shale and marl, thin-bedded limestone 70-370 ft (21-113m)
12. Dark-gray to black shale with numerous purplish-red siderite concretions and light-gray limestone concretions. 350-850 ft (107-259m)
13. Dark-gray siliceous shale, weathers light gray, numerous thin bentonite beds. 180-230 ft (55-70m)
14. Lenticular beds of light-gray sandstone, siltstone, dark-gray shale; few beds of impure coal and bentonite 0-95 ft (0-29m)
15. Black shale with a few red ferruginous concretions. 180-270 ft (55-83m)
16. Fall River Formation: Fine- to medium-grained yellowish-brown to brown sandstone with interbedded gray and black shale and gray siltstone. 95-200 ft (29-61m)
    Lakota Formation: White, light-gray, and yellowish-gray very fine to very coarse grained sandstone, conglomerate; brown, gray, red and black siltstone, mudstone and claystone. 45-300 ft (14-91m)

FIGURE 2A. GENERALIZED STRATIGRAPHIC COLUMN FOR THE NEWCASTLE-GILLETTE 1°X2° QUADRANGLE

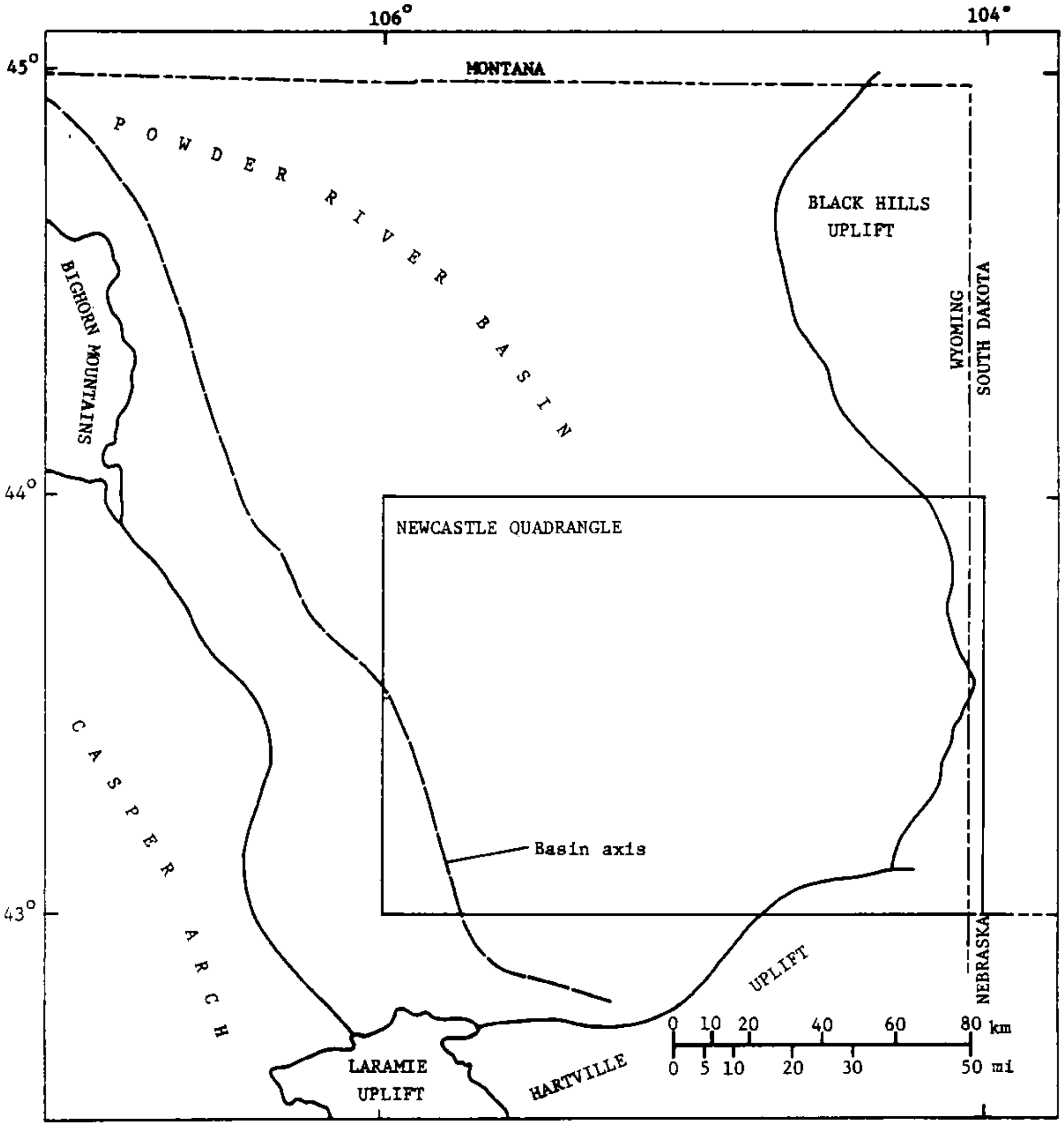


Figure 3.--Structural setting, Newcastle Quadrangle.

A small quantity of uranium has been produced from three small mines (Localities 177, 181, 182, and 183, Plate 2) in the Inyan Kara Group. The proximity to the Edgemont district to the east, where uranium has been produced from many mines in the Inyan Kara Group, suggests that in the Newcastle Quadrangle, this unit very likely contains undiscovered uranium deposits comparable in size and grade to those in the Edgemont district.

FAVORABLE AREA A

Area A (Pl. 1) in the western part of the quadrangle is underlain by the favorable facies in the Wasatch and Fort Union Formations. Delineation of Area A is based primarily on the extent of iron oxide-stained sandstone at the surface as mapped by Sharp and others (1964), Sharp and Gibbons (1964), and as described later under lithology of the Wasatch Formation. Based on the surficial distribution of red sandstone approximately the same area has been shown as favorable by Curry (1976). The zone of oxidized sandstone coincides with the zone of greatest permeability at the surface. Extensive exploration in the area indicates that the extent of oxidation, mineralization, and the zones of greatest permeability in the subsurface roughly coincides with that at the surface. The distribution of facies in the subsurface is shown by Raines and others (1978) who demonstrated that, because of a relationship of vegetation density to the type of local substrate, the facies distribution can be detected using computer-enhanced Landsat images. Sandstone pinchouts to the east and north are illustrated in the east-west cross sections of McKeel and Crew (1972) and the north-south sections of Davis (1970). The line that encloses the favorable area roughly marks a change in sandstone to mudstone ratio from >0.5 in the favorable area to <0.5 outside of it. Uranium deposits in this area are probably all sandstone-type deposits of Subclass 241 and, in the near-surface, modified remnants of Subclass 241 deposits.

Wasatch Formation

Stratigraphy and structure. The Wasatch Formation of Eocene age is unconformably overlain by the White River Formation of Oligocene age and rests on the Fort Union Formation of Paleocene age. There is a slight angular unconformity at the base of the Wasatch along the west flank of the Powder River Basin, but elsewhere the formations are concordant and separated by an erosion surface (Sharp and Gibbons, 1964). Throughout most of its extent the Wasatch is almost horizontal, with dips of less than one degree to the northwest. Along the west side of the basin strata dip 2° to 7° east and as much as 25° east beyond the quadrangle's boundary (Childers, 1970).

The Wasatch Formation attains its maximum thickness in the vicinity of Pumpkin Buttes, the only place in the quadrangle where the White River Formation rests on the Wasatch. Elsewhere, the upper part of the Formation has been removed by erosion and is absent along the east, west, and south flanks of the Basin. A thickness of 480 m (1575 ft) was measured by Sharp and others (1964) but Denson (1975) reported a maximum thickness of 566 m (1800 ft).

Lithology. The Wasatch Formation consists of mudstone and siltstone containing thick lenses of fine- to coarse-grained, crossbedded, arkosic sandstone. Thin beds of coal and carbonaceous shale are common in some areas. A dominant fine-grained facies flanks the Basin on three sides and a dominant coarse-grained facies is present in the central and southern parts. The fine-grained facies consists of thinly interbedded siltstone, fine- to medium-grained sandstone, and coal or carbonaceous shale. Southward and toward the center of the Basin siltstone and carbonaceous shale decrease in amount; thick lenticular sandstone beds become more prominent and sandstone makes up as much as one-half the formation. Within the coarse-grained facies the grain size of the sandstone increases generally southward and, at the southern extremity of the outcrop, pebble conglomerate appears as lenses and stringers in the coarse-grained sandstone. In addition to this increase in grain size, the sandstone units themselves thicken generally from north to south. Sandstone lenses as much as 46 m (150 ft) thick were mapped by Sharp and Gibbons (1964) at the southwest edge of the outcrop and 91 m (300 ft) of uninterrupted sandstone has been penetrated in drill holes.

Uranium deposits in the Wasatch Formation are closely associated with abrupt color changes that reflect alteration of iron-bearing minerals by oxidizing ground waters. On the outcrop most sandstone is colored dull shades of gray, yellow, or brown. In the subsurface, below the zone of weathering, most sandstone is medium to light gray. In a well-defined zone along the axis of the Basin, however, some of the sandstone at the surface is predominantly pale pink to grayish red and orange. Some lenses are only partly red and some are entirely drab. The red tint, where present, commonly affects a large continuous mass of sandstone and does not occur as isolated splotches of color. The contact of the red color within partly red sandstone lenses is generally convex into the drab sandstone. The outcropping red sandstone is restricted to an area about 113 km (70 mi) long and 8-32 km (5-20 mi) wide Curry (1976). The long axis of the red sandstone zone closely parallels the axis of the Basin and extends from beyond the southern margin of the quadrangle to several kilometers north of North Butte.

In the subsurface, at depths as much as 250 m (820 ft), abrupt changes from altered red, orange, and yellow iron-oxide-bearing sandstone on one side to unaltered gray, pyrite-bearing sandstone on the other side occur roughly below the same zone where the sandstone is red at the surface. Called roll fronts, the color boundaries exhibit no preferred orientation and are very sinuous in plan. In section, the color contact is convex into the gray sandstone and a progressive change in color from grayish red to orange to yellow occurs as the unaltered side and upper and lower bounds of the host unit are approached. Individual roll fronts have been traced in the subsurface for lengths exceeding 16 km (10 miles) and, in many places, several roll fronts separated by mudstone or siltstone occur one above the other. Buturla and Schwenk (1976), Dahl and Hagmaier (1976), Langen and Kidwell, (1971), Davis (1970), and Rubin (1970) all published papers describing various aspects of roll-fronts and their associated uranium deposits in the Powder River Basin.

Sedimentary structures. The coarse- and fine-grained rocks of the Wasatch Formation form thin to thick tabular and lenticular beds which complexly interfinger with one another on both a large and small scale. Most narrow sandstone bodies fill discrete channels cut in the underlying rocks and are roughly plano-convex in cross section. The more widespread sandstone bodies, some of which have been traced for more than 19 km (12 mi), commonly have flatlying lower contacts over much of their extent. Toward their edges these sandstone bodies become fine-grained and silty. Normal to their sedimentary trends they may pinch out in several different ways, the most common of which is by the thinning of tongues away from the main parts of the bodies. Sandstone lenses may decrease in thickness from 12 m (40 ft) to 0 m over a distance of 91 m (300 ft). In some localities channels have been cut down through intervening fine-grained strata into a lower sandstone body; thus, the sandstone filling the upper channel is in direct contact with the lower one. The contact is marked in places by a reworked shaly sandstone zone as much as 1 m (3.3 ft) thick and it is impossible to delineate the contact between the two sandstone bodies where this shaly zone is absent.

The most conspicuous sedimentary structure in sandstone is cross lamination. A typical cross-laminated bed is about 46 to 61 cm (1.5 to 2.0 ft) thick and is overlain by as much as a dozen similar beds in a vertical distance of 6 m (20 ft). Festoon crossbedding in northward-plunging troughs 0.3 to 1.8 m (1-6 ft) wide are common. In some places cross stratification is very complex and the direction of dip may change several times in as many meters of strata.

Another conspicuous feature of sandstone lenses is epigenetic concretions where sand grains are tightly cemented by calcium carbonate. These are most common in thick sandstone lenses. Their shape and size range from spherical masses usually 15 to 25 cm (6-10 in) in diameter to cylindrical masses 2 m (6 ft) in diameter and as much as 15 m (50 ft) long.

Depositional environment. Of fluvial, floodplain, and paludal origin, strata of the Wasatch Formation were deposited in a slowly subsiding basin dominated by a warm humid climate. The facies distribution, along with grain size and current direction studied by Seeland (1976), indicate that northward-flowing paleostreams deposited sand derived from a granitic source area located south and southwest of the quadrangle. Following the deposition of the underlying Fort Union Formation, the thick coarse-grained sandstones of the Wasatch in the southern part of the basin record a renewed uplift of the source area and an increase in size and transporting power of the streams entering the basin. These streams probably were aggrading their courses fairly rapidly, perhaps rising on wet alluvial fans of sandy material. At flood stage, lower areas on either side of the stream courses received a layer of overbank silt and clay. Deposits of organic matter accumulated in heavily forested swamps that developed on the interfluves between stream courses.

Fort Union Formation

Separated from the overlying Wasatch Formation by an unconformity, the Fort Union Formation of Paleocene age has a maximum thickness of about 1158 m (3800 ft) in the Newcastle Quadrangle. It conformably overlies the Lance Formation of Late Cretaceous age and consists of two units, a lower Tullock Member and an upper Lebo Member (Denson and Horn, 1975). Strata in both units are of fluvial, floodplain, and paludal origin. The Tullock Member, whose thickness ranges from 305 to 457 m (1000-1500 ft), is composed of fine-grained sandstone with some interbedded siltstone, shale, carbonaceous shale, and thin coal beds. The sandstone is massive to thin bedded, and tan, white, pink, and pale orange in color. The shales are dark gray or brown. The Tullock is distinguishable from the conformably overlying Lebo Member which generally has a lighter overall color and a predominance of siltstone and shale. The Lebo Member, whose maximum thickness ranges from 518 to 853 m (1700-2800 ft), is composed of interbedded siltstone, claystone, carbonaceous shale, and coal beds with varying amounts of fine- to very coarse-grained conglomeratic sandstone. Thin bedded calcareous ironstone concretions interbedded with massive white sandstone and light- to dark-gray, slightly bentonitic shale occur throughout the unit. Locally, coal beds are as much as 24 m (80 ft) thick. The coarse-grained and conglomeratic sandstone lenses occur in the southern and western part of the Basin. In an area just west of the quadrangle Childers (1970) reported an aggregate of 274 m (900 ft) of medium- to coarse-grained sandstone in numerous lenses scattered throughout both units of the Fort Union. Outcrops on the east side of the Basin contain no coarse-grained sandstone. Apparently a coarse to fine facies change occurs in the subsurface from west to east and from south to north much the same as in the overlying Wasatch Formation.

Depositional environment. Like the Wasatch Formation, strata of the Fort Union Formation were deposited in a slowly subsiding basin dominated by a warm humid climate. Similar to other early Tertiary rocks, strata of both members are of fluvial, floodplain, and paludal origin. Thick sequences of well-sorted sandstone in the lower member suggests much reworking of the detrital material before eventual burial. Occasional beds of coal record local swampy conditions. The change from massive, fine-grained sandstone of the lower member to siltstone, claystone, coal, and minor sandstone of the upper member marked the end of a balance between deposition and subsidence recorded in the lower sequence. The landscape during the period of deposition may have consisted of a swampy forested lowland threaded by shallow shifting streams. The stability during late Fort Union time is recorded best by coal beds 6 to 30 m (20-100 ft) thick which formed in widespread swamps. Accumulation of coal-forming material on this scale indicates that deposition of detrital sediments generally failed to keep pace with subsidence during much of late Fort Union time. The absence of thick coals at the south end of the Fort Union outcrop suggests that the supply of detrital material was greater here than elsewhere as would follow if the material came from the south. Older sedimentary rather than crystalline rocks were probably the source of most of Fort Union strata.

Hydrology. Recharge areas for ground water in the Wasatch and Fort Union Formations are along the east, west, and south flanks of the Powder River Basin. Present-day ground-water flow is generally northward along the axis of the Basin and is discharged to the valley of the Powder River in the northern part of the Basin. This northward direction of flow has probably persisted since Early Tertiary time. There is a progressive change in chemical composition in which sulfate-bicarbonate-rich water in the recharge area becomes bicarbonate-rich water in the discharge area. The sulfate is thought to be removed by reduction to hydrogen sulfide through the action of methane produced from the diagenesis of organic carbon and by sulfate-reducing bacteria. Anomalous quantities of uranium occur only in the sulfate-rich waters and uranium is thought to be removed by reduction in the zone where hydrogen sulfide is generated (Hagmaier, 1971 and Dahl and Hagmaier, 1976).

Uranium deposits

All uranium deposits in Area A (Pl. 1) are classed as roll-type (Subclass 241, Austin and D'Andrea in Mickle and Mathews, 1978) because they occur in fluvial sediments near the boundary between red, orange, and yellow sandstone on one side and gray sandstone on the other side. In the Wasatch Formation, uranium concentrations associated with roll fronts typically occur in the unaltered gray sandstone and attain their highest grade nearest to the altered side. The grade gradually diminishes to background values with distance from the color boundary. Thin zones of uraniferous sandstone called "tails" or "limbs" occur parallel to and in contact with the upper and lower bounds of the host unit and extend away from the main mass of ore at the front to well back into the altered side.

Although uranium occurs at roll fronts in many places, the entire length of a particular roll front may not contain mineable concentrations. Along much of their length, grade is either too low or the volume of uraniferous rock is too small to warrant attempts at recovery under present economic conditions. Dimensions of roll-front deposits are only poorly known except that they vary greatly from one deposit to another and from place to place within the same deposit. At the Highland mine (Pl. 2, No. 158), a segment of roll front is continuously of ore grade parallel to the front, through a distance of 3.2 km (2 mi). More typical, however, is the size and distribution of ore deposits along the extension of this roll front to the west as shown by Dahl and Hagmaier (1976, p. 248). There, many small disconnected uranium concentrations, the longest of which is about 740 m (2430 ft), are distributed along the roll front. The horizontal dimensions of deposits perpendicular to the roll front range from less than 2 to 50 m (6.5-165 ft); vertical dimensions range from less than 1 to 16 m (3.3-52 ft).

The distribution of uranium in near-surface oxidized deposits is very erratic and in some ways conspicuously unlike that in the deeper roll-front deposits. The close association with iron-oxide-colored sandstone, however, suggests that they are related. The near-surface deposits are, very likely, remnants of roll-front deposits which have been partially destroyed and greatly modified by oxidation in the vadose zone after erosion stripped away the overlying strata.

Uranium minerals in deposits below the water table are coffinite and, subordinately, uraninite. Above the water table carnotite and tyuyamunite are the most common minerals but small amounts of liebigite, zellerite, uramophane, autunite, and uraninite are also present (Sharp and Gibbons, 1964). In the near-surface deposits, the gangue minerals are calcite, gypsum, pyrite, hydrated iron oxides, and barite. Less common gangue minerals are manganite and pyrolusite. Below the water table, calcite, pyrite, and marcasite are the primary gangue minerals; the calcite occurs as cement in sandstone. Although small concentrations of iron sulfides exceed 5 percent, the overall concentration in ore is less than one percent.

No uranium has been mined from the Fort Union Formation in the Newcastle Quadrangle so the nature of the uranium deposits can only be inferred from drill-hole data and from observations of the outcrop outside the quadrangle boundaries. In an area west of the quadrangle, Childers (1970) described sandstone lenses distributed throughout the Fort Union Formation. At the outcrop these lenses are in part gray and in part pink, red, and lavender. Yellow uranium minerals occur on the outcrop near the boundary between gray- and red-tinted sandstone. Iron-oxide-stained sandstone and radioactive anomalies were encountered in drill holes at depths of up to 304.8 m (1000 ft) in this area and segments of several roll fronts were delineated. It would appear, therefore, that the ore deposits are, like those in the Wasatch, roll-front deposits and probably contain the same ore and gangue mineral assemblages found in the Wasatch deposits. The extent of close-spaced drilling over deposits in the Fort Union suggests that they are all small in comparison to the larger deposits in the Wasatch.

Outcrops of Fort Union on the east flank of the Basin are not known to contain altered sandstone lenses like those described by Childers (1970) on the west flank and but little is known about the eastward limit of altered and mineralized ground in the subsurface. One clue to the eastward extent of mineralized ground is the occurrence of gamma-ray anomalies in two oil well tests (Pl. 5A, nos. 204 and 214) within the Lebo Member. The location of these anomalies suggests that mineralization in the Fort Union may be co-extensive with that in the Wasatch Formation. Little, also, is known about the depth to which altered and mineralized ground may extend. A gamma-ray anomaly occurs at a depth of 61 m (2000 ft) in an oil test about 1.6 m (1 mi) north of the quadrangle. Although many other oil well tests are located within the quadrangle, very few are logged for radioactivity through the entire Fort Union interval so it is not certain that the anomaly mentioned represents the maximum depth at which mineralization occurs or if it is associated with a roll-type deposit.

Three sources for the uranium in the Wasatch and Fort Union Formations have been proposed. Uranium, contained in detrital minerals derived from a granitic source area, was mobilized when the minerals were altered or destroyed during diagenesis. A second possible source is uranium leached from uraniferous granite and introduced into the host rocks by surface and ground water, some during deposition and some after lithification of the host rocks. A third possible source is uranium released by devitrification of volcanic ash in the overlying White River Formation and introduced into the host rocks in downward percolating ground water. It is possible that all three sources could have contributed to the total uranium content in the Tertiary units. Rosholt and Bartel (1969) measured the concentrations of uranium, thorium, and lead isotopes in rocks of the Granite Mountains and calculated that as much as 10^{11} kg (22^{11} lbs) of uranium was removed by leaching of near-surface granitic rocks at some time during the Cenozoic. This amount is several orders of magnitude greater than the total production and known reserves for all Wyoming basins. It was noted that many roll-type uranium deposits in rock units of different ages throughout the western states occur within, at most, a few hundred meters below a pre-Oligocene erosion surface once covered by tuffaceous rocks (H. C. Granger, written commun., 1980), In some places oxidized tongues related to these roll-type deposits can be traced up dip to this erosion surface or can be inferred to have once extended to this surface. Uranium in solution was initially precipitated more or less uniformly in the host rocks probably as a result of reduction by hydrogen sulfide and by carbonaceous material. The concentration of uranium in this initial phase may have been less than 10 ppm.

It is believed that when the host rocks were exposed by erosion in late Tertiary time, oxygenated water entered the outcrops, or near-surface subcrops, and dissolved and transported uranium downdip to where reducing conditions were sufficient to cause redeposition of uranium. Ages determined from the lead-to-uranium ratios in uraninite samples range from 7 to 13 million years (Sharp and Gibbons, 1964, p. D-32) and tend to support this interpretation concerning ore-forming processes. Through this process uranium, sparsely distributed throughout a large mass of rock, was concentrated in a relatively small volume of rock along roll-fronts. Apparent ages based on lead and uranium isotopes in four samples of ore from the Highland mine deposit (Pl. 2, occ. no. 158) indicate that the time of mineralization was 2.5± 1.5 m.y. (K. R. Ludwig, written commun., 1980). The range in ages tend to support the idea that the concentration of uranium is a continuing process rather than a single event.

As of January 1, 1970, 769,922 kg (1,697,679, lbs) of U_3O_8 had been produced from 69 near-surface deposits, the largest of which accounted for 252,663 kg (557,133 lbs) (USAEC production records). These deposits are of three types: (1) Small high-grade concretionary deposits which contain generally less than 28 mt of ore having an ore grade of one percent or more. The concretions, occurring in red sandstone, are composed of uraninite and oxides of iron and manganese and are surrounded by yellow uranium minerals. (2) Deposits which contain about 5500 mt of ore averaging 0.5 percent U_3O_8 occurring in buff-colored sandstone at the contact with pink or red sandstone. (3) Large deposits containing as much as 55,000 mt of ore with grades averaging 0.2 to 0.3 percent U_3O_8. These deposits occur in white to buff sandstone as much as 100 m (330 ft) from the contact with red sandstone. The deposits are irregularly tabular with their long axis parallel to the red-buff contact. Although most are smaller, one such deposit was as much as 305 m (1000 ft) long, 120 m (400 ft) wide, and 15 m (50 ft) thick in places. In these, as in type 2 deposits, uranium vanadate minerals are disseminated in the white or buff sandstone (Mrak, 1958).

Production since 1970 has been mainly from large roll-front deposits below the present water table. Currently in operation the deposit at the Highland mine (Pl. 2, occ. no. 158) occurs at depths of from 30 to 210 m (100-700 ft) along three northwesterly trending roll-fronts one above the other, each in a sandstone lense about 12 m (40 ft) thick. Reserves in this deposit total nine million metric tons containing between one and three kilograms of U_3O_8 per ton (Dahl and Hagmaier, 1976). At the Bear Creek mine (Pl. 2, occ. no. 135), also currently operating, six scattered deposits occur at depths of 30 to 85 m (100-280 ft) along a sinuous roll-front that has been traced through a distance more than 16 km (10 miles). Total reserves in the six deposits is seven million tons of ore containing three kilograms of U_3O_8 per ton (Jackson, 1977). The South Morton Ranch mine (163, Plate 2) is one of several shallow deposits still being mined in which, as in type 3 deposits above, oxidized uranium minerals are disseminated in buff to white sandstone. No data are available as to reserves here but the deposit probably exceeds 50,000 metric tons of ore.

Descriptions of the many near-surface deposits in the Wasatch Formation appear in Sharp and others (1964) and in Sharp and Gibbons (1964). Mrak (1958) described the general geologic features and distribution of these near-surface deposits and listed 80 producing properties. Dahl and Hagmaier (1976) as well as Langen and Kidwell (1971), described the ore deposit at the Highland mine, the largest in the area. Buturla and Schwenk (1976) described the ore deposits at the Bear Creek mine.

Rock units of Eocene, Paleocene, and latest Cretaceous age have similar lithologies and contacts between them cannot be distinguished on any available logs of holes drilled in the area. It was, therefore, impossible to generate credible isopach maps or cross sections depicting variations in thickness of the Wasatch Formation or of the two members of the Fort Union Formation. To calculate the volume of the Wasatch in the favorable area A (Pl. 1), arbitrary, but reasonable, thicknesses for this unit were chosen for various parts of the area. In the vicinity of North Pumpkin Butte the logs of several holes show a conspicuous break in the subsurface about 120 m (400 ft) above a thick coal bed. The span between the elevation of this break and the projected elevation of the White River-Wasatch contact on North Butte equals the 549 m (1800 ft) reported by Denson and Horn (1975) as the maximum thickness of the Wasatch. The height above this break of the general land surface elevations at the base of North Butte indicates a thickness of 244 m (800 ft) of uneroded Wasatch in this area. It was assumed that the unit's thickness diminishes uniformly eastward to zero at the eroded margin of the outcrop.

The thick coal bed in the subsurface at North Butte does not extend into the southern part of the favorable area. Here, based on the position of the contact as drawn by Denson and Horn (1975) a short distance west of the Pacific Power and Light coal mine, the base of the Wasatch is assumed to be about 122 m (400 ft) below the top of what is known as the Badger coal. It is assumed that, where the Badger coal is absent, the Wasatch thins uniformly to zero at the limits of the outcrop. The hypothetical isopach lines are assumed to be generally parallel to structure contours drawn on Late Cretaceous strata below the Lance Formation. Plate 2A is an isopach map showing the assumed thicknesses used to calculate the total volume of Wasatch Formation in Area A. Areas between pairs of adjacent isopach lines were measured with a polar planimeter and each area was multiplied by the average thickness between the adjacent lines. Measured this way, the total area of Wasatch in Area A is 2828 km^2 (1092 mi^2) and the total volume is 483 km^3 (115.8 mi^3). Wasatch strata in the favorable area average 25 percent sandstone, so the volume of sandstone is 121 km^3 (140 mi^3).

The area underlain by the Fort Union Formation is 3103 km^2 (1198 mi^2). Unlike in the Arminto Quadrangle to the west where favorable sandstone units are distributed throughout the Fort Union Formation from top to bottom, only the uppermost 305 m (1000 ft) contain favorable sandstone in the Newcastle Quadrangle. This thickness yields a volume of 946 km^3 (227 mi^3) for the favorable part of the formation in this quadrangle. Area A_2 on plate 1 represents portions of the Lance and Fort Union Formations. Drill hole data in the adjoining Arminto Quadrangle indicate that some parts of these, mainly within the Arminto Quadrangle, are favorable. For details about the volume and character of these favorable rocks the reader is referred to the report on the evaluation of the Arminto Quadrangle.

Land Status and Culture

With altitudes that range from 1505 to 1843 m (4950-6050 ft), most of the area in which the Wasatch and Fort Union Formations are favorable is characterized by rolling grasslands separated by broad valleys. Some of the high areas of grassland, which are almost level, have been informally named flats. Used almost exclusively for cattle and sheep grazing, the area is sparsely populated, with most of land being owned by ranchers. Small tracts of state and federal public land are interspersed among the privately-owned tracts. The Pacific Power and Light Company operates an open-pit coal mine in the southwestern part of the favorable area, the coal being used to fuel a power plant located south of the quadrangle. The Exxon Company, U. S. A. and the Rocky Mountain Energy Company each have a mill at their uranium mining properties (Pl. 2, occ. nos. 135 and 158). Although no large oil fields exist in the area, oil is produced from numerous scattered wells and from a cluster of wells in the vicinity of Pumpkin Buttes. A network of paved and unpaved county roads connecting with Wyoming State Highways 59 and 387 provide access to the area from the towns of Gillette, Douglas, Glenrock, Edgerton, and Midwest.

FAVORABLE AREA B

Area B on Plate 1 encompasses the Inyan Kara Group from the limits of its outcrop to a depth of 1,500 m (5000 ft). Uranium deposits likely to be found in this area are, like those in the nearby Edgemont district, peneconcordant sandstone deposits both channel-controlled (Subclass 243) and non-channel-controlled (Subclass 244). It is possible that some deposit in the subsurface may be of the sandstone roll-type both of Subclass 241 and 242.

Inyan Kara Group

Stratigraphy and structure. The Inyan Kara Group includes the Lakota and Fall River Formations; the Lakota Formation constitutes approximately the lower two-thirds and the Fall River Formation the upper one-third of the Group. The Lakota Formation is further subdivided into a lower Chilson and upper Fuson Member. The Minnewaste Limestone Member, present in adjacent areas, does not extend into the Newcastle Quadrangle. The Group is conformably overlain by the Skull Creek Shale and rests on an erosion surface cut into the Morrison Formation. The Group ranges in thickness from 100 to 182 m (325 to 600 ft) on the outcrop and thins to slightly less than 60 m (200 ft) in the subsurface (Pl. 1A).

Lithology. Having two distinct parts, the Chilson Member includes a basal unit consisting of brown and gray to black carbonaceous mudstone and siltstone interlayered with some sandstone. A typical 15 m (50 ft) section of the lower unit consists of, from top to bottom, 3 m (10 ft) of gray silty mudstone, 1.5 m (5 ft) of white fine-grained sandstone, 9 m (30 ft) of gray carbonaceous silty mudstone, and 1.2 m (4 ft) of gray siltstone lying on the Morrison Formation. The overlying unit consists of fine- to coarse-grained, yellow to reddish brown loosely cemented sandstone in a complex of anastomosing channel fillings that finger out laterally and are enclosed by mudstone (Brobst, 1961).

The Fuson Member consists of three distinct units. The lower unit consists of white to yellow and reddish-brown, fine- to coarse-grained sandstone and of conglomerate. The sandstone is quartzose and, locally, chert pebble conglomerate predominates. Well-rounded pebbles are white, gray, and black and are as much as 1.3 cm (0.5 in.) in diameter. Matrix in the conglomerate is mixed sand and clay. A middle mudstone unit is a heterogenous sequence of rocks composed of varicolored mudstones, gray siltstones, and some white to yellow sandstone and conglomerate. Mudstone, colored gray, yellow, green, or red is the most abundant rock type but discontinuous thin laminae of sandstone are common. Much of the mudstone is carbonaceous, especially in the lower part of the unit. Very fine to medium-grained quartzose sandstone, which locally contains small amounts of conglomerate, is interbedded with the mudstone. The sandstone is white to yellow, but some is dark brown, green, or pink. The uppermost unit of the Fuson Member consists of yellow to gray medium-grained quartzose sandstone containing abundant lenses of conglomerate. The conglomerate consists of rounded pebbles of gray and brown chert and rounded aggegates of quartz grains as long as 0.63 cm (0.25 in.) in diameter; the matrix is sand and clay.

The lowest of three distinct units of the Fall River Formation is a sequence of gray to black laminated carbonaceous siltstone; the carbonaceous matter occurs as black laminae generally less than 1 cm (0.4 in.) thick. Some thin layers of sandstone as much as 7.5 cm (3 in) thick are intercalated with the siltstone. Locally, the unit is a black silty shale. The contact of this unit with the underlying Lakota Formation is a regional unconformity. The middle unit is a yellow to reddish-brown, coarse- to fine-grained, crossbedded quartzose sandstone. Carbonaceous matter is disseminated throughout the unit. Lenses of lignite 7 to 70 cm (2.8 to 28 in) thick and as much as 15 m (50 ft) long occur locally. Scattered irregular fragments and pods of red clay 5 to 7.5 cm (2 to 3 in) thick and 61 cm (2 ft) in diameter are common. Clasts of the underlying carbonaceous siltstone and mudstone as large as 30 cm (1 ft) across are found in the lower parts of the sandstone. The upper part of the Fall River Formation is a complex lithologic unit consisting chiefly of interlayered mudstone and carbonaceous fine- to very fine-grained sandstone. Quartzose sandstone colored gray, yellow, brown, or red occurs as discontinuous beds that range from 2.5 to 61 cm (1-24 in) in thickness. The mudstones are chiefly yellow or gray, but some are black or various shades of red. Carbonaceous matter is common as minute disseminated fragments or concentrated in laminae.

Sedimentary structures. The most conspicuous sedimentary structures in the Inyan Kara Group are scour-and-fill features involving the removal of from a few meters to as much as of 15 m (50 ft) of rock. Sandstone units throughout the Group fill scours cut into the underlying fine-grained units in many places and the sandstone units themselves are a complex of channel deposits cut one into the other. Crossbedding, more prevalent in coarse-grained than in fine-grained sandstone, is also conspicuous, particularly near the base of scour fillings. The direction of crossbedding indicates a northerly to northeasterly direction of transport in the Lakota units and a northwesterly direction in the Fall River units. Rip clasts of mudstone and siltstone at the base of sandstone units are another common feature.

Depositional environment. Of fluvial, floodplain, and lacustrine origin, strata of the Lakota Formation were deposited in a warm humid climate. The discovery of marine fossils by Dondanville (1963) together with reports of crocodile and marine plesiosaur remains in the Fall River Formation led Harris (1976) to propose brackish to fresh-water conditions, as well as a warm climate, during deposition of the Fall River which, on the outcrop, is of mixed fluvial, deltaic, and marine origin. From east to west the Fall River becomes progressively more completely marine and the subsurface portion down to 1500 m (5000 ft) may be largely of marine and marginal-marine origin.

Hydrology. Studies by Gott and others (1974) indicate that little of the ground water in the Inyan Kara Group was introduced by direct surface recharge. Based on variations in chemical composition, temperatures, and tritium content they concluded that water in the Minnelusa Formation, rising under artesian pressure, entered the aquifers of the Inyan Kara and accounts for the bulk of the water in this unit. As ground water migrates upward into the Inyan Kara and then basinward within the Lakota and Fall River aquifers, the composition of the water changes from a predominantly calcium-sulfate to a sodium-sulfate water and locally, to a sodium-bicarbonate water. The first detectable change in composition occurs within the ascending waters where a loss of carbon dioxide causes precipitation of calcite, which results in a decrease in the proportion of calcium to other cations. A second change takes place within the Inyan Kara where a further decrease of calcium ions, as well as magnesium ions, is accompanied by a proportionate increase in sodium ions.

Uranium concentrations in water from springs in the Minnelusa Formation range from 4.7 to 17.0 ppb. Uranium concentration in ground water of the Inyan Kara decreases in a basinward direction from 1.0 to less than 0.25 ppb as calcium-sulfate water is modified to a sodium-sulfate water and simultaneously is subjected to minor sulfate reduction. Where intensive reduction of sulfate occurs within the more carbonaceous rocks, and the water is modified to the sodium-bicarbonate type, the uranium content decreases very rapidly until less than 0.1 ppb remains in solution. The decrease in uranium concentration in the basinward-flowing waters is interpreted to be the result of the precipitation of uranium. The decrease in uranium concentration does not result from dilution by less uraniferous water because such dilution would be accompanied by a simultaneous dilution in tritium content, which does not occur.

Redox potentials and pH recorded in water flowing from wells also indicate precipitation of uranium rather than dilution by less uraniferous water. High uranium values are present in calcium-sulfate waters having high redox and pH values representing oxidizing conditions. Conversely, low uranium concentrations (<0.5 ppb) are present in sodium-sulfate or sodium-bicarbonate waters in which low redox and pH values indicate the presence of reducing conditions that could precipitate uraninite.

Uranium deposits

Uranium deposits in the Inyan Kara Group display characteristics of both channel-controlled (Subclass 243) and non-channel-controlled (Subclass 244) peneconcordant sandstone deposits. Most deposits are non-channel-controlled except for the fact that the depositional environment of the host strata is not a wet alluvial fan (Austin and D'Andrea, 1978). Most of these deposits more closely resemble Uravan mineral belt than Monument Valley deposits. The most favorable hosts are the lower fluvial unit of the Chilson Member of the Lakota Formation and the lower part of the Fall River Formation, although small occurrences of uranium are found throughout the Group. Deposits in the Fuson Member of the Lakota occur only where a fluvial unit of the Fall River fills scours cut into this member. Deposits occur in a sequence of alternating fine-grained sandstone and laminated carbonaceous siltstone in the basal 6 to 9 m (20-30 ft) of the Fall River Formation. The greatest concentrations of ore minerals are in a widespread sandstone bed that is generally less than 1.5 m (5 ft) thick. This ore-bearing unit is a blanket-like sequence that was deposited over the southern part of the Black Hills. Subsequent to its deposition extensive deep-cut channels were formed. These channels were then filled by fluvial units. All of the partly oxidized deposits in the basal part of the Fall River Formation are near the margins of sandstone channels. The location of the deposits suggests that the mineralizing solutions may have migrated from the fluvial channels into the reducing environment of the basal sandstone and carbonaceous siltstone of the Fall River Formation.

Even though none of the descriptions in the literature indicates that any are roll-type deposits, their existence is a distinct possibility. The mixed-marine and nonmarine character of the Fall River Formation and the progressive change to a more marine environment westward from the outcrop suggest that subsurface "Texas" roll-type deposits of Subclass 242 might be present.

Uranium minerals in oxidized deposits are chiefly carnotite, tyuyamunite, and metatyuyamunite. These yellow minerals occur with variable amounts of calcite, iron oxide, carbonaceous material, and clay minerals interstitial to the quartz grains that make up the bulk of the host sandstone. Ore minerals in partially oxidized deposits are corvusite, rauvite, carnotite, and tyuyamunite, all of which occur interstitial to quartz grains. These deposits contain small amounts of calcite and pyrite. Ore minerals in unoxidized deposits are uraninite, coffinite, paramontroseite, and haggite (Gott and Schnabel, 1963). These minerals occur interstitially in sandstone and are intimately associated with calcite, pyrite, marcasite, and jordisite. Uranium, vanadium, and iron minerals occur principally as banded nodules, pods, lenses, or fracture fillings in the sandstone. Characteristically, either a core of pyrite or a core of hematite is surrounded by a mixture of vanadium and uranium minerals. Gangue minerals are iron oxides, iron sulfides, and calcite as cement in the host sandstone units.

Many deposits of uranium minerals are selectively concentrated around carbonized wood fragments and macerated plant remains. In many other deposits, in which this relation does not exist, the uranium minerals seem to have been precipitated by an ephemeral agent, probably hydrogen sulfide. Analyses of water in wells in the Inyan Kara indicate the presence of as much as 150 ppm hydrogen sulfide (Gott and others, 1974). The presence of hydrogen sulfide was attributed to bacterial reduction of sulfate where sufficient carbonaceous material is available to support the bacteria.

Some data suggest that the Inyan Kara Group may not be uniformly favorable in the subsurface. Because the Fall River Formation may be entirely marine in some part of the subsurface it is unlikely to contain peneconcordant uranium deposits such as occur at the outcrop. Those peneconcordant deposits that may exist at depth will be confined to the Lakota part of the Group. Oxidation-reduction potentials of well water from the Inyan Kara Group, some lower than -400 mv, are shown by Gott and others (1974) to decrease from zero near the outcrop to -150 mv in the subsurface 1.6 to 8 km (1-5 mi) basinward from the outcrop. These data would suggest that uranium in solution derived from the remobilization of uranium in near-surface deposits cannot migrate to any great distance downdip and that any roll-front deposits that might exist in the subsurface are likely to be less than 8 km from the outcrops. It would seem, therefore, that the most favorable part of the Inyan Kara Group is some portion considerably above a 1500 m depth where both peneconcordant and roll-front deposits could occur in both the Fall River and Lakota Formations. Basinward from this more favorable part, only peneconcordant deposits can occur and only in the Lakota Formation.

Assuming that the favorable part of the Inyan Kara is above a 750 m (2500 ft) depth, calculations of the volume of rock above this depth were made.

That this may represent a reasonable cut-off between the two parts is suggested by a report of roll-front deposits in the Inyan Kara at a depth of 610 m (2000 ft) near Alzada, Montana (C. G. Bowles, written commun., 1980). Area B was measured at 2036 km^2 (606 mi^2). An overall average thickness of 122 m (400 ft) for this part yields a volume of 251 km^3 (45.87 mi^3).

Culture and Land Status

With a population of about 3,500, Newcastle, Wyoming, the largest town in the area, serves as a local center for ranching, railroad, lumbering, and oil-field activities. Other villages in the area are Osage and Lance Creek, both with populations of less than 400. U.S. Highway 18-85 traverses the area north and south and intersects U.S. Highway 16 at the town of Newcastle. Tracks of the Chicago, Burlington and Quincy Railroad traverse the northeastern corner of the quadrangle. Several large oil fields including, among others, the Lance Creek, Clareton, Mush Creek, and Fiddler Creek fields are located within Area B. Except in the vicinity of Newcastle, the area is sparsely populated, with most of the land being owned by ranchers. Small tracts of state land are interspersed among the privately owned tracts. Most of the area is rolling grassland with some forested land on the west flank of the Black Hills. A network of paved and unpaved county roads connecting with the federal highways provides easy access to most of the area.

ENVIRONMENTS UNFAVORABLE FOR URANIUM DEPOSITS

Unfavorable environments include most rock units of Jurassic and older ages below the Inyan Kara Group, all rock units of Cretaceous age above the Inyan Kara Group and, all rock units of Tertiary age younger than the Wasatch Formation.

Units of Paleozoic age include the Pahasapa Limestone, Minnelusa Formation, Opeche Formation, Minnekahta Limestone and part of the Spearfish Formation. All are of marine origin and consist largely of limestone and evaporites. Clastic components are nearly all red and include shale, siltstone, and minor fine-grained sandstone virtually devoid of organic matter. The overall low permeability, red colors, and lack of organic reductants make all these rocks unlikely hosts for uranium deposits.

Units of Mesozoic age include part of the Spearfish Formation, the Gypsum Spring Formation, the Sundance Formation, and the Morrison Formation. Except for the Morrison Formation and, possibly the Lak Member of the Sundance Formation, these units are all of restricted marine origin and are, mostly impermeable redbeds and gypsum that are devoid of carbonaceous materials. Although some controversy exists concerning the origin of the Spearfish Formation, whether marine or nonmarine, its overall redbed aspect, particularly the uniformly red color of sandstone units, and its lack of carbonaceous materials, indicate an unfavorable environment. The Morrison Formation is of floodplain and lacustrine origin and consists chiefly of claystone with minor thin beds of fine-grained sandstone. Little or no carbonaceous matter is known to occur anywhere in the unit.

Although several small uranium occurrences, one in the Spearfish Formation and two in the Minnelusa Formation, are known outside the quadrangle, it is unlikely that any of these units older than the Inyan Kara Group contain deposits within the quadrangle that can be expected to yield 100 mt of uranium at a grade of 0.01 percent or more.

Rocks of Cretaceous age younger than the Inyan Kara Group include the Skull Creek Shale, Newcastle Sandstone, Mowry Shale, Belle Fourche Shale, Greenhorn Formation, Carlile Shale, Niobrara Formation, Pierre Shale, Fox Hills Sandstone, and Lance Formation. With the exception of the Lance Formation and possibly the Newcastle Sandstone, all are of marine origin. The marine units, except for the Fox Hills Sandstone, consist almost entirely of marine shale, siltstone, and limestone and as such are unfavorable environments. Sandy zones in some of these units are reservoirs for oil.

The Newcastle Sandstone displays both marine and terrestrial affinities. Crossbedded arkosic sandstone along with plant fossils indicate a terrestrial environment of deposition. Massive sandstone together with fossil pelecypods, gastropods, and foraminifera, on the other hand, indicates a marine or brackish-water environment (Robinson and others, 1964). The unit may have been deposited partly in a marginal-marine and partly in a near-shore terrestrial environment and, as such, could possibly qualify as a host for Subclass 242 (Austin and D'Andrea, 1978) uranium deposits. Carbonaceous siltstone and coal beds in the unit could, furthermore, have acted as reductants or as a source for reductants. However, despite the fact that the formation was undoubtedly thoroughly prospected after uranium was discovered in the subjacent Inyan Kara Group, no occurrences are known to exist in it and, for reasons not readily apparent, empirically the unit has so far proved to be unfavorable.

Although it contains subsurface uranium deposits of the Subclass 242 type (Austin and D'Andrea, 1978) in the Gillette Quadrangle to the north, the Fox Hills Sandstone is apparently barren in the Newcastle Quadrangle. Outcrops of the unit were sampled at numerous places and signs of alteration marked by iron-oxide concentrations were sought but not found. Perhaps the absence of estuarine sandstone found in the Gillette Quadrangle accounts for the unit's unfavorability here. Except for some sandstone that is bleached white near the town of Lance Creek, outcrops are uniformly drab yellowish gray throughout the quadrangle. No uranium occurrences have been found in the unit and none of the oil test gamma-ray logs indicate the presence of anomalies in the subsurface. The uranium content in 9 rock samples of the Fox Hills Sandstone ranges from 0.99 to 4.13 ppm (Appendix B-1).

The Lance Formation, contains interbedded sandstone, carbonaceous shale, and coal beds, and is lithologically similar to Tertiary units in the vicinity which are hosts for uranium deposits. Several thin radioactive zones were detected in widely separated oil tests logs but, although uranium occurrences were found in adjacent areas, none are known in the Newcastle Quadrangle. The reasons for the apparent absence of mineralization in this unit are not clear. Like the favorable Tertiary units above, the truncated edges of this unit were once overlain by the White River Formation. Uranium, presumably leached from the White River, could have entered the unit's sandstone lenses to be fixed by the abundant carbonaceous matter present. Following the erosion of the White River, oxygenated water could have entered the, once again, exposed sandstone to move and concentrate uranium. The apparent absence of uranium deposits in the Lance suggests that the ore-forming processes that seem to have produced deposits in favorable Tertiary units did not operate in the Lance Formation. One reason may be that the White River Formation, contrary to what is believed by many, was not a source of uranium and that only the arkose and water transporting it supplied the uranium in the Tertiary strata. The absence of uranium deposits in the Newcastle and Fox Hills Sandstones, whose truncated edges were also once overlain by the White River Formation, might also be accounted for by this assumption. For whatever reasons, uranium deposits are not known to occur in the Lance Formation and the unit is here considered unfavorable.

Units of Tertiary age above the Wasatch Formation are the White River Formation of Oligocene age and the Arikaree Formation of Miocene age. The White River Formation consists predominantly of light- to medium-gray, green, and pink tuffaceous siltstone interbedded with minor very coarse-grained sandstone and conglomerate. Of the two occurrences found in this unit near the town of Lance Creek, one (Pl. 2, occ. no. 172) yielded 291 kg (648 lbs) of U_3O_8 mainly from siltstone and sandstone near the base of the unit. In the other, unproductive occurrence (Pl.2, occ. no. 170), uranium occurs as yellow minerals coating joint surfaces and as disseminations in the host sandstone within 5 cm (2 in) of coated joints. The uranium is associated with red and yellow iron oxides which also occur as coatings and disseminations. The uranium deposit is of very limited extent, as joints 3 m (9.8 ft) away on either side of the mineralized zone are devoid of uranium and iron oxide.

Tuffaceous strata in White River Formation may have been a source of uranium in the older Tertiary units but, apparently, very little was concentrated within the source rocks. The formation is devoid of carbonaceous matter and, apparently never was a reservoir for other types of ephemeral reductants. No mechanism for fixing or concentrating the uranium was present so that whatever uranium that may have been mobilized during devitrification of volcanic ash was almost completely removed by downward percolating water.

No uranium occurrences are known in the Arikaree Formation. Like the White River, it is devoid of carbonaceous matter and, apparently, other reductants. Because no concentrating processes are apparent it is not likely that either of these two Tertiary units contains the minimum endowment to qualify as being favorable.

INTERPRETATION OF RADIOMETRIC DATA

Using a fixed-wing aircraft, an aerial radiometric and total magnetic field survey was flown over the Newcastle Quadrangle by geoMetrics, Inc. during the months of August and September, 1978. The survey was flown in an east-west direction along lines spaced 4.83 km (3 mi) apart, with north-south tie-lines flown at 19.31 km (12 mi) intervals. Flown at an average speed of 217.2 km/hr (135 mph), the aircraft was maintained at a mean terrain clearance of 122 m (400 ft). Radiometric instrumentation consisted of a gamma-ray spectrometer utilizing a dual 256 channel capacity to provide spectral data in the 0.4 to 3.0 MeV range. Detectors consisted of two sodium-iodide crystals 58,731 cm^3 (3584 in^3) and 8390 cm^3 (512 in^3) respectively; the smaller one was used to monitor cosmic radiation and atmospheric radon. The magnetometer used for the survey was capable of 0.125 gamma sensitivity but was operated at 0.25 sensitivity.

A total of 86 uranium anomalies occur in the Newcastle Quadrangle and their locations are shown on Plate 3. Many of the anomalies have some degree of spatial association with artificial features. Sixteen anomalies occur on, or in close proximity to, various improved roads, 5 seem associated with a railroad alignment, and 8 have a strong spatial association with developed oil fields. Most of these are in areas where the bedrock represents environments unfavorable for uranium deposits, so it is likely that these anomalies reflect imported material used in construction. Anomalies 7, 20, 22, 73 and 77 are in outcrops of the Wasatch Formation and probably indicate concentration of uranium which are numerous in this unit. Anomalies 1, 8, 9, and 21 are in outcrops of the Fort Union Formation and, although no surface occurrences are known in this area, probably reflect a concentration of uranium. Several exploratory holes intersected uranium concentrations at depth in this area. Anomalies 4 and 6 are in or near outcrops of the White River Formation in which several small occurrences of uranium are known to exist, so it is likely that these anomalies reflect undiscovered concentrations of uranium. Anomalies 58, 66, 67 and 76 (Pl. 3) probably reflect uranium concentrations in the Inyan Kara Group.

A comparison of mean values of uranium in various units, values that are crucial for determining minumum statistical requirements for anomalies, indicates that the statistical method for identifying anomalies was poorly selected. In the Wasatch Formation which has a mean value of 29.3 ppm eU and in which many uranium deposits are exposed at the surface, few anomalies were detected. By contrast, in the Pierre Shale, which has a mean value of 31.7 ppm eU and in which no uranium deposits are known to exist, many anomalies were detected. The respective mean values of eU in these units indicate that many more anomalies should have been detected where the Wasatch is exposed and few or none where the Pierre Shale and other equally unfavorable units are exposed.

Analyses of a sample of Pierre Shale (MCY-065) collected at anomaly 26 (Pl. 3) indicate an unusual concentration of elements. Uranium and thorium contents, determined by neutron activation analysis, are 12.8 and 192 ppm, respectively; analysis by gamma-ray spectrometric methods indicate 389 ppm eU and 183 ppm eTh; and semiquantative spectrographic analysis detected 700 ppm lanthanum and 500 ppm cerium. The disparity between U and eU indicates a concentration of uranium daughter products rather than of uranium, the actual uranium content being lower than the mean radiometric value in the Pierre Shale. The content of rare-earth elements along with thorium indicates unusual processes of concentration inconsistent with the idea that uranium may have been selectively leached from a uranium deposit formerly in equilibrium.

It is not known to what extent the other anomalies in this and other unfavorable units are of a nature similar to anomaly 26 (Pl. 3). It is unlikely, however, that singly or collectively they represent significant concentrations of uranium or that their distribution might be used to infer the existence of uranium concentrations in some other units in the vicinity.

UNEVALUATED ENVIRONMENTS

Precambrian rocks and Paleozoic rocks older than the Pahasapa Formation are not exposed in the Newcastle Quadrangle but are within the 1,500 m (5,000 ft) depth limit for evaluation. Sedimentary units include the Whitewood Dolomite, and the Winnipeg and Deadwood Formations. Very little has been written about these units and no uranium is known to occur in them. The Whitewood Dolomite is probably of marine origin and, as such, is most likely unfavorable. The origin of the other two units could not be determined so their potential as host rocks are not evaluated. Precambrian rocks are exposed in the Black Hills northeast of the quadrangle. Aside from small quantities in pegmatite veins, uranium is known to occur in the Lower Protozoic Estes Conglomerate exposed in the northeastern part of the Black Hills (Hills, 1979). Interpreted as a fossil placer that may have lost some uranium because of leaching, it contains as much as 122 ppm uranium. Whether or not this unit extends into the subsurface of the Newcastle Quadrangle is not known. Fifty uranium occurrences were reported in the Precambrian rocks of the Laramie and Hartville uplifts to the south of the quadrangle, most of which seem to be related to a pre-Oligocene erosion surface (D. A. Seeland, written commun., 1980). Lack of data about the Precambrian in the subsurface prevents an evaluation of its potential as a source of uranium.

RECOMMENDATIONS TO IMPROVE EVALUATION

A hydrogeochemical study of ground water in the Fort Union Formation similar to one made by Hagmaier (1971) for the Wasatch Formation would be useful for more closely delineating the extent of uranium mineralization in the Fort Union. The study should entail the measurement of Eh, pH, and concentration of major anions and cations.

INTERPRETATION OF NATIONAL HSSR DATA

Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) data for the Newcastle Quadrangle did not reveal any areas that were not previously known to be potentially favorable for the occurrence of uranium deposits. Three of the four areas indicated as favorable by these data are located in and follow the trend of the Wasatch Formation which comprises the rocks exposed at the surface throughout most of Area A on Plate 1. The many uranium occurrences in this area are shown on Plate 2. Here the uranium in ground-water samples range from 20 to 1,000 ppb and in stream sediments from 10 to 500 ppm.

The forth area indicated as favorable by the HSSR data is located in the southeast part of the quadrangle within Area B on Plate 1. Outcrops of the Inyan Kara Group here contain several uranium occurrences as indicated on Plate 2. Uranium in ground-water samples from this area range from 20 to 200 ppb and is as high as 20 ppm in one stream sediment sample.

INTERPRETATION OF U.S. GEOLOGICAL SURVEY STREAM-SEDIMENT AND HYDROGEOCHEMICAL DATA,

by
Keith Robinson, Kristen A. Geer and Jo G. Blattspieler

In the summer of 1979, a geochemical survey was conducted in selected areas of the Newcastle Quadrangle. The primary objective was to identify areas that possibly contain anomalous concentrations of uranium.

This study incorporates the results of analyses for uranium from stream-sediment, and ground- and surface-water samples. The samples were collected by members of the USGS and analyzed under contract by GEOCO, Inc., Wheatridge, Colorado.

Hydrogeochemical and stream-sediment sampling was conducted in the quadrangle by both the USGS and the Los Alamos Scientific Laboratory (LASL), under the auspices of the NURE Program. Both geochemical surveys were made independently. Stream-sediment and water samples were collected over the entire quadrangle by the LASL. The samples have been analyzed at the LASL for uranium and other elements using multiple analytical techniques. A description of the various analytical methods and the results of the analyses will be contained in a report in preparation. The original intent was that USGS geochemical sampling would be conducted as a follow-up to the LASL survey and would be confined to areas of apparent uranium anomalies delineated by the LASL data. The results of the LASL Hydrogeochemical and Stream Sediment Reconnaissance (HSSR), however, were not available to serve as a basis for the USGS sampling or data interpretation.

A total of 348 stream-sediment, and 130 ground- and 2 surface-water samples were collected in the Newcastle Quadrangle, as part of the USGS sampling program. On the basis of the geologic favorability for the occurrence of uranium, sediment and water sampling was confined to selected outcrop areas of the Tertiary White River and Fort Union Formations, the Cretaceous Fox Hills Sandstone and the Inyan Kara Group. Several stream-sediment samples were also obtained from outcrop areas of the Pierre Shale, the Niobrara Formation, and the Carlile Shale, in order to investigate an aerial radiometric anomaly detected in the vicinity of Mule Creek. In general, known areas of uranium mineralization were deliberately excluded. Sample sites were located to afford optimum density, coverage, access, and integrity of the resultant geochemical data. Replicate and duplicate stream-sediment and water samples were obtained at several localities in order to test the variance of analytical results and sampling error. Analyses of the replicate samples indicates that reproducibility of analytical data is within the precision required by the USGS.

The sediment samples were obtained from the beds of both dry and actively flowing streams. Approximately 10 pounds of raw sample was collected at each site. The samples are composites of material collected at several points along the active drainage channel.

Stream-sediment samples were oven dried at a temperature of less than 100°F and sieved to obtain a less-than-170-mesh (88 micron) fraction. Pilot studies in similar terrane have shown that this size fraction is optimum for enhancement of uranium values, because it reduces the dilution of potentially interesting metals by major rock-forming elements, (Wenrich-Verbeek, 1976). The less-than-170-mesh fraction was routinely analyzed, without further preparation, for 34 elements, based on a 6-step, DC-arc, semiquantitative emission spectrographic method, described by Grimes and Marranzino (1968). Uranium concentration was determined by a modified extraction fluorometry method, described by the American Society for Testing and Materials (ASTM), in the Annual Book of ASTM Standards (1975). In addition, a weighed subsample of the fine fraction was ignited at 550°C for 10 minutes and the loss of weight in percent was calculated.

The water samples were collected from wells, springs, and streams. Water temperature, specific conductance, pH, and dissolved oxygen were measured at each site and three separate water samples were obtained. A 1000-ml sample was collected, filtered through a 0.45-mm membrane filter into an acid-rinsed polyethylene bottle and then acidified with an ultrex-grade concentrated nitric acid to a pH of <2. This sample was analyzed for uranium by an extraction fluorometry method, described by the ASTM (1975). An untreated and unfiltered 250-ml water sample was obtained and analyzed for the degree of alkalinity by titration with sulfuric acid to give equivalent $CaCO_3$ in mg/l. A 125-ml filtered, but untreated, sample was collected and analyzed by ion chromatography for sulfate, phosphate, and nitrate. The latter sample was kept at a near-freezing temperature until analysis was complete.

The areal distribution and relative concentrations of uranium in stream-sediment and water samples are shown on Plates 4A, B, and C. Each plate contains an accompanying histogram and cumulative-frequency probability plot of the distribution of uranium concentration in the sample media. Uranium values are represented by symbols on the map and have been grouped into specific class intervals based on a logarithmic scale. The symbols and their range of values are annotated on the histogram and cumulative-frequency probability plots. A graphical representation of analytical values, categorized into specific class intervals, permits easy observation of large variations in geographically clustered sample analyses and results in a smoothing of the data.

Statistical evaluation of stream-sediment geochemical data

For the purpose of statistical evaluation, stream-sediment samples have been separated into four groups. Each group of sediments is considered to reflect specific source-rock type and character. One group of sediments was collected from streams draining outcrop areas of the Fox Hills Sandstone. A second group of sediments was collected from streams draining outcrop areas of the Inyan Kara Group. A third group of sediments was collected from streams draining outcrop areas of the Tertiary Fort Union Formation, in the western part of the quadrangle, and from the White River Formation, in the eastern part of the quadrangle. The fourth group of sediments, consisting of 18 samples, was collected from streams draining outcrop areas of Cretaceous rocks in the Mule Creek area.

The distribution and relative concentration of uranium, measured in parts per million (ppm), in sediments collected from streams draining outcrops of the Fox Hills Sandstone, the Inyan Kara Group, the Tertiary sedimentary units, and the Mule Creek area, together with a histogram, cumulative-frequency probability plot, and other statistical parameters, is shown on Plate 4A. Stream-sediment sample numbers and locations are shown on Plate 5A. The analytical data from stream-sediment samples collected in areas of all rock units were combined into one population, because mixing does not unduly influence the statistical data or mask anomalous areas in individual formations or groups. The data from stream-sediments collected in areas of each rock unit are discussed separately in the following text. With the exception of samples from the Mule Creek area, individual statistics are calculated for each rock unit. The results of analyses, field data, and the coordinate locations of sediment samples collected in these areas are given in Appendix B-2, under the heading of "Fox Hills Sandstone", "Inyan Kara Group", "Tertiary Sedimentary Units", and the "Mule Creek Area". An explanation of the codes used in the columnar entries of Appendix B-2 is included.

A summary of all elements detected in sieved stream-sediment samples collected from areas of the Fox Hills Sandstone is given in Table 1. The following elements were also analyzed for, but were either not detected or were detected at a concentration less than the measureable lower limit of resolution (in parentheses):

Th (100 ppm), As (200 ppm), Au (10 ppm), Bi (10 ppm),

Cd (20 ppm), Li (100 ppm), Sb (100 ppm), W (50 ppm).

A complete statistical summary of selected geochemical data from stream-sediments collected in areas of the Fox Hills Sandstone is given in Appendix B-4.

A comparison of the median value for uranium of 1.0 ppm in Table 1, with the arithmetic mean of 1.75 ppm and geometric mean of 1.58 ppm, suggests that the uranium concentration in sediments from the Fox Hills Sandstone is more closely lognormally distributed. The histogram and cumulative-frequency distribution diagrams for uranium in sediments collected from areas of the Fox Hills Sandstone (Figure 4), suggest a single sample population. This conclusion is substantiated by the relatively close correspondence between median and mean uranium values. If the threshold value between anomalous and background values is placed at two geometric deviations above the geometric mean, then stream-sediment samples containing more than 3.9 ppm uranium may be significantly anomalous. Although uranium values greater than 3.9 ppm uranium are considered to be anomalous, this does not imply a sudden transformation occurs above this value in the uranium content of the samples. There is no abrupt change from samples representative of regional background, to samples indicative of potential uranium deposits. Rather, the samples considered to be anomalous are only slightly more enriched in uranium than other samples in

Table 1.--Summary of element concentrations in less-than 170 mesh (88-Micron) stream sediment samples collected from outcrop areas of the Fox Hill Sandstone, Newcastle Quadrangle

Element	Minimum	Maximum	Median	Mean	Standard Deviation	Geometric Mean	Geometric Deviation
				Data in percent			
Al	3	7	7	6.16	0.98	6.06	1.20
Fe	0.7	5	2	2.16	0.66	2.06	1.37
Mg	0.1	7	0.7	0.86	0.54	0.79	1.49
Ca	0.1	10	1.5	1.75	1.06	1.46	1.95
Na	0.7	3	1.5	1.46	0.50	1.38	1.39
Ti	0.15	0.7	0.3	0.29	0.09	0.28	1.33
				Data in parts per million			
U	L(1.0)	4.0	1.0	1.75	0.81	1.58	1.57
Mn	100	700	300	323.56	154.57	287.94	1.65
Ag	N(0.5)	7	L(0.5)	0.86	1.53	0.58	1.86
B	N(10)	50	20	19.05	7.48	17.66	1.48
Ba	100	1500	700	739.66	188.95	712.11	1.35
Be	1	15	3	7.39	5.68	5.07	2.51
Co	N(5)	15	10	8.59	3.04	8.03	1.46
Cr	10	150	70	69.91	26.27	64.50	1.54
Cu	7	50	20	21.56	7.38	20.50	1.37
La	20	150	100	78.10	26.54	73.15	1.46
Mo	N(5)	10	N(5)	-	-	-	-
Nb	N(10)	30	N(1)	12.74	4.75	12.05	1.37
Ni	L(5)	50	20	19.87	7.63	18.54	1.45
Pb	10	70	30	30.92	14.44	27.20	1.71
Sc	N(5)	20	15	12.41	3.66	11.78	1.41
Sn	N(10)	100	N(10)	34.09	30.07	24.08	2.40
Sr	L(100)	700	200	225.60	119.38	197.87	1.68
V	15	150	50	58.79	38.20	48.50	1.85
Y	10	150	30	32.13	18.17	28.18	1.66
Zn	N(200)	200	N(200)	-	-	-	-
Zr	50	G(1000)	300	391.00	241.79	315.34	1.99

N--not detected at the lower limit of determination, in parentheses.
L--detected, but below the lower limit of determination, in parentheses.
G--detected, but at a value greater than the upper limit of determination,

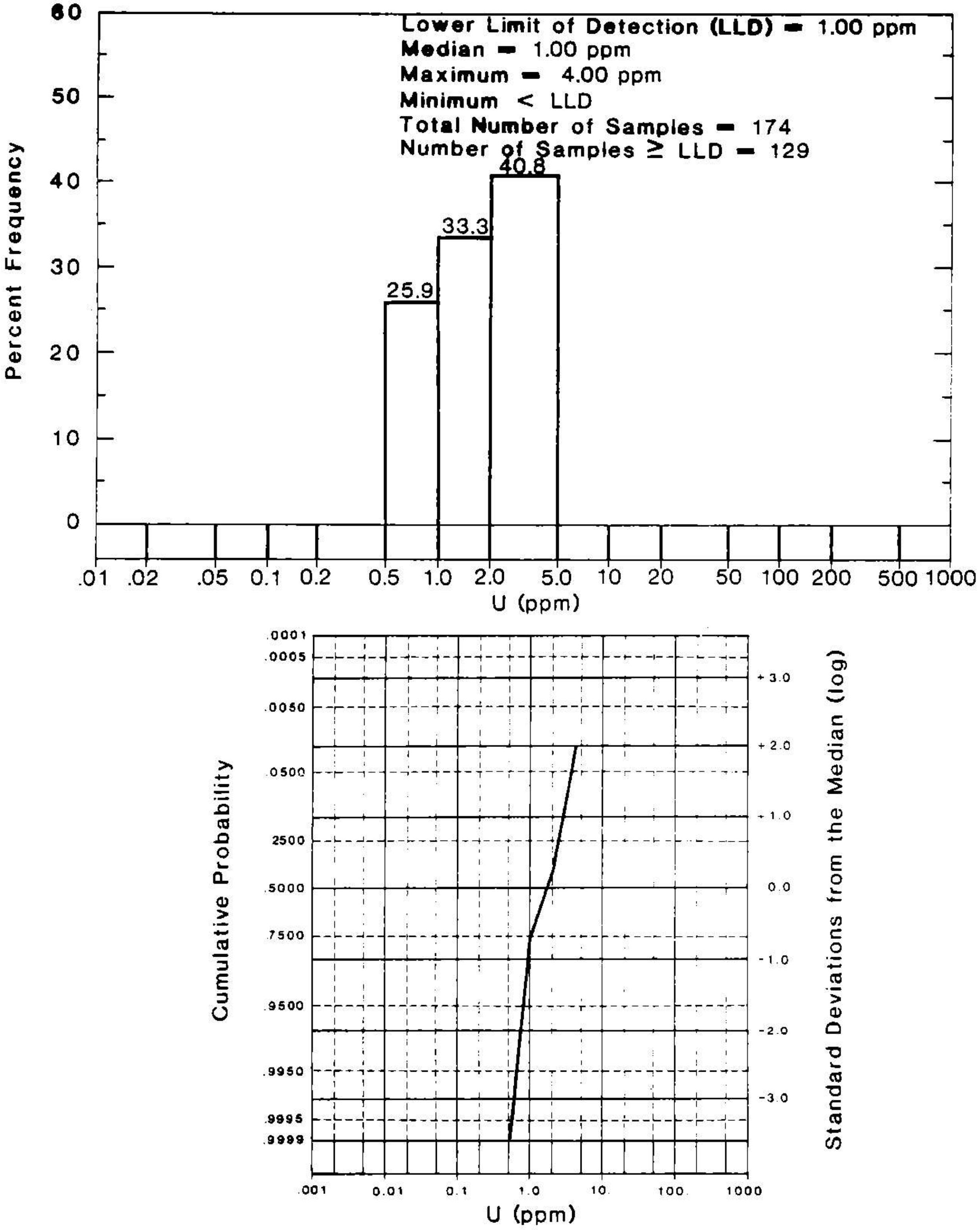


Figure 4. Histogram and cumulative frequency distribution of uranium (ppm) in stream - sediment samples from areas of the Fox Hills Sandstone, Newcastle Quadrangle.

the total data set. They serve only to define areas of possible uranium enrichment and not necessarily areas containing ore deposits. The cumulative probability plot (Figure 4), demonstrates that the samples defined to contain anomalous concentrations of uranium represent the upper percentile of uranium values for a single sample population. The anomalous values are an integral part of a continuous and regular distribution of uranium throughout the Fox Hills Sandstone.

A summary of all elements detected in the sieved stream-sediments collected from areas of the Inyan Kara Group is given in Table 2. Elements analyzed for but not detected, or detected at levels lower than the measureable lower limit of resolution, are the same as those for the Fox Hills Sandstone.

A complete statistical summary of selected geochemical data from stream-sediments collected in areas of the Inyan Kara Group is given in Appendix B-4.

A comparison of the median value of 1.0 ppm for uranium with the arithmetic mean of 1.76 ppm and geometric mean of 1.56 ppm, shown in Table 2, suggests that the uranium concentration in sediments from the Inyan Kara Group is more closely lognormally distributed. The semilogarithmic histogram of the frequency distribution for uranium in sediments collected from areas of the Inyan Kara Group (Figure 5), suggests a slight bimodal distribution and the presence of two intermixed populations. This conclusion may be more apparent than real because of the large number of samples with uranium concentrations below the lower limit of detection. The lumping of samples with uranium values below the detection limit, into one class, biases the data. The cumulative logarithmic probability diagram (Figure 5) shows no evidence of a bimodal distribution. This strongly corroborates the assumption that the stream-sediment samples are truly representative of a single population. If the threshold value between anomalous and background values is placed at two geometric deviations above the geometric mean, then stream-sediment samples containing more than 4.1 ppm uranium may be significantly anomalous and, based on subjective judgment, samples containing uranium values in the range 4-4.1 ppm may be considered marginal or weakly anomalous. The remarks made previously, to qualify the definition of what constitutes an anomaly in the Fox Hills Sandstone, are also applicable to the Inyan Kara Group.

A summary of all elements detected in the sieved stream-sediment samples collected from areas of the Tertiary Fort Union and White River Formations is given in Table 3. Elements analyzed for but not detected, or detected at levels lower than the measureable lower limit of resolution, are the same as those for the Fox Hills Sandstone, with the addition of Mo (5 ppm) and Zn (200 ppm), and the deletion of Au (10 ppm).

A complete statistical summary of selected geochemical data from stream-sediments collected in areas of the Tertiary sedimentary units is given in Appendix B-4.

A comparison of the median value of 2.0 ppm for uranium with the arithmetic mean of 2.08 ppm and geometric mean of 1.93 ppm, shown in Table 3,

Table 2.--Summary of element concentrations in less-than 170 mesh (88-Micron) stream sediment samples collected from outcrop areas of the Inyan Kara Group, Newcastle Quadrangle

Element	Minimum	Maximum	Median	Mean	Standard Deviation	Geometric Mean	Geometric Deviation
Data in percent							
Al	3	7	7	5.88	1.11	5.76	1.23
Fe	1	5	2	2.07	0.79	1.96	1.39
Mg	0.2	2	0.7	0.76	0.50	0.63	1.88
Ca	0.2	15	2	2.97	3.06	1.60	3.37
Na	0.2	2	0.7	0.90	0.35	0.85	1.45
Ti	0.15	0.7	0.3	0.31	0.11	0.29	1.37
Data in parts per million							
U	L(1.0)	4.0	1.0	1.76	0.95	1.56	1.62
Mn	30	3000	300	380.48	407.22	283.28	2.09
Ag	N(0.5)	0.5	N(0.5)	-	-	-	-
B	10	50	20	22.59	10.75	20.33	1.59
Ba	300	1000	700	672.29	146.76	654.31	1.28
Be	L(1)	15	10	8.74	5.36	6.53	2.39
Co	N(5)	30	10	9.63	4.79	8.69	1.57
Cr	20	150	70	72.05	29.00	66.39	1.52
Cu	10	50	20	25.96	10.31	24.20	1.45
La	50	150	100	80.12	26.98	75.39	1.43
Mo	N(5)	20	N(5)	15.00	7.07	14.14	1.63
Nb	N(10)	30	10	12.50	5.13	11.77	1.38
Ni	L(5)	150	20	23.64	17.34	20.14	1.76
Pb	10	50	30	32.29	13.46	29.14	1.62
Sc	5	30	15	12.89	3.59	12.37	1.35
Sn	N(10)	20	N(10)	11.67	4.08	11.22	1.33
Sr	L(100)	1000	200	286.59	234.53	219.82	2.03
V	15	200	30	60.06	48.49	45.33	2.10
Y	10	150	30	36.14	21.97	30.98	1.74
Zn	N(200)	200	N(200)	-	-	-	-
Zr	100	G(1000)	500	488.31	262.06	416.63	1.81

N--not detected at the lower limit of determination, in parentheses.
L--detected, but below the lower limit of determination, in parentheses.
G--detected, but at a value greater than the upper limit of determination, in parentheses.

Table 3.--Summary of element concentrations in less-than 170 mesh (88-Micron) stream sediment samples collected from outcrop areas of Tertiary Sedimentary Units, Newcastle Quadrangle

Element	Minimum	Maximum	Median	Mean	Standard Deviation	Geometric Mean	Geometric Deviation
Data in percent							
Al	4	7	7	6.23	0.91	6.16	1.17
Fe	0.7	3	2	1.88	0.64	1.77	1.43
Mg	0.15	1	0.5	0.54	0.25	0.47	1.72
Ca	0.15	15	1.5	2.45	2.92	1.16	3.78
Na	0.5	7	1	1.31	1.13	1.07	1.81
Ti	0.2	G(1)	0.3	0.36	0.17	0.33	1.51
Data in parts per million							
U	L(1.0)	5.0	2.0	2.08	0.81	1.93	1.50
Mn	30	700	200	237.53	151.00	191.81	1.99
Ag	N(.5)	.5	L(.5)	-	-	-	-
Au	N(10)	10	N(10)	-	-	-	-
B	L(10)	50	10	14.75	6.73	13.64	1.46
Ba	500	5000	700	938.36	621.07	848.32	1.47
Be	7	30	10	11.64	3.93	11.07	1.37
Co	N(5)	15	10	9.29	3.34	8.65	1.48
Cr	10	200	70	75.21	40.00	64.84	1.78
Cu	5	30	15	18.97	6.72	17.76	1.46
La	20	700	100	105.07	76.56	94.09	1.54
Nb	N(10)	50	10	14.03	6.64	12.96	1.46
Ni	N(5)	150	15	18.65	19.03	14.54	1.95
Pb	N(10)	50	50	42.36	10.00	41.05	1.30
Sc	N(5)	30	10	12.29	4.74	11.41	1.49
Sn	N(10)	30	N(10)	14.00	6.58	12.97	1.47
Sr	100	700	300	306.85	216.24	233.60	2.15
V	15	70	30	30.68	11.88	28.68	1.44
Y	10	150	20	34.93	25.50	27.70	1.98
Zr	100	G(1000)	300	412.07	262.96	348.35	1.76

N--not detected at the lower limit of determination, in parentheses.
L--detected, but below the lower limit of determination, in parentheses.
G--detected, but at a value greater than the upper limit of determination, in parentheses.

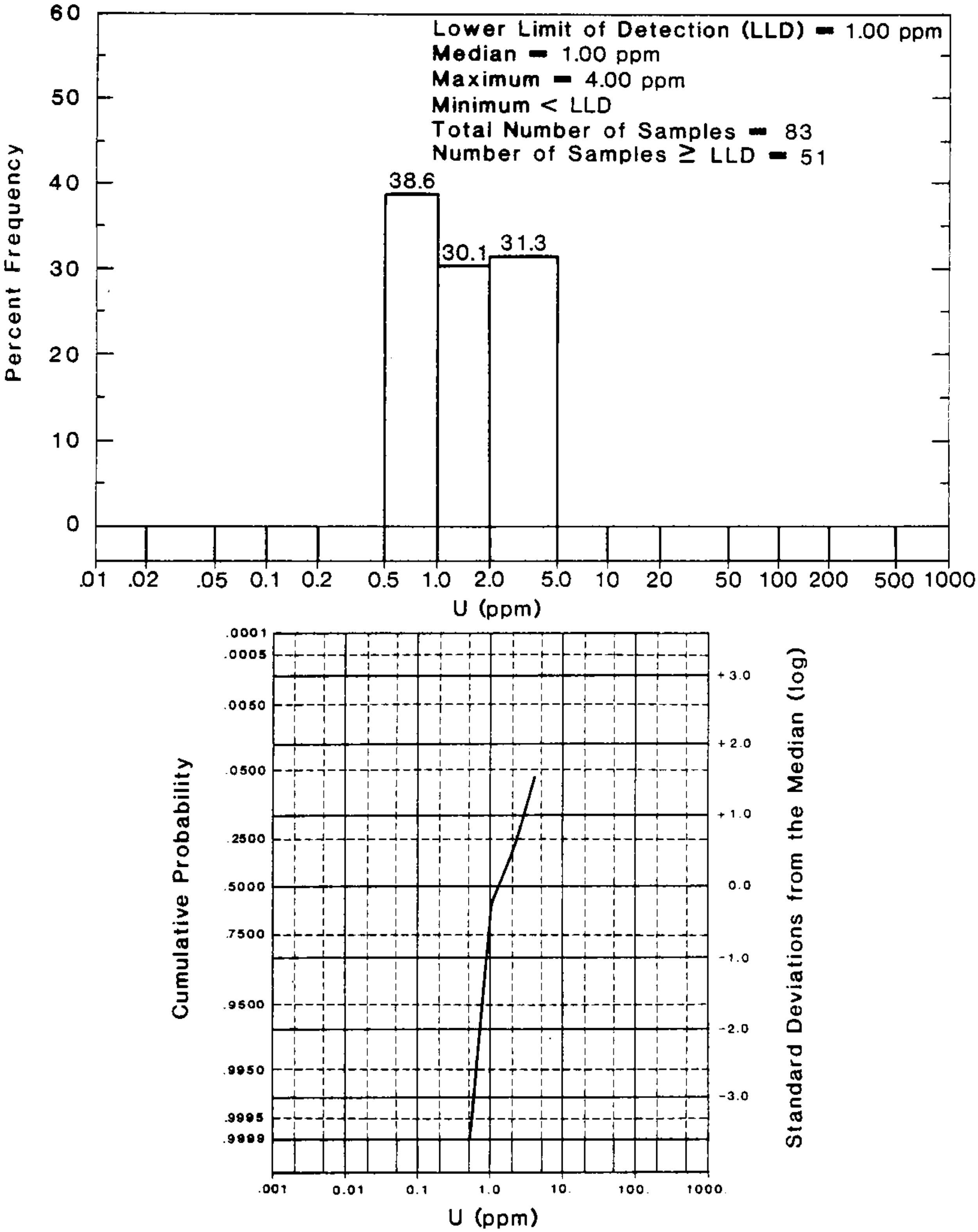


Figure 5. Histogram and cumulative frequency distribution of uranium (ppm) in stream - sediment samples from areas of the Inyan Kara Group, Newcastle Quadrangle.

suggests that the uranium concentration in sediments from the Tertiary Fort Union and White River Formations is probably lognormally distributed. The semilogarithmic histogram of the frequency distribution for uranium in sediments collected from areas of the Tertiary sedimentary units (Figure 6), suggests a single sample population. This is substantiated by the relative correspondence between median and geometric-mean uranium values. The cumulative logarithmic probability diagram (Figure 6), corroborates the assumption that the stream-sediment samples are representative of a single population. If the threshold value between anomalous and background values is placed at two geometric deviations above the geometric mean, then stream-sediment samples containing more than 4.3 ppm uranium may be significantly anomalous and, based on subjective judgment, samples containing uranium values in the range 4-4.3 ppm may be considered marginal or weakly anomalous. The qualifying remarks on the definition of an anomaly in the Fox Hills Sandstone are also applicable to the Tertiary sedimentary units.

Statistical evaluation of ground- and surface-water hydrogeochemical data

For the purpose of statistical evaluation, ground- and surface-water samples collected in the hydrogeochemical sampling program in the Newcastle Quadrangle have been treated as one population. The ground and surface waters were combined into one population because of the sparse surface-water sample coverage, which is directly attributable to the lack of available surface waters throughout the quadrangle. A total of 130 ground-water and 2 surface-water samples were obtained. Although the uranium data for water samples from ground and surface sources are not strictly comparable, the mixing of the populations does not influence the statistical data. It is possible to detect any surface-water samples containing anomalous concentrations of uranium by the normalization of uranium content with conductivity.

The distribution and relative concentration of uranium, measured in parts per billion (ppb), in ground and- surface-waters, is shown on Plate 4B, together with a histogram, a cumulative-frequency probability plot, and other statistical parameters. Water-sample numbers and locations are shown on Plate 5C. If available, water samples were collected in the same areas as stream-sediment samples. The results of analyses, field data, and the coordinate locations of samples collected in these areas are given in Appendix B-3, under the heading of "Ground Water" and "Surface Water". An explanation of the codes used in the columnar entries of Appendix B-3 is included.

A summary of the chemical analyses and measured physical parameters of water samples is given in Table 4.

A complete statistical summary of selected geochemical data from water samples is given in Appendix B-4

Ground- and surface-water samples were normalized for comparative purposes by multiplying the uranium concentration in ppb times 1000, and dividing by conductivity (μ mhos/cm). This procedure has the effect of normalizing the data in samples collected from different sources, and

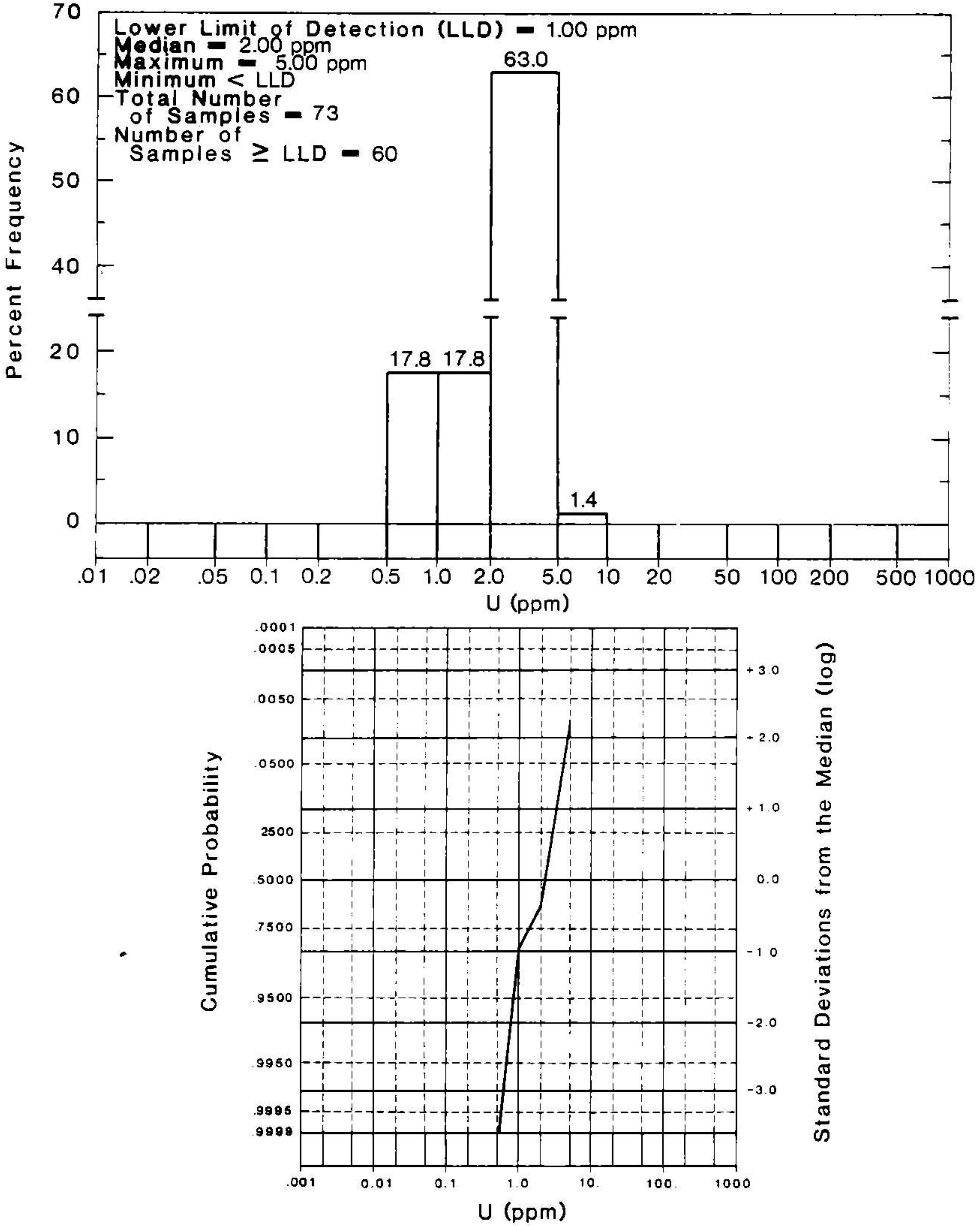


Figure 6. Histogram and cumulative frequency distribution of uranium (ppm) in stream - sediment samples from areas of Tertiary sedimentary units, Newcastle Quadrangle.

Table 4.--Summary of chemical analyses and physical parameters in Ground and Surface Water Samples, Newcastle Quadrangle

	Minimum	Maximum	Median	Mean	Standard Deviation	Geometric Mean	Geometric Deviation
U (ug/l)	L(.05)	810.00	8.00	18.86	71.60	7.77	3.10
SO4 (mg/l)	4.4	4528.6	571.40	875.79	877.71	477.88	3.78
PO4 (mg/l)	L(1.0)	1.0	L(1.0)	1.0	0	-	-
NO3 (mg/l)	N(1.0)	377.0	1.00	22.27	61.55	6.50	4.05
Alkalinity (mg/l)	L(2)	2350.00	440.50	489.34	297.01	407.61	1.91
Temperature (°C)	5.0	25.0	12.0	12.07	2.56	11.82	1.22
pH	4.65	9.35	7.72	7.76	0.66	7.73	1.09
Conductivity (umhos/cm)	260.00	8800.00	2300.00	2596.44	1611.94	2136.19	1.95
Dissolved Oxygen (ppm)	1.10	12.00	4.30	4.84	2.63	4.12	1.80
Ux1000/cond	0.06	623.08	3.53	11.38	54.98	3.64	3.24

N--not detected at the lower limit of determination, in parentheses.
L--detected, but below the lower limit of determination, in parentheses.
G--detected, but at a value greater than the upper limit of determination, in parentheses.
Analyses for SO_4, PO_4 and NO_3 by H. C. Day, U.S. Geological Survey

correcting for dilution effects, by giving a measure of the uranium content compared to the total amount of dissolved material in solution. The distribution and relative concentration of uranium in water samples, normalized by conductivity, is shown on Plate 4C, together with a histogram, a cumulative-frequency probability plot and other statistical parameters. Those samples whose uranium content was below the lower limit of detection have not been included in the normalized data set. The locations of these samples are indicated on Plate 4C using the letter L to denote uranium concentrations which are below the lower limit of detection.

A comparison of the median value for uranium of 8.00 ppb in Table 4, with the arithmetic mean of 18.86 ppb and the geometric mean of 7.77 ppb, suggests that the uranium concentration in water samples is lognormally distributed. This same conclusion appears true for the uranium concentration normalized by conductivity, the median and geometric means being 3.53 and 3.64 respectively. The semilogarithmic histogram and cumulative-frequency probability plot for uranium in water samples, shown on Plate 4B, suggest a single sample population that is slightly irregularly distributed. The presence of a single sample population is substantiated by the close correspondence between median and geometric mean values. The cumulative logarithmic probability plot on Plate 4B, shows clearly defined breaks in slope at 20 ppb and 50 ppb uranium values. If the water samples are representative of a single population, and if the threshold value between anomalous and background values is placed at two geometric deviations above the geometric mean, then water samples containing more than 75 ppb uranium may be significantly anomalous, and samples containing uranium values in the range 50-75 ppb may be considered marginal or weakly anomalous.

The histogram and cumulative-frequency probability plot for uranium concentration in water samples, normalized by conductivity, shown on Plate 4C, substantiate the presence of a single sample population. A clearly defined break in slope occurs at 10, Ux1000/conductivity values, on the cumulative-frequency probability plot. If the threshold between anomalous and background values is placed at two geometric deviations above the geometric mean, then water samples containing more than 38 normalized uranium units may be significantly anomalous, and samples containing normalized uranium values in the range 20-38 units may be considered marginal or weakly anomalous.

Interpretation of Results

At the 95-percent confidence level, sediments collected from streams draining outcrop areas of the Fox Hills Sandstone show a statistically significant correlation between uranium and manganese, boron, copper, and vanadium. The correlations suggest the possibility that some of the uranium may occur in a labile form and be associated with secondary oxide minerals. At the same confidence level, statistically significant negative correlations exist between uranium and lanthanum, beryllium, lead, and scandium. There is essentially a zero correlation with zirconium. These correlations suggest that the uranium in the Fox Hills Sandstone is generally not associated with resistate or refractory-type heavy minerals.

At the 95-percent confidence level, sediments collected from streams draining outcrop areas of the Inyan Kara Group show a statistically significant positive correlation between uranium, and copper and strontium. Until the results have been studied in detail, no explanation is offered for these correlations.

At the 95-percent confidence level, sediments collected from streams draining outcrop areas of the Tertiary sedimentary units show statistically significant correlations between uranium and lanthanum, niobium, nickel, yttrium, and zirconium. This suggests an igneous source rock contributing to the sediments and the possibility that some of the uranium may be associated with uranium-bearing resistate or refractory-type heavy minerals. The stream-sediment samples showing a relationship between uranium with elements characteristic of heavy-mineral suites, are primarily confined to outcrop areas of the Fort Union Formation, located in the western part of the quadrangle. In the eastern part of the quadrangle, several water samples obtained from aquifers in the White River Formation contain anomalous concentrations of uranium. This indicates the presence of a labile form of uranium in the White River Formation and attests that not all the uranium in the Tertiary sedimentary units is contained in refractory minerals.

At the 95-percent confidence level, ground- and surface-water samples collected in the quadrangle show no statistically significant correlation between uranium and any other analyzed or measured parameter.

Interpretation of geochemical data resulting from a stream-sediment and hydrogeochemical survey conducted in the Newcastle Quadrangle is based on an integration of available statistics established for all sample media. The interpretation is subjective. Threshold values of uranium between anomalous and background concentrations in both sediment and water samples have been utilized in defining areas of possible uranium enrichment.

Within the geographic and sample density limitations of the geochemical survey conducted by the USGS in selected areas of the Newcastle Quadrangle, 11 stream-sediment and 12 water samples appear to contain anomalous or slightly enriched concentrations of uranium. The location of these samples is shown on Plate 4D. Where relevant the water samples include both actual and normalized uranium concentrations. In general, the uranium concentration in stream sediments is relatively low, but it is considered to be above the background level established for stream sediments in the respective outcrop areas. At each locality, the sample type, well depth if relevant and available, sample number, and the concentration of uranium and/or normalized uranium is given.

In outcrop areas of the Tertiary sedimentary units, 3 stream-sediment and 8 ground-water samples are considered to be significantly enriched in uranium, or in the case of water, and/or uranium normalized by conductivity. With the exception of stream-sediment MCZ017, the samples are all confined to outcrop areas of the White River Formation, located in the eastern part of the quadrangle. The enriched water samples in this area suggest that the uranium is being leached out of volcanic ash, in the White River Formation, by highly oxygenated ground water. The uranium in the stream-sediment samples does not appear to be associated with elements generally contained in heavy minerals. Sediment sample MCZ017 is located in outcrop areas of the Fort Union Formation, in the western part of the quadrangle. It is the only sample collected in this area that appears to be significantly enriched in uranium. The sample also contains high concentrations of zirconium, lanthanum, niobium, and yttrium. This suggests the uranium may be associated with uranium-bearing resistate or refractory-type heavy minerals. No water samples were obtained from this area.

In outcrop areas of the Fox Hills Sandstone and Inyan Kara Group, 8 stream-sediment and 4 ground-water samples are considered to be significantly enriched in uranium, and/or normalized uranium. The uranium does not appear to be associated with elements generally accepted as being indicative of the presence of heavy minerals. Five of the sediment samples are enriched in vanadium.

Stream-sediment samples collected in the Mule Creek area were obtained to investigate an apparent aerial radiometric anomaly. The samples were taken from streams draining outcrop areas of marine shales in the Pierre Shale, the Niobrara Formation, and the Carlile Shale. The samples have not been statistically evaluated. They do, however, contain the highest concentration of uranium as a group, of all stream-sediment samples collected in the quadrangle. The median value is 7 ppm uranium, with a maximum value of 16 ppm. This may assist in explaining the radiometric anomaly.

The overall results of the USGS geochemical survey, in the Newcastle Quadrangle, suggest that the Fox Hills Sandstone and the Inyan Kara Group are favorable host rocks for the accumulation of uranium deposits. Samples containing anomalous concentrations of uranium were detected throughout the sampling areas. The uranium does not appear to be generally associated with heavy minerals and some may be present in a labile form that is available to contribute to potential ore deposits. Although the levels of uranium enrichment are extremely low, several sample localities delineated by the USGS geochemical data may warrant further investigation. Hydrogeochemical data from ground-water samples collected in the Tertiary White River Formation indicate considerable amounts of uranium in solution. This suggests that the White River Formation may be an important source area for uranium. Analysis of stream-sediment samples collected from the Tertiary Fort Union Formation indicate the presence of only one sample containing anomalous uranium content. The uranium in this sample appears to be associated with heavy minerals. No water samples were collected in this area. In the areas sampled by stream sediments, the surface outcrop expression of the Fort Union Formation must be considered to have low favorability for any significant accumulations of uranium. No assessment can be made of the subsurface extension this formation.

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