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GEOLOGY AND URANIUM OCCURRENCES IN THE MILLER HILL AREA CARBON COUNTY, WYOMING*

By

James D. Vine and George E. Prichard

May 1956

Trace Elements Investigations Report 227

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

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TEPCO, RPS, Washington (including master)	2
	47

CONTENTS

TABLES

ILLUSTRATIONS

Page

GEOLOGY AND URANIUM OCCURRENCES IN THE MILLER HILL AREA CARBON COUNTY, WYOMING

By James D. Vine and George E. Prichard

ABSTRACT

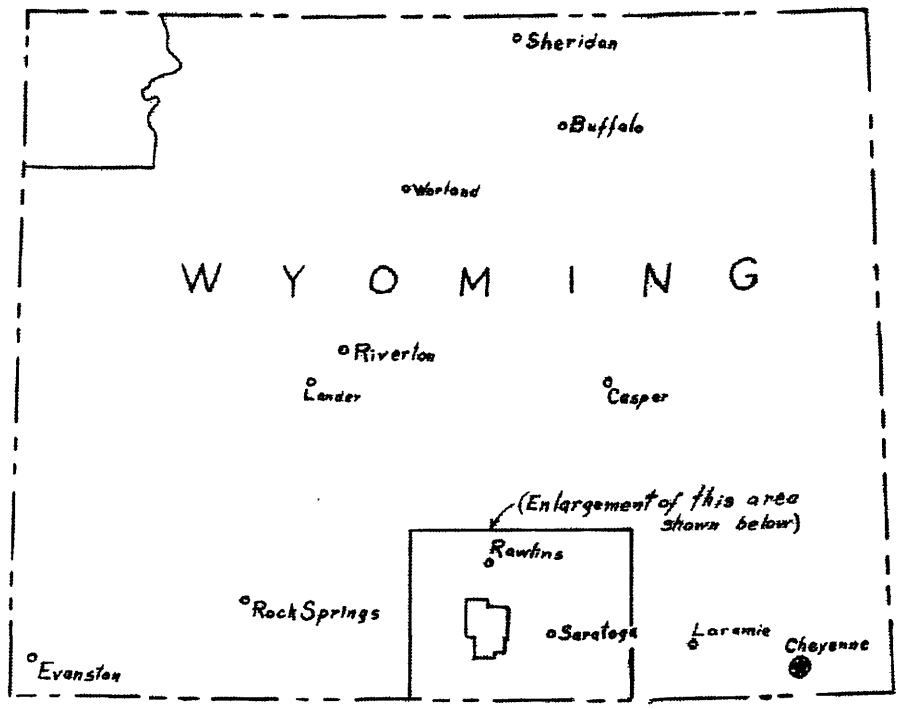
Uranium occurs in the North Park(?) formation of Pliocene(?) age in the Miller Hill area, about 25 miles south of Rawlins, Carbon County, Wyo. As much as 0.5 percent uranium is contained in grab samples, but only about 1000 tons of rock are known to contain as much as 0.03 percent uranium. Beds of brecciated, silicified limestone 3 to 10 feet thick contain the principal concentrations of uranium. Lesser concentrations are found in calcareous sandstone and quartzite. Uranophane, $Ca(UO_2)_2Si_2O_7 \cdot 6H_2O$, the principal uranium mineral, has been deposited in vugs, as fracture and surface coatings, and as a disseminated constituent of the rock. Uranium also occurs in quantities too small to be megascopically visible in dark-colored chalcedony, limestone, sandstone, and quartzite beds.

The North Park(?) formation in the Miller Hill area is at least 800 feet thick and unconformably overlies all older rocks. It consists principally of water-worked fine-grained pyroclastic debris and detrital mineral grains and includes several fresh-water limestone beds. The uranium deposits in the Miller Hill area are thought to be a secondary concentration deposited by ground water solutions that leached uranium from a disseminated source consisting of thick, porous beds of tuffaceous sandstone in the North Park(?) formation. It is suggested that the mechanism for deposition was the reaction of silica- and uranium-rich ground water upon contact with limestone. The higher grade concentrations may represent a further recent surficial enrichment of uranium due to evaporation of capillary moisture. Where uraniferous limestone is continuously exposed to weathering for a relatively long period of time, however, the uranium is eventually leached. The data from 31 semiquantitative spectrographic analyses of mineralized limestone samples indicate that Pb, Ba, Mn, Cu, Ni, Mo, and Fe are concentrated with uranium, whereas Na is present in lesser amounts in the uranium-bearing limestone than in nearly barren limestone.

INTRODUCTION

Purpose and scope of the report

The Miller Hill area is in Carbon County, Wyo., about half way between Rawlins and the Colorado border. (See index map, fig. 1.) An airborne radioactivity survey of the area reported by Meuschke and Moxham (1953) indicates several anomalies in the vicinity of Miller Hill, and a preliminary surface investigation of anomalies found by airplane was reported by Love (1953). During the investigation covered by this report an area of about 188 square miles was mapped in reconnaissance on aerial photographs, and a detailed study was made of about 2 square miles in the area of highest radioactivity. About 45 new localities of above normal radioactivity were found. The work was done by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.



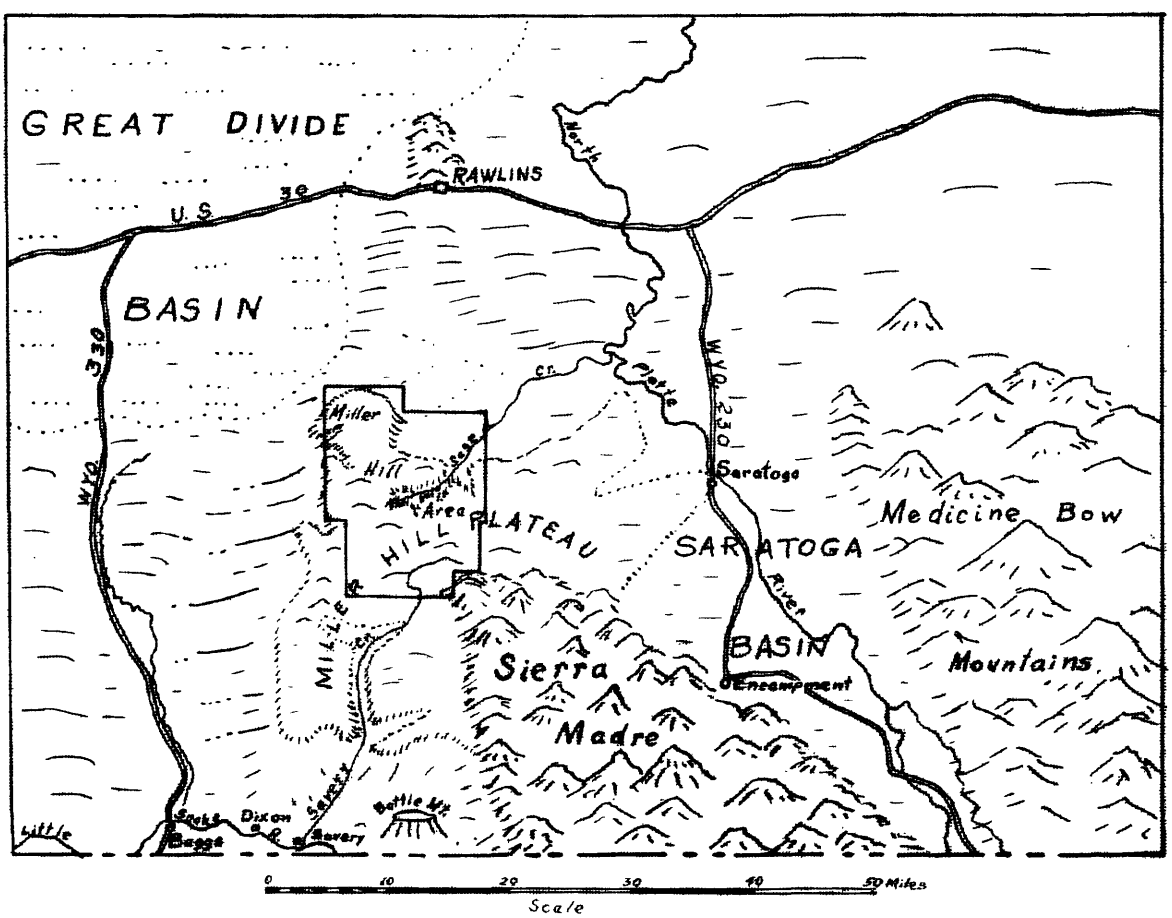


FIGURE 1.- INDEX MAP OF THE MILLER HILL AREA, CARBON COUNTY, WYOMING

Location and geographic setting

The Miller Hill area, located in southern Wyoming, is a dissected plateau that forms an apron-like area surrounding the northern end of the Sierra Madre, the Wyoming portion of the Park Range. The area is transected by the Continental Divide which separates the drainage of Sage Creek and associated tributaries of the North Platte River on the northeast from Savery Creek and other tributaries of the Little Snake River on the southwest. The plateau is formed on a surface of moderate relief at an elevation of 7,500 to 8,300 feet. Major streams flowing in V-shaped valleys are deeply incised on the plateau and flow onto the surrounding plains at elevations of 6,500 to 7,000 feet. The area is accessible in good weather through a network of secondary roads and trails. The main county road leads to Rawlins, about 20 miles to the north, and other roads provide access to Saratoga, about 22 miles to the east, and to Savery, about 24 miles to the south. Vegetation is sparse on the plains though both conifer and deciduous trees grow in sheltered valleys and slopes.

Acknowledgments

E. E. Murany and J. P. McDowell assisted during the field work in 1953 and made many contributions to the study. Chemical, radiometric, and spectrographic analyses and mineralogical identifications were made in the Geological Survey's Denver Laboratory. Donald H. Johnson visited the field to assist with mineralogical identification.

GEOLOGIC SETTING

The high plateau that forms the major physiographic feature in the Miller Hill area is an erosion remnant of a tuffaceous sandstone and limestone sequence of late Tertiary age. This sequence of Tertiary rocks lies unconformably on the folded Mesozoic and older rocks. (See geologic map, fig. 2A.) At the base of these Tertiary rocks is a moderately resistant conglomerate bed. In the northern part of the area this conglomerate forms a prominent escarpment at altitudes of 500 to 1000 feet above the surrounding plains. (See fig. 3A.) Folded Mesozoic strata make up the middle and lower slopes below the escarpment as well as the lower plains and benchlands to the north and east. A prominent anticlinal fold in Mesozoic strata extends northward through the Hatfield oil field and terminates at the complexly faulted southern end of the Rawlins uplift. To the east, the high plateau merges with the Saratoga basin where erosion has exposed a sequence of Tertiary strata generally referred to the Browns Park formation of Miocene age, and the North Park formation of questionable late Miocene or early Pliocene age (McGrew, 1951 and 1953). Southeast of the mapped area, Precambrian rocks in the Sierra Madre rise above the onlapping rocks of late Tertiary age. To the south in the valley of the Little Snake River, rocks equivalent to the late Tertiary strata of the Miller Hill area appear to overlie a similar but distinguishably different sequence of Tertiary strata. These underlying Tertiary rocks are thought to correlate with the Browns Park formation as mapped by Bradley (1945) at the southern margin of the Washakie Basin west of Baggs, Wyo.

STRATIGRAPHY

Work during the 1953 field season was directed primarily towards finding and studying uranium deposits. As no areas of unusually high radioactivity were found in the pre-Tertiary rocks, very little time was devoted to the study of these older rocks. The rocks of late Tertiary age are described in considerably greater detail because of their association with uranium mineralization in the area. The following descriptions of the pre-Tertiary rocks are adapted from J. D. Love (1953) who summarized previous work, including data from a thesis by Gene Del Mauro (1953) available at the University of Wyoming.

Precambrian rocks

The several types of Precambrian rocks exposed in the southeastern part of the area are undifferentiated on the geologic map, figure 2A. The rocks consist chiefly of gneiss and schist with smaller quantities of intrusive igneous rocks, pegmatites, and numerous veins of white quartz.

Paleozoic rocks

Though not exposed in the mapped area Paleozoic rocks are known from well data and are exposed on the west flank of the Sierra Madre south of the mapped area. These units are from oldest to youngest: unnamed sandstone of Cambrian age, 285 feet; the Madison limestone of Mississippian age, 80 feet; the Amsden formation and Tensleep sandstone of Pennsylvanian age, 600 feet; unnamed limestone, dolomite and sandy shale of Permian age, 225 feet.

Triassic rocks

Beds in the upper part of the Chugwater formation of Triassic age are the oldest rocks, other than Precambrian, which crop out in the area. The total thickness of Triassic rocks is probably between 800 and 1,100 feet. The characteristic red sandy shale and red siltstone of the Chugwater is well exposed in the Big Sage, Littlefield, and McKinney Creek areas. A conspicuous ocher-colored zone about 10 feet thick near the top of the formation is exposed along Big Sage Creek, and a prominent pink- to lavender-colored sandstone zone is exposed in the Littlefield and McKinney Creek areas. The Alcova limestone member was not seen in the mapped area.

Jurassic rocks

Three formations of Jurassic age, the Nugget sandstone, the Sundance formation, and the Morrison formation are present in the area. For convenience in mapping, the Nugget sandstone and Sundance formation are mapped as Jurassic undifferentiated (fig. 2A) and the Morrison formation is mapped separately. The Nugget sandstone consists of cliff-forming grayish-yellow to white medium-grained sandstone about 60 to 100 feet thick. Several springs in Sage Creek basin emerge from the Nugget sandstone. The Sundance formation overlying the Nugget sandstone consists of pale red, pink and gray sandstone and siltstone in the lower part and grayish yellow-green to yellowish-gray shale and sandstone containing abundant marine fossils in the upper part. The total

thickness of the Sundance formation is about 135 feet. The Morrison formation consists of about 250 feet of interbedded gray to pale varicolored shale and siltstone, nodular freshwater limestone, and thin silty sandstone. It forms slopes that are commonly covered by talus and landslide material from sandstones in the overlying Cloverly formation.

Cretaceous rocks

Six formations of Cretaceous age are exposed in the area and are mapped individually (fig. 2A).

The Cloverly is the oldest formation of Cretaceous age. Exposures consist chiefly of cliff-forming medium- to coarse-grained white to yellowish-gray clean quartz sandstone and chert pebble conglomerate, which weather into large, angular limonite-stained blocks. The sandstone is characterized by a sparkly appearance in sunlight caused by the reflection of light off numerous crystal faces of quartz. Locally the sandstone beds are intercalated with black carbonaceous shale partings. The formation is 130 feet thick where exposed on Little Sage Creek.

The Thermopolis shale overlies the Cloverly formation and consists of about 100 feet of dark-gray to black marine shale in the lower part and black shale interbedded with thin beds of brown to gray, ferruginous sandstone (the so-called "Muddy" sandstone) in the upper part. The unit is generally poorly exposed.

Overlying the Thermopolis shale is about 350 feet of Mowry shale, a hard, black, gray-weathering siliceous shale, which forms bare slopes paved with hard broken shale chips. Fossil fish scales are abundant in the formation.

The Frontier formation overlies the Mowry shale and consists of about 700 feet of gray to brown sandstone interbedded with gray to black shale and thin lenticular beds of chert pebble conglomerate. Carbonaceous plant fragments are locally present in the sandstone.

The Niobrara formation overlies the Frontier formation and consists of nearly 1,200 feet of soft gray shale and yellowish-gray calcareous shale.

The Steele shale overlies the Niobrara formation and consists mainly of gray sandy marine shale that becomes more sandy toward the top. The total thickness is about 3,600 feet but only the lower part is present in the mapped area.

Tertiary rocks

North Park(?) formation

The thick sequence of nearly flat-lying non-fossiliferous, predominantly arenaceous strata in the Miller Hill area that lies unconformably on tilted and truncated rocks of Mesozoic, Paleozoic, and Precambrian age is herein referred to as the North Park(?) formation. The name was originally applied to rocks of Tertiary age in North Park, Colo., so named by the King Survey in 1876. Arnold Hague and

S. F. Emmons in volume II of the King Survey (1877) first describe the rocks in the Miller Hill area, which they call the Savory Plateau Region, as follows:

> "This region is principally covered by horizontal beds of the North Park Tertiary, which, as proved by exposures in the deeper cuts on its northern edge, overlie the upturned edges of Cretaceous and earlier beds, while the higher portions of the ridges are capped by remnants of the Wyoming conglomerate."

The North Park(?) formation underlies well over half of the Miller Hill area, as shown on figure 2A. To the southeast it overlaps and thins out against the resistant rocks of Precambrian age that compose the Sierra Madre. Throughout the central part of the area the North Park(?) formation forms a plateau at altitudes ranging from about 7,500 to 8,300 feet. To the northeast, north, and northwest the limit of the North Park(?) formation is characterized by prominent escarpments (fig. 3A), particularly where erosion has cut deeply into underlying soft shale of Cretaceous age. These strata are as much as 800 feet thick locally, but the original thickness was probably greater because the present top is a surface of erosion.

The North Park(?) formation is divided into two members for convenience in mapping and description. The lower member is a basal conglomerate as much as 100 feet thick and the upper member is a sequence of fine- to medium-grained sandstone, tuff, and limestone beds as much as 700 feet thick.

The basal conglomerate member of the North Park(?) formation consists of a pebble and boulder conglomerate with boulders up to 3 feet across in a matrix of finer clastic material. The boulders include rocks composed of quartzite, limestone, granite and gneiss, presumably derived from the Paleozoic and Precambrian rocks exposed in the Sierra Madre. White quartz pebbles and cobbles are a conspicuous constituent of the conglomerate in most areas. Black chert pebbles are also common, particularly in the northern part of the area. The basal conglomerate is typically cross-stratified[1/] and composed of alternating

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1/ Use of the terms for stratification and cross-stratification follow those suggested by E. D. McKee and G. W. Weir, 1953, Terminology for stratification and cross-stratification in sedimentary rocks: Bull. Geological Society of America, v. 64, p. 380-390.

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lenses of coarse and relatively finer clastics. Medium to large scale cross-stratification, graded bedding, and irregular bedding (figs. 3B and 3C) suggest that much of the material was deposited by rivers in flood stage.

The relatively high resistance to erosion of the basal conglomerate of the North Park(?) formation is the reason for the Miller Hill escarpment that rises abruptly above less resistant Cretaceous rocks in the northern part of the area. This escarpment is characterized by a zone of landslide debris at its base and snow banks that last into the late spring or early summer.

Figure 3A.--Escarpment formed by the basal conglomerate of the North Park (?) formation. Arrow indicates unconformity between rocks of Cretaceous and Tertiary ages. View looking northwest from sec. 10, T. 17 N., R. 88 W.

Figure 3B.--Local disconformity between two units of graded bedding within the basal conglomerate of the North Park(?) formation, sec. 7, T. 18 N., R. 88 W.

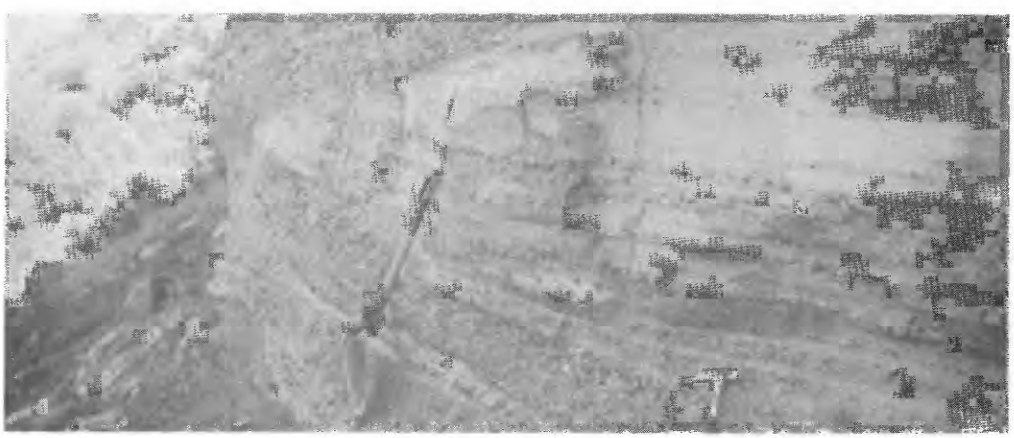
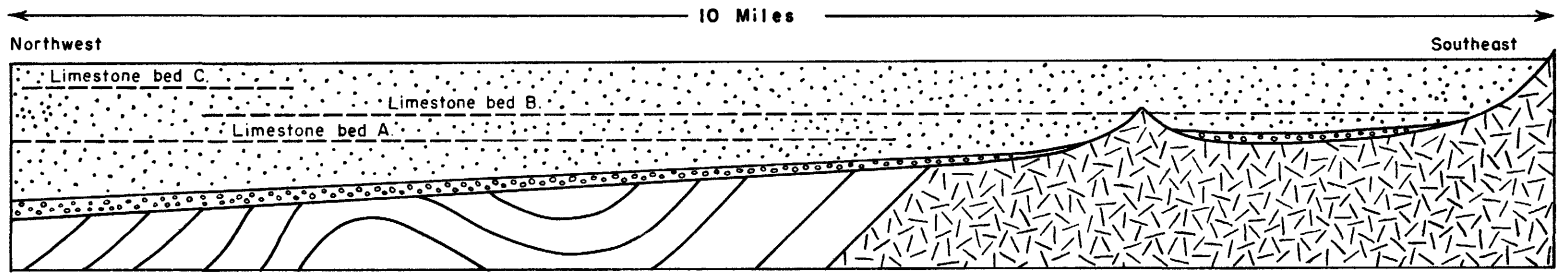


Figure 3C.--Cross-stratification and graded bedding within the basal conglomerate of the North Park(?) formation, sec. 7, T. 18 N., R. 88 W.

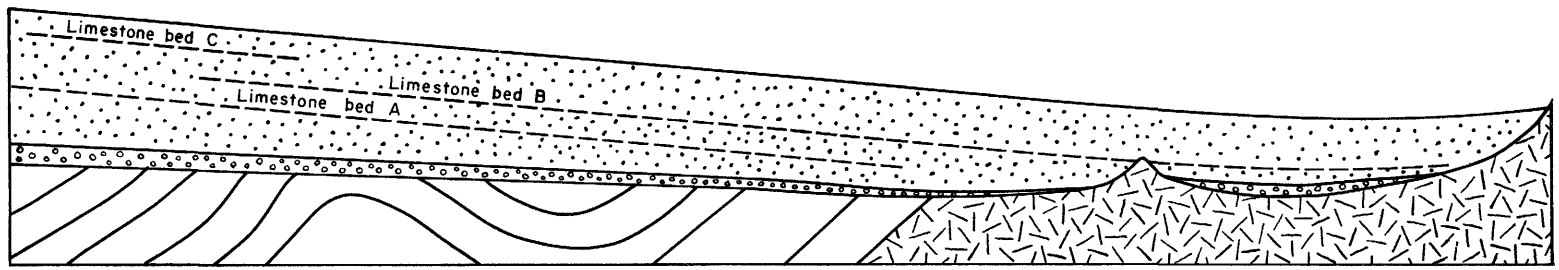
Three diagrammatic sections, figure 4, show the probable relation of the base of the North Park(?) formation to the underlying strata.

Directly overlying and transitional with the basal conglomerate member is the upper member or main body of the North Park(?) formation. The upper member consists of a sequence of sandstone, tuffaceous sandstone, tuff, and limestone beds. The bulk of the upper member is composed of very light-gray to yellowish-gray laminated sandstone, generally horizontally stratified, though small scale planar cross-lamination is locally present (figs. 5A and 5B). Sandstone beds contain detrital sand grains mixed in varying proportions with glass shards and clay minerals (fig. 6A). Sand grains range from very fine to medium-grain size and include angular, subrounded, and rounded forms. Small grains are generally more angular than large ones. Most of the grains appear to be quartz, though plagioclase feldspar, glass shards, ferromagnesian minerals and opaque mineral grains are also present. Clayey tuff beds up to 4 feet thick consisting of glass shards about 0.1 mm in length in a matrix of clay minerals are interbedded with the sandstone.

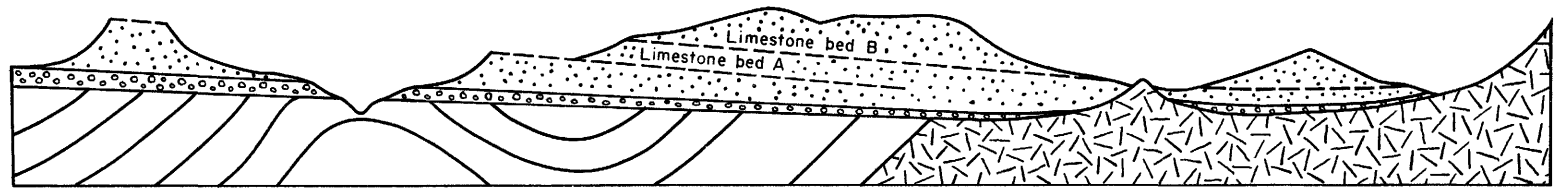
The sandstone beds weather out in flaggy to massive units with varying degrees of induration ranging from well indurated to friable, though the bulk of the sandstone is slightly indurated. In the northern part of the area, notably along the southwest side of the drainage divide that extends from near the center of sec. 5, T. 17 N., R. 88 W., to near the center of sec. 13 of the same township, the sandstone beds are cemented with silica to form an extremely resistant quartzite. This



A.-- Deposition of the North Park(?) formation on a gently tilted erosion surface.



B.--Uplift of basin area relative to the Sierra Madre.



C.-- Erosion to present land form.

FIGURE 4-- DIAGRAMMATIC CROSS SECTIONS SHOWING SEQUENCE OF EVENTS DURING LATE TERTIARY HISTORY MILLER HILL AREA, CARBON COUNTY WYOMING.

(Vertical exaggeration about 5 times.)

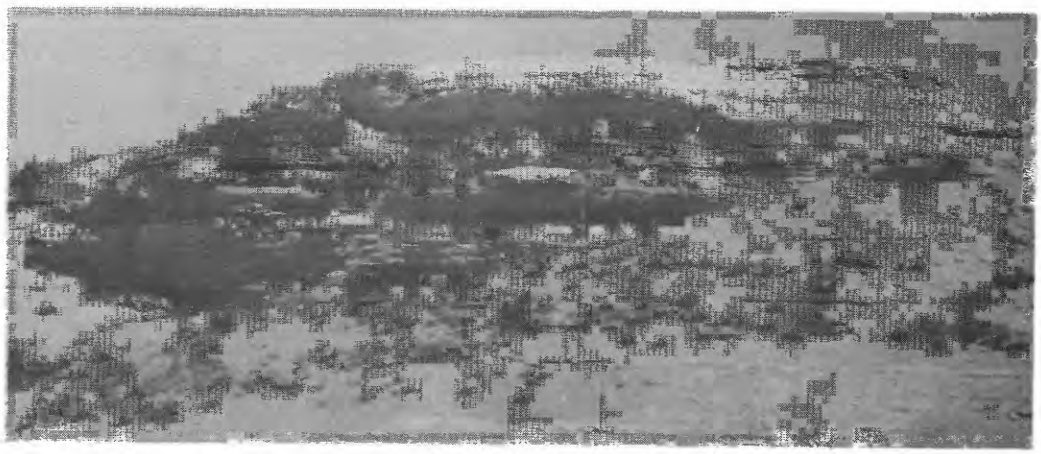


Figure 5A.--A typical outcrop of the North Park(?) formation of the Miller Hill area showing characteristic horizontal stratification. Arrow indicates position of hammer shown in figure 5B. View along main road in SE corner, sec. 31, T. 17 N., R. 87 W.

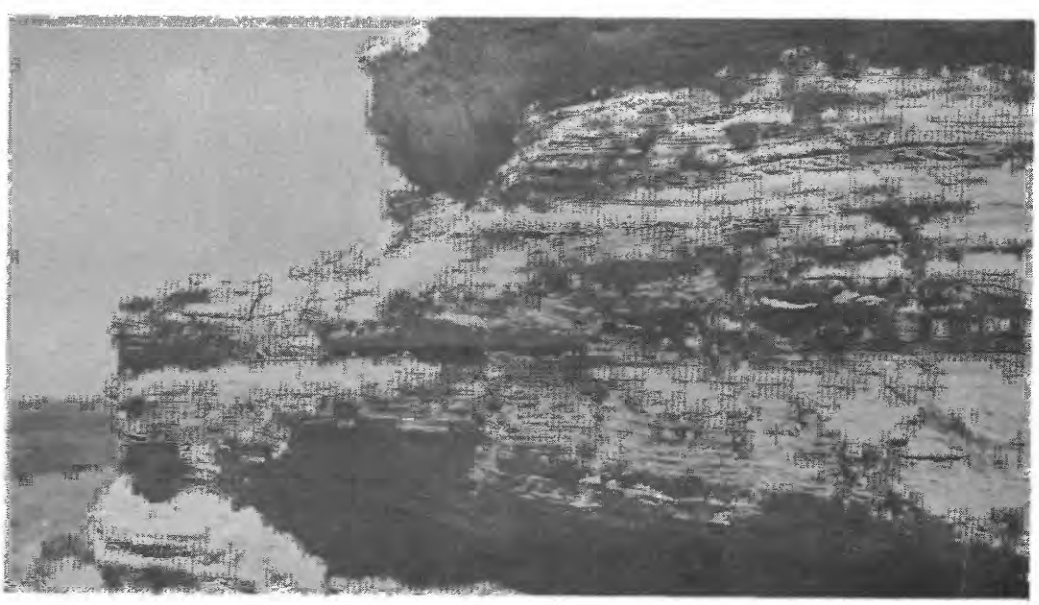


Figure 5B.--Close-up view of the same outcrop as shown in figure 5A. Note the small scale cross-lamination.

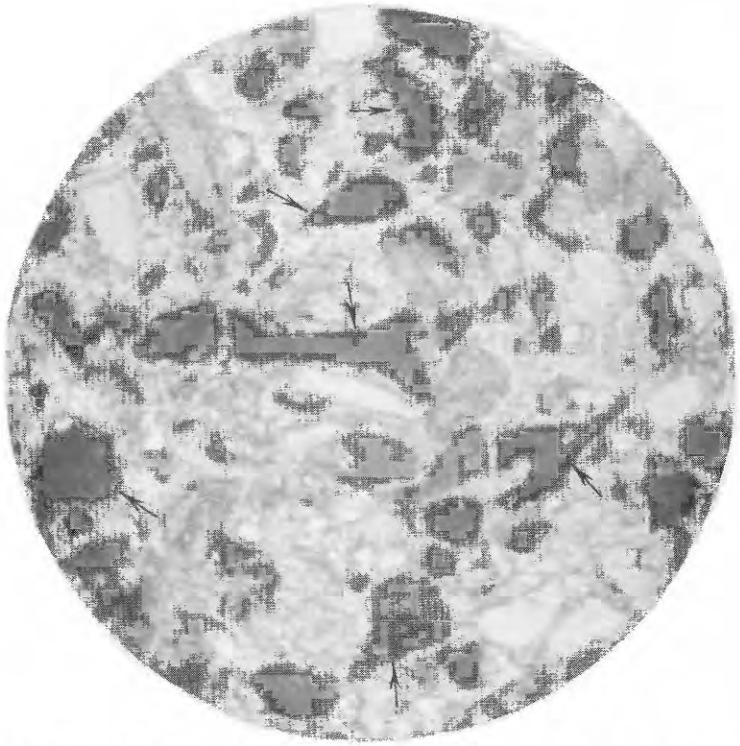


Figure 6A.--Photomicrograph of sandstone from the North Park(?) formation of the Miller Hill area. Arrows indicate typical glass shards. Magnification: 80 X. Crossed nicols.

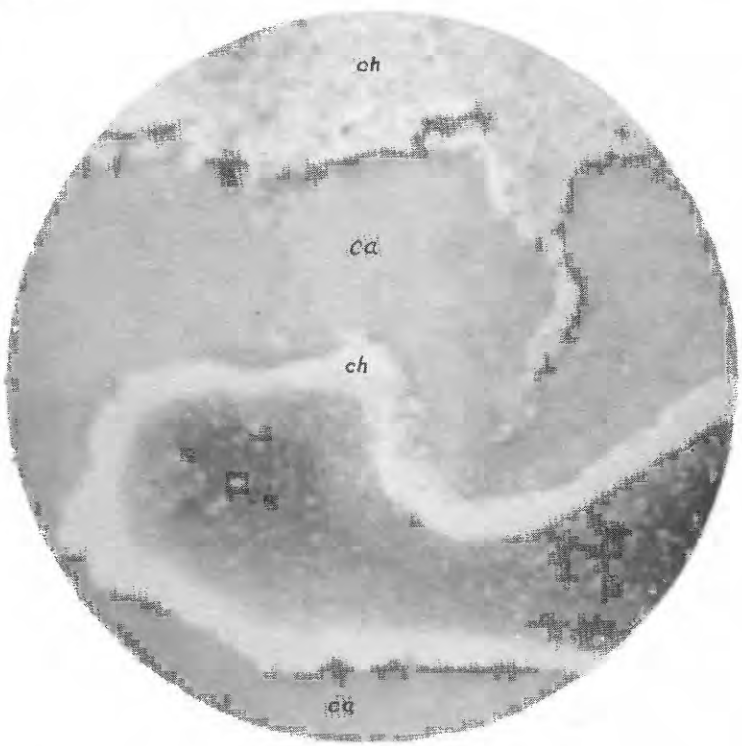


Figure 6B.--Photomicrograph of siliceous limestone from the North Park(?) formation of the Miller Hill area. Explanation: ca, calcium carbonate; ch, chalcedony. Magnification: 16 X. Plain light.

cementation seems to be restricted to near the surface and is not apparent in the same strata where exposed in nearly vertical cliffs along the northeast facing escarpment.

Locally, sandstone beds are cemented with calcium carbonate and form more resistant ledges than the non-calcareous sandstone beds. Calcareous sandstone beds grade into sandy limestone beds and they, in turn, grade into beds of dense limestone. Limestone beds are locally brecciated and partially replaced by chalcedony (fig. 6B). Most of the uranium occurrences are associated with silicified limestone.

In the area drained by Big Sage Creek and Little Sage Creek two locally radioactive limestone beds designated Bed A and Bed B were mapped as shown on figure 2A. In the area southwest of the Continental Divide the lower two of three limestone beds designated Bed A ?, Bed B ?, and Bed C ? are tentatively correlated with Bed A and Bed B north of the divide. The two main limestone beds, A and B, and the intervening strata occupy a stratigraphic zone about 135 to 150 feet thick and contain most of the abnormally radioactive rocks found in the Miller Hill area. Though this stratigraphic zone is thought to maintain a fairly uniform thickness, the interval between this zone and the basal conglomerate is thought to range from a feather edge near the Sierra Madre to about 275 feet near the southeast corner of T. 17 N., R. 88 W., and as much as 400 feet about 10 miles northwest of the mountains.

Rocks mapped as the North Park(?) formation in the Miller Hill area have yielded no fossils useful in determining the age and correlation of the strata. For this reason various names and correlations have been suggested beginning with the King Survey (1876 and 1877), which used the name North Park Tertiary. Ball and Stebinger (1910) preferred to use the name Bishop conglomerate but suggested that it might be the westward continuation of rocks that Veatch (1907) mapped as North Park Tertiary in the coal fields of east-central Carbon County, Wyo. The Geologic Map of Wyoming by M. R. Campbell and others (1925) also shows these rocks as the Bishop conglomerate of Pliocene and Miocene age. In a description of the Tertiary stratigraphy of the Saratoga Basin McGrew (1951) recognized two units based on faunal differences, which he designates from oldest to youngest the Browns Park and North Park formations respectively. In describing the Browns Park he states: "To the west it extends around the north end of the Sierra Madre Mountains and from there southward where it approaches and may even be continuous with the Browns Park near Craig, Colorado." The use of the name Browns Park for rocks in the Miller Hill area has been followed more recently by Love (1953), Del Mauro (1953), and by Love, Weitz, and Hose (1955).

During a reconnaissance investigation of uranium occurrences in the Saratoga area Stephens and Bergin (in press) experienced difficulty in distinguishing the Browns Park from the North Park formation on the basis of lithology. Rocks in the Miller Hill area are similar

in many respects to rocks in both the Browns Park and North Park formations in the Saratoga area. In the absence of faunal evidence, detailed stratigraphic and petrographic studies would be required to make correlations between the two areas. The interval of about 10 miles between the area near Saratoga investigated by Stephens and Bergin and the area investigated for the present report is characterized by prominent high angle faulting, the displacement of which would have to be determined before it would be possible to trace rock units from the Saratoga Basin into the Miller Hill area. However, there appear to be at least two distinct major lithologic units represented by the rocks within the area that McGrew (1951) indicated as underlain by Browns Park, one unit in the Miller Hill area and extending south to Browns Hill and Green Ridge (T. 14 N., Rs. 88 and 89 W.) and the other unit extending south from there to the Little Snake River. (See the Savery 30' quadrangle sheet.)

The rocks to the south have been mapped by Prichard and Chisholm (personal communication) and are thought to be equivalent to rocks in the Poison Basin area near Baggs, which have been correlated with the Browns Park formation of Miocene age (Bradley, 1945).

The Browns Park formation north of the Little Snake River near Dixon and Savery can be distinguished from rocks in the Miller Hill area in being more friable, and characterized by medium- to large-scale trough type cross-stratification. The predominant lithology of the Browns Park near Dixon and Savery consists of fine- to medium-grained sand in a fine-grained matrix of angular glass fragments. Clay-size material, which is common in the sandstone beds in the Miller Hill area, is not so abundant. The basal conglomerate of the Browns Park formation lies below the level of the Little Snake River (about 6,400 feet) near Dixon but rises to an altitude of about 7,400 feet about 10 miles northeast of Dixon where it forms the south escarpment of the canyon of Loco Creek in sec. 4, T. 13 N., R. 89 W. At this point the tilted basal Browns Park conglomerate appears to be truncated by the nearly horizontal basal conglomerate of the North Park(?) formation along a spur of North Park that extends southward from Browns Hill into the northwest corner of T. 13 N., R. 89 W. This apparent unconformable relation between two distinctly different lithologic units and the correlation of the older of these two units with the Browns Park formation are the chief reasons for reverting to the name North Park for the rocks in the Miller Hill area. The question mark is used after the name North Park(?) in order to indicate the uncertainty of the correlation.

The age of the North Park formation has been the subject of controversy and confusion for some time. In many recent publications (McGrew, 1951, Love, Weitz, and Hose, 1955) the North Park has been designated as Pliocene in age. However, McGrew (1953) shows that the fauna from the North Park formation in the Saratoga area is equivalent to the Barstow formation of California; in accordance with the Wood Committee (1941), which considers the Barstovian to be latest Miocene, McGrew calls the North Park latest Miocene in age. The U. S. Geological Survey, however, still recognizes the North Park formation as Pliocene(?) in age. Therefore, the designation used in this report is North Park(?) formation of Pliocene(?) age, using the query following both the age and name designations to show the uncertain correlation of the rocks in the Miller Hill area with the North Park formation and the uncertain age of the North Park formation.

Uncorrelated Tertiary rocks

In the southeast part of the area mapped (adjacent to the west flank of the Sierra Madre) and in the southern part of the Savery quadrangle beyond the mapped area, there are several exposures of Tertiary strata that differ so markedly from those described above that additional formational units may be present. Adjacent to a projecting spur of Precambrian rocks in the southeast corner of T. 16 N., R. 88 W. is a conglomerate-capped hill which is higher than any of the surrounding Tertiary strata. The conglomerate, at least 100 feet thick, is composed

of deeply weathered, limonite-stained Precambrian boulders. It is in fault contact with rocks of the North Park(?) formation of the Miller Hill area as well as with Precambrian rocks and is interpreted to be a post-North Park(?) conglomerate that has been down faulted. A similar conglomerate has been described by Stephens and Bergin (in press) in an area about 7 miles west of Saratoga. Still farther south, just beyond the limits of the area mapped, on East Fork and Dirtyman Fork there are several exposures of coarse clastic material. This appears to be reworked sandstone from the North Park(?) formation of the Miller Hill area mixed with coarse detritus from the Precambrian rocks exposed in the Sierra Madre. The relationship between these rocks and the typical North Park(?) formation of the Miller Hill area is not clear. However, many hills adjacent to the Sierra Madre are covered by a mantle of soil and boulders which is probably an incipient pediment deposit formed during Pleistocene or Recent time. The heterogeneous deposit mentioned above may be a dissected pediment deposit.

Quaternary deposits

Pleistocene and Recent deposits in the area include alluvium, colluvium, landslide material, terrace gravel, and pediment gravel. Alluvium is confined to small areas along the valley bottoms of major streams. Colluvium has been mapped where steep valley slopes are mantled by recent debris which does not have the jumbled character of landslide material. Landslide material covers the lower slopes of nearly the entire north and east facing escarpment of the North Park(?)

formation of the Miller Hill area. Landslide material also occupies a large area in the lower valley of Big Sage Creek. In these areas the material consists of locally derived debris from steep slopes. Terrace gravels occur adjacent to streams near the mountains and on interstream divides away from the mountains. Pediment deposits consisting of a thin mantle of gravel covering slopes of low gradient are adjacent to the Precambrian rocks of the Sierra Madre.

STRUCTURE

Several periods of structural deformation are recorded in the rocks of the Miller Hill area. The earliest of these involved only the Precambrian rocks as evidenced by steeply dipping quartzite beds. Sedimentary features in the Paleozoic and Mesozoic rocks, including unconformities, and coarse clastic rocks indicate minor fluctuations in the earth's crust. Laramide deformation, which affected rocks of Eocene and pre-Eocene age, uplifted the Precambrian rocks of the Sierra Madre and formed several large folds involving Mesozoic and older strata in the Miller Hill area. GeneDel Mauro (1953) describes the pre-Tertiary structure of the area and shows the Miller Hill anticline, trending northeast through the northeastern corner of T. 17 N., R. 89 W. to be a major structural feature with a closure of several hundred feet. This anticline, as well as several lesser structural features, has been tested for oil and gas without notable success.

No Eocene or Oligocene rocks are present in the Miller Hill area to record early Tertiary history. In the southern part of the Savery quadrangle the Browns Park formation of Miocene age overlies all older rocks with marked angular unconformity so it may be assumed that there was a period of pre-Browns Park uplift and erosion. As an unconformable relationship apparently exists between the North Park(?) formation and the underlying Browns Park formation, there must also have been a post-Browns Park and pre-North Park period of uplift and erosion. The pediment-like surface upon which was deposited the North Park(?) formation of the Miller Hill area must have formed during this brief time. Regional uplift and normal faulting, probably in late Pliocene or Pleistocene time, caused the North Park(?) formation to be tilted gently towards the Sierra Madre as shown in figure 4.

As a result of the sequence of events described above the Miller Hill area is a high plateau formed from an erosion remnant of late Tertiary rocks that dip 2 or 3 degrees to the south or southeast toward the Sierra Madre. Locally these Tertiary rocks are broken by high angle faults with 25 to 50 feet displacement and possibly more.

Where erosion has removed the mantle of Tertiary rocks, folds related to the Laramide orogeny are revealed in the older rocks. These include the northeast-trending Miller Hill anticline exposed along Littlefield and Mc Kinney Creeks in the northern part of T. 17 N., R. 89 W. Rocks as old as the Chugwater formation of Triassic age crop out below the North Park(?) formation in the valley of Littlefield Creek. A syncline trending parallel to the Miller Hill anticline and about 2 1/2 miles to the southeast brings the Niobrara formation directly below the North Park(?) escarpment in sections 3 and 4, T. 17 N., R. 88 W. The northeastward plunging nose of another anticline as indicated by the outcrop pattern of the Frontier and Mowry formations is visible north of Middlewood Hill. The exposures of northwestward dipping Triassic and Jurassic rocks in the Sage Creek basin probably represent the northwest flank of the same anticlinal feature though the surface trace of the crest line is not reflected in the structure of the superjacent North Park(?) formation.

A number of high angle faults, each with only a few feet displacement, are exposed near the contact of the Steele shale and Niobrara formation in the northeastern part of the area. The age of these faults might normally be considered as Laramide because they displace rocks of Cretaceous age but elsewhere as in section 18, T. 17 N., R. 87 W., and along Littlefield Creek similar faults are exposed that displace both Mesozoic and North Park(?) rocks, indicating a much younger age of movement for many of the faults.

URANIUM OCCURRENCES

General description

Uranium is erratically distributed throughout parts of the North Park(?) formation in the Miller Hill area. It is most abundant in those beds that are both calcareous and siliceous, though small amounts are also present in sandstone beds, particularly where limonite staining is apparent. The yellow uranium mineral uranophane, $Ca(UO_2)_2Si_2O_7 \cdot 6H_2O$, occurs as fracture coatings and vug fillings in brecciated and silicified beds of limestone and sandy limestone. Some small pellets of sandstone enclosed in the limestone contain disseminated uranophane. Uranophane also occurs with calcite and opal in secondary travertine-like coatings on the under side of broken limestone fragments. No discrete uranium minerals have been identified from much of the limestone, chalcedony, and sandstone in the North Park(?) formation that contains less than 0.1 percent uranium.

The locations of radioactivity anomalies are shown on the sketch map, figure 2B. An isoradioactivity map and a locality map, figures 7A and 7B, were prepared of several square miles in which most of the more promising localities of high radioactivity occur. Analyses of rock samples are listed in Appendix A. The majority of the radioactivity anomalies are found in one or the other of two limestone beds or in the interval between them. In the area containing most of the occurrences of uranium these two limestone beds, designated bed A and bed B, are about 275 and 410 feet respectively above the basal conglomerate. Locally

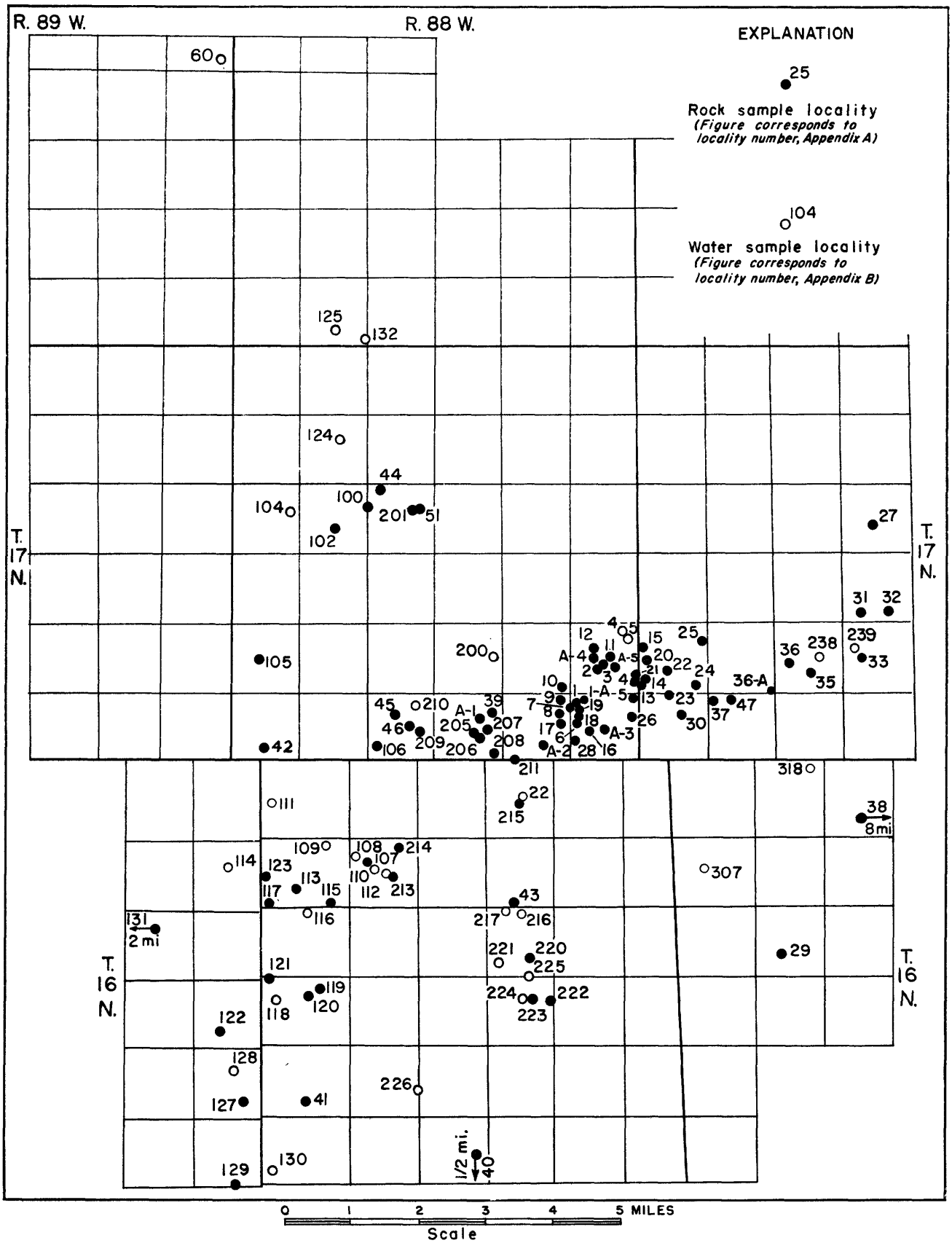


FIGURE 2B-MAP SHOWING SAMPLE LOCALITIES, MILLER HILL AREA, CARBON COUNTY, WYOMING

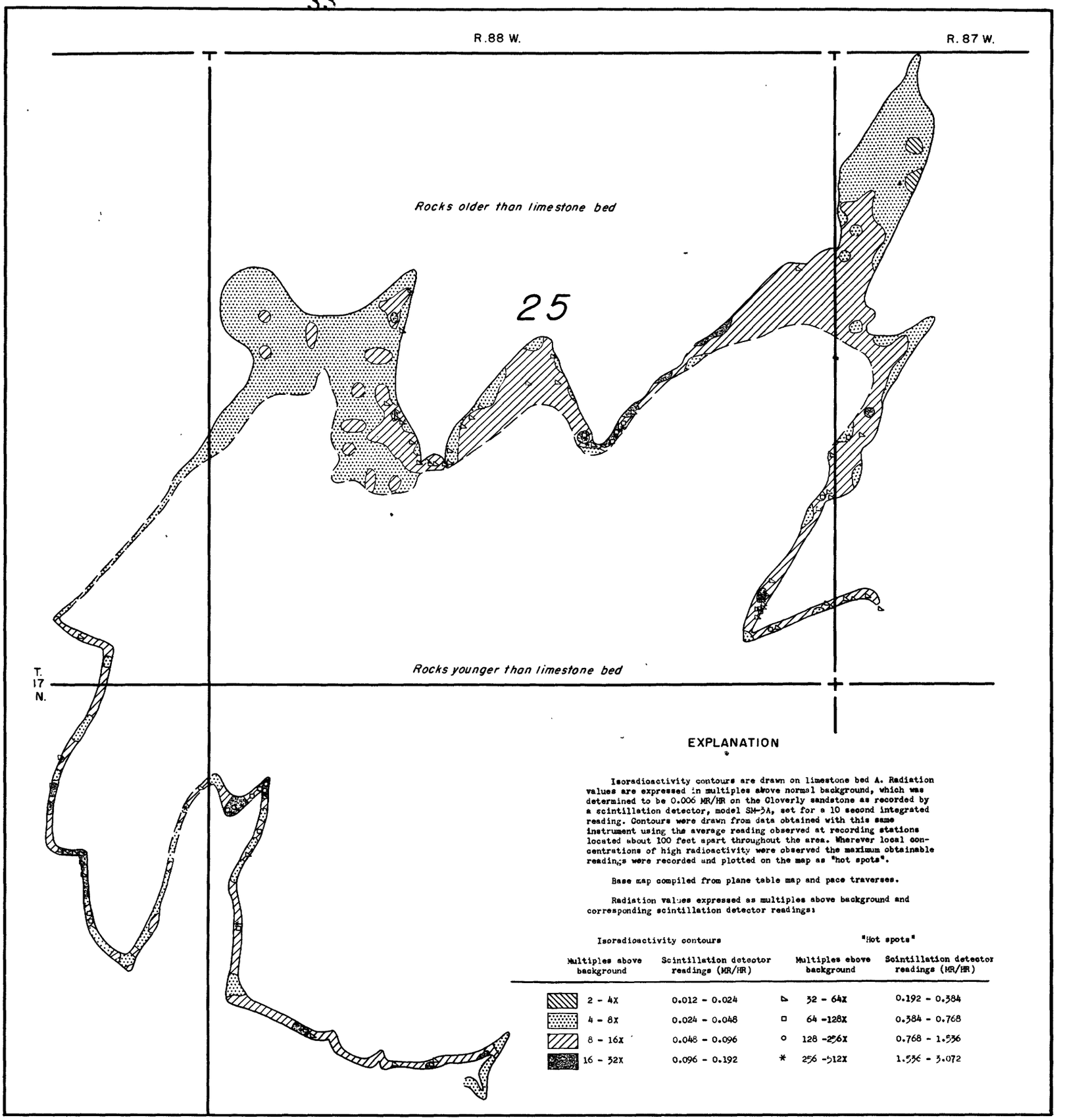


FIGURE 7A.—ISORADIOACTIVITY MAP OF A PART OF THE MILLER HILL AREA, CARBON COUNTY, WYOMING.

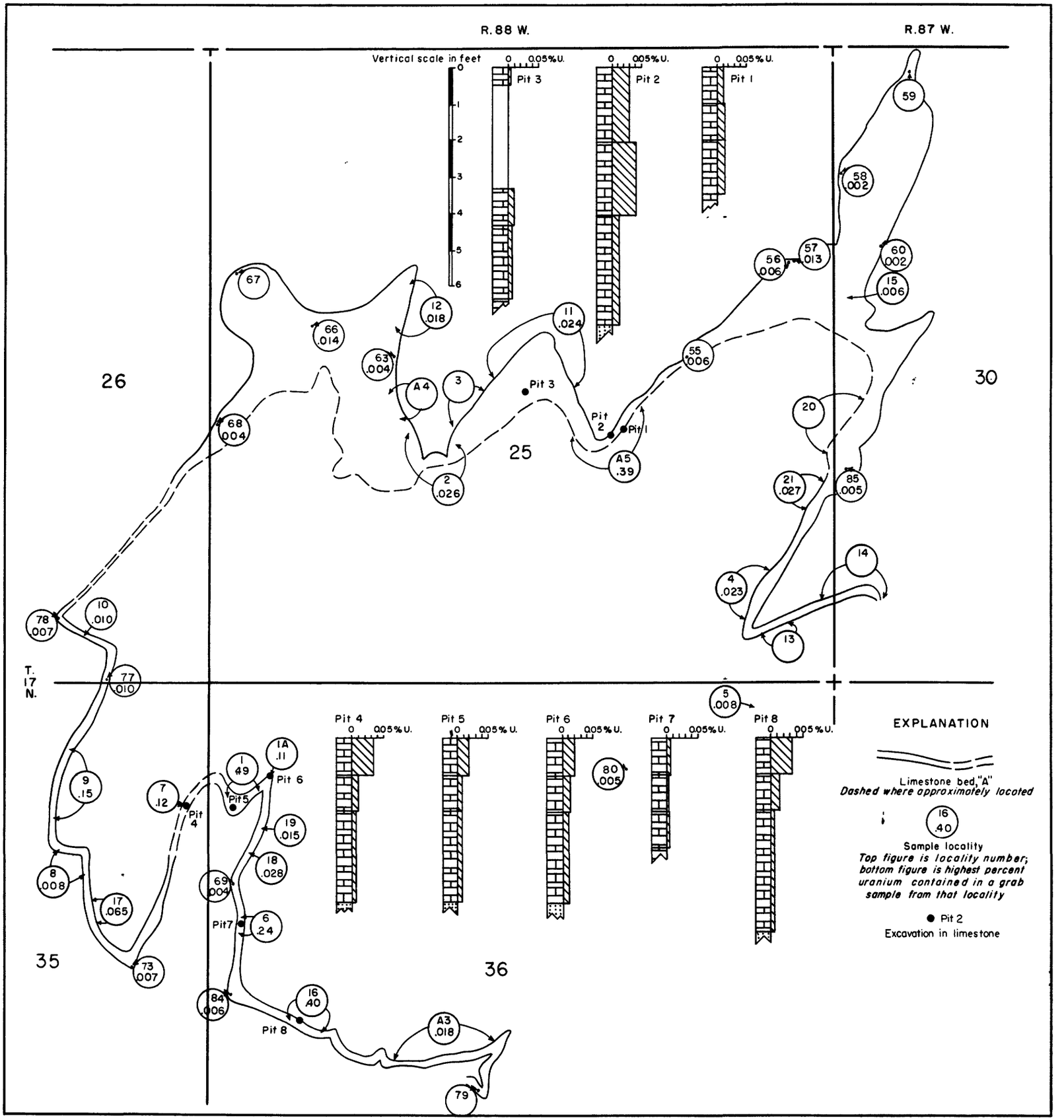


FIGURE 7B —MAP SHOWING SAMPLE LOCALITIES, TEST PITS AND URANIUM CONTENT IN A PART OF THE MILLER HILL AREA, CARBON COUNTY, WYOMING

500 0 500 1000 Feet

uranium also occurs in younger or older zones, as in the Sage Creek basin where several localities occur in strata 50 to 100 feet above the basal conglomerate.[1/] No anomalous radioactivity was detected in rocks older than the North Park(?) formation.

1/ Uranophane has been discovered in the Ketchum Buttes area, about 2 miles southwest of the area mapped. This deposit occurs in claystone and sandstone probably less than 200 feet above the basal conglomerate of the North Park(?) formation.

Silicified, brecciated limestone containing over 0.1 percent uranium in grab samples was collected from seven localities in sections 25, 35, and 36, T. 17 N., R. 88 W. To test the continuity with depth and the extent of uranium mineralization, eight pits were dug in this area in cooperation with the Atomic Energy Commission (fig. 7B). Channel samples from these pits, which penetrated 4 to 8 feet into the limestone, indicate that the uranium content is highest at or near the top of the bed and decreases abruptly downward. (See analyses of rock samples in the appendix.) Equivalent uranium shows a similar vertical distribution but is generally higher than the uranium content at the top of the bed and less than or equal to the uranium content at the bottom of the bed.

A certain range of uranium content is fairly characteristic of the various lithologies represented in the North Park(?) formation. An average of about 0.01 to 0.02 percent uranium is found in small lenses and irregular masses of dark gray or brown chert and chalcedony commonly associated with limestone beds. A maximum of about 0.01 percent uranium is found in limonite-stained sandstone, quartzite, and calcareous sandstone. Higher values for uranium up to about 0.1 percent are associated with brecciated and recemented limestone where the recementation of the limestone is partly accomplished by minutely disseminated brown chalcedony and small blebs of light gray chert. Thin greenish films of fluorescent uranophane are present as fracture coatings in this type of rock. The highest values for uranium, up to about 0.5 percent, occur in brecciated and partly silicified limestone where recementation is incomplete. Microcrystalline aggregates of bright yellow uranophane associated with colloform opal are found in vugs in this type of rock (fig. 8A). The bright yellow crystals of uranophane do not fluoresce. More commonly, however, vugs are lined with a pale-green dendritic mineral aggregate composed of an intimate intergrowth of calcite, opal, and uranophane that fluoresces yellow-green (fig. 8B). The pale green intergrowths of calcite, opal, and uranophane grade imperceptibly into whitish intergrowths that fluoresce yellow-green but probably contain less uranophane. The whitish intergrowths are found both in vugs and as travertine-like coatings on the underside of limestone fragments.

Figure 8A.--Photomicrograph of radiating crystal aggregates of uranophane occurring in opal lined vug in brecciated limestone from locality A-5. Magnification: 16 X. Plain light.

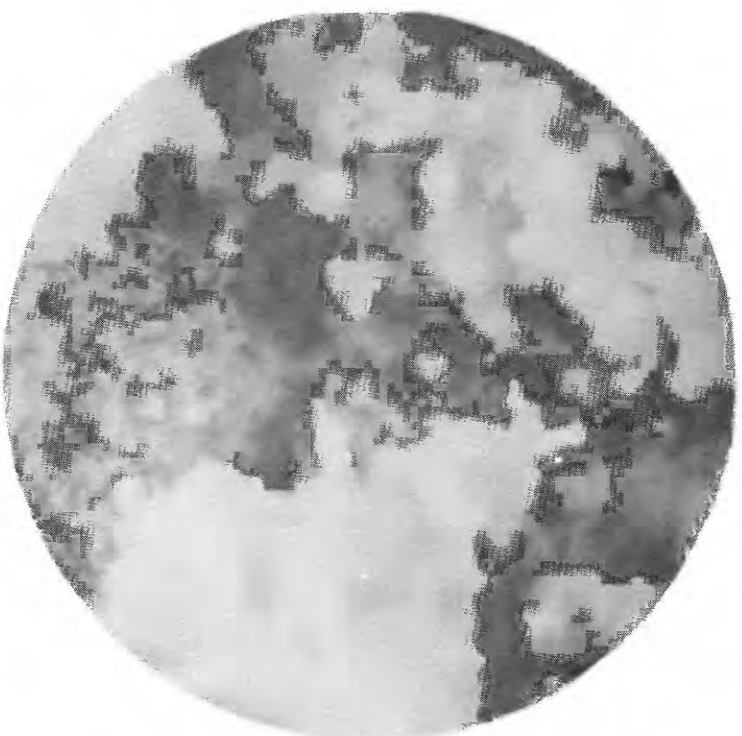


Figure 8B.--Photomicrograph of fluorescent travertine-like aggregate of uranophane, opal and calcite from locality A-5. Magnification: 16 X. Ultraviolet light.

Descriptions of selected uranium localities

From the many localities of uraniferous rocks in the Miller Hill area the following nine have been selected to be described in more detail: A-5, 1, 1A, 6, 7, 9, 11, 16, and 17. These include all the localities that are highly radioactive and together they provide enough detail to define the habit of uranium occurrences in this area. These localities are found in sections 25, 35, and 36, T. 17 N., R. 88 W.

Locality A-5 was discovered by aerial radioactivity survey in October 1952, and was referred to as anomaly 47-16.6 on the preliminary anomaly map (Meuschke and Moxham, 1953). At least 7,500 square feet of the exposed surface of limestone bed A is moderately to highly radioactive in this area. Shallow trenches, designated A to G (fig. 9) were excavated along joints in the limestone and mapped in detail by Atomic Energy Commission personnel (J. P. Hadfield in charge). Pits designated 1 and 2 were later excavated into the massive limestone to depths of 4 and 7 feet respectively. Pit 2 obliterated trench B and penetrated to the base of the massive limestone.

Limestone bed A forms a narrow outcrop band 50 to 100 feet wide at locality A-5. The bed is composed of light-gray, dense to sandy limestone and contains irregular masses that are highly brecciated and silicified. The silicification includes gray chert or chalcedony, brown chalcedony, and opal, apparently deposited in that sequence. Gray chert or chalcedony occurs in small blebs and irregular masses that

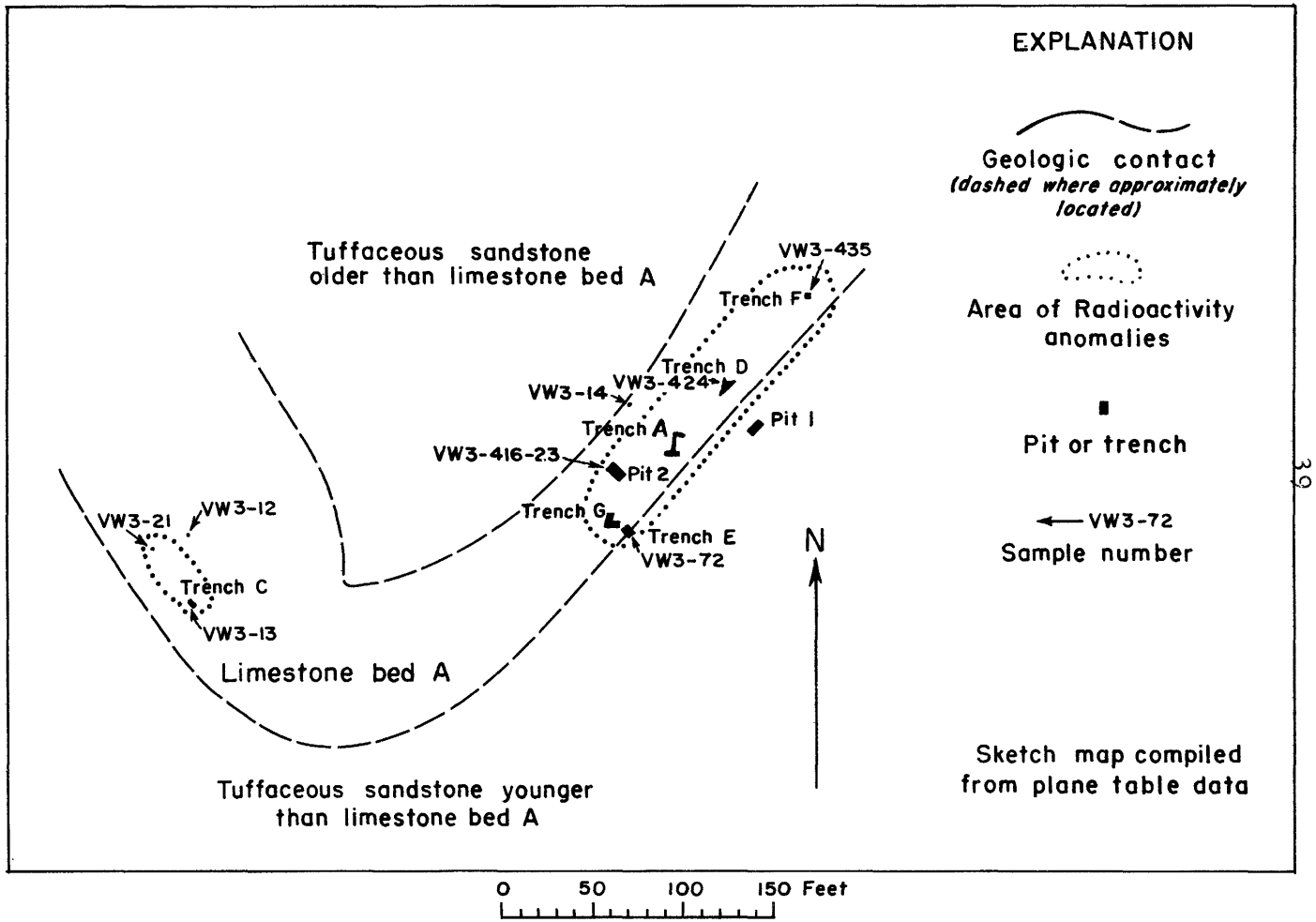


FIGURE 9--SKETCH MAP OF LOCALITY A-5 SHOWING LOCATION OF RADIOACTIVITY ANOMALIES AND PITS FROM WHICH SAMPLES WERE COLLECTED FOR ANALYSIS, SECTION 25, T. 17 N., R. 88 W., CARBON COUNTY, WYOMING

replace limestone. Brown (and locally white) chalcedony occurs in finely disseminated form in the limestone and locally fills tiny fractures in brecciated and recemented limestone. Opal occurs as colloform coatings in vugs and cavities in brecciated, but incompletely recemented limestone, and locally forms small-scale stalactite-like pendants that hang from the upper surface of the vugs. Radiating crystal aggregates of bright yellow uranophane up to 0.5 mm in diameter locally dot the surface of opal in vugs (fig. 8A). Vug fillings of a pale-green dendritic mineral aggregate composed of calcite, opal, and a trace of uranophane occur abundantly (fig. 8B). These pale-green mineral aggregates fluoresce a bright yellow green in ultraviolet light in contrast to the discrete uranophane crystals, which do not fluoresce. A similar mineral aggregate of calcite, opal, and uranophane commonly occurs as a travertine-like coating as much as 5 to 10 mm thick on the bottom side of broken limestone fragments near the weathered surface of an outcrop. Though these travertine-like coatings seldom have as noticeable a greenish tint as the vug occurrences, they fluoresce the same bright yellow green color in ultraviolet light. Locally, joint surfaces in the silicified limestone are coated with a pale green radioactive material that is probably similar in composition to the calcite, opal, and uranophane aggregates because the material fluoresces a similar color. Rarely, friable sandstone pellets as much as 10 mm across occur in the limestone and have a pale greenish color that suggests the presence of uranophane.

The top foot of siliceous limestone at locality A-5 may contain as much as 7,500 cubic feet, or 625 tons of rock with an average grade of not more than 0.03 percent uranium.

Locality 1 occurs on a small point formed by limestone bed A where the outcrop band varies from about 50 to 150 feet wide. Moderate to high radioactivity was detected within an area of about 4,800 square feet on the weathered surface of the limestone. As at locality A-5, shallow trenches designated H to L were opened up along the joints and fractures in the limestone and pit 5 was excavated to a depth of 4.5 feet in the limestone (fig. 10). The lithology of the limestone bed at locality 1 and the occurrence of the uranium is similar to that at locality A-5. In general, there is less gray chert, more minutely disseminated brown chalcedony, and fewer open vugs at locality 1. Visible uranium minerals occur in the same variety of ways as at locality A-5, including yellow microcrystalline uranophane and pale green mineral aggregates in vugs, as green coatings on joints, and as travertine-like coatings on the bottom side of limestone fragments.

A comparison of the analyses of samples collected from the shallow trenches opened along joints and from pit 5 (appendix B) indicates that relatively intense mineralization is confined to the upper part of the limestone, particularly along the joints. A 12-inch channel sample from near a joint contained as much as 0.49 percent uranium, but the uranium content of limestone exposed in pit 5 ranged from 0.019 at the top to 0.009 at the bottom and had a weighted average of only 0.011 percent.

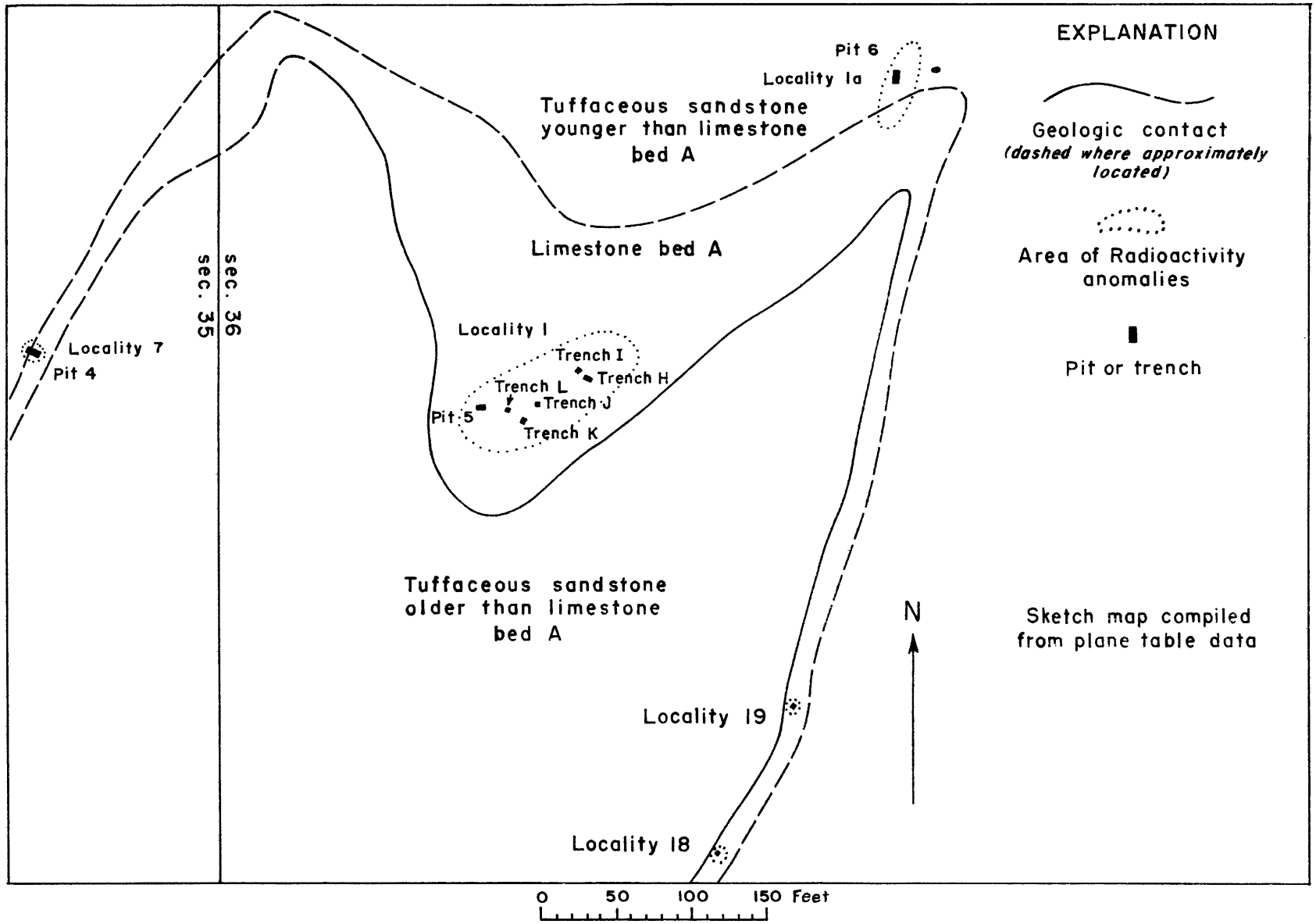


FIGURE 10--SKETCH MAP OF LOCALITY I AND ADJACENT AREAS SHOWING LOCATION OF RADIOACTIVITY ANOMALIES AND PITS FROM WHICH SAMPLES WERE COLLECTED FOR ANALYSIS, T. 17 N., R. 88 W., CARBON COUNTY, WYOMING.

It is estimated that the top foot of siliceous limestone at locality 1 may contain as much as 4,800 cubic feet or 400 tons of rock with an average grade of not more than 0.02 percent uranium.

Locality 1A is a small area of moderate to high radioactivity about 300 feet northeast of locality 1, figures 7B and 10. The occurrence of uranium is very similar to locality 1 except that most of the visible uranium mineral occurs as pale green fracture coatings. Abundant travertine-like coatings on limestone fragments are almost colorless but fluoresce bright yellow green. The uranium content of 54 inches of limestone exposed in pit 6 ranges from 0.020 to 0.008 and has a weighted average of only 0.011 percent.

Probably less than 50 tons of rock from locality 1A contains as much as 0.02 percent uranium.

Localities 6, 7, and 16 lie within the narrow outcrop band of limestone bed A extending southeast and southwest from localities 1 and 1A, figures 7B and 10. These three localities are all very small and each consists essentially of a few square feet of area where high radioactivity and visible uranium minerals were found. In each area the occurrence of uranium is very similar to the localities previously described. Pits 7, 4, and 8 were excavated to depths of 3 to 5.5 feet but the uranium minerals visible on the surface did not extend more than a few inches into the limestone and in each area the uranium content decreased rapidly with depth to an average of about 0.006 percent uranium at the bottom of the pits.

Locality 9 consists of several small areas of moderate and one area of high radioactivity along a narrow partly covered ledge of limestone bed A, figure 7B. The limestone bed varies from a dense limestone to a sandy limestone with small greenish tinted sand pellets, and contains irregular masses of dark purplish gray chert or chalcedony. No uranium minerals were identified.

Locality 17 is unique in that moderate to high radioactivity is associated primarily with lenses up to several inches thick and several feet across of dark purplish gray chert and brown to white chalcedony. No uranium minerals were identified.

Locality 11 consists of a large triangular area of several acres near the center of sec. 25, T. 17 N., R. 88 W. where the entire broad stripped surface of the limestone is weakly radioactive, and there are several small spots of moderate radioactivity. Most of the points of moderate radioactivity are associated with irregular masses of dark gray chert or chalcedony that stand up as knobby mounds 6 to 12 inches above the general surface of the limestone. Pit 3 was excavated to a depth of 6 feet to determine whether or not more intense mineralization might exist below the weathered surface of the limestone. The results showed strikingly little variation in the uranium content with depth below the surface. Such variations as were encountered seemed to be related more to the amount of chalcedony in the limestone than to any other single factor.

Potential reserves

No uranium-bearing deposits of sufficient size and grade to be considered profitable to mine were observed in the area investigated. Selected grab samples containing more than 0.1 percent uranium were collected from several places in the area, but these higher grade samples represent only small discontinuous mineralized areas.

Several small areas of siliceous limestone described in the preceding section contain on the order of several hundred tons of rock averaging about 0.02 to 0.03 percent uranium. In addition, there may be several hundred million tons of siliceous limestone, limestone, and calcareous sandstone containing an average of 0.005 to 0.01 percent uranium. Because it is of no economic interest, the areal extent of this low-grade uraniferous rock was not determined.

URANIUM CONTENT OF NATURAL WATERS

Thirty water samples were collected and submitted for uranium analysis as shown in appendix B. Most of the water samples are from springs in the North Park(?) formation though a few samples were collected from ponds or reservoirs. The analyses of these water samples show from 1 to 14 parts per billion uranium and average about 6 parts. Analyses of many spring waters throughout the western United States indicate that the average uranium content is probably less than 0.5 parts per billion (Fix, personal communication). Although the analyses of natural waters from the Miller Hill area indicate that it is a uraniferous region, the low range of values makes difficult any attempt to outline favorable areas for further exploration using water analyses.

DISTRIBUTION OF ELEMENTS

A study was made of the distribution of elements in a selected suite of uranium-bearing limestone samples from the mineralized parts of the North Park(?) formation in the Miller Hill area to learn more about the geochemical environment of deposition of uranium in this type of deposit. Semiquantitative spectrographic analyses were obtained for 31 representative samples from the most highly mineralized parts of the limestone. The samples include 3 channel samples from each of 8 pits, plus 1 grab sample with visible uranium minerals from each of 7 pits. The uranium content of these samples, as determined by chemical analysis, ranges from 0.003 to 0.49 percent.

Table 1 shows the raw analytical data. The spectrographic data are reported in 3 sub-groups for each 10-fold increment. The sub-group range and midpoint values for each are shown in table 2. Table 3 shows the nearly 60 elements looked for in the spectrographic analyses and the average threshold values for each element. Of the nearly 60 elements looked for, 18 elements in addition to uranium were found in enough samples to warrant statistical analysis and interpretation.

The average, geometric mean, and standard deviation for uranium and each of the other 18 elements were calculated by substituting the midpoint value for each sub-group. The resultant values are listed in table 4 and in figures 11 and 12. Data for the average composition of limestone (Rankama and Sahama, 1950, p. 226) are listed in table 4, and on figure 12 for comparison with the samples from the Miller Hill area.

Table 1.--Analyses of 31 mineralized limestone samples from the Miller Hill area, Carbon County, Wyoming

Field sample number	Locality number	Elements detected 1/ 2/																	
		Si	Al	Fe	Ti	Mn	Ca	Mg	Na	K	Ba	Cr	Cu	Mo	Ni	Pb	Sr	V	Zr	U
VW3-452	1	B+	C	C+	D-	C-	A	C	C-	O	D+	E-	E-	D	F+	E-	D	E	E-	0.49
43	16	A	C	B-	D-	D+	A	C+	C-	O	C-	E-	E+	E-	E-	E-	D+	E	E+	.40
72	A-5	B+	C+	C+	D-	C-	A	C	C-	O	D+	E-	E+	D-	F+	E	D	E	E	.39
65	6	B+	C+	C+	D	C	A	C	C-	O	D+	E-	E	D-	E-	D-	D+	E	E	.24
68	7	A	C+	B-	E+	D+	A	C	D	O	D	E-	D-	E+	E	E	D-	E-	O	.12
442	1A	B+	C+	C+	D-	C-	A	C+	C-	O	D+	E-	E-	O	F+	Tr	D+	E	E-	.11
435	A-5	B+	C-	B-	E+	D+	A	C+	C-	O	D+	E	E	Tr	E-	E	D+	D-	Tr	.10
443	7	A	C+	B-	D-	D+	A	C	C-	O	C-	E	E+	E+	E-	Tr	D-	E	E-	.035
447	16	A	C-	B-	E+	D+	A	C	D+	O	D+	E	E	O	E-	Tr	D	E	E-	.035
419	A-5	A	C	C+	D-	D+	A	C	C-	O	D+	E	E	E	F+	O	D	E	Tr	.020
439	1A	B+	C+	B-	D-	D+	A	C+	C-	O	D+	E	E+	O	E-	O	D-	E	E	.020
456	1	A	C-	B-	E+	D+	A	C	D	O	D-	E	E	D-	E-	O	D-	E-	E-	.019
420	A-5	A	C+	B-	D+	D+	A	C	C	C	D+	E	E	Tr	F+	O	D	E	E	.014
448	16	B+	C-	C+	E+	D+	A	C+	D+	O	D-	E	E	O	F+	O	D	E	Tr	.014
431	A-5	A	C	B-	D-	D	A	C	C-	O	D	E	E+	Tr	E-	O	D	E+	E-	.012
421	A-5	A	C+	C+	D	D+	A	C	C	C	D+	E	E	E	F+	O	D	E	E+	.010
440	1A	B+	C	C+	D-	D+	A	D+	C-	O	D	E-	E	O	F+	O	D-	E	E-	.010
444	7	A	C	B-	D-	D+	A	C-	D+	O	D+	E	E	E	E-	O	D-	E	E-	.010
457	1	A	C	C+	D-	D+	A	C+	C-	O	D-	E-	E-	E+	F+	O	D	E-	E-	.009
458	1	B+	C+	C	D	D+	A	C+	C	O	D-	E-	F+	D-	F+	O	D+	E	E	.009
412	11	B+	C-	C+	D-	D	A	C-	D+	O	D-	E-	E	O	E-	O	D-	E	E	.008
441	1A	B+	B-	C+	D	D+	A	C+	C	C+	D-	E-	E-	O	F+	O	D	E	E	.008
445	7	B+	C+	C+	D	D+	A	C+	C	C	D-	E-	F+	E	F+	O	D	E	E-	.007
449	16	B+	C+	C+	D	D+	A	C+	C	C	D-	E-	E-	O	F+	O	D	E	E-	.006
459	6	B+	C	C	D-	D+	A	C+	C-	O	D-	E-	E-	E+	F+	O	D	E	E-	.006
410	11	B-	C-	C	E+	D+	A	C	D+	O	E+	F+	F+	O	Tr	O	D+	E-	Tr	.005
413	11	B	C-	C	D-	D	A	C	C-	O	D-	E-	E-	O	F+	O	D-	E-	E	.005
461	6	A	C+	C+	D-	D+	A	C+	C	O	D	E-	E-	D-	F+	O	D	E-	E	.005
433	A-5	B+	C	C+	D-	D+	A	C+	C	O	E+	E-	E-	O	F+	O	D+	E+	E+	.004
460	6	B+	C	C	D-	D+	A	C+	C-	O	D-	E-	E-	E+	F+	O	D	E-	E	.004
432	A-5	A	C	B-	D-	D+	A	C+	C-	O	D-	E	E	O	E-	O	D	E+	Tr	.003

1/ Uranium analyses are chemical determinations; all others are semiquantitative spectrographic analyses. See table 2 for key to values for spectrographic data listed here and table 3 for a list of the elements looked for and their threshold values.

2/ Spectrographic determinations were made by G. W. Boyes, N. M. Conklin, P. J. Dunton, and R. G. Havens under the supervision of A. T. Myers.

Table 2.--Key to values for spectrographic data listed in table 1.

Analyses listed by group letter designation with plus and minus notation for the sub-group designation, as follows:

Designation	Sub-group range (percent)	Sub-group midpoint (percent)
A	over 10	32
B+	4.6 - 10	6.8
B	2.1 - 4.6	3.2
B-	1.0 - 2.1	1.5
C+	0.46 - 1.0	0.68
C	0.21 - 0.46	0.32
C-	0.10 - 0.21	0.15
D+	0.046 - 0.10	0.068
D	0.021 - 0.046	0.032
D-	0.010 - 0.021	0.015
E+	0.0046 - 0.010	0.0068
E	0.0021 - 0.0046	0.0032
E-	0.0010 - 0.0021	0.0015
F+	0.00046 - 0.0010	0.00068
F	0.00021 - 0.00046	0.00032
F-	0.00010 - 0.00021	0.00015
Tr	(near threshold)	
O	(less than threshold)	

Table 3.--Threshold values (in percent) for the elements determined by the spectrographic method (A. T. Myers, May 22, 1952).

Ag - 0.0001	Hf - 0.1	Pt - 0.005
Al - 0.001	Hg - 1.0	Re - 0.005
As - 0.1	In - 0.001	Rh - 0.005
Au - 0.005	Ir - 0.005	Ru - 0.005
B - 0.005	K - 1.0	Sb - 0.05
Ba - 0.0001	La - 0.005	Sc - 0.001
Be - 0.0001	Li - 0.01	Si - 0.001
Bi - 0.001	Mg - 0.005	Sm - 0.01
Ca - 0.001	Mo - 0.001	Sn - 0.001
Cd - 0.005	Mn - 0.0005	Sr - 0.0005
Ce - 0.05	Na - 0.05	Ta - 0.05
Co - 0.0005	Nb - 0.005	Te - 0.5
Cr - 0.0005	Nd - 0.01	Th - 0.05
Cs - 1.0	Ni - 0.0005	Ti - 0.001
Cu - 0.0001	Os - 0.005	Tl - 0.05
Fe - 0.001	P - 0.5	V - 0.001
Ga - 0.001	Pb - 0.001	W - 0.01
Gd - 0.05	Pd - 0.0005	Y - 0.001
Ge - 0.0005	Pr - 0.005	Zn - 0.05
		Zr - 0.001

Table 4.--Abundance of elements[1] in uranium-bearing limestone from the Miller Hill area, Carbon County, Wyoming, compared with the average composition of limestone and showing the correlation coefficients of each element with uranium.

Element	Average composition of limestone (percent) (Rankama and Sahama, 1950)	Composition of limestone in Miller Hill area (percent) (calculated from 31 samples) Average	Mean	Correlation coefficient with uranium
Ca	30.45	>10.	>10.	--
Si	2.42	17.	12.	+.06
Fe	0.40	0.90	0.79	+.32
Mg	4.77	0.49	0.42	-.15
Al	0.43	0.44	0.36	+.001
Na	0.037	0.17	0.14	-.41
K[2]	0.27	< 0.10	< 0.17	-.22
Mn	0.0385	0.080	0.072	+.62
U[3]	0.00013	0.066	0.020	--
Ba	0.012	0.044	0.031	+.71
Sr	0.0765	0.032	0.031	+.20
Ti	--	0.018	0.015	-.16
Mo[2]	--	< 0.0051	< 0.00079	+.33
V	0.001	0.0035	0.0030	+.14
Cu	0.002	0.0033	0.0025	+.45
Zr[2]	--	< 0.0026	< 0.0018	+.04
Cr	0.0002	0.0021	0.0019	-.16
Pb[2]	0.001	<0.0012	<0.00053	+.85
Ni	0	0.0010	0.00092	+.34

1/ Two major constituents of limestone, C and O, are not detected by the spectrographic method. In addition, however, Li, B, F, P, S, Cl, Zn, Ga, Se, Ag, I, Au, and Hg are listed by Rankama and Sahama (1950) as being present in minor or trace amounts in the average limestone but were not detected in the samples from the Miller Hill area. The elements Li, B, P, Zn, Ga, Ag, Au, and Hg are presumed to occur, if present at all, in quantities less than the threshold values listed for these elements, table 2, whereas F, S, Cl, Se, and I are not detected by the spectrographic method.

2/ These values for the Miller Hill samples include one or more analyses listed as Tr (trace) or 0 (not found). In order to assign a value to these analyses that could be used in calculating the average and mean, Tr was considered to be in the next sub-group below that listed and 0 was considered to be 2 sub-groups below that listed.

3/ Average and mean values for uranium in the Miller Hill area were calculated from chemical rather than spectrographic analyses.

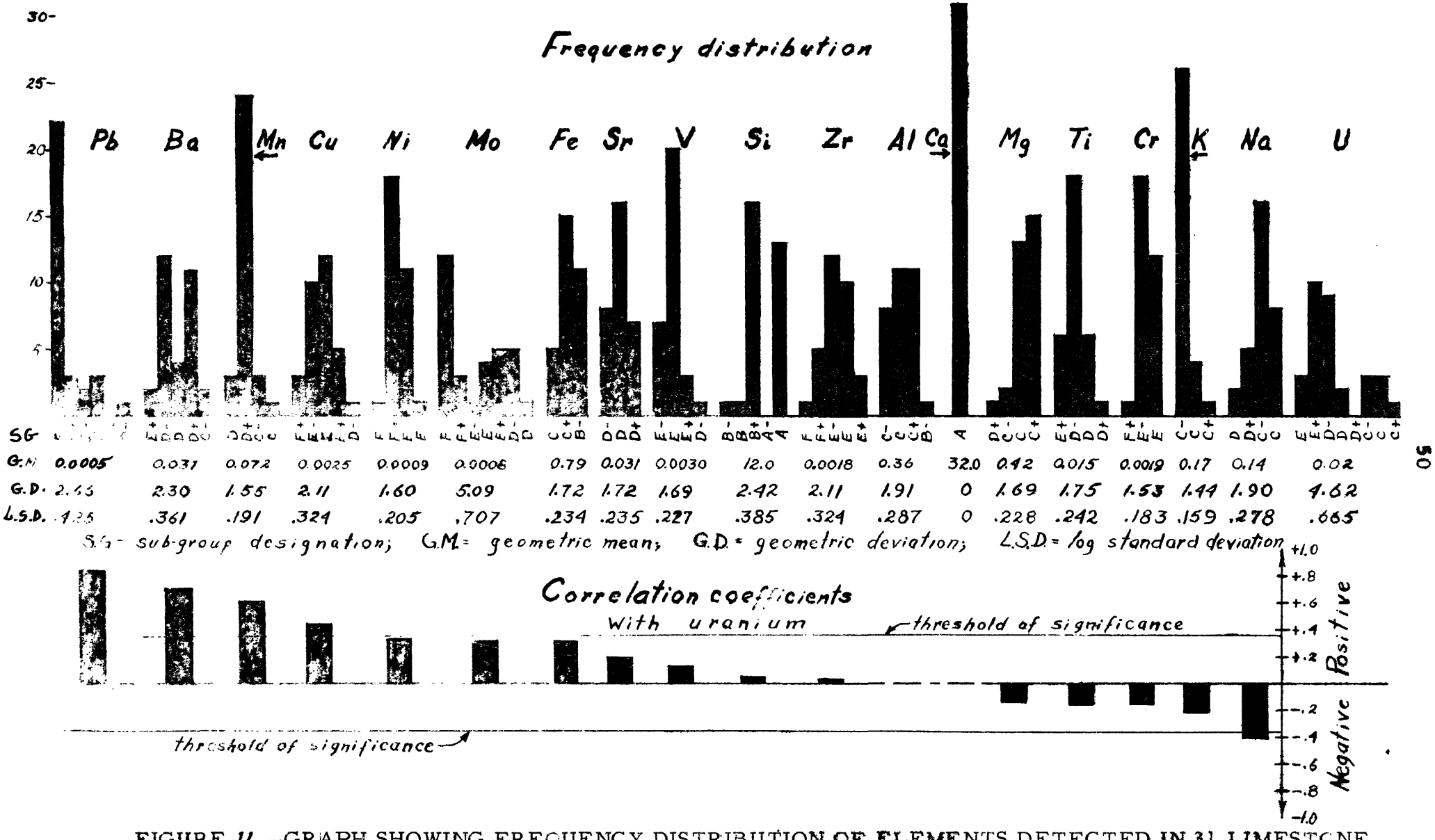


FIGURE 11. --GRAPH SHOWING FREQUENCY DISTRIBUTION OF ELEMENTS DETECTED IN 31 LIMESTONE SAMPLES AND CORRELATION COEFFICIENTS FOR EACH ELEMENT WITH URANIUM, MILLER HILL AREA, CARBON COUNTY, WYOMING.

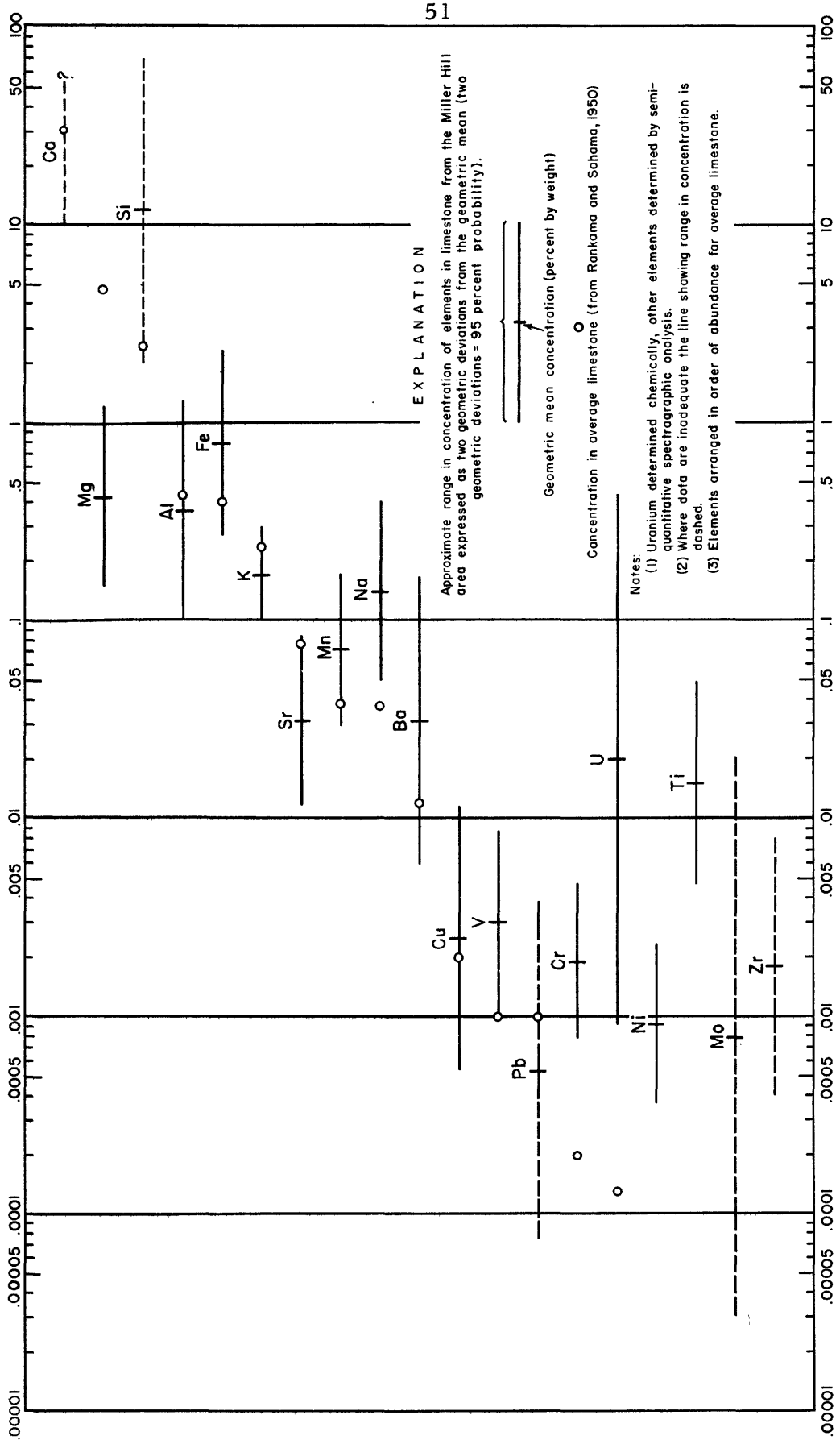


FIGURE 12 - GRAPH SHOWING COMPARISON OF ELEMENT CONCENTRATION IN 31 SAMPLES OF MINERALIZED LIMESTONE FROM MILLER HILL AREA WITH ELEMENT CONCENTRATION IN AVERAGE LIMESTONE.

These data indicate the mineralized limestone in the Miller Hill area contains more Si, Fe, Na, Mn, U, Ba, V, and Cr than the average limestone. Values for Ti, Mo, and Zr are not listed by Rankama and Sahama for the average limestone and Ni is listed as zero, so presumably these elements are present in only trace quantities or are not detectable in the average limestone. Presumably the data for the average composition of limestone are heavily weighted in favor of marine limestones, whereas the limestone in the Miller Hill area was deposited in a restricted lake and this difference may account for some of the difference in composition.

Correlation coefficients[1/] were calculated from the analytical data to show the relation between uranium and other elements (table 4 and fig. 11). A correlation coefficient of plus 1 indicates a perfect positive (or direct) linear relation between the pairs of values for the 2 elements, whereas a correlation coefficient of minus 1 indicates a perfect negative (or inverse) linear relation between the pairs of values. A correlation coefficient close to zero indicates a random or non-linear relation. For the number of samples involved in this study a correlation coefficient of about plus or minus 0.36 is considered to be the threshold of significance (95 percent probability).

1/ Refer to any standard text book on statistics for the definition and use of correlation coefficients.

The calculated correlation coefficients are not uniformly reliable. For example, the values shown for Pb and K are not trustworthy because the analyses for a number of samples are reported as less than the threshhold value of the analytical technique. A similar difficulty exists for Si and Ca because the analyses for a number of samples are reported as 10 percent or more. Thus each of these elements has one class for which an accurate midpoint value cannot be determined. The significance of the value listed for Ba is open to question because of the marked bimodal frequency distribution.

Keeping these difficulties in mind, however, it is noted that Pb, Ba, Mn, and Cu have significant positive correlation with uranium, while Ni, Mo, and Fe have nearly significant positive correlation. Only Na has a significant negative correlation. The remainder of the elements detected show essentially a random distribution with respect to uranium.

The following suggestions are offered as possible interpretation of these data. Correlation of uranium and lead may be due in part at least to the addition of lead of radiogenic origin. Since the only known uranium mineral in the area is a hydrous calcium uranyl silicate the correlation of uranium with Ba, Mn, Cu, Ni, Mo, and Fe cannot be attributed to chemical combination in the form of discrete minerals. More likely the correlation is due to a similar behavior in this specific geochemical environment, and may possibly signify a common origin. Conversely, sodium reacts quite differently from uranium and is probably soluble in the same environment that uranium and its associated elements precipitate.

It is noted that while uranium is far more abundant in the limestone of the Miller Hill area than in the average limestone so also are most of the elements that correlate with uranium, though the disparity is not so great as for uranium. This relation suggests that the associated elements were introduced along with uranium, rather than the uranium being deposited in an environment already rich in these elements. Sodium, however, is also more abundant in the Miller Hill area in spite of its inverse correlation with uranium. This seems somewhat paradoxical, but the explanation may lie in the fact that an unusually high content of this element was present in the environment of deposition for the Miller Hill limestone. Limestone in the Miller Hill area contains more vanadium than the average limestone, but vanadium is notably low compared to uranium, and its distribution is essentially random with respect to uranium. Considering the close association of uranium and vanadium in many uranium deposits, the poor correlation here is striking but probably indicates simply that the source for the uranium was deficient in vanadium.

ORIGIN OF URANIUM DEPOSITS

If it can be determined what geologic processes resulted in the concentration of uranium in the Miller Hill area, it may be possible to formulate guides to prospecting that may be useful in searching for new occurrences of uranium. Included among the hypotheses for the origin of uranium deposits that may be considered in the Miller Hill area are the following: hydrothermal deposition, concentration by living organisms, chemical concentration by evaporation of saline solutions, and concentration by leaching from a disseminated source and redeposition.

Hydrothermal deposition

No evidence for hydrothermal activity other than the presence of uranium in Tertiary rocks and a small prospect for copper in the Precambrian rocks was observed in the Miller Hill area. Igneous rocks of Tertiary age are present 20 miles to the south and consist of basaltic flows, plugs, and dikes on Battle Mountain and adjacent areas in the valley of the Little Snake River. Nevertheless, because hydrothermal solutions have been proposed as the origin of uranium in other districts far removed from any known source of hydrothermal or igneous activity, the fact that no source is evident need not eliminate consideration of the hypothesis. Generally, a hydrothermal deposit is recognized by its physical setting and the mineralogy of the deposit, but neither the age of the rocks, the distribution and shape of the occurrences, nor the relatively simple mineralogy of the uranium occurrences in the Miller Hill area provide unequivocal evidence in favor of ascending juvenile solutions. The top preferential distribution of the uranium in the limestone beds suggests opposition to this hypothesis but is not conclusive.

Concentration by living organisms

During a preliminary study of the uranium in the Miller Hill area, Love noted the association of uranium with algal limestone. This observation led to the suggestion (Love, 1953, p. 9) that the uranium in the limestone may have been concentrated by the living organisms, whose calcareous remains were then incorporated in the limestone bed. He suggested that the lake waters might become weakly uraniferous by the leaching of tuffaceous material that composes the bulk of the sedimentary deposit and from this water the organisms extracted the uranium. Two additional mechanisms were then proposed: (1) ground water deposition of silica and uranium to explain the association of uranium with chalcedony, and (2) fracture control for the deposition of chalcedony to explain the association of chalcedony with the uraniferous algal limestone, which is considered to be more brittle than the other strata. Presumably the association of microcrystalline uranophane with limestone would require further explanation.

Chemical concentration by evaporation of saline solutions

If the uraniferous limestone in the Miller Hill area were formed partly as a chemical precipitate then consideration might be given to the possibility that uranium was concentrated by evaporation of saline solutions. The evidence to show whether this was an important mechanism for the concentration of uranium in limestone is inconclusive. It is inadequate, of course, to explain the occurrence of uranium in sandstone and quartzite.

Concentration by leaching from a disseminated source and redeposition

An epigenetic theory of origin of uranium deposits by leaching and reconcentration from Tertiary tuffaceous rocks has been suggested to explain several widely separated occurrences in the Rocky Mountain region. Investigation of uranium-bearing lignites in the western Dakota area in 1950 by Denson, Bachman, and Zeller (in preparation) indicated the possibility of such a source for the uranium. Shortly thereafter, Love (1952) suggested a similar origin for the sandstone-type uranium deposits in the Pumpkin Buttes area, and similar hypotheses have been suggested for uranium-bearing sandstone deposits in the Slim Buttes area, Harding County, S. Dak. (Gill and Moore, 1955) in the White River Badlands of South Dakota (Moore and Levish, 1955) and in the Poison Basin area, Wyoming (Vine and Prichard, 1954). These last named areas all have certain features in common: (1) uranium occurs in or closely associated with tuffaceous rocks of Tertiary age; (2) the areas are in basins of thick sedimentary deposits, remote from igneous activity; (3) uranium occurs chiefly in the form of secondary minerals. These features are also common to the Miller Hill occurrences. It seems desirable, therefore, to consider carefully this hypothesis for the origin of uranium and determine if it is also applicable here.

Uranium is one of many metallic elements in addition to the common rock-forming elements present in at least trace amounts in magma. During the formation of plutonic igneous rocks it is generally thought that uranium is normally concentrated in the residual liquor, from which it is deposited in pegmatites or veins (Rankama and Sahama, 1950, p. 634-5). When magma is extruded explosively and deposited as ash falls, uranium does not have an opportunity to crystallize out and consequently is disseminated throughout the volcanic rock, particularly in the glassy portion. Weathering and devitrification of the glassy material to form rock minerals would probably release uranium and other trace elements that are not required to enter into the crystalline structure of the minerals formed. Waters and Granger (1953, p. 20-22) have discussed the sequence of events that would take place following the devitrification of volcanic tuff. Included in this sequence of events is the release of excess silica and the resulting silicification of adjacent rocks.

Though the analytical data indicate no linear correlation between uranium and silicon the field investigations show that at most places the dark-colored chert is somewhat uraniferous and that minutely disseminated chert or chalcedony is abundant in the vicinity of the higher grade uranium occurrences. A relation certainly exists between uranium and silica though it may not be a direct linear function. Partial replacement of brecciated limestone by silica indicates much of the silica is secondary. Stalactite-type deposits of chalcedony and opal in vugs indicate deposition of silica in air-filled spaces, presumably above the present water table

and probably continuing up to the present time. The deposition of travertine-like aggregates of calcite, opal, and uranophane on the undersides of limestone fragments as well as in vugs indicates simultaneous transportation and deposition of calcium carbonate, silica, and uranium even up to the present time.

This evidence suggests a local source for the uranium, probably from a sparsely disseminated form in the enclosing sediments. Limestone beds appear to have provided the environment where silica- and uranium-rich ground water precipitated part of its dissolved solids. This process is not unique to this area. Goldschmidt (1954, p. 360) states: "It is well known that the presence of dissolved carbonate of lime reduces the solubility of silica in water." The greater concentration of uranium at the top of the limestone probably indicates that the principal direction of movement of the ground water was downward from the overlying sediments, then laterally along the upper surface of the limestone. This process of redistribution of uranium formerly disseminated through a large volume of rock and concentration at a chemically favorable zone probably accounts for a concentration of uranium up to about 0.03 percent in limestone and chalcedony.

Concentrations of uranium over 0.03 percent are confined to the top part of the limestone beds in areas where the overlying sediments have only recently been stripped off the limestone. Where broad benches are formed on the stripped surface of limestone beds, uranium occurs chiefly in lenses and irregular masses of chert or chalcedony over most

of the broad expanse of limestone, but local deposits with visible uranophane are located along a narrow margin where limestone has only recently been exposed to weathering. Pits dug back from the margin where the limestone has a thin cover of other rocks yielded no visible uranium minerals. This suggests that uranophane is being deposited only where limestone has recently been exposed to weathering. The process by which travertine-like coatings of uranophane, calcite, and opal form directly below the exposed surface of limestone is probably by evaporation of capillary pore moisture, similar to the process by which caliche is formed. The fact that similar coatings are barren of uranium where found farther out on the limestone benches suggests that long exposure to the weather eventually causes the uranium to be leached, leaving only the calcite and opal.

Mobility of the uranium in the zone of weathering is further suggested by the disequilibrium of uranium and its daughter products, particularly in channel samples. The values for equivalent uranium are invariably higher than for uranium in the top foot of limestone, while the lower part of the limestone more nearly approaches equilibrium. It is also noteworthy that sodium is apparently depleted from the samples containing the most uranium. Evidently sodium is much more soluble even than the uranium and is leached from the same environment in which uranium is concentrated.

GUIDES TO PROSPECTING FOR URANIUM

If, as a working hypothesis, the foregoing suggestion is accepted -- that uranium in the Miller Hill area was concentrated by ground water solutions as a result of leaching from a disseminated source and redeposition -- then guides to prospecting may be devised that should have application in other districts as well. For this purpose the following conditions will be assumed: (1) Uranium in soluble form is available to ground water solutions passing through certain types of porous rock that contain volcanic detritus. (2) The original content of uranium in the porous volcanic rock, which may be called the source rock, need not exceed that normally found in many igneous and sedimentary rock units. However, certain characteristics make some tuffaceous sandstone units better source rocks than many other rock units with the same uranium content: (a) the availability of the uranium ion to migrating ground water solutions, (b) high porosity and permeability, and (c) the large volume of rock from which uranium may be leached. (3) Once in solution the uranium will be transported by ground water until a chemical or physical change in the ground water environment reduces the solubility of the uranium.

A consideration of these three conditions leads directly to the following suggestions to search for uranium deposits: (1) Uranium may be concentrated in or adjacent to thick permeable rock units that contain a large amount of volcanic detritus similar to that contained in the North Park(?) formation. (2) Uranium may be concentrated in or adjacent to those rock units or structural features that tend to concentrate the flow of ground water solutions. (3) Within these rock units uranium will tend to be concentrated only if the water in which it is being carried encounters a change in its physical or chemical environment that adversely affects the solubility of the uranium. Such a change might be encountered at the contact between sandstone and limestone or calcareous sandstone, as in the Miller Hill area, or at the contact between sandstone and coal. Thus, the three conditions, a suitable source rock, a mechanism for transportation, and a favorable host rock or structural feature are all essential to the formation of a uranium deposit and should be borne in mind in searching for new deposits of uranium.

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APPENDIX A

Analyses of rock samples 1/

Loc. no. or pit 2/	Field no. 3/	Lab. no.	Location (sec., T., and R.)	Sampled interval or type 4/	eU (percent)	U (percent)	Rock type 5/	Stratigraphic position 6/
A-1	203	D92356	34-17-88	36	0.007	0.007	ls	A
	204	D92357		36	.004	-	ls	A
A-2	77	D98773	35-17-88	G	.012	.013	br ss	A-20'
	78	D99823		G	.004	-	gr ct	A
A-3	41	D94717	36-17-88	G	.024	.018	ls w/ dk gr ch	A
	42	D94718		192	.007	.006	ls	A
A-5	12	D92375	25-17-88	CG	.007	.008	ls w/ ch	A
Pit 1	426	200099		12	.003	-	ss and soil	A
(NE side)	~~427~~	~~200100~~		12	.012	.009	ls w/ ch	A
	428	200101		12	.012	.012	ls w/ ch	A
	429	200102		18	.010	.012	ls w/ ch	A

1/ Analyses by H. E. Bivens, R. F. Dufour, E. J. Fennelly, S. P. Furman, J. McGurk, J. Meadows, W. Mountjoy, J. Patton, J. P. Schuch, J. L. Siverly, D. L. Stockwell, J. Wahlberg, and J. E. Wilson under supervision of L. F. Rader, Jr.

2/ See figs. 2B and 7B. Pits numbered 1 through 8 and trenches lettered A through L are located within the area of the next previously listed locality number.

3/ All field numbers have the prefix: VW3.

4/ Thickness of channel samples given in inches. Channel samples from pits listed in sequence from top to bottom. Samples other than channel samples are listed as follows: G-Grab; SG-select grab (selected for high grade); CG-composite grab (chips collected over an area of outcrop).

5/ Abbreviations used to describe rock types are as follows: ls - limestone; ss - sandstone; ct - chert; ch - chalcedony; qtz - quartzite; U - uranophane; v - vuggy; tlc - travertine-like coatings; jt - joints; gr - gray; br - brown; dk - dark; lt - light; sdy - sandy; ca - calcareous; w/ - with.

6/ Limestone beds shown on map listed here as A, B, C, A?, and B?. Distance above and below tops of these beds listed here as A+20', or B-50' (meaning 20 feet above bed A, or 50 feet below bed B).

Loc. no. or pit 2/	Field no. 3/	Lab. no.	Location (sec., T., and R.)	Sampled interval or type 4/	eU (percent)	U (percent)	Rock type 5/	Stratigraphic position 6/
A-5 (cont.)								
Pit 1								
(SW side)	430	200103	25-17-88	18	0.004	-	ss and soil	A
	431	200104		12	.014	0.012	ls w/ ch	A
	432	200105		12	.008	.003	ls w/ ch	A
	433	200106		12	.006	.004	ls w/ ch	A
Pit 2	423	200096	25-17-88	CG	.018	.029	ls w/ tlc	A
	422	200095		CG	.052	.042	v ls w/ U	A
(N side)	416	D99849	25-17-88	24	.036	.025	ls w/ ch	A
	417	D99850		24	.035	.035	ls w/ ch	A
	418	200091		36	.008	.008	ls w/ ch	A
(E side)	419	200092	25-17-88	24	.026	.020	ls w/ ch	A
	420	200093		24	.017	.014	ls w/ ch	A
	421	200094		36	.010	.010	ls w/ ch	A
Trench A	434	200107	25-17-88	14	.015	.011	ls w/ ch	A
	435	200108		CG	.13	.10	ls w/ U	A
Trench C	13	D92376		20	.088	.044	ls w/ ch	A
	21	D92384		SG	.090	.029	ls w/ ch	A
Trench D	424	200097		CG	.065	.053	ls w/ U on jt	A
Trench E	436	200109		10	.20	.11	ls w/ U	A
	72	D97423		CG	.39	.39	v ls w/ U	A
Trench F	425	200098		12	.042	.038	ls w/ tlc and U	A
Trench G	437	200110		6	.064	.060	ls	A
	438	200111		10	.042	.030	ls	A

Loc. no. or pit 2/	Field no. 3/	Lab. no.	Location (sec., T., and R.)	Sampled interval or type 4/	eU (percent)	U (percent)	Rock type 5/	Stratigraphic position 6/
1	31	D93543		CG	0.011	0.007	ls w/ ch	A
Trench H	32	D93544		SG	.37	.27	ls w/ ch	A
	71	D97423		SG	.39	.39	ls w/ ch and U	A
	451	200080		12	.089	.093	ls w/ ch	A
Trench I	452	200081		12	.51	.49	v ls w/ U	A
Trench J	453	200082	36-17-88	12	.022	.021	ls w/ ch	A
Trench K	454	200083		12	.055	.040	ls w/ ch	A
Trench L	455	200084		8	.032	.034	ls w/ ch	A
Pit 5	70	D97429		SG	.12	.035	ls w/ ch	A
	456	200085		12	.038	.019	ls w/ ch	A
	457	200086		12	.015	.009	ls w/ ch	A
	458	200087		30	.006	.009	ls w/ ch	A
1A	30	D93542		48	.012	.007	ls w/ ch ledge	A
Pit 6	442	200071		SG	.12	.11	ls w/ ch and U	A
	439	200068	36-17-88	12	.031	.020	ls w/ ch	A
	440	200069		12	.023	.010	ls w/ ch	A
	441	200070		30	.007	.008	ls w/ ch	A
2	6	D92369	25-17-88	72	.006	.006	ls	A
	7	D92370		G	.038	.026	dk gr ch	A
4	48	D94724	25-17-88	SG	.039	.023	dk gr ch	A
5	61	D97424	36-17-88	36	.011	.008	ca br ss	A + 100'
6	65	D97418	36-17-88	SG	.32	.24	ls w/ U	A

Loc. no. or pit 2/	Field no. 3/	Lab. no.	Location (sec., T., and R.)	Sampled interval or type 4/	eU (percent)	U (percent)	Rock type 5/	Stratigraphic position 6/
Pit 7	459	200088	36-17-88	12	0.008	0.006	ls w/ ch	A
	460	200089		12	.006	.004	ls w/ ch	A
	461	200090		12	.005	.005	ls w/ ch	A
7	68	D97421	35-17-88	SG	.17	.12	ls w/ U on jt	A
Pit 4	446	200075		SG	.10	.080	ls w/ U	A
	443	200072		12	.079	.035	ls w/ ch	A
	444	200073		12	.022	.010	ls w/ ch	A
	445	200074		30	.012	.007	ls w/ ch	A
8	34	D93546	35-17-88	CG	.008	.008	ls w/ ch	A
9	35	D93547	35-17-88	CG	.007	.009	ls	A
	36	D93548		G	.084	.080	ls w/ ch	A
	73	D98774		SG	.16	.15	ls w/ ch	A
10	74	D98775	26-17-88	G	.012	.010	ls	A
11	8	D92371	25-17-88	72	.001	-	ls	A
	9	D92372		SG	.035	.024	dk gr ch	A
	10	D92373		48	.003	.004	ls	A
	11	D92374		60	.003	.002	ls	A
	75	D98771		G	.016	.002	ch w/ ls	A
Pit 3	410	D99843		5.5	.005	.005	ls	A
(N. side)	411	D99844		34	.002	-	ss	A
	412	D99845		12	.009	.008	ls w/ ch	A
	413	D99846		24	.005	.005	ls w/ ch	A
(S. side)	414	D99847	25-17-88	12	.004	-	ls	A
	415	D99848		16	.004	-	ls	A

Loc. no. or pit 2/	Field no. 3/	Lab. no.	Location (sec., T., and R.)	Sampled interval or type 4/	eU (percent)	U (percent)	Rock type 5/	Stratigraphic position 6/
12	24	D92365	25-17-88	CG	0.014	0.009	ls w/ ch	A
	25	D92366		SG	.030	.018	dk gr ch	A
	63	D97426		SG	.034	.017	dk gr ch	A
	64	D97427		G	.003	.004	lt gr ls	A
14	49	D94725	30-17-87	CG	.003	-	ls w/ ch	A
15	62	D97425	30-17-87	G	.009	.006	ls w/ ch and tlc	A
16	43	D94719	36-17-88	SG	.036	.40	br ch w/ ls and U	A
	66	D97419		SG	.25	.22	ls w/ br ch and U	A
Pit 8	447	200076		12	.050	.035	ls w/ ch	A
	448	200077		12	.022	.014	ls w/ ch	A
	449	200078		40	.008	.006	ls w/ ch	A
	450	200079		12	.004	-	ca ss	A
17	69	D97428	35-17-88	SG	.11	.065	dk gr ch	A
18	67	D97420	36-17-88	SG	.041	.028	ls w/ ch and U ?	A
19	76	D98772	36-17-88	SG	.042	.015	ls w/ ch	A
21	46	D94722	25-17-88	SG	.039	.027	gr ch	A
22	308	D97436	30-17-87	96	.003	.003	ls w/ ch	A
	311	D97439		72	.016	.008	ls w/ ch	A
	312	D97440		84	.005	.006	ls w/ ch	A
	313	D97441		60	.010	.005	sdy ls	A + 30'
	314	D97442		60	.030	.027	sdy ls	A + 40'

Loc. no. or pit 2/	Field no. 3/	Lab. no.	Location (sec., T., and R.)	Sampled interval or type 4/	eU (percent)	U (percent)	Rock type 5/	Stratigraphic position 6/
23	309	D97437	30 and 31-17-87	G	0.018	0.009	ls w/ ch	B
	310	D97438		G	.019	.009	ls w/ ch	B
	315	D97443		CG	.008	.007	ca ss	B + 15'
	316	D97444		CG	.014	.013	sdy ls	B - 55'
24	87	D99829	30-17-87	G	.017	.018	ls w/ ch	B
	88	D99830		G	.022	.018	sdy ls	B + 15'
	306	D97434		CG	.020	.009	ch w/ ls	B
25	305	D97443	30-17-87	CG	.004	.004	ls	A
	303	D97431		G	.021	.012	ch	A + 55'
	304	D97432		CG	.003	.003	ca ss	A
26	317	D97445	36-17-88	CG	.013	.008	ch	B
27	52	D96772	15-17-87	CG	.012	.013	ls	A
30	84	D99826	31-17-87	CG	.013	.012	ls w/ ch	B ?
31	86	D99828	22-17-87	G	.013	.011	ls w/ ch	B ?
	235	D96785		G	.016	.013	sdy ls	B ?
32	237	D96787	22-17-87	G	.009	.007	ca ss	B ?
33	242	D96790	27-17-87	G	.013	.009	ls w/ ch	B - 50'
35	244	D96792	28-17-87	G	.014	.001	ch	B

Loc. no. or pit 2/	Field no. 3/	Lab. no.	Location (sec., T., and R.)	Sampled interval or type 4/	eU (percent)	U (percent)	Rock type 5/	Stratigraphic position 6/
36	240	D96788	28-17-87	G	0.011	0.009	ch	B
	241	D96789		G	0.012	.010	ch	B
	242	D96790		G	.013	.009	ct w/ ls	B
36A	243	D96791	29-17-87	G	.015	.013	ct	B
37	83	D99825	31-17-87	G	.010	.009	gr ch	B
	236	D96786		G	.017	.016	gr ch	B
38	301	D97430	1-16-86	CG	.006	.004	ch	?
39	202	D92355	34-17-88	36	.006	.005	ls	A
	79	D99824		G	.008	.007	ls	A
41	126	D94727	30-16-88	SG	.019	.012	br ch	C
42	2	D92368	31-17-88	G	.006	.004	br ch	?
43	218	D93565	10-16-88	G	.007	.007	ls w/ ct	A ?
	219	D93566		G	.007	.007	sdy ls	A ? - 10'
44	404	D99842	16-17-88	G	.009	.005	qtz	A - 300'
45	402	D99840	33-17-88	12	.018	.019	sdy ls	A - 100'
46	403	D99841	33-17-88	12	.017	.013	sdy ls	A - 100'
47	85	D99827	32-17-87	G	.015	.011	ca ss	B

Loc. no. or pit 2/	Field no. 3/	Lab. no.	Location (sec., T. and R.)	Sampled interval or type 4/	eU (percent)	U (percent)	Rock type 5/	Stratigraphic position 6/
51	1	D92367	16-17-88	12	<0.001	-	ls	A
55	15	D92378	25-17-88	60	.006	0.006	ls w/ ct	A
56	16	D92379	25-17-88	60	.005	.004	ls w/ ct	A
57	17	D92380	25-17-88	G	.015	.013	ch	A
58	18	D92381	30-17-87	60	.004	.002	ls w/ ch	A
59	19	D92382	30-17-88	12	.002	-	ls w/ ct	A
60	20	D92383	30-17-87	60	.004	.002	ls w/ ct	A
63	23	D92364	25-17-88	60	.005	.004	ls w/ ct	A
66	26	D98781	25-17-88	G	.019	.024	ls w/ ct	A
67	27	D93539	25-17-88	24	.001	-	ls	A
68	28	D93540	25-17-88	96	.008	.004	ls w/ ct	A
69	29	D93541	36-17-88	60	.005	.004	ls	A
73	33	D93545	35-17-88	72	.007	.007	ls	A
77	37	D93549	26-17-88	CG	.012	.010	ls	A

Loc. no. or pit 2/	Field no. 3/	Lab. no.	Location (sec., T., and R.)	Sampled interval or type 4/	eU (percent)	U (percent)	Rock type 5/	Stratigraphic position 6/
78	38	D93550	26-17-88	72	0.007	0.007	ls	A
79	39	D93551	36-17-88	120	.002	-	ls	A
80	40	D94716	36-17-88	72	.005	.005	sdy ls w/ ch	A
84	44	D94720	36-17-88	48	.006	.006	ls w/ ct	A
85	45	D94721	30-17-87	72	.005	.005	ls	A
100	100	D92350	16-17-88	CG	.001	-	ls	A
102	102	D92351	17-17-88	84	.001	-	ls	A
105	105	D92353	30-17-88	G	.001	-	ls	A ?
106	106	D93552	33-17-88	G	.002	-	ls	A + 50'
107	107	D92354	8-16-88	24	.001	-	ls	A ?
113	113	D93553	7-16-88	48	.002	-	ls	A ? + 50'
115	115	D93554	7-16-88	24	.003	-	ls	A ?
117	117	D93555	7-16-88	G	.001	-	ls	A ?
119	119	D93556	19-16-88	G	.004	-	ls w/ ct	A ?
120	120	D93557	19-16-88	G	.004	-	ls	A ? - 30'

Loc. no. or pit 2/	Field no. 3/	Lab. no.	Location (sec., T., and R.)	Sampled interval or type 4/	eU (percent)	U (percent)	Rock type 5/	Stratigraphic position 6/
121	121	D93558	19-16-88	60	0.002	-	ls	A ?
122	122	D93559	24-16-89	96	.002	-	ca ss	A + or - ?
123	123	D93560	7-16-88	96	.002	-	sdy ls	A ?
127	127	D94728	25-16-89	G	.004	-	ls w/ ct	B ?
129	129	D94729	36-16-89	SG	.004	-	ls w/ ct	B ?
131	131	D96777	15-16-89	G	.003	0.001	ca tuff	B + or - ?
201	201	D92352	16-17-88	SG	.003	-	ls	A
205	205	D92358	34-17-88	G	<.001	-	ls	A
206	206	D92359	34-17-88	G	.004	-	ls	A
207	207	D92360	34-17-88	G	<.001	-	ls	A
208	208	D92361	34-17-88	G	.007	.005	ls	A
209	209	D92362	33-17-88	144	.002	-	sdy ls	A
211	211	D92363	3-16-88	G	.003	-	ls	A
212	212	D93561	8-16-88	120	.001	-	sdy ls	A ?

Loc. no. or pit 2/	Field no. 3/	Lab. no.	Location (sec., T., and R.)	Sampled interval or type 4/	eU (percent)	U (percent)	Rock type 5/	Stratigraphic position 6/
213	213	D93562	8-16-88	120	0.002	-	sdy ls	A ?
214	214	D93563	8-16-88	120	.002	-	sdy ls	A ?
215	215	D93564	3-16-88	96	.001	-	ls	A
220	220	D94730	15-16-88	G	.003	-	ls w/ ct	A ?
222	222	D94731	22-16-88	G	.008	0.006	ls w/ ct	A ?
223	223	D94723	22-16-88	72	.002	-	ls	A ?

APPENDIX B

Analyses of water samples 1/

Field no. 2/	Lab. no.	Location (sec., T., and R.)	Sample type	U (ppb)	Stratigraphic position 3/
4	D92386	25-17-88	pond	12	Tnpc
5	D92387	25-17-88	pond	10	Tnpc
22	D92388	3-16-88	spring	10	Tnpl
60	D96800	12-18-89	pond	1	Tnpc
104	D92389	18-17-88	spring	6	Tnpl
108	D92390	8-16-88	spring	5	Tnpl
109	D92391	7-16-88	spring	5	Tnpl
110	D92392	8-16-88	spring	8	Tnpl
111	D93530	6-16-88	spring	6	Tnpl
112	D93531	8-16-88	spring	5	Tnpl
114	D93532	12-16-89	spring	9	Tnpl
116	D93533	18-16-88	spring	6	Tnpl
118	D93536	19-16-88	spring	7	Tnpl

1/ Chemical analyses by W. Mountjoy and J. P. Schuch.
2/ All field numbers have the prefix VW3.
3/ The following abbreviations are used to indicate stratigraphic position:

Tnpc - basal conglomerate North Park(?) formation.
Tnpl - lower North Park(?) formation (between basal conglomerate and limestone bed A).
Tnpm - middle North Park(?) formation (between limestone beds A and B).
Jn - Nugget sandstone.

Analyses of water samples.--Continued

Field no. 2/	Lab. no.	Location (sec., T., and R.)	Sample type	U (ppb)	Stratigraphic position 3/
124	D93537	8-17-88	spring	8	Tnpc
125	D93538	32-18-88	spring	3	Tnpc
128	D94710	25-16-89	spring	14	Tnpl
130	D94711	31-16-88	spring	8	Tnpl
132	D96796	32-18-88	pond	2	Tnpc
200	D92393	27-17-88	spring	4	Jn
210	D92394	33-17-88	spring	13	Tnpl
216	D93534	15-16-88	spring	4	Tnpl
217	D93535	15-16-88	spring	6	Tnpl
221	D94712	15-16-88	spring	5	Tnpl
224	D94713	22-16-88	spring	3	Tnpl
225	D94714	22-16-88	spring	2	Tnpl
226	D94715	29-16-88	spring	4	Tnpl
238	D96798	28-17-87	spring	5	Tnpl
239	D96799	27-17-87	spring	7	Tnpc
307	D97435	7-16-87	spring	6	Tnpm
318	D98779	5-16-87	spring	5	Tnpl

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