Geology and Mineralogy

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

# GEOLOGIC INVESTIGATIONS OF RADIOACTIVE DEPOSITS

## SEMIANNUAL PROGRESS REPORT

December 1, 1956 to May 31, 1957

July 1957

Trace Elements Investigations Report 690*

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

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# FOREWORD

This report is a statement of progress during the six-months' period from December 1, 1956 to May 31, 1957 on investigations of radioactive materials in the United States and Alaska, undertaken by the U. S. Geological Survey on behalf of the Division of Raw Materials and the Division of Research of the Atomic Energy Commission. The program sponsored by the Division of Raw Materials, which includes geologic mapping, geologic topical studies, geophysical investigations, geochemical investigations, mineralogical investigations, and laboratory services and research on techniques in the fields of radioactivity, spectrography, and chemistry is reported on pages 25 to 531. The program sponsored by the Division of Research, which comprises fundamental studies relating to the geology of uranium and thorium, is reported on pages 532 to 571.

# INTRODUCTION

The broad objective of the Geological Survey's program on behalf of the Atomic Energy Commission is the investigation of the fundamental geology, mineralogy, and geochemistry of uranium and other radioactive materials, for the purpose of discovering and delimiting areas favorable for the future production of uranium and other radioactive ores. During the first phase of the program, which began in 1947, emphasis was placed on the immediate discovery of minable uranium deposits. In 1954 and 1955, however, the rapid increase in the Nation's production of uranium made possible a reorientation of the program toward long-range, fundamental studies of the geologic processes that govern the emplacement of uranium deposits. These long-range studies involve systematic geologic mapping and research, supported by appropriate geophysical and geochemical studies, required to develop information on the size, shape, and mineralogy of our potential reserves and resources of radioactive materials. The Survey's present program, therefore, is designed with a view not so much toward the immediate needs of the United

States as toward the unknown but certainly large requirements of the foreseeable future.

A second and equally important objective of the Survey's program in uranium geology is the dissemination of information by the publication, as expeditiously as possible, of the results of its investigations. These results are published as Geological Survey Professional Papers, Bulletins or Bulletin chapters, or maps, or as papers in scientific journals. During the six months covered by this report, publications stemming from the program include 12 Bulletins or Bulletin chapters, 47 maps, and 21 papers and 37 abstracts in scientific journals. During the same period one report was placed on open file and one report was sent to the Technical Information Service Extension of the Atomic Energy Commission for reissue and distribution to the public. In addition, geologists working on the uranium program presented 18 papers at scientific meetings.

Since June 1954--approximately the date when reorientation of the program began, and when easing of security restrictions made possible the publication of much data that previously had been classified--three Professional Papers, 56 Bulletins or Bulletin chapters, 53 Circulars, and 305 maps have been published by the Survey, and 129 papers by scientists working on the program have been published in scientific journals. During the same period 85 reports have been placed on open file and 22 reports have been sent to the Technical Information Service Extension for reissue and distribution.

The Semiannual Reports, "Geologic Investigations of Radioactive Deposits," of which this volume is one, were prepared originally as administrative reports for use within the Geological Survey and the Atomic Energy Commission; but beginning with TEI-330, issued in June 1953, each has been reissued and made available to the public by the Technical Information Service Extension. These Semiannual Reports have as a rule been confined to the accomplishments of the six-months' period which they cover, only enough of the work of preceding periods being given to provide a proper perspective. So far as continuing projects are concerned, this practice is adhered to in the present volume. However, field and laboratory work on a considerable number of projects has been completed within the past six months, and final reports for Survey publication have been or are being prepared. Of necessity considerable time will elapse before all of these reports can be published. In order to make available at this time the more important results of these investigations, reports in this volume that describe completed projects are essentially expanded abstracts of the final report for Survey publication, and contain as much of the pertinent illustrative and tabular matter as the restrictions inherent in preparing a report of this nature permit. Reports of this type are included for the following mapping projects:

### Colorado Plateau region

Bull Canyon area
Sage Plain area
San Rafael Swell
East Vermilion Cliffs
Slick Rock area
La Sal Creek area
Elk Ridge

### Black Hills

Edgemont NE quadrangle
Cascade Springs quadrangle
Flint Hill quadrangle
Carlile quadrangle
Burdock quadrangle
Dewey quadrangle
Jewel Cave quadrangle

### Other areas

Southern Powder River Basin, Wyoming
Cave Hills, Harding County, South Dakota
Maybell-Lay area, Moffat County, Colorado
Hiland-Clarkson Hill area, Wyoming
Jarbridge quadrangle, Nevada
Thomas Range, Utah
Front Range, Colorado
Phosphate deposits and their "leached zones" in northern Florida

Other reports in this volume that describe completed projects are those on the Permian beds of Texas (p. 425-427); Pennsylvanian sediments of the Mid-continent region (p. 427-428); Radon and helium studies (p. 535-536); and Uranium in natural waters (p. 536-541).

Inclusion of the comparatively long reports on completed projects has necessitated a considerable increase in the size of this Semiannual Report as compared with other volumes of the series. It is felt, however, that the increase is more than justified by the advantages to be gained by making information on the areas available to the public at this time.

## GEOLOGIC MAPPING

### Colorado Plateau region

Geologic mapping as part of the uranium investigations on the Colorado Plateau was started in southwestern Colorado early in 1947. Since that time the original program has been extended and prior to this report period field work had been completed in the following areas: Southwestern Colorado; Monument Valley, Arizona; Monument Valley, Utah; Carrizo Mountains, New Mexico; Capitol Reef, Utah; White Canyon, Utah; Clay Hills, Utah; and Deer Flat, Utah.

During the report period field and office work continued in the following areas: Bull Canyon district, Slick Rock district, Uravan district, Western San Juan Mountains, Ute Mountains, Colorado; Sage Plain, La Sal Creek, Lisbon Valley, Utah and Colorado; Moab-Inter-river, Orange Cliffs, San Rafael Swell, Circle Cliffs, Elk Ridge, Abajo Mountains, Utah; East Vermilion Cliffs, Arizona; Grants, and Laguna, New Mexico.

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

Finnell, T. L., 1957, Structural control of uranium ore at the Monument No. 2 mine, Apache County, Arizona: Econ. Geol., v. 52, no. 1, p. 25-35.

Smith, J. F., Jr., Huff, L. C., Hinrichs, E. N., and Luedke, R. G., 1957, Preliminary geologic map of the Loa 1 NE quadrangle, Utah: U. S. Geol. Survey MF-100.

_______, 1957, Preliminary geologic map of the Loa 1 SE quadrangle, Utah: U. S. Geol. Survey MF-101.

Smith, J. F., Jr., Huff, L. C., Hinrichs, E. N., and Luedke, R. G., 1957, Preliminary geologic map of the Loa 4 NE quadrangle, Utah: U. S. Geol. Survey MF-102.

_______, 1957, Preliminary geologic map of the Notom 1 SW quadrangle, Utah: U. S. Geol. Survey MF-103.

_______, 1957, Preliminary geologic map of the Notom 2 NE quadrangle, Utah: U. S. Geol. Survey MF-104.

_______, 1957, Preliminary geologic map of the Notom 2 NW quadrangle, Utah: U. S. Geol. Survey MF-105.

_______, 1957, Preliminary geologic map of the Notom 2 SW quadrangle, Utah: U. S. Geol. Survey MF-106.

_______, 1957, Preliminary geologic map of the Notom 2 SE quadrangle, Utah: U. S. Geol. Survey MF-107.

_______, 1957, Preliminary geologic map of the Notom 3 NE quadrangle, Utah: U. S. Geol. Survey MF-108.

_______, 1957, Preliminary geologic map of the Notom 3 NW quadrangle, Utah: U. S. Geol. Survey MF-109.

_______, 1957, Preliminary geologic map of the Notom 3 SW quadrangle, Utah: U. S. Geol. Survey MF-110.

_______, 1957, Preliminary geologic map of the Notom 3 SE quadrangle, Utah: U. S. Geol. Survey MF-111.

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_______, 1957, Preliminary geologic map of the Notom 4 NW quadrangle, Utah: U. S. Geol. Survey MF-113.

_______, 1957, Preliminary geologic map of the Notom 4 SW quadrangle, Utah: U. S. Geol. Survey MF-114.

_______, 1957, Preliminary geologic map of the Notom 4 SE quadrangle, Utah: U. S. Geol. Survey MF-115.

Witkind, I. J., and others, 1957, Preliminary geologic map of the Dinnehotso NE quadrangle, Arizona-Utah: U. S. Geol. Survey MF-93.

Witkind, I. J., and others, 1957, Preliminary geologic map of the Dinnehotso SE quadrangle, Arizona: U. S. Geol. Survey MF-94.

_______, 1957, Preliminary geologic map of the Dinnehotso NW quadrangle, Arizona-Utah: U. S. Geol. Survey MF-92.

_______, 1957, Preliminary geologic map of the Dinnehotso SW quadrangle, Arizona: U. S. Geol. Survey MF-95.

_______, 1957, Preliminary geologic map of the Boot Mesa NW quadrangle, Arizona-Utah: U. S. Geol. Survey MF-84.

_______, 1957, Preliminary geologic map of the Boot Mesa NE quadrangle, Arizona-Utah: U. S. Geol. Survey MF-85.

_______, 1957, Preliminary geologic map of the Boot Mesa SE quadrangle, Arizona: U. S. Geol. Survey MF-86.

_______, 1957, Preliminary geologic map of the Boot Mesa SW quadrangle, Arizona: U. S. Geol. Survey MF-87.

_______, 1957, Preliminary geologic map of the Agathla Peak NW quadrangle, Arizona-Utah: U. S. Geol. Survey MF-88.

_______, 1957, Preliminary geologic map of the Agathla Peak NE quadrangle, Arizona-Utah: U. S. Geol. Survey MF-89.

_______, 1957, Preliminary geologic map of the Agathla Peak SE quadrangle, Arizona: U. S. Geol. Survey MF-90.

_______, 1957, Preliminary geologic map of the Agathla Peak SW quadrangle, Arizona: U. S. Geol. Survey MF-91.

## Bull Canyon district, Colorado

by

C. H. Roach and R. M. Wallace

The Geological Survey has conducted geologic studies in the Bull Canyon district since 1953. The objective of the studies was to obtain data concerning the features responsible for localizing the uranium-vanadium ore deposits in the district and, by means of these guides to ore, to delineate areas favorable for the discovery of concealed ore

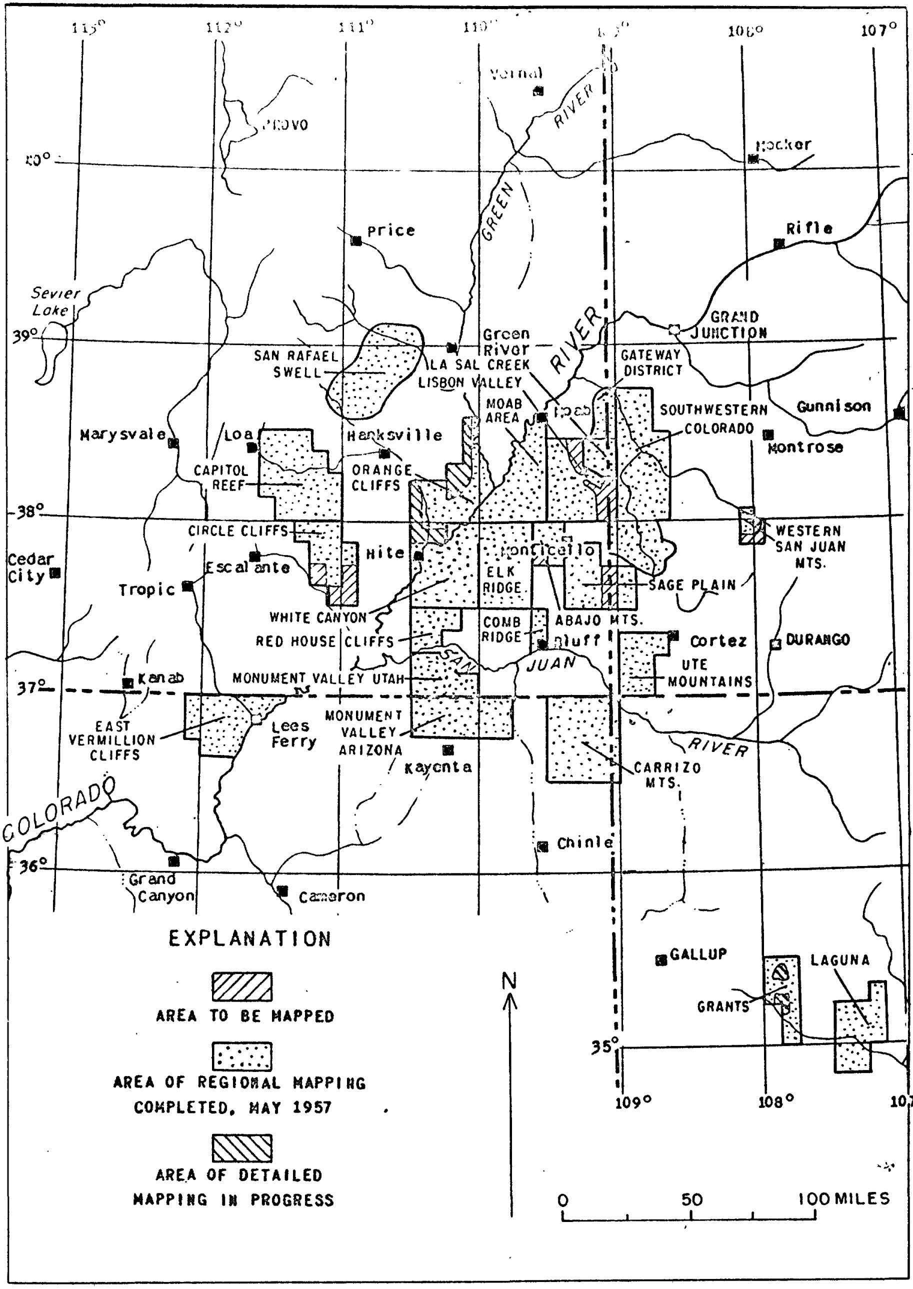

FIG. 1.--INDEX MAP OF PART OF THE COLORADO PLATEAU SHOWING LOCATION OF MAPPING PROJECTS.

deposits. The district was divided into two separate project areas, designated the Jo Dandy area and the Monogram Mesa-Bull Canyon area (fig. 2).

Mine studies

In the Monogram Mesa-Bull Canyon area, detailed mine-mapping studies have been completed in three mines that represent the variation in habits and mineralogy typical of the uranium-vanadium deposits in the Bull Canyon area. The accumulated data indicate that most ore deposits in the district are associated with one or more of the following physical characteristics of the host rock:

1) A sandstone-mudstone facies.
2) Areas where the host-rock unit changes greatly in thickness.
3) Pinchout of the host rock.
4) Host-rock units occurring on the flanks of paleostream channels.
5) Mudstone "lenses" or layers in the host-rock unit.
6) Mudstone-pebble conglomerates or "trash pockets".
7) Sandstone with lenticular bedding.
8) Constriction structures formed by the convergence of two diastems.

These physical features have one common characteristic: all represent parts of the host rock where there is a great reduction in the volume of sandstone within the host-rock unit. Figure 3a shows an ore body that has been localized adjacent to a constriction formed by the convergence of two prominent bedding planes. The side of the deposit adjacent to the constriction is normally characterized by better-than-average grade ore and the contact between mineralized and barren rock is commonly very sharp. The opposite side of the deposit is commonly characterized by an assay wall and the mineralized rock grades imperceptively into barren rock. In this example, the host-rock unit, which

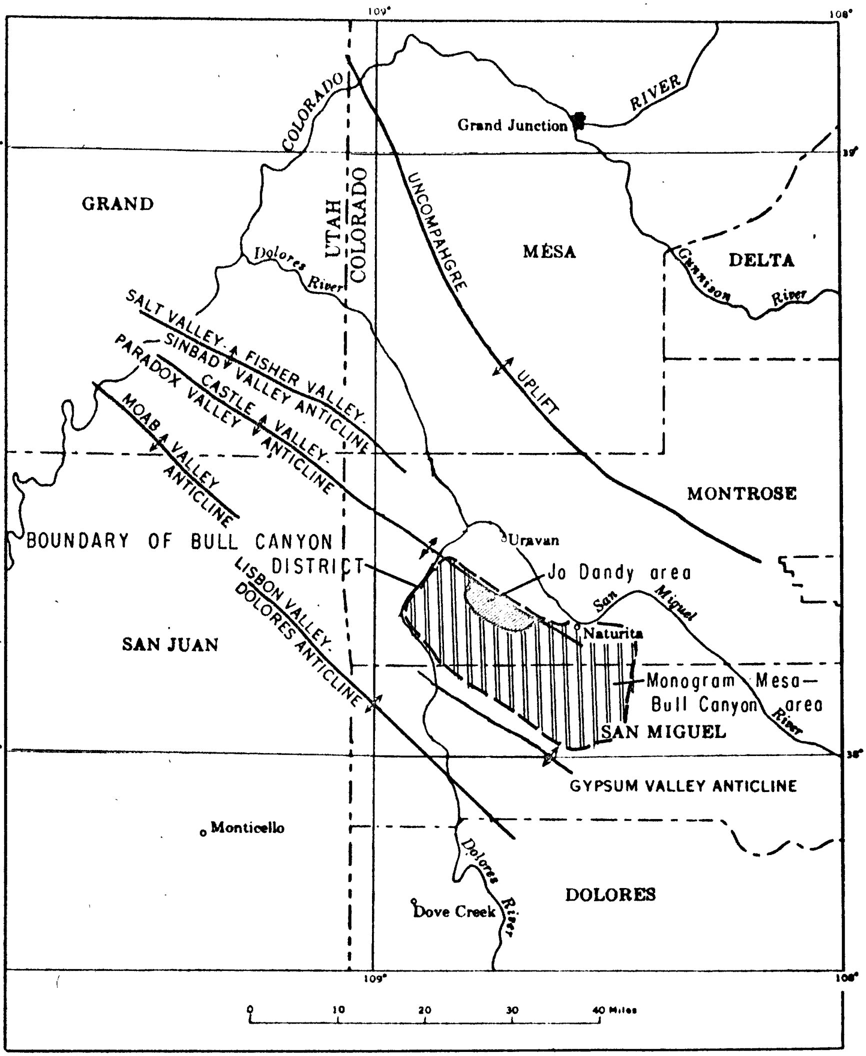

FIG. 2.--INDEX MAP SHOWING LOCATION OF BULL CANYON DISTRICT, MONTROSE AND SAN MIGUEL COUNTIES, COLORADO.

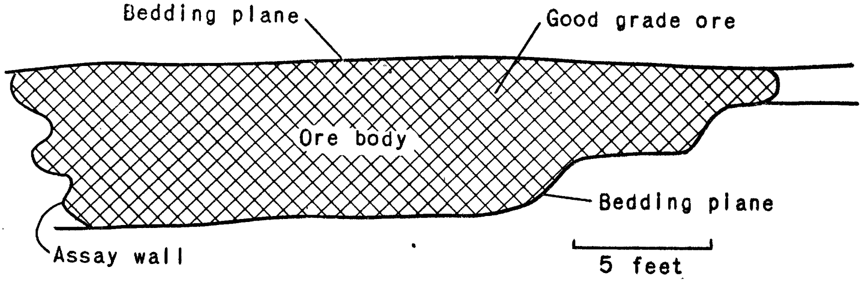

Fig.3a.--Ore body localized by a natural constriction

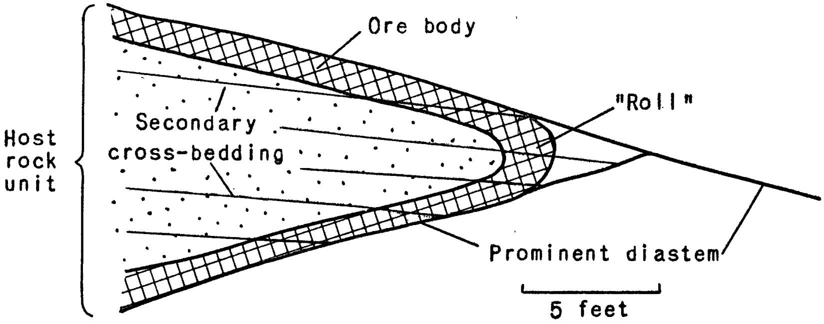

Fig.3b.--"Roll" localized near intersection of two prominent diastems

is considered to be the volume of sandstone between the two prominent bedding planes, thins abruptly at the constriction.

Mine studies have revealed that many so-called roll ore bodies are localized adjacent to the constrictions where one prominent diastem intersects another. Figure 3b shows a roll ore body localized near a constriction of this type. The layer of ore cuts sharply across the bedding of the sandstone between the two prominent diastems, but nowhere does it traverse the two more prominent surfaces. In some mines, the spatial relations between rolls and constriction structures of this type are so consistent in their relative orientation that it may be possible to infer the general direction of movement of the mineralizing fluid.

Figure 4 shows an ore body localized in mudstone-pebble conglomerate adjacent to a type of sandstone that is commonly a host to ore, but in this locality is barren. These mudstone-pebble conglomerates are commonly characterized by abundant carbonized plant remains and contorted bedding, and therefore have come to be known as "trash pockets". Commonly the mudstone pebbles are highly mineralized with vanadium minerals. This type of host rock is characterized by great lithologic changes. The mudstone-pebble conglomerate represents a great reduction in volume of sandstone relative to the adjacent sandstone units.

Figure 5 shows a generalized cross section of two ore bodies localized on the flanks of a paleostream channel. Here, the host-rock unit is defined as the unit of sandstone bounded at the bottom by the mudstone-sandstone contact at the base of the channel, and at the top by

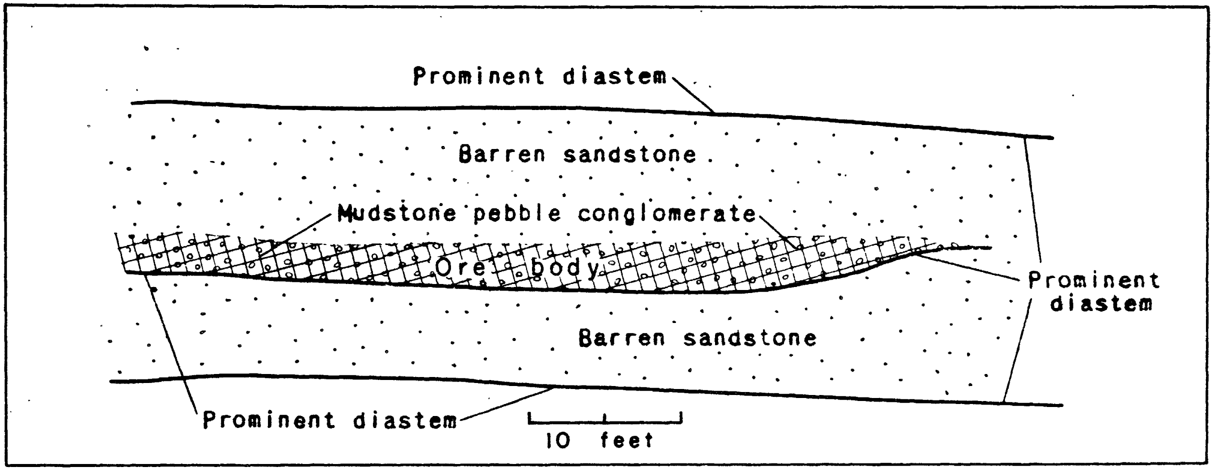

Fig.4.--Ore body localized in a mudstone pebble conglomerate

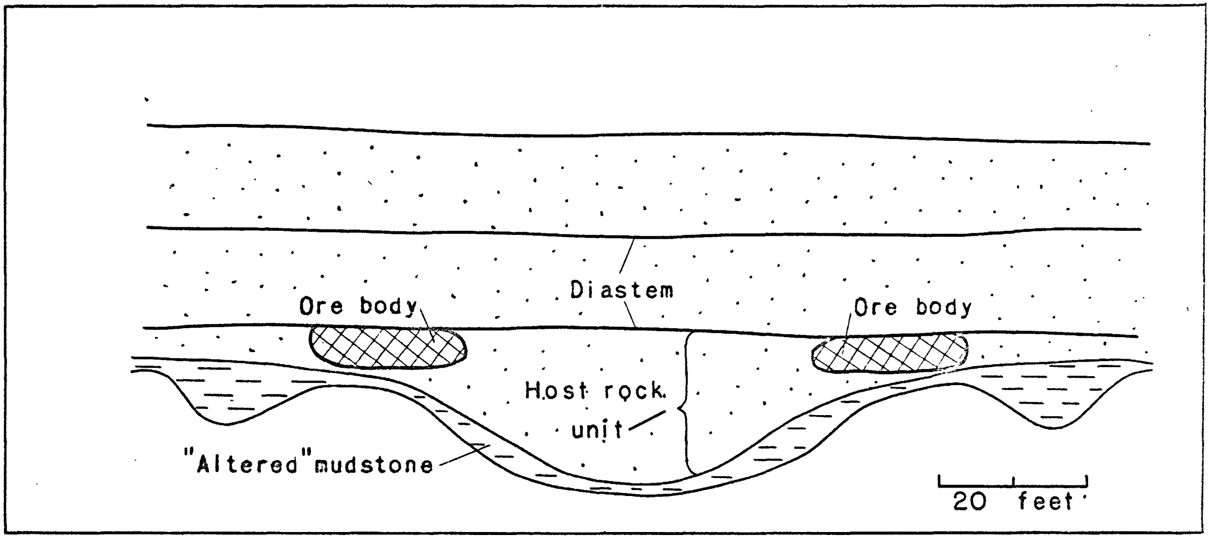

Fig.5.--Morrison paleostream channel showing relations between thickness of "altered" mudstone at base of host rock and position of ore bodies

the first prominent diastem above the base of the channel. The ore bodies occur on the flanks of the paleostream channel where the host-rock unit is greatly thinned.

Geologists familiar with uranium ore deposits in the Morrison formation are well aware of the importance of gray-green mudstone "alteration" at the base of the host rock as a guide to ore. Weir (1952) has shown that the thickest "altered" mudstone commonly occurs near the ore deposits and that the thickness decreases laterally from the deposit. In the vicinity of ore deposits in the Bull Canyon district, it is common to find similar although slightly different spatial relations between these features. The paleostream channel shown on figure 5 has been extensively drilled on 50-foot centers and a great amount of data on the distribution of green "altered" mudstone at the base of the host rock is available. The areas of thickest "altered" mudstone do not coincide in detail with the position of the ore bodies but have a slight lateral displacement away from the ore bodies and are more distant from the channel axis. Some of the drill holes which penetrated thick ore-grade material found no green mudstone at the base of the host rock. All drill holes penetrating more than four feet of "altered" mudstone are located beyond the limits of the ore bodies. Detailed observations in mines and on outcrops indicate that lateral displacement between areas of maximum mudstone "alteration" and the position of the adjacent ore body may be more common than previously noticed.

## Hypothesis of ore deposition

It has been mentioned above that the uranium ore deposits in the Bull Canyon district occur in places where there is a great reduction in the volume of sandstone within the host-rock unit. Such physical changes should modify appreciably the hydraulic characteristics of an ore fluid moving through the host rock, and the following hypothesis is offered in an attempt to show how the physical features might have influenced deposition of ore metals. Figure 6 shows a uranium ore body that has been localized near a constriction of the host-rock unit formed by the convergence of two prominent bedding planes. Permeability measurements of sandstone adjacent to the bedding planes indicate that the permeability is much less in a direction normal to the bedding planes than parallel to them. These relations suggest that prominent bedding planes would serve to channelize the movement of any fluid through the host rock. If it is assumed that an ore fluid was moving under steady flow conditions, the velocity vectors on figure 6 show qualitatively the increase in velocity of the ore fluid that must occur as it approaches the constriction. Bernoulli's principle states, in part, that under such conditions "pressure on the moving solution varies inversely as the square of the velocity". The graph of the hydraulic grade line at the top of the figure shows that the pressure on the moving ore fluid would be the least where the velocity is the greatest; that is, at the constriction. As all of the other physical features previously discussed can be analyzed similarly, it appears that most ore deposits in the Bull Canyon district may have been localized in areas where a decrease in pressure on the ore fluid occurred.

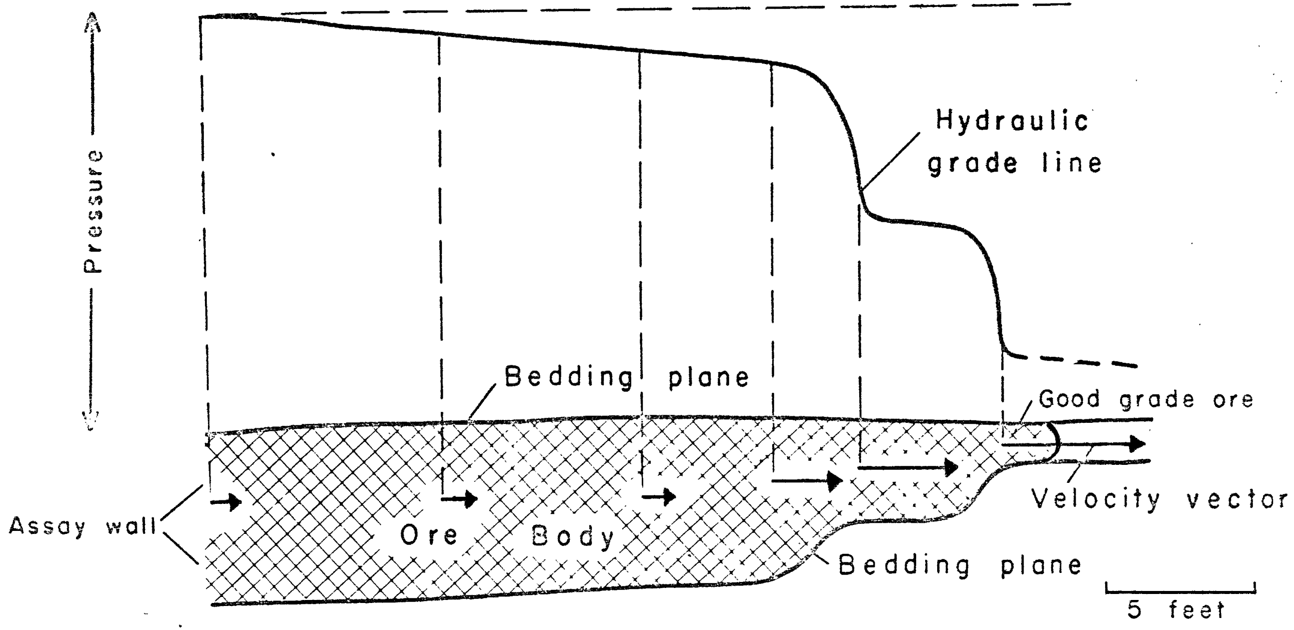

Fig. 6.--Ore body localized by a natural constriction

A decrease of pressure might cause deposition of ore metals from an ore fluid. Le Chatlier's principle states, in part, "a solution in equilibrium undergoes that change, following pressure decrease, which is accompanied by an increase in volume." Since the volume of most solutions is less than the sum of the solute and solvent, a decrease in pressure might be expected to cause precipitation of the solute. In most systems, the increase of volume as a result of a decrease in pressure probably would be small; however, in systems in which one or more of the components are volatile, the change in volume created by a decrease of pressure may be very great. Garrels (written communication, 1957), Pommer (written communication, 1957), Gruner, 1956, p. 498), and others, have pointed out the ease with which carbonate or bicarbonate solutions can transport uranium and vanadium in solution. If such a solution should move into an area where the decrease in pressure is less than that needed to keep $CO_2$ in solution, "boiling off" of volatile $CO_2$ would occur. This loss of $CO_2$ could be accompanied by large changes in the pH of the fluid remainder and by a drop in temperature. The exsolution of $CO_2$ from such an ore fluid might cause deposition of the ore metals by loss of solvent capacity; and as Garrels and Richter (1955, p. 456) have suggested, "the 'bleached' shales that so often underlie or overlie ore bodies might be the result of slow solution of $CO_2$ in the pore waters of the rock, with concomitant removal of hematite cement and solution and recrystallization of calcite". If these changes occur under dynamic conditions, as here proposed, this mechanism could easily explain the common lateral displacement between the ore deposits and areas of maximum mudstone "alteration". Exsolution of $CO_2$ from the ore fluid might also explain the observed (Archbold, 1957) sparsity of carbonate cement within ore bodies where $CO_2$ concentrations might have been relatively high, and a concentration of carbonate cement in adjacent barren sandstone where the concentration of $CO_2$ might have been relatively low.

If exsolution of $CO_2$ from the ore fluid did occur during mineralization, the concentration of $CO_2$ probably would be related to the degree of pressure reduction. It seems possible that the rate of precipitation of vanadium and uranium from a bicarbonate ore fluid could be delicately controlled by the amount of $CO_2$ evolved from the ore fluid. Possibly the variation in $V_2O_5$-$U_3O_8$ ratios commonly noted for individual mines or mining districts might be explained as zoning due to differing degrees of exsolution of $CO_2$ from the ore fluid. This mechanism might also explain the previously reported zoning, within individual ore bodies, of certain trace elements (Shawe, 1956, Botinelly and Fischer, written communication, 1955).

Geochemists have stressed the importance of carbonaceous material in causing a reduction of Eh and thereby causing precipitation of the ore metals from solution. The fact that much carbonaceous material is commonly associated with the ore deposits in the Bull Canyon district would seem to lend support to this hypothesis. However, within a cluster of ore deposits, carbonaceous material is nearly ubiquitous. Abundant carbonaceous material occurs both in lenses of mineralized sandstone and in adjacent lenses of barren sandstone. Furthermore, some ore deposits have been localized in lenses of sandstone containing little or no visible carbonaceous material, while adjacent lenses contain abundant carbonaceous material but no ore. Close inspection of these occurrences reveals that the ore bodies are consistently related to one or more of the physical features which cause a reduction in the volume of the sandstone within the host-rock unit. Data obtained from mine studies in the Bull Canyon district indicate that although carbonaceous material is one feature that, by a reduction in Eh, could have influenced the deposition of ore metals, it is not the only, or necessarily major, factor causing precipitation of ore minerals. It is possible that highly reducing volatiles such as $H_2S$ might, in some places, have "boiled off" from the ore fluid due to a decrease in pressure. Such reducing volatiles could induce precipitation of ore metals. It seems reasonable to assume, however, that the physical features so consistently associated with the ore deposits had at least an equal role in causing precipitation of ore metals. The ore deposits in the Bull Canyon district may have been localized by a combination of: (1) exsolution of volatiles caused by a pressure reduction on the ore fluid, and (2) the reducing action of carbonaceous materials.

The following reports on mine studies in the Monogram Mesa-Bull Canyon area have been published:

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

Thompson, M. E. and Roach, C. H., 1955, Mineralogy of the Peanut mine, Montrose County, Colorado (abstract): Geol. Soc. America Bull., v. 66, p. 1625-1626.

## References

Archbold, N. L., 1957, Relationships of calcium carbonate to lithology and vanadium-uranium deposits in the Salt Wash sandstone of southwestern Colorado: U. S. Geol. Survey Open File Report.

Garrels, R. M. and Richter, D. H., 1955, Is carbon dioxide an ore-forming fluid under shallow-earth conditions?: Econ. Geology, v. 50, p. 456.

Gruner, J. W., 1956, Concentration of uranium in sediments by multiple migration-accretion: Econ. Geology, v. 51, p. 498.

Shawe, D. R., 1955, Significance of roll ore bodies in genesis of uranium-vanadium deposits on the Colorado Plateau, in Page, L. R., Stocking, H. E., and Smith, H. B., Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland; 1955: U. S. Geol. Survey Prof. Paper 300, p. 239-241.

## Slick Rock district, Colorado

by

D. R. Shawe, G. C. Simmons, and N. L. Archbold

The Slick Rock district comprises about 570 square miles in the western part of San Miguel and Dolores Counties, Colorado (fig. 7). The Geological Survey began geologic work in the district in 1953, with the objectives of evaluating previous diamond drilling in the district, extending exploratory drilling to areas where possible uranium deposits are deeply buried, synthesizing previous geologic studies pertaining to the district, and undertaking additional studies. The purpose was to present a comprehensive picture of the geology and ore deposits of the Slick Rock district, and to discern the origin and genesis of the deposits.

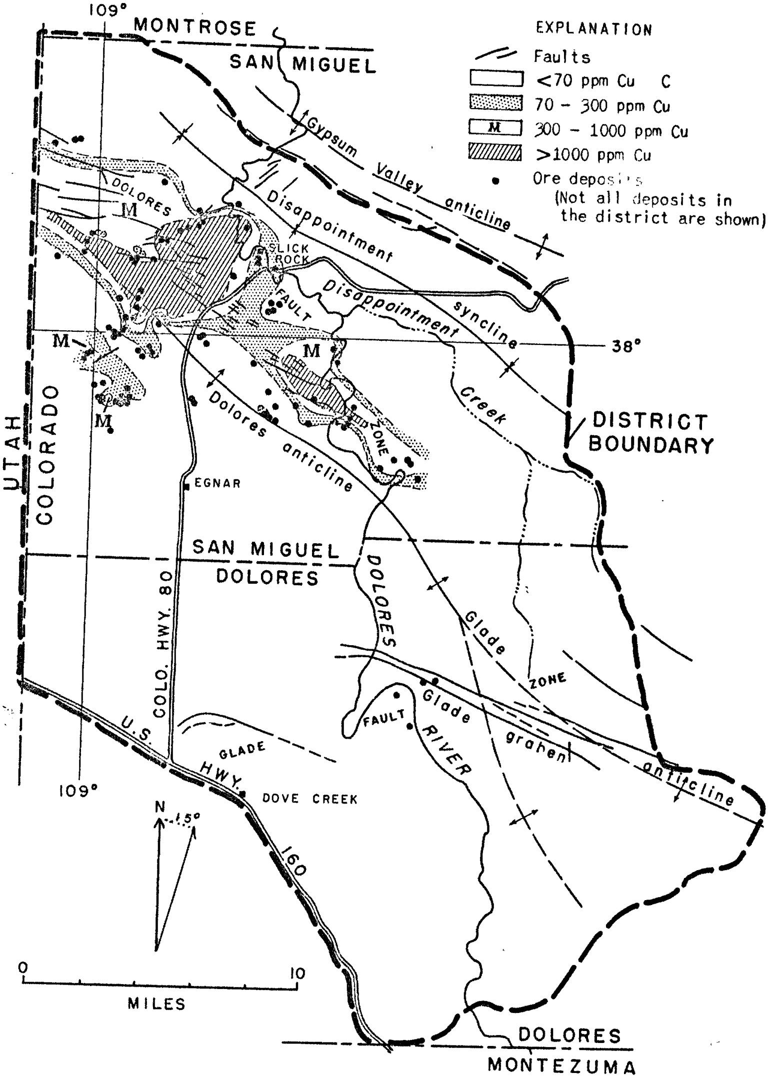

Fig. 7 .--MAP OF THE SLICK ROCK DISTRICT SHOWING MAJOR STRUCTURAL FEATURES AND AMOUNT OF COPPER IN URANIUM-VANADIUM DEPOSITS, SAN MIGUEL AND DOLORES COUNTIES, COLORADO.

## Stratigraphy

Consolidated sedimentary rocks cropping out in the Slick Rock district range in age from Permian to Cretaceous. Older sedimentary rocks which underlie these are known to rest on igneous and metamorphic rocks of a probable Precambrian basement. Maximum thickness of exposed sedimentary rocks in the district is about 4,700 feet and the total section of sedimentary rocks underlying the district is about 13,000 feet. Only one igneous intrusive rock is known in the district, but several igneous sills and dikes probably related to the San Juan volcanic province lie not far to the east.

Data on consolidated sedimentary rocks in the district are summarized in table 1.

## Structure

The Slick Rock district is in the Paradox Basin at the southwest edge of the salt anticline region. Major folds in the district trend about N. 55° W. and parallel the collapsed Gypsum Valley anticline (fig. 7). The Dolores anticline is about nine miles southwest of the Gypsum Valley anticline; the Disappointment syncline lies between the two anticlines. In the southeast part of the district the Glade anticline branches eastward from the Dolores anticline.

A zone of faults bounding the southwest edge of the collapsed core of the Gypsum Valley anticline occurs along the southwest limb of the anticline. The Dolores fault zone is about two miles northeast of and parallel to the axis of the Dolores anticline. Individual faults in the zone strike N. 60° to 85° W. and form a series of small en echelon

Table 1.—Generalized stratigraphic section of rocks in the Slick Rock district, San Miguel and Dolores Counties, Colorado

| Age | Formation and member | Thickness in feet | Character | Distribution and remarks |
|---|---|---|---|---|
| Quaternary | Soil, alluvium, and talus | | Thin residual soils, talus deposits, recent alluvium. | Covers small areas throughout district. |
| | Loess | | | Thin blanket covers high plains in south part of district |
| | Terrace gravel | | Well-rounded cobbles and pebbles derived from volcanic rocks of San Juan Mountains. | At least five levels occur along Dolores River and its tributaries. |
| | Landslide, mudflow, and alluvial fan deposits | | | Developed along canyon walls. |
| | Glacial till | | Poorly sorted, fine grained to boulder size, angular to rounded volcanic materials. | Found on Glade Mountain in southeast part of district. |
| | Unconformity | | | |
| Late Cretaceous | Mancos shale | 2,300 | Dark-gray calcareous mudstone and minor limestone, bentonitic claystone, and sandstone. Contains abundant invertebrate fossils. | No complete section known in district. Lower 855 feet separable into six fossil zones. From base upward: Early Greenhorn, Late Greenhorn, Earlier Carlile, Later Carlile, Earlier Niobrara, and Later Niobrara. |

Table 1.—Continued

| Age | Formation and member | Thickness in feet | Character | Distribution and remarks |
|---|---|---|---|---|
| Late Cretaceous | Dakota sandstone | 120-180 | Fine-grained quartzose sandstone, carbonaceous shale, coal, and locally conglomeratic sandstone. | Forms present surface of much of district, forms cliffs where exposed in canyons. In Disappointment Basin lower contact conformable, but sharp. Thickest in Disappointment syncline. |
|  | Unconformity |  |  |  |
| Early Cretaceous | Burro Canyon formation | 80-300 | Fine-grained to conglomeratic light-gray to light-brown quartzose sandstone, greenish-gray shale and siltstone, and greenish-gray to gray limestone and chert. | Sandstone caps benches, forms cliffs; shale and siltstone with minor sandstone, limestone, chert, forms smooth ledgy slopes. Contact with underlying Brushy Basin member of Morrison transitional, in places intertonguing or disconformable. Thickest in Disappointment syncline. |
| Late Jurassic | Morrison formation<br>Brushy Basin member | 300-720 | Predominantly reddish-brown bentonitic mudstone of volcanic origin. | Crops out as smooth slope with low ledges. Thickest in Disappointment syncline, thinnest on Dolores anticline. |
|  | Salt Wash member | 275-450 | Lenticular quartzose sandstone, interbedded reddish-brown mudstones. Sandstone lenses in top part dominantly light-brown or light-gray, contain abundant carbonaceous material; those in lower part mainly light reddish-brown, contain sparse carbonaceous material | Commonly crops out as alternating series of steep slopes and benches. Sandstone to mudstone ratio ranges between 1:1 and 2:1; higher ratios bear no relation to structural features, occur in northwest part of district where most of known uranium-vanadium deposits occur. Thickest in Disappointment syncline, thinnest on Dolores anticline. |

Table 1.--Continued

| Age | Formation and member | Thickness in feet | Character | Distribution and remarks |
|---|---|---|---|---|
| Late Jurassic | Junction Creek sandstone | 20-150 | Light-buff fine-grained sandstone with sweeping crossbeds in south part of district. Changes northward to light reddish-brown fine-grained horizontally bedded sandstone, seems to merge with Summerville. | |
| | Summerville formation | 60-140 | Reddish-brown horizontally bedded sandy siltstone; locally near top has layers of limy nodules parallel to bedding. | Forms smooth slope interrupted by thin sandstone ledge in upper part. |
| | Entrada | 90-150 | Fine-grained moderately to well-sorted light-brown, light reddish-brown sandstone. | Crops out as conspicuous smooth cliff in Dolores River and tributary canyons. |
| Late and Middle Jurassic | Carmel formation | 30 | Reddish-brown very fine grained silty sandstone; near base contains coarse reworked Navajo sandstone, thin limestone beds, conglomerate. | Forms "humpy-faced" vertical cliff. |
| | Unconformity | | | |

Table 1.—Continued

| Age | Formation and member | Thickness in feet | Character | Distribution and remarks |
|---|---|---|---|---|
| Jurassic and Jurassic(?) | Navajo sandstone | 150± | Fine-grained, well-sorted, probably wind-deposited sandstone. In places grains coarser near top. Light brown in most of district, light reddish-brown in places. | Forms cliffs, broad benches. Thickest in Disappointment syncline, absent in places on Dolores anticline. |
| Jurassic(?) | Kayenta formation | 180 | Purplish-gray to purplish-red siltstone and sandstone; poorly sorted, largely fluvial with interbedded shales and mudstones, local conglomerates. | Crops out in series of steep closely spaced cliffs. |
| Late Triassic | Wingate formation | 170-270 | Very fine to fine-grained, generally well-sorted, probably wind-deposited sandstone; light buff in Summit Canyon, light reddish-brown in Dolores River Canyon. | Forms a sheer cliff. Contact with underlying Chinle formation is gradational; change in lithology takes place by gradual upward thickening and coarsening of individual siltstone beds; slight angular discordances present at base. Thickest in west part of district, thins eastward. |

Table 1.--Continued

| Age | Formation and member | Thickness in feet | Character | Distribution and remarks |
|---|---|---|---|---|
| Late Triassic | Chinle formation | 490-620 | Fluvial reddish-brown siltstone and greenish-gray shale, sandstone, and conglomerate. Divided into five units. Unit 5 composed of siltstone; averages 165 feet thick. Unit 4 composed of siltstone with thin beds of dark greenish-gray conglomerate; averages 240 feet thick. Unit 3 composed of interbedded lenses of dark brownish-red to dark greenish-gray sandstone and conglomerate; from 3 to 20 feet thick. Unit 2 composed of greenish-gray shale with minor reddish-brown shale and greenish-gray sandstone and conglomerate; averages 70 feet thick. Unit 1 composed of lenses of greenish-gray sandstone and conglomerate, slight angular unconformity with Cutler formation; averages about 50 feet thick. | Crops out as steep slope broken by few ledges of resistant siltstone, lower slope broken by two receding sandstone and conglomerate cliffs. The Temple Mountain, Shinarump, Monitor Butte, and Owl Rock members, found elsewhere on Colorado Plateau, are not present in district. Unit 1 is probably Moss Back, Unit 2 possibly facies of Petrified Forest or part of Church Rock, Units 3, 4, and 5 lithologically similar to and likely equivalents of Church Rock. |

Unconformity

Table 1.—Continued

| Age | Formation and member | Thickness in feet | Character | Distribution and remarks |
|---|---|---|---|---|
| Permian | Cutler formation | 1,930 | Brownish-red, brownish-orange, and light-brown arkosic sandstone, siltstone, and shale. | Upper 240 feet exposed in bottom of Dolores River Canyon; crops out as series of closely spaced receding ledges with indentations caused by erosion of softer beds. |
| Pennsylvanian and Permian(?) | Rico formation | 710 | Brown to brownish-red and gray very fine to medium-grained sandstone, siltstone, shale, and gray very fine to fine-grained fossiliferous limestone. | Marks transition from marine deposits to overlying continental deposits. |
| Pennsylvanian | Hermosa formation<br>Upper limestone member | 1,270 | Light to dark gray very fine to fine-grained fossiliferous limestone, contains some grayish-green sandstone, siltstone, and shale near top. | |
| | Paradox member | 2,000-4,300 | Dense dark-gray anhydrite, gray to light-gray punky and powdery anhydrite, fine- to medium-grained clear and gray halite, some gray containing inclusions of anhydrite, minor gypsum; some dark-gray carbonaceous shale. | Thickest on Dolores anticline. |
| | Lower limestone member | 180 | Gray fine-grained limestone. | |

Table 1.—Continued

| Age | Formation and member | Thickness in feet | Character | Distribution and remarks |
|---|---|---|---|---|
| Pennsylvanian | Molas formation | 100 | Reddish-brown and greenish-gray shales. | |
| Unconformity(?) | | | | |
| Mississippian and Devonian(?) | Leadville and Ouray(?) limestones undifferentiated | 240 | Gray fine-grained limestone. | |

grabens. The zone extends northwestward toward the Lisbon Valley anticline in Utah. A few faults normal to the Dolores fault zone in the northwest part of the district form a conjugate system. The south part of the district is cut by the Glade fault zone, which trends about N. 80° E. and extends westward into the Verdure graben in Utah. Individual faults in the zone strike about N. 60° to 70° W.; depression of a long narrow block between two of these faults has formed the Glade graben.

A major set of fractures is oriented parallel to the principal faults in the district; a less prominent set, approximately parallel to the fault zone normal to the Dolores fault zone, is oriented about normal to the major set.

Sandstone dikelets in the Navajo sandstone along fractures striking about N. 30° W. in the area of the Dolores fault zone, may have formed when the Navajo was partly unconsolidated, suggesting initiation of fracturing in Early Jurassic time. At least two stages of fracturing are shown in the district; some fractures pre-date epigenetic alteration of the rocks and have controlled the alteration, whereas some post-date epigenetic alteration.

## Sedimentary petrology

Some accessory heavy minerals in the rocks exposed in the Slick Rock district contain appreciable amounts of some of the elements known in the ore deposits in the Morrison formation. The rocks of Late Cretaceous age contain traces of elements that may be related to the advent of volcanism in the region of the Colorado Plateau near the end of the Cretaceous period.

All the clastic sedimentary rocks in the Slick Rock district older than the Mancos shale and younger than the Rico formation contain several hundredths to a few tenths of a percent heavy detrital minerals including zircon, tourmaline, and leucoxene. Some of the rocks contain traces of garnet, staurolite, and rutile. Heavy minerals that are authigenic in most of the rocks include carbonates, leucoxene, barite, and anatase. All the reddish rocks in the stratigraphic sequence contain in the order of a tenth of a percent black opaque minerals including hematite, magnetite, and ilmenite. These black opaque minerals constitute about half of the total heavy minerals in the rocks. Almost all the light-gray, greenish-gray, and light-brown rocks in the stratigraphic sequence contain little if any ilmenite, magnetite, and hematite, but do contain pyrite or limonite that has probably been altered from pyrite. These light-colored rocks have about half as much total heavy mineral content as do the reddish rocks.

Black opaque heavy minerals in reddish rocks of the Morrison formation average about 0.017 percent copper, 0.004 percent lead, 0.006 percent nickel, 0.13 percent vanadium, 0.24 percent chromium, 0.20 percent zirconium, and 0.019 percent niobium. Magnetites commonly contain vanadium, and as much as 4.84 percent vanadium in magnetite has been reported (Palache, Berman, and Frondel, 1944, p. 702). Spectrographic analyses of black opaque heavy minerals from reddish rocks of the Morrison formation have not detected uranium in these minerals. However, some vanadium-rich ilmenites contain a few tenths to several percent uranium, as well as lead, chromium, zirconium, and other elements (Bannister and

Horne, 1950; R. G. Coleman, written communication, 1956; Lawrence, 1957; Mawson, 1944). Some non-vanadiferous ilmenites contain a few hundredths to 0.20 percent $U_3O_8$ (Palache, Berman, and Frondel, 1944, p. 537). It is possible that black opaque heavy minerals in reddish rocks of the Morrison contain a few hundredths of a percent uranium that could not be detected by spectrographic analysis.

Spectrographic analyses of many samples of pyrite separated from the Mancos shale show that pyrite from rocks about 300 feet above the base of the Mancos, at the base of the Later Carlisle fossil zone, contains anomalous amounts of metallic elements including copper, chromium, silver, gold, zinc, tin, vanadium, yttrium, nickel, and zirconium. The trace element content in pyrite decreases upward from that horizon, and pyrite about 600 feet above the base of the formation contains about the same amount of the metallic elements as does pyrite in the lower 300 feet of the Mancos.

## Rock alteration

Color differences in the sedimentary rocks of the Slick Rock district are related to the position of the uranium-vanadium deposits; to clarify the relations a special study was made of the causes of color differences. At least four types of post-depositional changes that involve color differences have taken place; two of these changes are thought to be diagenetic and two are considered epigenetic.

One type of change that is considered to be diagenetic took place where sediments were deposited in an oxidizing environment in which no carbonaceous material was present. Detrital magnetite and ilmenite were partly oxidized to form hematite and leucoxene respectively. Iron was redistributed and redeposited as hematite coatings on sand grains and clay fragments, imparting a reddish color to the rocks. This change probably brought the "red beds" as such into being (see also Miller and Folk, 1955).

A second type of diagenetic change took place under reducing conditions where abundant carbonaceous material was deposited with the sediments. Magnetite and ilmenite were partly destroyed, and pyrite apparently developed from the liberated iron. Sedimentary rocks formed in this environment are light greenish gray to gray in color.

A third type of post-depositional change was epigenetic. It consisted of almost complete destruction of magnetite, ilmenite, and hematite (including hematite coatings on grains), and entailed formation of pyrite from liberated iron and recrystallization of barite and leucoxene. Rocks affected by this epigenetic alteration are light greenish gray to gray. They are similar in gross aspect to light greenish-gray to gray rocks formed where abundant carbonaceous material was deposited. For convenience in mapping, the two types have been grouped and called "altered" rocks.

The epigenetic alteration described above is associated with at least two major structural features in the Slick Rock district. It is found in rocks within and near the Dolores fault zone, and occurs along the axial part of the Dolores anticline in the upper part of the Entrada sandstone and adjacent to joints in sandstone of the Entrada and Salt Wash.

A fourth type of post-depositional change took place where "altered" rocks were exposed to weathering. The epigenetic change resulted as pyrite oxidized to limonite; light greenish-gray to gray rocks became light brown to buff.

## Geologic history

Little is known of the Precambrian history of the Slick Rock district, but the area was probably base-leveled by Paleozoic time. The first known sediments--carbonate rocks of the Ouray(?) (Devonian?) and Leadville (Mississippian) limestones and the arenaceous Molas formation (Pennsylvanian)--were deposited in a shallow sea. With development of the Paradox Basin during the Pennsylvanian period, carbonate and evaporite rocks of the Hermosa formation were deposited, followed by the coarse clastic rocks of the Cutler formation of Permian age.

From Early Triassic to Late Cretaceous time fluvial deposition predominated in the region around the Slick Rock district. During this period the Dolores anticline was periodically folded, acquiring several hundred feet of structural relief relative to the Disappointment syncline. Folding was accelerated during or shortly after the deposition of the Navajo sandstone and again during the deposition of the Morrison and Burro Canyon formations. Faulting and fracturing along the Dolores fault zone probably began during one of these periods of accelerated folding of the Dolores anticline.

In Late Cretaceous time gradual encroachment of the sea covering eastern Colorado brought a change in sedimentation, and clay size material was deposited to form the Mancos shale. Periodically during early Late Cretaceous time volcanic ash falls from volcanic eruptions in the San Juan and Rocky Mountains to the east of the district were buried in the Mancos shale. By the end of deposition of the Mancos structural relief between the Disappointment syncline and the Dolores anticline was probably at least 1,500 feet at the horizon of the Cutler and Chinle contact and more than 1,000 feet at the top of the Salt Wash member of the Morrison formation.

At the start of Later Carlisle time, during deposition of the Mancos, unique and numerous volcanic eruptions, possibly submarine, may have introduced abnormal amounts of several heavy metals into sea water. These elements apparently were precipitated in diagenetic pyrite forming in the Mancos.

After deposition of the Mancos shale several thousand feet of sedimentary rocks of the Mesaverde, Wasatch, and Green River formations of latest Cretaceous and Eocene age probably were deposited in the district. Erosion, accompanied by a recurrent rise of the Dolores anticline and a second period of faulting and fracturing, possibly started near the middle of the Tertiary. During the last part of the Tertiary and in Pleistocene time an additional 2,000 feet of structural relief developed between the Dolores anticline and the Disappointment syncline.

Near the close of the Tertiary period and during the Quaternary period a variety of surficial deposits were deposited in the district.

## Stratigraphic and areal distribution of the uranium-vanadium deposits

Most of the known uranium-vanadium deposits in the Slick Rock district are in the Salt Wash member of the Morrison formation. Scattered deposits occur in the Brushy Basin member of the Morrison and in the lowest unit of the Chinle formation. The topmost sandstone unit of the Salt Wash is the principal ore-bearing horizon.

Most of the known ore deposits are in the north part of the Slick Rock district in a belt called the Dolores ore zone, which trends about N. 55° W. The zone is about 20 miles long, 10 miles wide near the northwest corner of the district, and narrows to about two miles southeastward. It lies within, and normal to, the southern end of the Uravan mineral belt as defined by Fischer and Hilpert (1952). The only known deposits in the district outside the Dolores ore zone are small deposits along the Dolores River Canyon east of Dove Creek and newly discovered deposits west of Egnar. Within the Dolores ore zone are narrower zones to which the ore deposits are confined; these zones are a few thousand feet wide and generally trend about N. 70° W. to east-west.

In the Slick Rock district uranium-vanadium deposits are chiefly tabular to lenticular and parallel roughly the sedimentary bedding. Some ore bodies, however, are narrow, elongate, and curve sharply across bedding; these bodies have been called "rolls" by the miners (Fischer, 1942). Tabular deposits seem to be localized in massive sandstones where clay and mudstone are interstitial, in scattered and streaked gall and pebble accumulations, and in discontinuous lenses, whereas roll deposits appear to be confined to sandstones where clay and mudstone are in numerous thin well-defined connecting layers. Most of the ore deposits are in the lower part of the principal ore-bearing unit where crossbedding is more prevalent.

Narrow zones of ore deposits within the Dolores ore zone are oriented almost parallel to sedimentary trends, which average about S. 70° E. as shown by current lineations in the principal ore-bearing sandstone unit. Individual ore bodies within a single deposit also follow this trend.

All ore deposits occur where abundant carbonaceous material was deposited with the sediments.

### Relations of the uranium-vanadium deposits to structural features

The Dolores ore zone coincides with the Dolores fault zone and is widest where the fault zone is intersected by the northeasterly trending fault set to form a conjugate fault system. Ore deposits along the Dolores River Canyon east of Dove Creek lie in the Glade fault zone. Narrow zones of ore deposits within the Dolores ore zone are oriented almost parallel to the trend of principal faults and fractures in the district but do not seem to be directly associated with individual faults.

### Mineralogical and chemical composition of the ores

The mineralogy of the uranium-vanadium deposits in the Slick Rock district is similar to that of deposits in other districts in the Uravan mineral belt (Weeks, 1956). Copper-bearing minerals are more abundant in some deposits in the district than in deposits elsewhere in the belt.

Gangue minerals that have been introduced during formation of the uranium-vanadium ore bodies include carbonates and barite. Carbonate in mineralized rock appears to be more magnesium-rich than carbonate in barren rock near ore bodies. Barite in mineralized rock is pale yellow and contains traces of several metallic elements, whereas barite in barren rock is colorless and contains lesser amounts of the metallic elements.

Mineral zoning is evident in some oxidized ore bodies in the Slick Rock district, and is similar to zoning noted in some oxidized and unoxidized deposits in other parts of the Colorado Plateau. Roll ore bodies with C-shaped cross sections are paralleled by carbonate-rich zones close to the concave side of the roll, or near both sides (Archbold, 1955). In some places a thin layer or concentric layers of goethite, altered from pyrite, are found in barren rock near the concave edge of the roll. Selenides and sulfides are concentrated in a thin layer along the concave edge of the roll. Vanadium appears to be contained largely in chlorite on the concave side of the roll, whereas it is in both chlorite and mixed-layered mica-montmorillonite on the convex side (J. C. Hathaway, written communication). Barite is more abundant in the roll ore bodies than in barren rock.

Uranium-vanadium deposits mined in the Slick Rock district to date average about 0.22 percent $U_3O_8$, 1.7 percent $V_2O_5$, and 0.07 percent copper. The $U_3O_8$:$V_2O_5$ ratio is about 1:8, slightly lower than the average of deposits in the Salt Wash sandstone member in other parts of the Uravan mineral belt. On the other hand, Slick Rock deposits are uniquely high in copper content compared to deposits in the rest of the mineral belt; some deposits in the district average as much as 0.3 percent copper. Ore deposits in the Slick Rock district also contain on the average about 0.018 percent lead, 0.0014 percent cobalt, 0.0008 percent nickel, 0.022 percent zinc, 0.021 percent arsenic, 0.0044 percent molybdenum, and less than 0.0001 percent antimony.

Neither $U_3O_8$:$V_2O_5$ ratios nor amounts of uranium or vanadium show a recognizable pattern of distribution in the Slick Rock district. Copper and lead, however, are distinctly most abundant in the ore deposits within and immediately toward the edge of the zone (fig. 7). The area of high copper and lead content is widest where the northeasterly-trending fault set intersects the Dolores fault zone, and minor copper and lead highs are situated along the northeasterly-trending set southwest of the intersection of the faults. Within the Dolores ore zone selenium appears to be most abundant in deposits closest to Gypsum Valley, and less abundant southwestward along the northeasterly-trending fault set. Molybdenum and some other trace elements in the ore deposits show no recognizable patterns of distribution.

Uranium and vanadium appear to have no systematic pattern of distribution within individual ore bodies. $U_3O_8$:$V_2O_5$ ratios may range, seemingly haphazardly, from 1:1 to 1:20 within individual ore bodies. On the other hand, copper, lead, and selenium are distinctly high in barren rock just adjacent to the concave edge of roll ore bodies, reflecting the zonal distribution of minerals in the rock.

## Ore deposits and associated alteration

Tabular ore bodies in the Slick Rock district average about 3 feet but vary from 1 to 20 feet in thickness. They range from a few feet to about 250 feet long and contain from a few tons to several tens of thousands of tons of ore. Elongate lens-shaped tabular bodies with simple geometrical outlines are found in homogeneous sandstone, whereas more complexly shaped bodies are in heterogeneous rock.

Roll ore bodies in Slick Rock uranium-vanadium deposits range from several inches to more than 5 feet wide, a foot or so to more than 15 feet high, several feet to several hundreds of feet long, and contain a few tons to many hundreds of tons of ore. They commonly are near and parallel to the edges of, and within, elongate sandstone lenses, and are oriented with the concave side of the roll toward the center of the lens.

Uranium-vanadium deposits in the Slick Rock district occur only in sandstone that is considered to be epigenetically altered. Mudstone close to ore deposits has been extensively altered and is greenish gray, whereas mudstone in and near ore-bearing sandstones farther from deposits is largely reddish brown. The most extensive changes in epigenetically altered sandstone have occurred close to ore bodies. In barren rock on the concave side of rolls extensive solution of quartz grains and partial replacement by barite has occurred, whereas on the convex side of rolls quartz overgrowths on quartz grains are common. Authigenic anatase is appreciably more abundant immediately above some tabular ore bodies than elsewhere. Minute amounts of pyrite, galena, and possibly other sulfides are more evident in the vicinity of unweathered ore deposits than elsewhere in the zones that have undergone epigenetic alteration.

## Origin of the ore deposits

The origin of the uranium deposits in sedimentary rocks of the Colorado Plateau has been ascribed by different workers to different processes and has, at various times, been described as syngenetic, vaguely "hydrothermal", and hypogenetic. Determination of the probable Late Cretaceous age of formation of minerals in the ore deposits (Stieff, Stern, and Milkey, 1954) indicates that "penesyngenetic" processes can be excluded as a possible origin. On the other hand, the conclusion that lead and uranium isotope abundances in the ores require that the uranium came directly from the Precambrian basement by way of leaching solutions (Stieff, Stern, and Milkey, 1954) seems unreasonable; it presupposes that (1) galena and uraninite would have been the chief sources of lead and uranium in the basement, and (2) all the isotopes of lead and uranium in the basement could not pass through a sedimentary cycle and end up in the ore deposits in the ratios they are known to have. If the first assumption is true, it is likely that the second is also. However, it is quite possible that the first assumption is not true. Lead and uranium in the Precambrian basement may not occur chiefly in galena and uraninite but rather in one mineral, or in two closely associated chemically and physically similar minerals, such as magnetite and ilmenite. If this assumption is true, then neither supposition named above is true, and there would be no way of determining by isotope frequencies whether lead and uranium in the deposits were derived from minerals in the basement or from the same mineral occurring as detritus in sedimentary rocks.

It is not likely that cooling magmas of the size and "dryness" of the Colorado Plateau laccolithic intrusions could have been accompanied by the volume of solutions required to traverse the thousands of cubic miles of rock that appear to have been epigenetically altered on the Colorado Plateau. Similar difficulties confront the suggestion that the elements were transported by solutions from the basement to the ore deposits. A theory involving leaching of elements from minerals in sedimentary rocks by heated connate water, circulation of the resulting solutions through structural elements as a result of heating near the igneous intrusion, and deposition of the elements in chemically favorable locales that are a result of primary sedimentary features of the rocks is indicated by the geologic relationships observed in the Slick Rock district.

The deposition of relatively thick, laterally extensive, permeable carbonaceous sandstones in the Salt Wash member of the Morrison formation was prerequisite to the ultimate genesis of the uranium-vanadium deposits in the Slick Rock district. Of importance to the origin of the deposits was the presence in the sedimentary rocks of abundant black opaque detrital minerals that contain abnormal amounts of vanadium, copper, lead, nickel, and other metallic elements including perhaps uranium.

Development of the Dolores fault zone prior to the deposition of ore provided a permeable zone that would permit extensive lateral movement of solutions through the sandstones. The advent of igneous activity in nearby intrusive centers provided a means of initiating wide-scale heating and circulation of the connate waters. Epigenetic changes in the sedimentary rocks attest to the movement of vast amounts of heated solutions, and the distribution of epigenetic alteration shows clearly the influence of structural features on movement of the solutions. Further, destruction of detrital minerals, which in unaltered rocks are known to contain many of the elements present in the ore deposits, provided an adequate source in the sedimentary rocks for the elements of the ore deposits.

Spatial relationship of the Dolores fault zone with the Dolores ore zone suggests a relationship of one to the other. Zoning of elements in the ores, such as copper and lead, relative to the Dolores fault zone strengthens this conclusion, and in addition suggests that copper and lead were more readily precipitated from solution than were uranium and vanadium. Uranium-vanadium ore deposits are not associated directly with individual faults, but are in a zone made more permeable by numerous faults and fractures.

Clear association of the uranium-vanadium deposits with abundant carbonaceous material in the sedimentary rocks strongly suggests that the carbonaceous material exerted a chemical influence on the deposition of ore minerals.

Roll ore bodies have formed near the impermeable boundaries at the edges of elongate permeable sandstone lenses. Solution of quartz appears to have been most pronounced in the space between rolls occurring on opposite sides of a lens, and the effects of deposition from solution are evidenced by formation of the ore minerals and barite in the rolls, and by silica overgrowths in barren rock beyond the rolls. It is concluded that deposition of ore must have occurred at an interface between moving, heated connate water solutions passing through the elongate sandstone lenses and "dead" cooler connate water trapped against the impermeable edges of the sand lenses. Zoning of the metals in the rolls also suggests that copper and lead were more readily precipitated from solution than uranium and vanadium. Interfaces between the ore-bearing solution and trapped, "dead" connate waters must have been numerous and widespread, but ore metals were deposited only where abundant carbonaceous material provided a suitable strongly reducing environment.

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## Uravan district, Colorado

by

R. L. Boardman

During the report period office work was continued on the Uravan district project, southwestern Colorado. Compilation of the results of the Geological Survey's program of exploration and geologic studies in the Uravan district, which began in 1948, will be completed in the summer of 1957, and a summary of the history and results of the program will be given in the next semiannual report.

## Western San Juan Mountains, Colorado

by

A. L. Bush, O. T. Marsh, and R. B. Taylor

Compilation of structural data indicates that the structural framework of the Placerville quadrangle extends into the Little Cone and Gray Head quadrangles, but apparently dies out toward the igneous centers of the Wilson group and the Dolores Peaks (TEI-390, p. 111-112; TEI-440, p. 28-30; TEI-490, p. 40-41; TEI-590, p. 31-32; TEI-620, p. 47-50; TEI-640, p. 47-49). This framework consists of a series of broad anticlines and synclines with numerous warps, both along the axes and on the flanks, cut by a system of horsts and grabens. Generally the fold axes trend northwest to north-northwest. The grabens characteristically swing from a southerly to a southeasterly trend along their extent from north to south (fig. 8).

Detailed compilation and broad interpretation indicate that in the southern parts of the Little Cone and Gray Head quadrangles the graben system is absent, and the fold system merges into a very broad synclinal structure which rises southward to merge with the north flank of the Rico dome. The Wilson and Dolores Peaks igneous centers lie on this limb, closer to the synclinal than the anticlinal axis. Minor warps are present, and it is believed that the Little Cone laccolith may overlie one of these small domes.

Abrupt monoclinal bends are present in a few places in the Little Cone and Gray Head quadrangles. In most cases they have been broken by normal faults with displacements of hundreds of feet. It is likely that

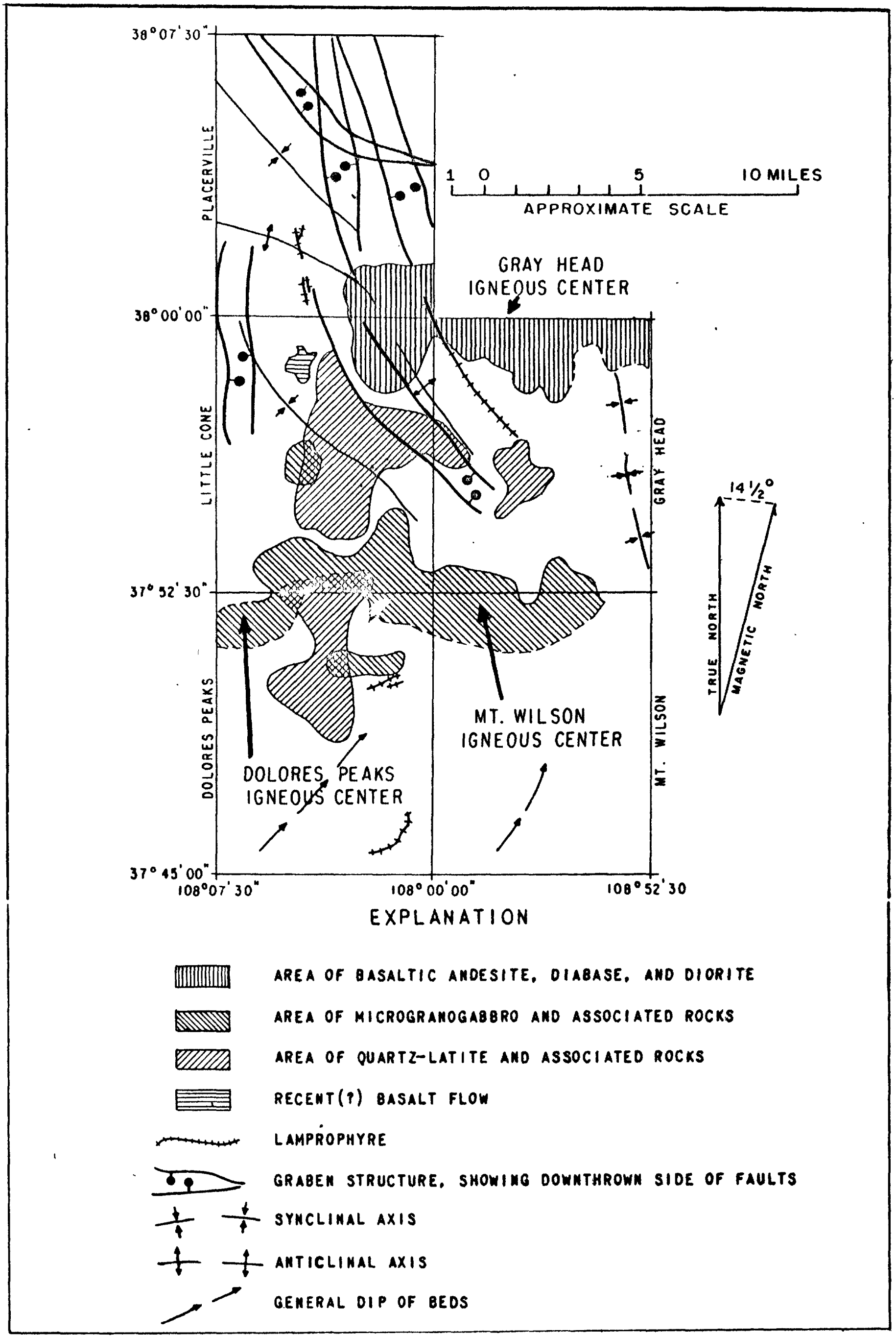


FIG. 8.--SKETCH MAP OF PART OF THE WESTERN SAN JUAN MOUNTAINS, COLORADO, SHOWING STRUCTURAL FEATURES AND MAIN AREAS AND CENTERS OF IGNEOUS ROCKS.

the bends are controlled by deep-seated faults in the basement rocks, and that the later faults represent renewed movement, in the opposite direction, along the basement faults.

There is increasing evidence that major igneous activity in the Western San Juan Mountains was confined largely to the Upper Miocene. The igneous rocks crosscut both the Telluride conglomerate and the overlying San Juan tuff. Microgabbro, olivine basalt, and minette dike rocks appear to be the youngest igneous rocks. Samples of a minette dike in the Gray Head quadrangle have a potassium-argon age of about 15 million years (S. S. Goldich, written communication, 1957), placing the rocks in the late Miocene.

Evidence of the relative age of faulting and intrusion of the igneous bodies, in addition to that found in the Placerville quadrangle, is found in the offset of granodiorite and rhyolite(?) sills in the Little Cone quadrangle by faults of the graben set. Dike rocks in the northeastern corner of the same quadrangle are also cut by faults of the same system. It is thus suggested that most of the faults are late Miocene or younger. To date no faults definitely older than the igneous rocks have been recognized.

Selenium minerals are now known from all the vanadium-producing districts in the Western San Juan Mountains (fig. 9). Clausthalite

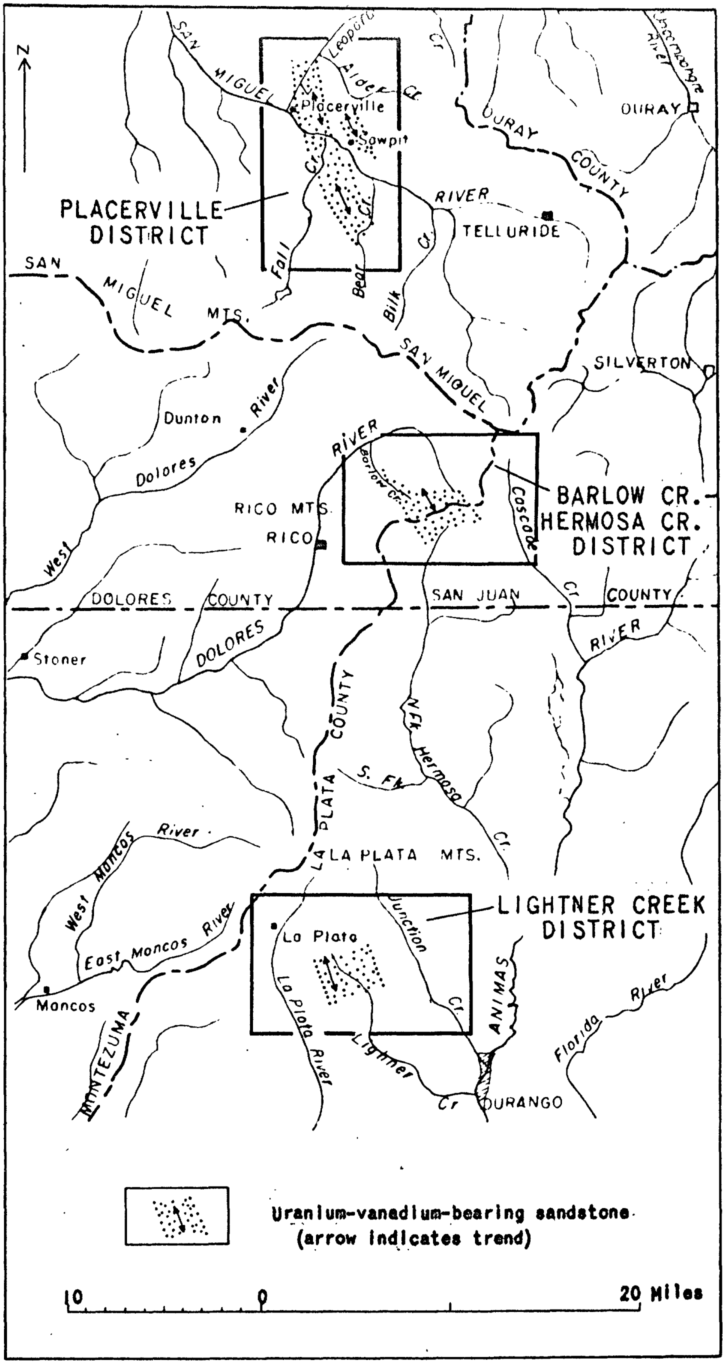


FIG. 9 .—INDEX MAP OF THE WESTERN SAN JUAN MOUNTAINS, COLORADO, SHOWING THE URANIUM-VANADIUM-BEARING SANDSTONE BELTS IN THE PLACERVILLE-BARLOW CREEK-HERMOSA CREEK, AND LIGHTNER CREEK DISTRICTS.

has been identified from the deposits of the Placerville and Lightner Creek districts, and ferroselite is present in the Barlow Creek-Hermosa Creek district. The significance of this difference in mineralogy is not understood.

During the report period a Mineral Investigations Field Studies Map of the Placerville quadrangle was published:

Bush, A. L., Bromfield, C. A., and Pierson, C. T., 1956, Preliminary geologic map of the Placerville quadrangle, Colorado: U. S. Geol. Survey Min. Inv. Map MF-96.

## Ute Mountains, Colorado

by

E. B. Ekren and F. N. Houser

Additional study of the relationships of the Burro Canyon formation of Early Cretaceous age and the Morrison formation of Late Jurassic age indicates that the lithologic differences observed in the mudstones of the two formations in the Four Corners area (TEI-640, p. 51) are observable elsewhere on the Colorado Plateau. These differences are also present in the mudstones of the Morrison formation and Stokes' (1944 and 1952) Cedar Mountain formation, which is the probable equivalent of the Burro Canyon formation, in east-central Utah.

The lithology of the Burro Canyon formation in southwesternmost Colorado reflects a considerable reduction in bentonite deposition compared with the amount deposited in the Brushy Basin formation. A new sedimentation cycle was initiated by uplift which probably was to the west. The "basal" conglomerate of the Burro Canyon, a channel-filling well-rounded pebble conglomerate, is indicative of this uplift.

The similarities between the lithologies, stratigraphic position, and possible sources of this "basal" conglomerate and the Buckhorn conglomerate member of the Cedar Mountain of Stokes suggests that the two may be lithogenetic equivalents.

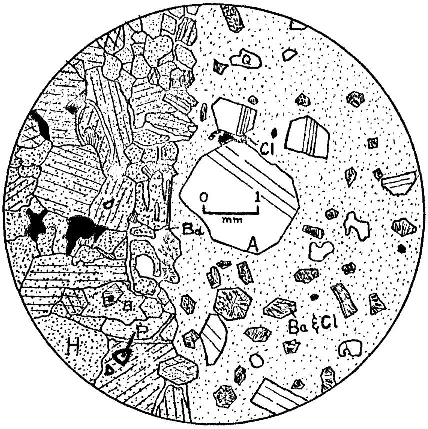
Geologic mapping in the McElmo Canyon area has shown that the Salt Wash member of the Morrison formation averages about 200 feet in thickness in the eastern part of the area where the Recapture member is absent. It thins westward to about 100 feet where the Recapture member is present. Throughout McElmo Canyon the Salt Wash member consists of continuous lenses or rims of sandstone separated by lenses of reddish-brown mudstone. In some places four or more distinct rims are present. In other places the mudstone lenses are extremely thin and the member forms a single thick sandstone unit. Very little green "altered" mudstone is present below or above the individual sandstone lenses and where present was never found to be more than a few inches thick. Mudstone pebbles and seams within the sandstones, however, are commonly green. No "trash piles" of carbonaceous material are known but carbon is fairly abundant as fine particles along bedding planes.

The lack of extensive "altered" mudstone, the absence of accumulations of carbon in the form of "trash piles", and the relatively nonlenticular character of the sandstones in the Salt Wash in this area as compared to uranium producing areas, suggests that the ground is generally unfavorable for uranium deposits. The main underlying cause for this unfavorableness is probably the environment under which the sandstones were deposited; an environment that did not promote large carbon accumulations or the development of well-defined channels of variable transmissivity.

Hornblendic inclusions are very numerous in the diorite and monzonite-diorite porphyries of the Ute Mountains. Figure 10 is a camera lucida drawing of a thin section cut along the contact of a hornblendite inclusion in monzonite-diorite porphyry. This inclusion is over 90 percent hornblende and contains biotite, magnetite, pyrite, and apatite. The pyrite is commonly ringed with magnetite. The hornblende has been partly altered to fine-grained, yellow-brown biotite near the contact. The monzonite-diorite porphyry consists of phenocrysts of andesine, quartz, and pseudomorphs after hornblende of brown biotite and chlorite. A few hornblende pseudomorphs (not shown in the figure) contain minute shreds of sericite. The groundmass, holocrystalline but extremely fine-grained, consists of sodic plagioclase, potash feldspar, quartz, and biotite.

The inclusion shown in figure 10 shows no banding or lineation. Some inclusions, however, show distinct banding; these usually contain abundant augite and/or plagioclase, and in some instances potash feldspar. Studies thus far have shown the plagioclase in the inclusions to be more calcic than the plagioclase in the enclosing porphyry.

E. M. Shoemaker and W. L. Newman (written communication, 1953) observed the inclusions during their reconnaissance study in 1952. They believe the hornblendites to be the products of accumulation of intratelluric crystals on the floor of the magma chamber. Eckel (1949,



A - ANDESINE

B - BIOTITE BOOKS

Ba - SECONDARY BIOTITE

Cl - CHLORITE

H - HORNBLENDE

P - PYRITE

Q - QUARTZ

SOLID BLACK - MAGNETITE

Fig.10.--CONTACT OF HORNBLENDITE INCLUSION AND MONZONITE-DIORITE PORPHYRY.

p. 34) observed numerous inclusions in the La Plata Mountains, which probably have an origin similar to the Utes, and concluded, "Most of the inclusions, including all types of gneiss and granite, were almost certainly derived from the Precambrian basement rocks through which the porphyry magmas were forced. The hornblende inclusions closely resemble in megascopic appearance the Irving Greenstone of the Needle Mountains, but without petrographic study it is impossible to be certain whether they were derived from the rock or are genetically related to the porphyry."

Hornblendes have been separated from two inclusions and from two porphyries and are being analyzed chemically and spectrographically. It is hoped that with these data the possible modes of origin will be narrowed and the derivation determined.

References

Eckel, E. B., 1949, Geology and ore deposits of the La Plata district, Colorado: U. S. Geol. Survey Prof. Paper 219.

Stokes, W. L., 1944, Morrison formation and related deposits in and adjacent to the Colorado Plateau: Geol. Soc. America Bull., v. 55, p. 951-992.

_______, 1952, Lower Cretaceous in Colorado Plateau: Am. Assoc. Petroleum Geologists Bull., v. 36, p. 1766-1776.

## Sage Plain area, Colorado-Utah

by

L. C. Huff and F. G. Lesure

Geologic mapping in the Sage Plain area began in 1954 and is scheduled for completion in the summer of 1957. The area includes the uplands near Monticello, Utah and Montezuma Canyon and its tributaries. The exposed rocks range in age from Jurassic and Jurassic(?) to Cretaceous. About 1,500 feet of sedimentary strata are exposed in the area; the beds are essentially flat-lying, the dips being mostly southward at angles of less than 1°. The older formations, including the Navajo sandstone of Jurassic and Jurassic(?) age and the Carmel, Entrada, and Summerville formations of Jurassic age, are exposed in Montezuma Canyon and some of its tributary canyons. The Morrison formation of Jurassic age, which here includes the Salt Wash, Westwater Canyon, and Brushy Basin members, is exposed in all the canyons in the area. The upland surface near Monticello is developed on the Mancos shale of Upper Cretaceous age, and is separated from the canyons by a steep cliff formed by sandstones of the Burro Canyon formation of Lower Cretaceous age and the Dakota sandstone of Upper Cretaceous age. Pediment gravels and loess, probably of early Pleistocene age, mantle the upland near Monticello, and thick alluvium floors most of the canyon. The character, distribution, and thickness of the formations in the Sage Plain area are given in table 2.

A system of faults and small grabens trending east and west crosses the head of Montezuma Canyon. A fault near the confluence of Verdure Creek

Table 2.--GENERALIZED STRATIGRAPHIC SECTION OF ROCKS EXPOSED IN THE MONTEZUMA CANYON AREA, SAN JUAN COUNTY, UTAH.

| Age | | Formation and member | Thickness (feet) | Character | Distribution |
|---|---|---|---|---|---|
| Quaternary (Wisconsin and Recent) | | Alluvium | 0-50 | Silt and sand, some interbedded gravel. | Forms alluvial plains and low terraces along major streams. |
| | | Landslide deposits | 0-50 | Large sandstone blocks mixed with smaller rock fragments, sand, and clay; derived by sliding from adjacent uplands. | Forms nearly continuous colluvial cover on bench formed by the Brushy Basin member below Burro Canyon formation. Smaller masses present locally along inner canyon walls. |
| | | Loess | 0-25 | Well-sorted red silt and very fine sand; largely wind deposited, reworked in part by water; overlies deeply weathered soil zone developed on older rocks. | Forms agricultural soils on uplands. |
| Quaternary (pre-Wisconsin) | | Pediment gravel | 0-50 | Boulders, cobbles, and pebbles in a sandy matrix. | Forms upland surfaces near Monticello; underlies loess locally. |
| | | UNCONFORMITY | | | |
| Upper Cretaceous | | Mancos shale | 0-380± | Gray marine shale, prominent *Gryphaea* zone near base. | Forms a few gentle hills above upland surface. |
| | | Dakota sandstone | 80-150 | Light-brown and yellowish-brown sandstone, interbedded gray lenticular carbonaceous claystone and coal; plant fossils abundant. Thin conglomerate at base locally. | Crops out at crest of the "rim rock" cliff which separates upland from canyons. |
| | | UNCONFORMITY | | | |
| Lower Cretaceous | | Burro Canyon formation | 50-180 | Light-colored conglomeratic sandstone; interbedded green lenticular mudstone; silicified sandstone and limestone at top locally. | Forms face of "rim rock" cliff which separates upland surface from canyons. |
| Jurassic | Morrison formation | Brushy Basin member | 200-440 | Varicolored mudstone; some sandstone and conglomerate lenses. | Forms slope below upland and above steep-walled inner canyons; generally covered with colluvium. |
| | | Westwater Canyon member | 0-180 | Yellow and greenish-gray lenticular sandstone and interbedded mudstone. | Forms intermediate slope below the gentle slope of the Brushy Basin and above the steep cliffs of the Salt Wash member in southern part of Montezuma Canyon area. Member grades into Brushy Basin to the north. |
| | | Salt Wash member | 300-520 | Light-colored lenticular sandstone interbedded with red-brown siltstone and mudstone. Contains uranium-vanadium deposits locally. | Forms series of steep cliffs and small benches in inner canyons. |
| | | Summerville formation | 80-130 | Even-bedded red sandstone interbedded with reddish-brown siltstone and mudstone. | Forms steplike slope below steep canyon walls formed by the Salt Wash member of the Morrison. |
| | | Entrada sandstone | 150-165 | Light-colored massive crossbedded sandstone. | Forms rounded cliffs along the base of the canyon walls in upper Montezuma Canyon and its tributaries. |
| | | Carmel formation | 40-45 | Irregularly bedded red siltstone and sandstone. | Crops out locally in upper Montezuma Canyon. |
| | | UNCONFORMITY | | | |
| Jurassic and Jurassic(?) | | Navajo sandstone | 26+ | Light-colored massive crossbedded sandstone, base not exposed. | A few scattered outcrops in upper Montezuma Canyon near creek level. |

with Montezuma Creek has a throw of 180 feet, the largest measured in the area.

The uranium deposits of the Sage Plain area are chiefly in thick, massive sandstone beds of the Salt Wash member of the Morrison formation. Most deposits are in prominent lenticular sandstone beds from 20 to more than 100 feet thick, but some are in thinner sandstones; at least two deposits are in beds only about 10 feet thick. The mineralized rock may occur in the middle, upper, or lower part of a particular lens, anywhere between the center and the edge of the lens. Very few ore bodies occupy distinct "channels". Many ore bodies are about midway between the upper and lower contacts and near the edges of the large lenses, and commonly are near accumulations of carbonaceous materials, such as fossil logs. Near ore bodies the normally red mudstones and sandstones of the Salt Wash member are "bleached" or "altered"; this "alteration" is most conspicuous where the normally red mudstones have been changed to a light greenish-gray along contacts with permeable sandstone. Similar features are widespread throughout the Salt Wash member but are most prevalent near the uranium-vanadium deposits.

Many of the significant ore deposits are in a relatively small area in Middle Montezuma Canyon, and all of the important mines are in one large lens of sandstone in the middle of the Salt Wash member. This lens has a maximum exposed thickness of 110 feet and a length of 13,000 feet, and grades at both ends into thinner sandstone beds separated by tongues of mudstone. Drill-hole information indicates that the ore sandstone is a sinuous asymmetric lens having a maximum thickness of about 150 feet. No systematic relationship between the location of the ore deposits and the shape of the lens has been found. Some ore deposits are near the edges of the lens; some are near the top; one deposit is near the middle; and still others are near the base of the lens.

Geochemical studies to investigate the distribution of the ore and associated elements within (1) all geologic formations present; (2) the Salt Wash member of the Morrison formation; and (3) ore bodies indicate that the uranium-vanadium content of the rocks is at essentially "background" levels beyond 10 to 20 feet from the deposits. This narrow mineralized halo limits the feasibility of geochemical prospecting for these deposits.

Mine mapping and detailed study of the uranium-vanadium deposits has revealed a systematic zoning which is most easily recognized in the smaller deposits, all of which are similar both in the well-defined zonation of mineralized and barren rock and in the general shape of the mineralized zones. Most such deposits consist of three concentric zones called the ore zone, the brown zone, and the gray zone. The ore zone is a layer or "shell" of olive-gray sandstone that is impregnated with the uranium-vanadium minerals simplotite, metarossite, carnotite, metatyuyamunite, and other unidentified minerals. The brown zone forms a core inside the ore zone or shell and consists of iron-stained porous sandstone commonly containing abundant carbonaceous material or plant fragments. The gray zone, which occurs outside and around the ore zone, is a light-gray sandstone tightly cemented with carbonate minerals and commonly freckled with limonitic specks. Radiometric studies and chemical analyses of these zones indicate a sharp reduction in quantity of the ore minerals in both the brown and gray zones as compared with the ore zone (table 3). Geochemical studies show that in comparison with the gray zone, both the ore zone and the brown zone contain an abundance of iron, cobalt, nickel, molybdenum, magnesium, and other elements commonly abundant in uranium-vanadium ores. The gray zone contains very little besides the common rock-forming elements of the quartzose sandstone and its calcite cement.

Table 3.--Uranium-vanadium content of samples from three geochemically defined zones*

| Mine | Zone | $U_3O_8$ (percent) | $V_2O_5$ (percent) | Ratio $U_3O_8/V_2O_5$ |
|---|---|---|---|---|
| Coyote No. 1 | Brown | 0.004 | 0.11 | 1:27 |
| | Ore | 0.012 | 2.75 | 1:229 |
| | Gray | 0.001 | 0.38 | 1:380 |
| Bradford No. 6 | Brown | 0.007 | 0.46 | 1:65 |
| | Ore | 1.54 | 4.35 | 1:3 |
| | Gray | 0.015 | 0.23 | 1:15 |
| Blue Jay No. 3 | Brown | 0.006 | 0.015 | 1:2 |
| | Ore | 0.021 | 1.76 | 1:84 |
| | Gray | 0.021 | 0.27 | 1:13 |
| Strawberry | Brown | 0.006 | 0.48 | 1:80 |
| | Ore | 0.024 | 2.23 | 1:93 |
| | Gray | 0.004 | 0.13 | 1:32 |

* Chemical analyses by C. G. Angelo, J. P. Schuch, and J. S. Wahlberg.

The size and shape of the ore zone is similar in all of the small deposits. The zone is commonly between 20 and 40 feet in length, 10 and

20 feet in width, and 4 and 10 feet in thickness, and commonly is shaped like an irregular flattened ellipsoid. Local irregularities in shape are caused by mudstone layers and by abundant carbonaceous material, such as trees or accumulations of macerated plant material in trash pockets.

The ore layer itself is commonly between 0.3 and 2 feet in thickness. Locally it follows the bedding or crossbedding planes of the sandstone lenses; elsewhere the ore zone cuts across one crossbedded lens into another and curves around to form the ends or the sides of the ellipsoidal shell. No obvious or consistent control of the location, direction of elongation, or size of the ore bodies by jointing, crossbedding, or other sedimentary structures has been observed.

Similar zones are recognizable by detailed study at some of the larger uranium deposits. The ore zone at the Lucky Boy mine is more than 70 feet wide and 120 feet long (fig. 11); the cross section (fig. 12) shows that it is somewhat irregular but is a single continuous surface. In some of the larger mines the zonation is more complicated, indicating that there may have been several stages of overlapping zonal development.

Chemical rather than physical controls appear to offer the best explanation for the formation of the zoned deposits. Because of the ellipsoidal shape of the ore zone and its radial symmetry it appears that the ore minerals may have been transported toward it from all directions in the same manner as silica is transported from all directions towards a growing geode or concretion. This transportation of ore elements radially inward toward the ore bodies is more suggestive of diffusion in a nearly stagnant fluid saturating the sandstone than of

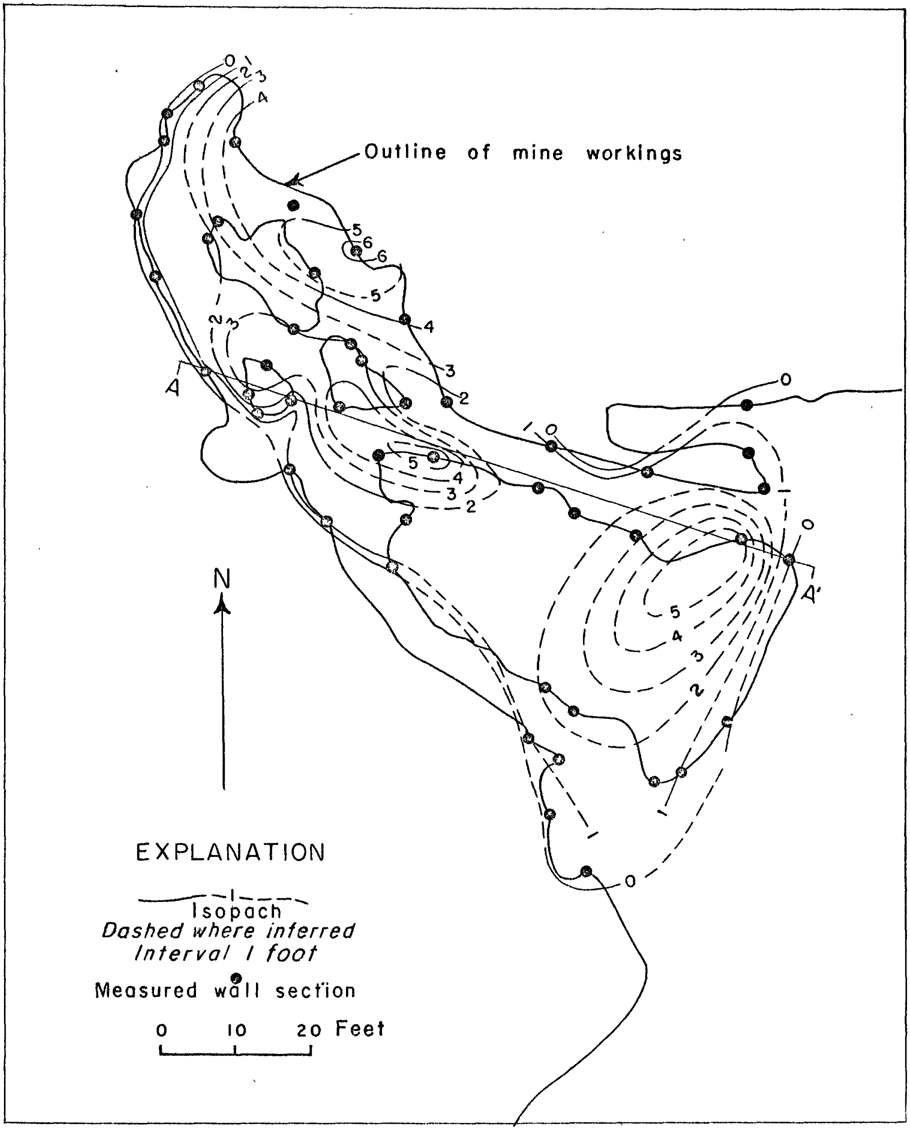


FIG.11 .--MINE MAP OF THE LUCKY BOY MINE, MONTEZUMA CANYON, SAN JUAN COUNTY, UTAH, SHOWING THICKNESS OF MINERALIZED SHELL

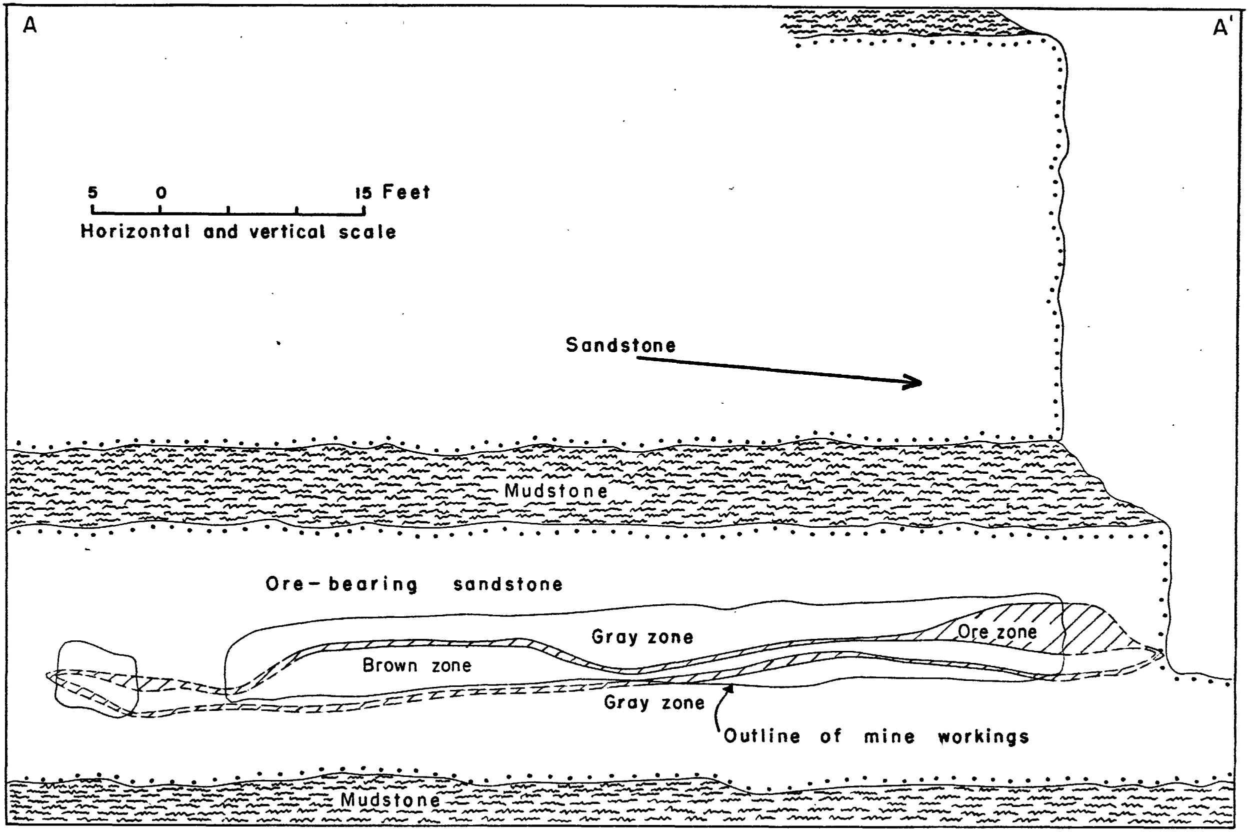


FIG. 12. — CROSS SECTION THROUGH THE LUCKY BOY MINE, MONTEZUMA CANYON, SAN JUAN COUNTY, UTAH, SHOWING ZONING OF THE DEPOSIT

solution flow. It is hypothesized that what is now the brown zone was once saturated with a reducing solution containing soluble organic compounds derived from the organic material. It is also hypothesized that the outermost zone was saturated with an oxidizing solution containing uranium and vanadium. As these two solutions reacted the ore metals diffused towards the brown zone and were reduced and precipitated in the ore layer. Weathering and oxidation has since altered the original primary minerals without noticeable leaching of the ore metals.

Zonation of the uranium-vanadium deposits is of economic interest as recognition of the presence and habit of these shells may be an aid to prospecting. In many mines and prospects ore has been mined either in the lower ore layer, the upper layer, or along part of the edge of an ellipsoidal ore shell, but in some places the possibility of finding more ore elsewhere along the edge of the brown zone has not been tested.

## La Sal Creek area, Colorado and Utah

by

W. D. Carter and J. L. Gualtieri

Geologic studies of and exploration for uranium-vanadium ore deposits in the Salt Wash member of the Morrison formation of Jurassic age in the La Sal Creek area (fig. 13) were started by the Geological Survey in 1952 and will be completed in the summer of 1957. The drilling program, which began in 1952 and was completed in 1954, outlined a favorable area known as the "La Sal Creek mineral belt", and discovered approximately 115,000 tons of indicated and inferred reserves, nearly half of which had been mined at the end of 1956. The potential reserves of the area are considered to be several times the figure quoted. Additional results of the program have been reported in TEI-540, p. 36-38, and TEI-620, p. 57-60.

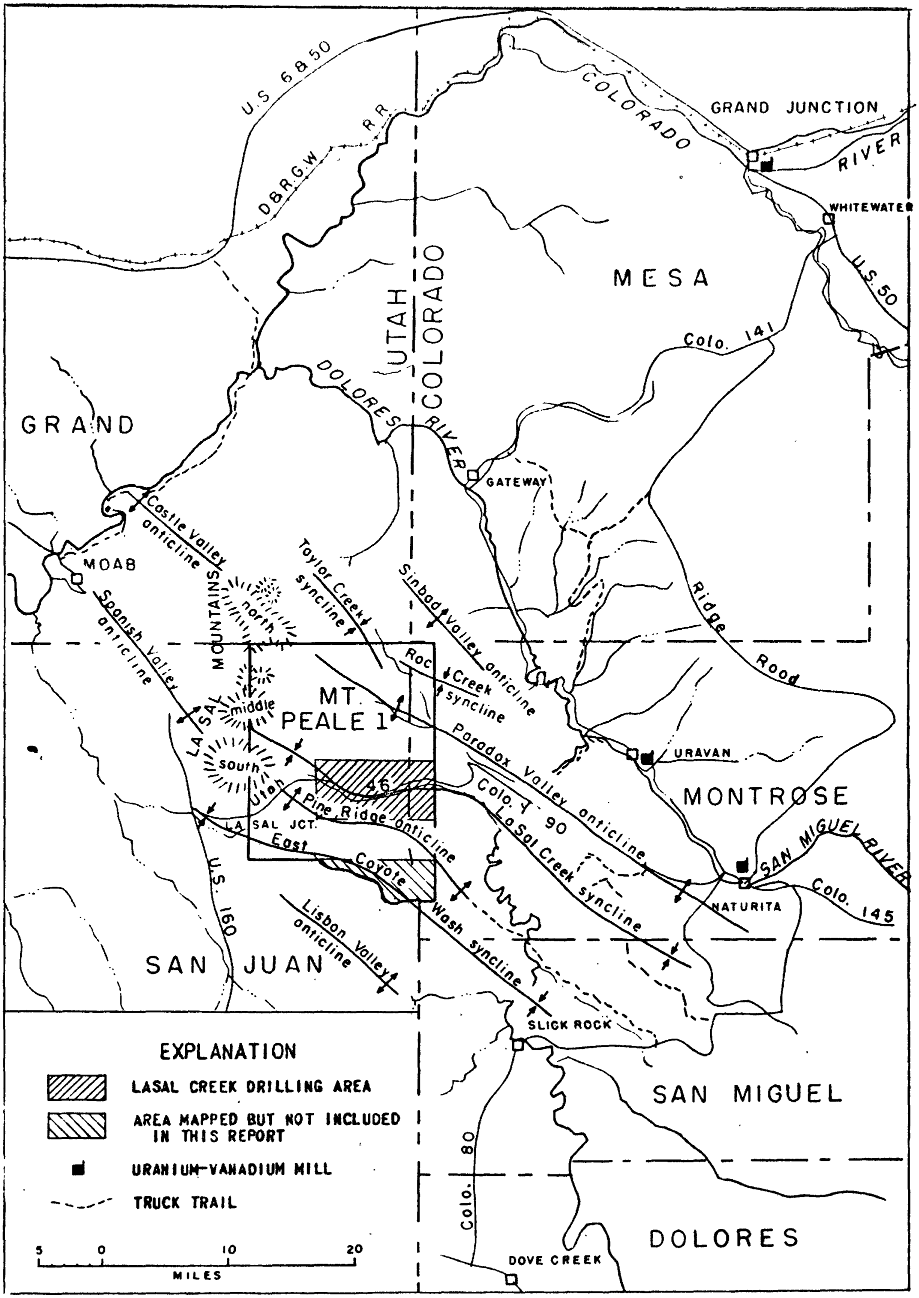


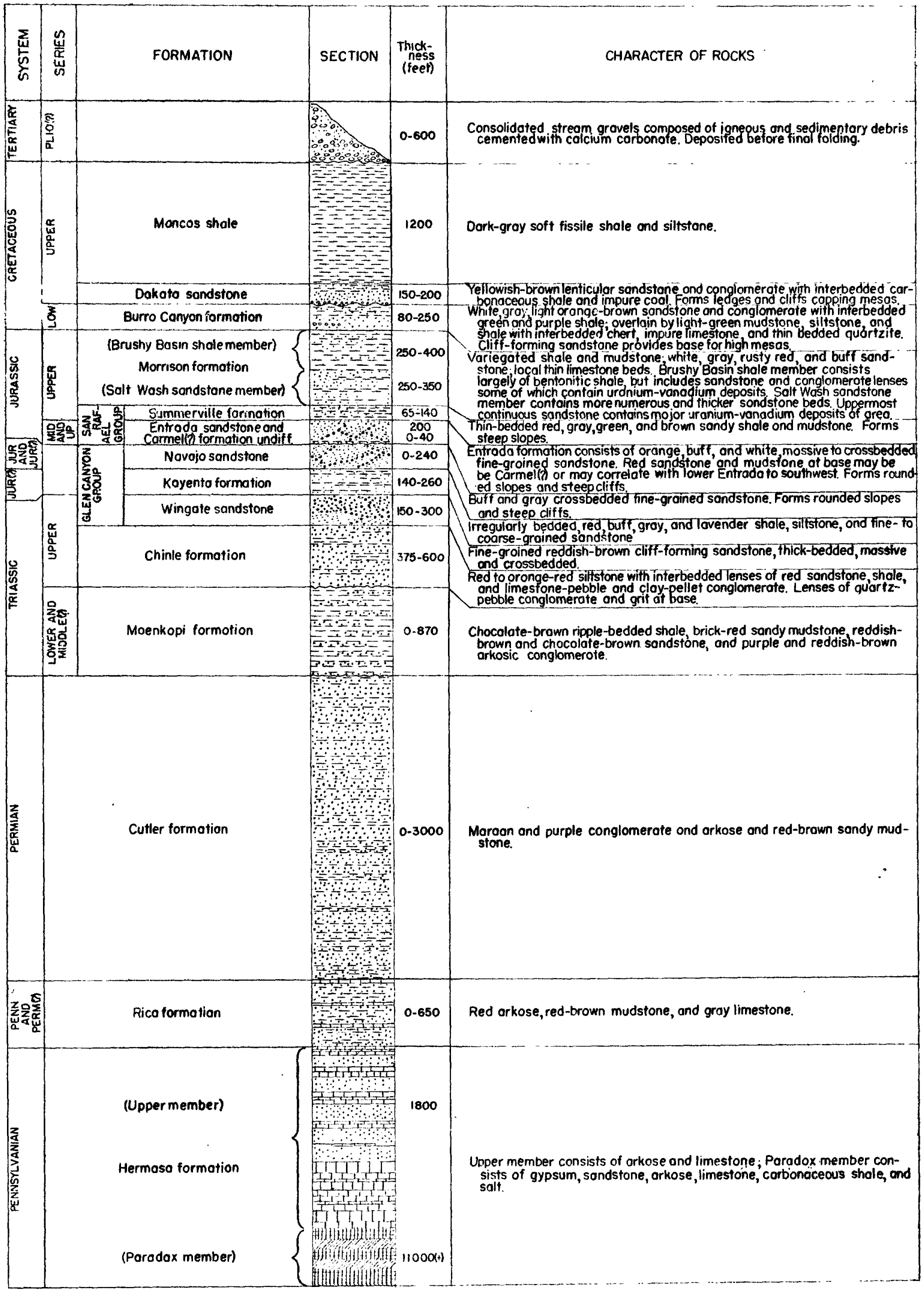
FIG. 13.—MAP SHOWING LOCATION OF THE MT. PEALE 1 QUADRANGLE, AND THE LASAL CREEK DRILLING AREA, SAN JUAN COUNTY, UTAH AND MONTROSE COUNTY, COLORADO.

Geologic mapping of the Mt. Peale-1 15-minute quadrangle (fig. 13), comprising approximately 240 square miles in San Juan County, Utah, and Montrose County, Colorado, was completed during the summer of 1956. The quadrangle contains, in its eastern part, portions of Sinbad and Paradox Valleys, which are collapsed and eroded salt anticlines now covered with broad sheets of alluvium. Sinbad and Paradox Valleys are surrounded by high cliffs composed of upturned sedimentary rocks. Near its western edge, the quadrangle includes part of the La Sal Mountains, the most prominent topographic feature of southeastern Utah. Elevations in the quadrangle range from 5,560 feet in the southeastern part to 12,721 feet on Mt. Peale, from which the quadrangle takes its name.

## Stratigraphy

The consolidated sedimentary rocks exposed in the mapped area range in age from Pennsylvanian to Tertiary and are described in the columnar section (fig. 14). In the western part of the area, these sediments were uplifted and intruded by laccolithic igneous rocks of late Cretaceous(?) and Tertiary age which form the core of the La Sal Mountains.

The oldest exposed sedimentary formation, the Hermosa formation of Pennsylvanian age, crops out in the floor of Sinbad Valley and consists of a highly deformed, uplifted intrusive core of plastic evaporite beds overlain by folded and faulted limestone beds. The Rico (Pennsylvanian and Permian(?)), Cutler (Permian), Moenkopi, Chinle, Wingate (all Triassic), and the Kayenta (Jurassic?) formations crop out along the margins of the floors of Sinbad and Paradox Valleys, in the cliffs surrounding those valleys, and in the hogbacks bounding the igneous rocks



| SYSTEM | SERIES | FORMATION | Thickness (feet) | CHARACTER OF ROCKS |
|---|---|---|---|---|
| TERTIARY | PLIO(?) |  | 0-600 | Consolidated stream gravels composed of igneous and sedimentary debris cemented with calcium carbonate. Deposited before final folding. |
| CRETACEOUS | UPPER | Mancos shale | 1200 | Dark-gray soft fissile shale and siltstone. |
|  |  | Dakota sandstone | 150-200 | Yellowish-brown lenticular sandstone and conglomerate with interbedded carbonaceous shale and impure coal. Forms ledges and cliffs capping mesas. |
|  | LOW | Burro Canyon formation | 80-250 | White, gray, light orange-brown sandstone and conglomerate with interbedded green and purple shale; overlain by light-green mudstone, siltstone, and shale with interbedded chert, impure limestone, and thin bedded quartzite. Cliff-forming sandstone provides base for high mesas. |
| JURASSIC | UPPER | Morrison formation<br>(Brushy Basin shale member)<br>(Salt Wash sandstone member) | <br>250-400<br>250-350 | Variegated shale and mudstone; white, gray, rusty red, and buff sandstone; local thin limestone beds. Brushy Basin shale member consists largely of bentonitic shale, but includes sandstone and conglomerate lenses some of which contain uranium-vanadium deposits. Salt Wash sandstone member contains more numerous and thicker sandstone beds. Uppermost continuous sandstone contains major uranium-vanadium deposits of area. |
|  | MID AND UP | SAN RAFAEL GROUP: Summerville formation | 65-140 | Thin-bedded red, gray, green, and brown sandy shale and mudstone. Forms steep slopes. |
|  |  | SAN RAFAEL GROUP: Entrada sandstone and Carmel(?) formation undiff. | 200<br>0-40 | Entrada formation consists of orange, buff, and white, massive to crossbedded fine-grained sandstone. Red sandstone and mudstone at base may be Carmel(?) or may correlate with lower Entrada to southwest. Forms rounded slopes and steep cliffs. |
| JUR AND JUR(?) |  | GLEN CANYON GROUP: Navajo sandstone | 0-240 | Buff and gray crossbedded fine-grained sandstone. Forms rounded slopes and steep cliffs. |
| JUR(?) |  | GLEN CANYON GROUP: Kayenta formation | 140-260 | Irregularly bedded, red, buff, gray, and lavender shale, siltstone, and fine- to coarse-grained sandstone |
| TRIASSIC | UPPER | GLEN CANYON GROUP: Wingate sandstone | 150-300 | Fine-grained reddish-brown cliff-forming sandstone, thick-bedded, massive and crossbedded. |
|  |  | Chinle formation | 375-600 | Red to orange-red siltstone with interbedded lenses of red sandstone, shale, and limestone-pebble and clay-pellet conglomerate. Lenses of quartz-pebble conglomerate and grit at base. |
|  | LOWER AND MIDDLE(?) | Moenkopi formation | 0-870 | Chocolate-brown ripple-bedded shale, brick-red sandy mudstone, reddish-brown and chocolate-brown sandstone, and purple and reddish-brown arkosic conglomerate. |
| PERMIAN |  | Cutler formation | 0-3000 | Maroon and purple conglomerate and arkose and red-brown sandy mudstone. |
| PENN AND PERM(?) |  | Rico formation | 0-650 | Red arkose, red-brown mudstone, and gray limestone. |
| PENNSYLVANIAN |  | Hermosa formation<br>(Upper member)<br>(Paradox member) | <br>1800<br>11000(+) | Upper member consists of arkose and limestone; Paradox member consists of gypsum, sandstone, arkose, limestone, carbonaceous shale, and salt. |

Fig.14 .--GENERALIZED COLUMNAR SECTION OF THE SEDIMENTARY ROCKS EXPOSED IN THE MT. PEALE 1 QUADRANGLE, UTAH-COLORADO

of North and South Mountains. The Navajo sandstone (Jurassic and Jurassic?), Entrada sandstone, Summerville formation and the Salt Wash member of the Morrison formation, all of Jurassic age, are exposed in fault blocks and cliffs surrounding the valleys, in the floors and cliffs of the deeper canyons, in the hogbacks of North and South Mountains, in outcrops within the Middle Mountain group and as an isolated block on top of Mt. Peale. The Brushy Basin member of the Morrison crops out on benches bordering deep canyons and in the more shallow canyons separating mesas capped by the Burro Canyon formation and Dakota sandstone of Cretaceous age which cover much of the area. The Mancos shale (Upper Cretaceous) crops out in synclinal folds such as those in La Sal and Geyser passes and along Geyser and Deep Creeks.

A consolidated conglomeratic sandstone composed of reworked fossiliferous Mancos shale, sandstone pebbles, boulders derived from rocks of almost the entire stratigraphic sequence, and igneous rock debris rests on folded beds of the Mancos along Geyser and Deep Creeks in the Taylor Creek syncline. This unit, for convenience here called Deep Creek conglomerate, is estimated to be as much as 600 feet thick near the synclinal axis. The beds are also folded, dipping westward as much as 25° toward their source in the mountains. The so-called Deep Creek conglomerate is overlain by unconsolidated gravels correlative with Richmond's (1957) Harpole Mesa formation, the oldest Quaternary formation in the La Sal Mountain region, and is therefore thought to be of Tertiary age and probably correlative with Hunt's (1956, p. 30) Castle Valley conglomerate which he believes to be of Pliocene age. Deposition of the so-called Deep Creek conglomerate, however, may have begun as early as or prior to Miocene time when the youngest igneous intrusions (date based on zircon age determinations by Howard Jaffe, U. S. Geological Survey) of North Mountain breached the surface and erupted exposively (Hunt, 1956, p. 43). Faulting along the crest of North Mountain and erosion of the overlying sediments may have facilitated such explosive action.

## Igneous rocks

The igneous rocks exposed in the map area consist of dioritic porphyries with hornblendic inclusions, and occur as stocks, dikes, sills, laccoliths, and bysmaliths. These rocks have been described by Gould (1926) and more recently by Hunt (in press) who describes two additional periods of intrusion, later than that of the dioritic rocks, marked by the presence of porphyritic monzonite and syenite. As the igneous rocks have already been studied in considerable detail, the La Sal Creek project was concerned mainly with the relationship of the igneous rocks to the structure of the surrounding sediments and to the uranium deposits in the area.

## Structure

The most prominent structural features in the area are the anticlinal uplifts of North and South Mountains, the intervening domal uplift of Middle Mountain and the collapsed anticlines of Sinbad and Paradox Valleys. These features trend N. 45°-60° W. North and South Mountains connect, respectively, the Paradox-Castle Valley and Gypsum-Spanish Valley anticlinal folds which were formed by periodic uplift of deformed plastic evaporites. Intrusive salt and gypsum masses are also believed to have formed the Pine Ridge anticline and Wray Mesa dome which lie between and connect the South Mountain and Gypsum Valley anticlinal structures. Between these major structures the sediments are gently folded into minor anticlines and synclines which, in many places, are faulted due to intrusion of igneous masses or to intrusion and collapse of plastic evaporites. The major faults, probably the result of tensional forces, parallel the crests of the anticlinal folds and a secondary set, of similar origin, are roughly perpendicular to the major set. Two rotational faults resulted from uplift by two intrusive masses located on opposite ends and on opposite sides of the fault plane. In the Middle Mountain area faults and fractures radiate from a central stock. Many of these fractures have been intruded by diorite porphyry dikes; others make the lateral limits of intrusive laccolithic lobes.

The structural history of the Mt. Peale-1 quadrangle is an integral but small part of the history of the Colorado Plateau in which changes of thickness and extent of sedimentary formations and angular, erosional surfaces along portions of their contacts, especially near salt anticlines, mark the periods of structural development. Uplift of the northwest-trending Uncompahgre arch, a highland of Precambrian rocks, at the end of the Pennsylvanian period was accompanied by faulting on its southwestern flank and rapid deposition of the arkosic sandstones and conglomerate of the Cutler formation of Permian age. The weight of these thick sediments along the southwest flank of the Uncompahgre appears to have iniatiated plastic flowage of the underlying evaporites of Pennsylvanian age, causing thinning near the Precambrian granitic arch and increased thicknesses farther away. The spacing and trend of the resultant anticlines may have been largely controlled by faults in the basement complex. Once the pattern was set it appears that individual salt plugs and sometimes clusters of them were uplifted in a fashion that was spasmodic both in time and geographical area. In general, however, the greatest anticlinal development took place during Permian through Middle Triassic time and in Late Cretaceous-Early Tertiary time. Between these periods of deformation these is local evidence of minor uplifts during Late Triassic, Early Jurassic, and possibly Late Jurassic time. Accompanying Late Cretaceous-Early Tertiary folding were intrusive igneous magmas which rose along faults from depths below the pre-Pennsylvanian basement and formed the laccolithic mountains of the Colorado Plateau. Of these, the La Sal Mountains form an isolated group consisting of three intrusive centers aligned along a north-south trend. The large laccolithic intrusions surrounding the north and south centers have uplifted the entire stratigraphic sequence from the Rico (in part, the upper Hermosa limestone) through the Mancos formation. In general the intrusions lie within and conform in shape and orientation to pre-existing anticlinal folds. The domal uplift of the Middle Mountain intrusive mass within the intervening syncline, however, presents a wider variety of geologic forms and structures.

Studies of the structural relationships between the sedimentary rocks and the laccolithic bodies of Middle Mountain suggest that there may be an inverse relationship between the stratigraphic position and order of emplacement of the various laccolithic lobes. For example, the Mt. Mellenthin laccolith, intruded in the Mancos shale, is on the downthrown side of an arcuate fault which separated it from the Mt. Peale bysmalith, and from the Two Mile Creek and Blue Lake laccoliths to the south and east. The Mt. Peale bysmalith, on the other hand, is on the upthrown side of the fault and is capped by beds of the Navajo(?), Entrada, Summerville, and Morrison formations. The Mt. Peale bysmalith, the adjacent Two Mile Creek laccolith, and possibly the Blue Lake laccolith appear to have been intruded along or below the Kayenta-Navajo contact. It appears that the Mt. Mellenthin laccolith formed first, intruding the most incompetent sediments within the syncline. The highly viscous nature of the magma and the load of the igneous mass may have combined to seal off the channels along which it had risen and thus forced later magmatic surges along less resistant avenues at lower stratigraphic horizons. Such a process combined with a radial fault and fracture pattern around the central stock may well account for both the radial and vertical distribution of the laccoliths.

### Ore deposits

Most of the 27 mined deposits in the map area are within the uppermost continuous sandstone of the Salt Wash member of the Morrison formation of Jurassic age. The Hesperus, Uranium Girl, and portions of the Maud mine are in a thin, lenticular sandstone situated a few feet above the main ore-bearing unit, but are within the Salt Wash. The Brushy Basin No. 1 and 2, Lucky No. 1, Sumner, and Too High deposits are contained in thin, lenticular conglomeratic sandstone of the overlying Brushy Basin member. The Jackpot mine is in a highly faulted area and is considered to be contained in a fault block of Wingate sandstone of Triassic age.

The principal ore-bearing sandstone of the Salt Wash is composed of very fine to medium-coarse grains of subrounded to angular quartz with minor amounts of red and green chert and black opaque accessory minerals, cemented together largely by carbonate minerals, and, in places, by silica. The sandstone ranges from a knife edge to about

100 feet in thickness and is a composite of many sandstone lenses of differing thickness and extent. Many of these are separated by layers of mudstone ranging from microscopic films to several feet in thickness.

Uranium-vanadium deposits occur as individual ore bodies or clusters of ore bodies in areas between the thickest parts of sandstone lenses and where the lenses begin to thin rapidly. The largest and the greatest number of ore bodies are situated near the base of the sandstone and appear to have been localized along an ancient stream channel. Drilling and mine mapping indicate that carbonaceous debris accumulated in or near stream scours bordered by cusps projecting into meandering channels. This debris, where accompanied by crossbedding in the sandstone, appears to have provided the proper environment to serve as centers within and around which ore elements in solution were concentrated and eventually precipitated. Localization appears to have been due largely to primary sedimentary structures in the sandstones. Fractures and faults in the area appear to be post-ore and are related only to deposits of oxidized minerals considered to be of later origin than the major deposits.

The ore minerals impregnate sandstone and replace fossil logs and finer carbonaceous debris; they are contained in flat-lying tabular layers, rolls, and pod-like ore bodies. A large suite of uranium, vanadium, and accessory minerals representative of both unoxidized and oxidized deposits has been identified. In most cases, the degree of oxidation in the deposits is indicated by the ratio of vanadium to uranium contained in the ore. In the La Sal Creek area these V:U ratios range from 4:1 to 14:1 and average about 6:1.

## Origin

Mapping revealed no evidence that the ore minerals of the La Sal Creek area were deposited from solutions associated with the La Sal Mountain intrusions. Study of a recently discovered occurrence of extremely small concentrations of radioactive asphaltitic(?) material near native silver in sandstone of the Chinle formation in the Cashin copper mine (just east of the map area) may indicate the presence of minerals possibly deposited by hypogene solutions. This occurrence, which suggests either a hypogene or petroliferous source for the metals, has not yet been directly associated with the major uranium-vanadium deposits of the area.

Any hypothesis of origin for the uranium-vanadium deposits in the La Sal Creek area must account for the following geologic relationships: (1) the deposits are contained in channel-type sandstone beds, and localization of the deposits is largely by sedimentary structure; (2) the deposits lie as clusters within a favorable belt-like area within channel scours of a major Salt Wash stream which can be traced or projected to other channel deposits in the surrounding area; (3) the distribution of deposits shows no relationship to any structural features, and where faults and fractures transect, or are close to, ore bodies the unoxidized minerals appear to be of earlier origin; and (4) recent discoveries of ore deposits and ground favorable for deposits near the igneous bodies of the La Sal Mountains have not shown any zonal arrangement of uranium-vanadium and copper deposits.

The following report was published during the report period:

Carter, W. D., 1957, Disconformity between Lower and Upper Cretaceous in western Colorado and eastern Utah: Geol. Soc. America Bull., v. 68, p. 307-314.

## References

Carter, W. D., 1956, The Burro Canyon-Dakota contact in the Mt. Peale No. 1 quadrangle, western Colorado and eastern Utah: Intermountain Assoc. of Petroleum Geologists 7th Ann. Field Conference Guidebook, p. 113-115.

_______, 1957, Disconformity between Lower and Upper Cretaceous in western Colorado and eastern Utah: Geol. Soc. America Bull., v. 68, p. 307-314.

Gould, L. M., 1956, The geology of the La Sal Mountains, Utah: Michigan Acad. Sci. Papers, v. 7, p. 55-106.

Hunt, C. B., 1956, Cenozoic geology of the Colorado Plateau: U. S. Geol. Survey Prof. Paper 279.

_______, in press, Structural and igneous geology of the La Sal Mountains, Utah: U. S. Geol. Survey Paper.

Richmond, G. M., in press, Pleistocene and Recent geology of La Sal Mountains, Utah: U. S. Geol. Survey Prof. Paper.

## Lisbon Valley, Utah-Colorado

by

G. W. Weir, V. C. Kennedy,
C. L. Dodson, and W. P. Puffett

Geochemical studies during the report period have been devoted mainly to preparation of samples for analysis, study of analytical results received, and a comparison of ore-bearing and barren rocks from the lower part of the Chinle formation.

The locations of mines that have produced ore from the Chinle formation in the Big Indian mining district are shown in figure 15. The $V_2O_5$:$U_3O_8$ ratios calculated from production records through 1956 are also shown. In general, the $V_2O_5$:$U_3O_8$ ratios decrease northwestward and downdip (toward the southwest); however, the rate of change of the ratio is much greater in the downdip direction. Even within the Mi Vida, the largest mine in the area, there is a definite difference in the ratio between the downdip and updip part of the ore

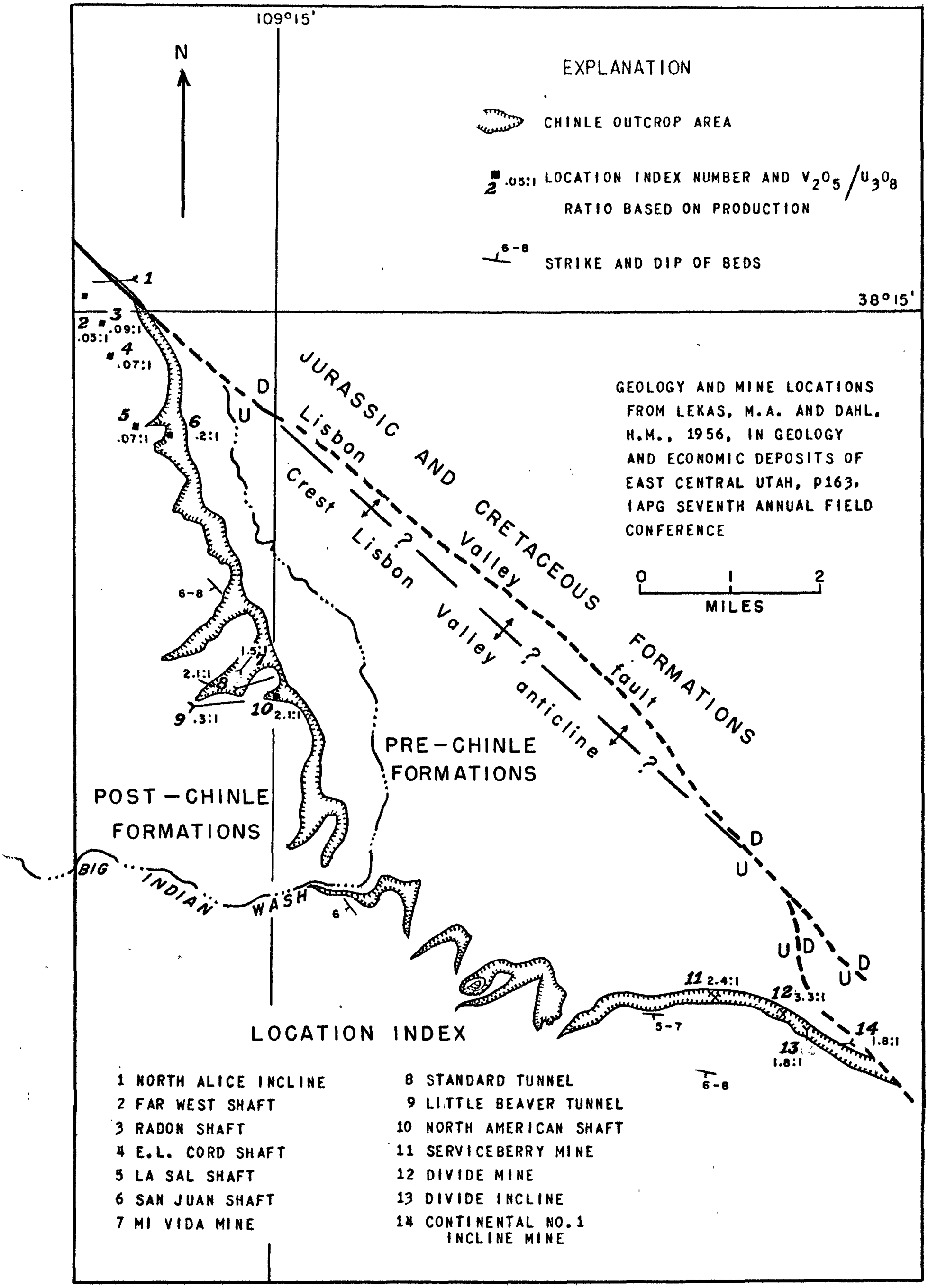
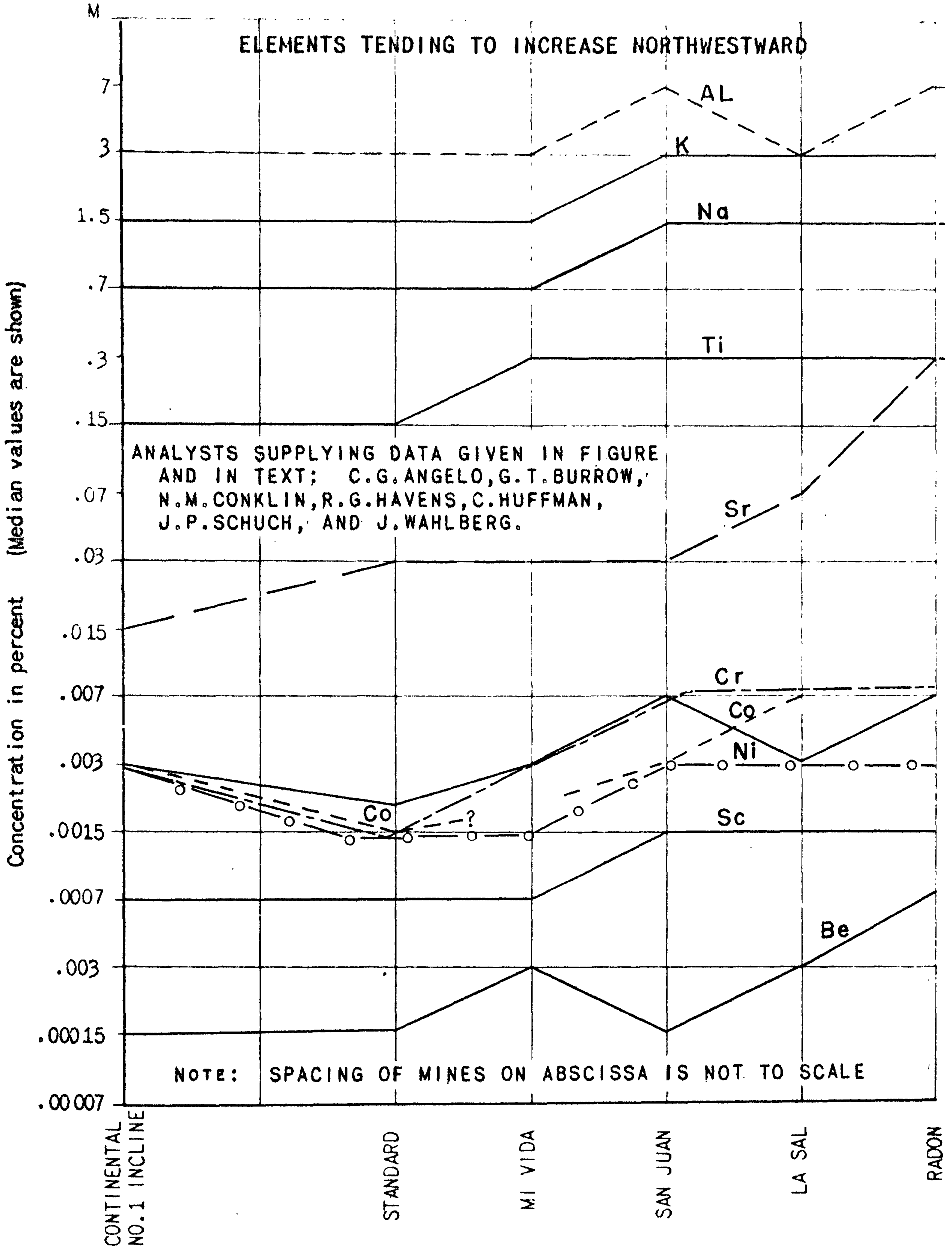


FIG. 15.--SKETCH MAP OF BIG INDIAN WASH AREA SHOWING LOCATION

body (N. E. Salo, U. S. Atomic Energy Commission, oral communication).

Analytical results from mill pulps representing six of the mines are summarized in figures 16, 17 and 18. Only vanadium, molybdenum, and strontium tend to change markedly in concentration from the southeast to the northwest part of the district—a distance of about 10 miles (figs. 16 and 17). Both vanadium and molybdenum show a pronounced decrease to the northwest whereas strontium increases to the northwest. The vanadium is present in most of the mines as vanadium clays and montroseite (T. Botinelly, U. S. Geological Survey, oral communication). Molybdenum occurs in the unoxidized ores as jordisite (colloidal $MoS_2$?, identified by E. J. Young, U. S. Geological Survey, written communication, 1956) and as molybdenite (T. Botinelly, oral communication). On oxidation the molybdenum sulfides react to form ilsemannite ($Mo_3O_8 \cdot nH_2O$?) which occurs as a blue coating on some of the ore in the Continental Incline No. 1 mine and at the Divide incline. No molybdenum minerals have been reported in ores from mines north of the Mi Vida. Strontium, which is low (0.01 to 0.02 percent) in mines in the southeastern part of the district, increases to a maximum of 0.7 percent in one mill pulp from the Radon ore body. Coarsely crystalline celestite occurs along a fault in the Radon mine (E. B. Gross, U. S. Atomic Energy Commission, oral communication).

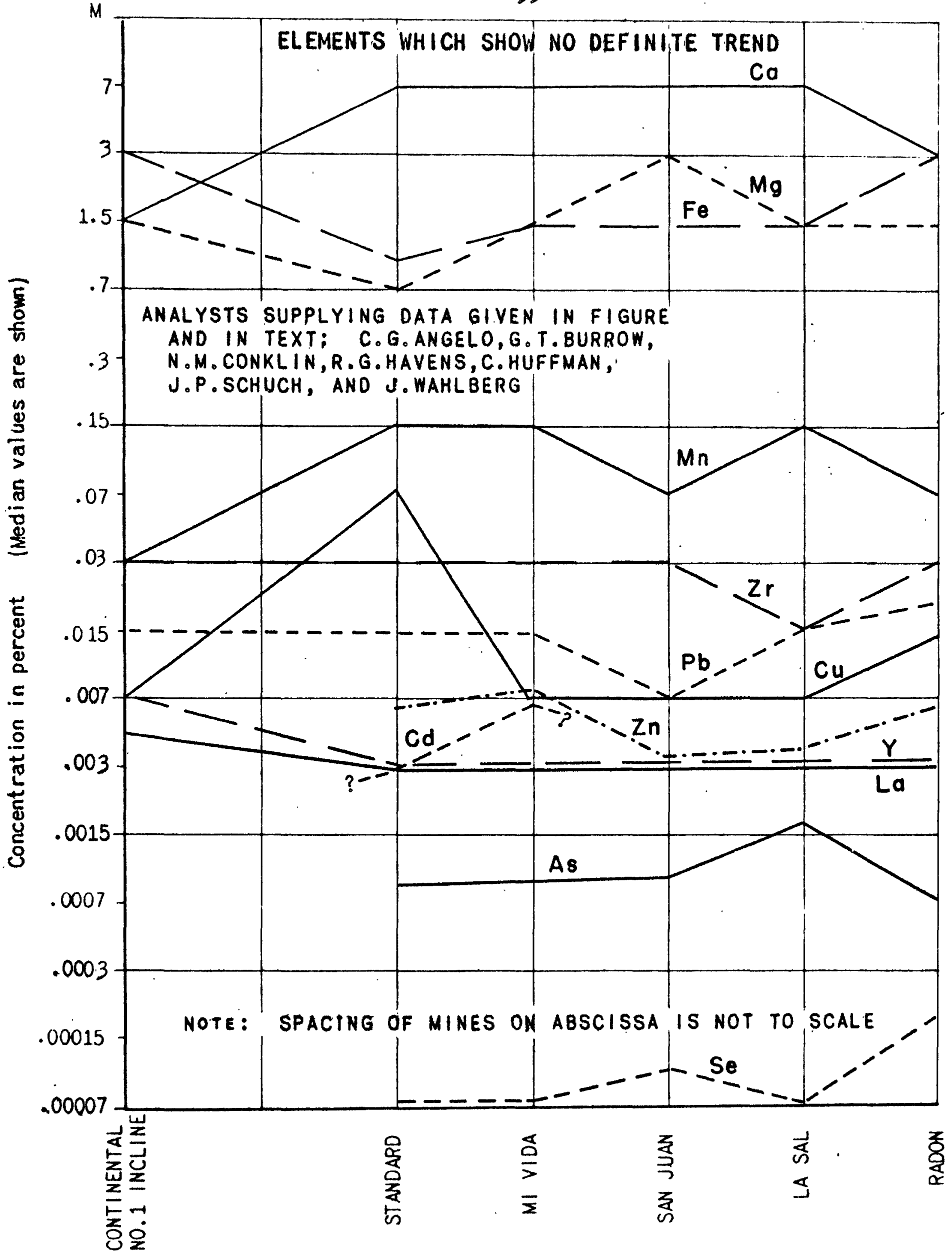
Lead, copper, and cadmium are present in some ore bodies in anomalous amounts; and galena, native copper, chalcopyrite, malachite, azurite, and greenockite (CdS) have been recognized in the ores. These elements, however, do not show a systematic change in concentration from the southeastern to the northwestern part of the district. Galena has been identified in the Continental Incline No. 1 mine, the Mi Vida



ANALYSTS SUPPLYING DATA GIVEN IN FIGURE AND IN TEXT; C.G.ANGELO, G.T.BURROW, N.M.CONKLIN, R.G.HAVENS, C.HUFFMAN, J.P.SCHUCH, AND J.WAHLBERG.

NOTE: SPACING OF MINES ON ABSCISSA IS NOT TO SCALE

Fig. 16.--PRELIMINARY RESULTS OF ANALYSIS OF MILL PULPS FROM BIG INDIAN WASH, SAN JUAN COUNTY, UTAH.



ELEMENTS WHICH SHOW NO DEFINITE TREND

ANALYSTS SUPPLYING DATA GIVEN IN FIGURE AND IN TEXT; C.G.ANGELO, G.T.BURROW, N.M.CONKLIN, R.G.HAVENS, C.HUFFMAN, J.P.SCHUCH, AND J.WAHLBERG

NOTE: SPACING OF MINES ON ABSCISSA IS NOT TO SCALE

Fig. 17.--PRELIMINARY RESULTS OF ANALYSIS OF MILL PULPS FROM BIG INDIAN WASH, SAN JUAN COUNTY, UTAH.

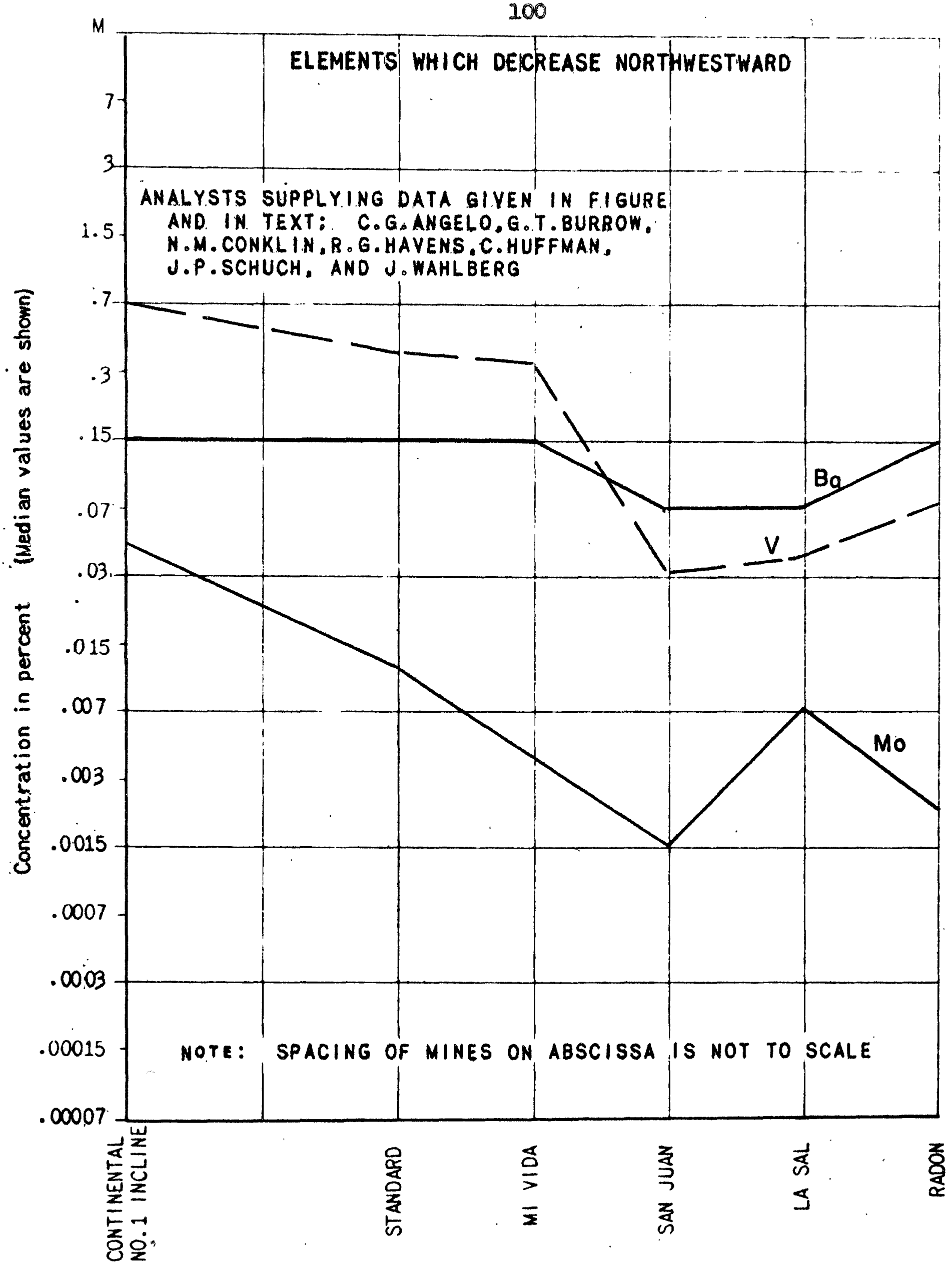


Fig.18.--PRELIMINARY RESULTS OF ANALYSIS OF MILL PULPS FROM BIG INDIAN WASH, SAN JUAN COUNTY, UTAH.

mine, and the La Sal shaft, and probably is present in other mines. Native copper and chalcopyrite occur in ore from the Standard mine; chalcopyrite is locally concentrated in the Mi Vida; and one sample high in chalcopyrite has been obtained from the Radon mine. Malachite and azurite commonly occur with the copper sulfides. Greenockite, to the writers' knowledge, has been found only in fossilized logs from the Mi Vida mine (E. B. Gross, oral communication).

Slight to moderate increases in the Al, B, Be, Cr, K, Na, Ni, Sc, and Ti content of the ores northwestward in the district suggest that the average grain size of the ore tends to decrease toward the northwestern part of the district as these elements are known to increase with decreasing grain size (Rankama and Sahama, 1950, p. 226).

Mine studies indicate that the boundary between completely barren rock and ore is generally sharp in the uranium-vanadium mines, but relatively few data are available to determine how sharp this boundary is for elements other than uranium and vanadium. Nonradioactive carbonaceous material near ore may contain unusual amounts of elements other than uranium, which might possibly form a "halo" of elements derived from the solution that deposited the uranium ore. Carbonaceous material in many places forms the core of high-grade ore masses, suggesting that such material was more reactive to the ore solutions than ordinary rock. If a "halo" is present around the ore, it should be readily detected in carbonaceous material. In a study of this problem a "barren" log—which was actually very slightly radioactive—in contact with high-grade uranium-vanadium ore in the Standard mine was compared in chemical composition with two samples of highly carbonaceous rock collected from drill core believed to be more than 1,000 feet from any mineralized area.

Each of the three samples were separated into six fractions on the basis of specific gravity, and fractions of equal specific gravity were compared chemically. The concentrations of the rare earths yttrium and ytterbium were higher by a factor of 5 to 10 times in fractions of organic material near ore than in similar fractions far from ore. Niobium was detected in the organic fractions near ore but not in most organic fractions far from ore. The concentrations of other elements in the organic material near ore were the same as or lower than that of organic material far from ore. Further work may indicate how far from uranium-vanadium ore anomalous concentrations of yttrium and ytterbium can be detected.

Vanadium and barium concentrations are higher in the mineral fraction of the sample near ore than in the mineral fraction far from ore, but vanadium and barium in the organic fractions near ore do not show a corresponding increase. Apparently, vanadium and barium, although available to the organic material near ore, were not precipitated to any great extent as metallo-organic compounds.

Analyses for uranium and equivalent uranium are available only for the fractions of the carbonaceous sample collected near ore. In the organic fractions the ratio of chemical uranium to its daughter products is high as indicated by U:eU ratios of 11:1 and 4:1. In the heavy mineral fractions, on the other hand, the daughter products are high relative to the uranium present and this is indicated by U:eU ratios of 0.02:1 and 0.2:1. Radioactivity analyses by John N. Rosholt (U. S. Geological Survey, written communication) indicate that most of the radioactivity in the heavy mineral fraction having a U:eU ratio of 0.2:1 is due to $Ra^{226}$, $Rn^{222}$, and $Pb^{210}$. This suggests that radium derived from the nearby ore may have been precipitated on barite present in the fossilized log. $Rn^{222}$ and $Pb^{210}$ are the daughter products of the $Ra^{226}$.

As part of the comparison of ore with barren rock in the Big Indian Wash area a study was made of ore samples, and of barren core from 45 drill holes, most of which are downdip from the producing area. The results of the study indicate that the ore is in, or closely associated with, highly quartzose sandstones of the basal part of the Chinle formation that have a median grain size that is fine to medium or coarser. This is in contrast to the barren core that commonly is composed of mudstone, siltstone, very fine to fine-grained sandstone, calcarenite, and mud or lime pebble conglomerate.

The following report on the minor structures in Lisbon Valley area was published during the report period:

Weir, G. W., Puffett, W. P., and Dodson, C. L., The collapse structure in Spanish Valley, San Juan and Grand Counties, Utah (abstract): Geol. Soc. America (53rd Ann. Meeting, Los Angeles, California, April 1957).

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

# Moab-Inter-river area, Utah

by

E. N. Hinrichs and W. J. Krummel, Jr.

Field work in the Moab-Inter-river area, Utah, which began in 1954, has been essentially finished and the project is scheduled for completion by July 1957.

More than 35 uranium deposits of both the bedded and fault-controlled types have been found in the Moab-Inter-river area, but less than a dozen have proved commercial. The deposits occur in the Rico formation of Pennsylvanian and Permian(?) age, the Cutler formation of Permian age, and the Chinle formation of Triassic age. The largest ore producers are in the Moss Back member of the Chinle formation. The two largest deposits are aligned on the south-southeast side of a structural terrace, shown by the 6,000-foot depression structural contour, along Indian Creek (fig. 19). The uranium deposits occur in and along west-northwest trending channels cut 10 to 15 feet into the Moenkopi formation. Throughout the area the Moss Back member of the Chinle formation is a gray conglomeratic sandstone, with minor amounts of siltstone and claystone. Within a few thousand feet of the two largest deposits are several masses of Moss Back which are red and brown due to hematite and goethite. These minerals probably formed as alteration products of pyrite. Spectrographic analyses of samples from near one of the largest deposits indicate that a zone of anomalously high barium and cobalt occurs within 10 to 40 feet of the deposit. The ore consists chiefly of uraninite, pyrite, sparse sphalerite, and galena. It is high in lime and low in vanadium and copper. The uraninite is associated with the younger of two generations of pyrite. Some of the

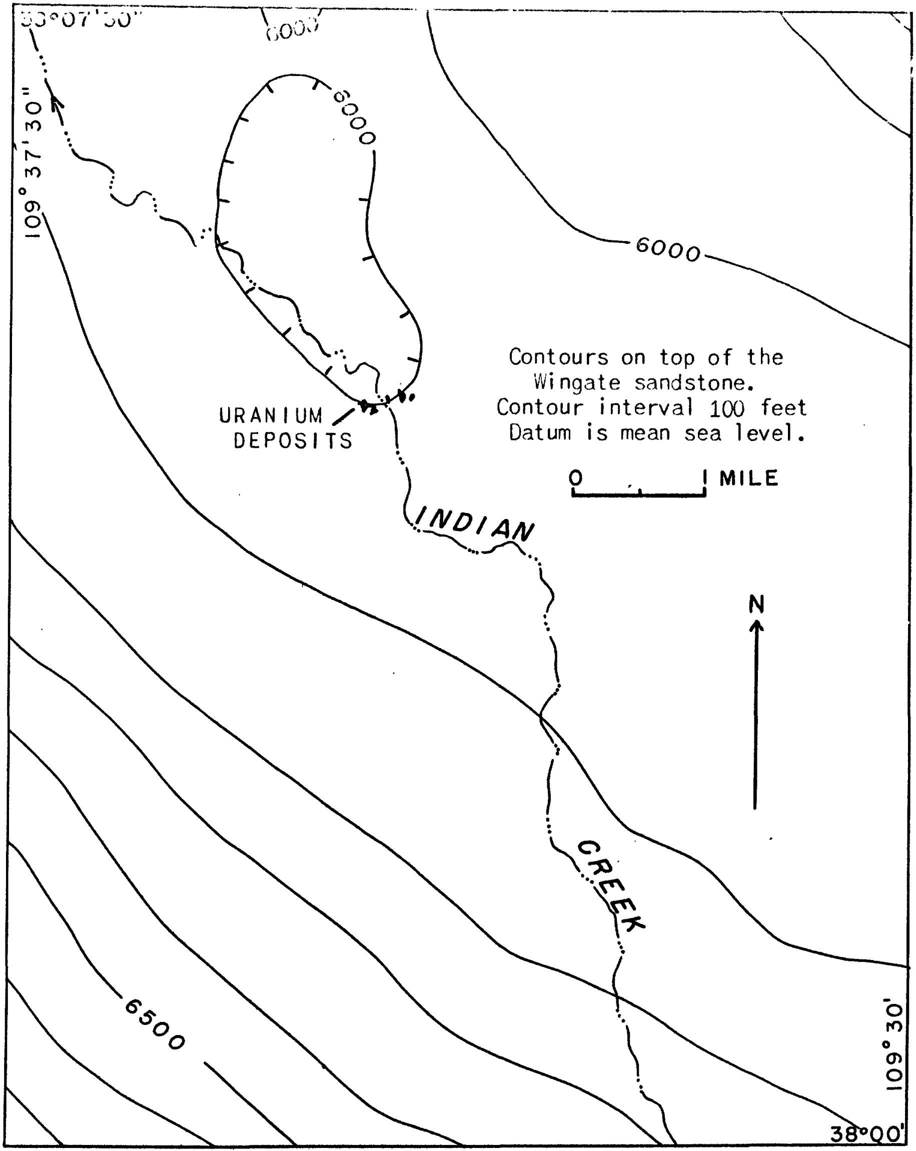


FIG. 19.--STRUCTURE CONTOUR MAP OF THE CARLISLE 4 SE QUADRANGLE, SHOWING URANIUM DEPOSITS ON A STRUCTURAL TERRACE, SAN JUAN COUNTY, UTAH.

younger pyrite is intergrown with cobaltite. Ilsemannite and bieberite appear on the rims of a few carbonaceous logs exposed to the air. The ore contains 2-3 percent iron, whereas barren Moss Back rock contains 0.5-1 percent iron. Most of this iron is probably in the form of pyrite. These pyritiferous deposits are relatively shallow, are being oxidized, and could perhaps be detected by temperature prospecting in dry shallow drill holes.

Asphaltite and petroliferous rocks are closely associated with uranium deposits on the crests of two oil- and gas-bearing anticlines. Oxidized uranium-vanadium-copper deposits with common asphaltite and barite occur along faults on the Cane Creek anticline. Tyuyamunite is disseminated in a bed of petroliferous sandy limestone in the Rico formation on the closely jointed crest of the Gibson anticline. Asphaltites, oil, and brine from the Paradox member of the Hermosa formation contain percentages of barium, chromium, strontium, and vanadium comparable to those in the uranium deposits. The Paradox is very possibly the source of the carbon compounds and vanadium in the deposits; vanadium in the ash of oil from wells on the Cane Creek anticline is as high as 5 percent.

Small oxidized copper-uranium deposits that lack conspicuous carbon compounds are numerous in the Cutler formation, particularly on the northern flanks of the Gibson and Lockhart anticlines. This distribution can perhaps be explained by the action of hydrogen sulfide that rose along joints and faults on the anticlines, dissolved in ground water, and flowed to the northeast down the regional dip. Uranium in the ground water could have been reduced and precipitated by hydrogen sulfide (Grutt, p. 5).

Reference

Grutt, E. W., Jr., 1957, Environment of some Wyoming uranium deposits: Am. Inst. Min. Met. Eng. Special Paper no. 57-NESC-69.

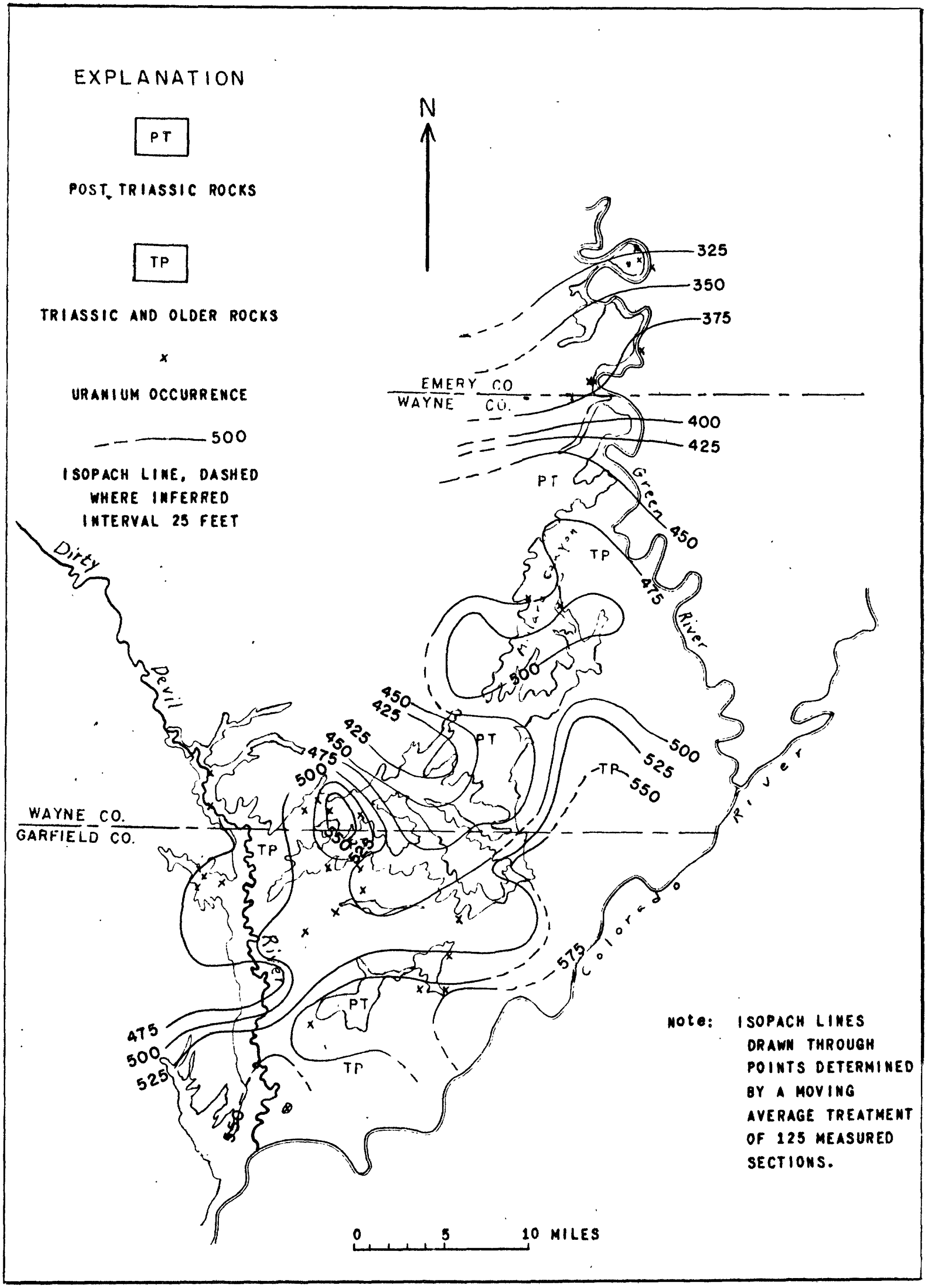
## Orange Cliffs, Utah

by
F. A. McKeown, P. P. Orkild, H. B. Dyer,
and R. W. Hallagan

Geologic mapping in the Orange Cliffs area was started in 1955. Photogeologic techniques have been used in conjunction with field mapping in the area of sixteen 7½-minute quadrangles and have proven most useful. The program will continue into next year, being scheduled for completion in the summer of 1958.

During the report period emphasis has been placed on study of regional guides to uranium deposits in the Orange Cliffs area. As part of this study, several isopach maps of various units were constructed; maps of the Chinle formation and its members, the Monitor Butte and Moss Back, are included in this report.

All of the uranium occurrences in the Orange Cliffs area are at or within about 20 feet of the Moenkopi-Chinle formational contact. The isopach maps do now show any clear-cut relation of uranium occurrences to regional variations in thickness or to pinchouts. A slight congruity of occurrences with the thick lobes of sediments of the Chinle formation trending east-west south of the Garfield-Wayne County line is suggested (fig. 20). A possible spatial relationship of uranium occurrences to the 40- and 60-foot isopach lines is also suggested in both figures 21 and 22. These associations, however, are not now considered significant.



Note: ISOPACH LINES DRAWN THROUGH POINTS DETERMINED BY A MOVING AVERAGE TREATMENT OF 125 MEASURED SECTIONS.

FIG. 20.--ISOPACH MAP OF THE CHINLE FORMATION IN THE ORANGE

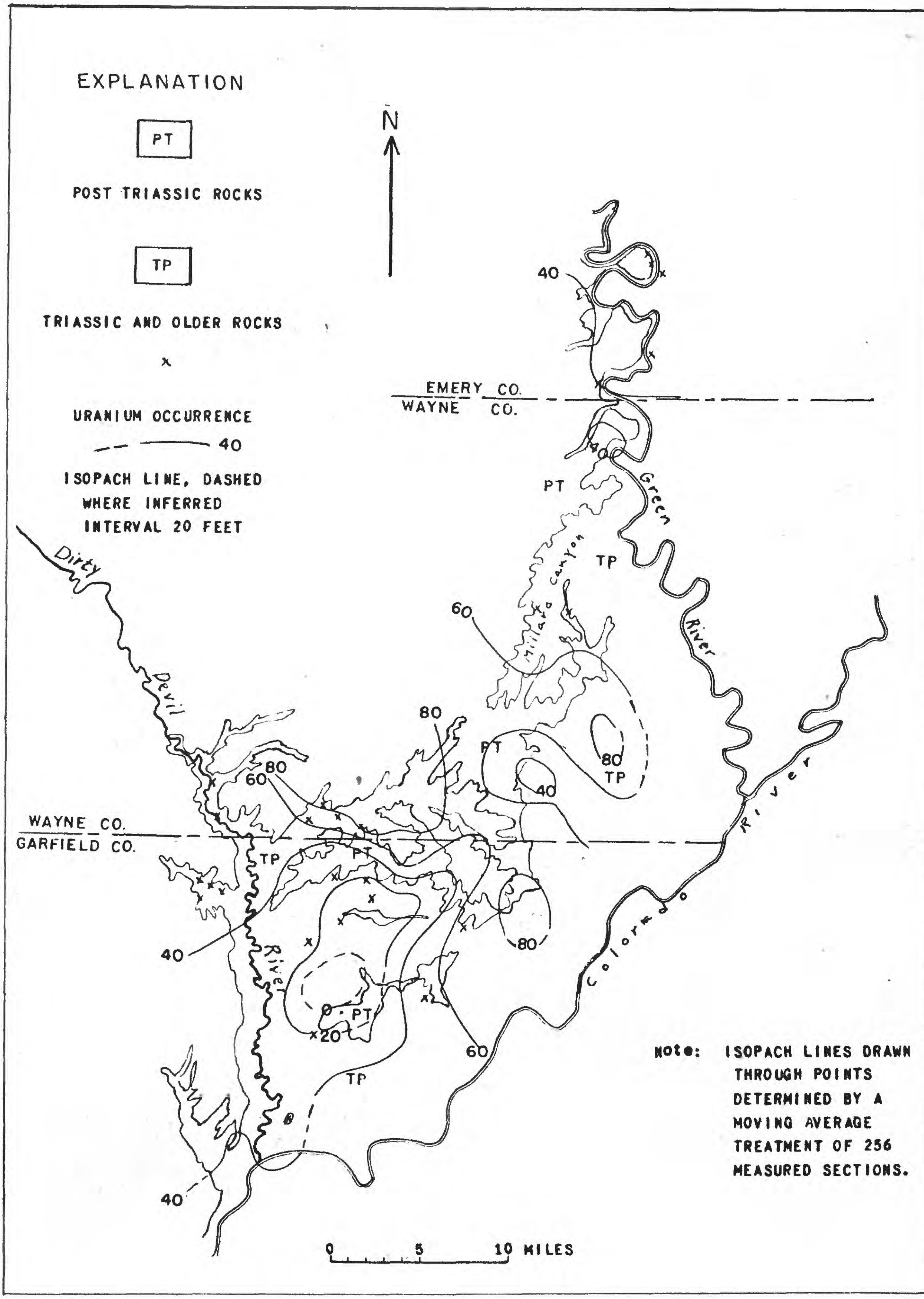


FIG. 21 .--ISOPACH MAP OF THE MOSS BACK MEMBER OF THE CHINLE FORMATION IN THE ORANGE CLIFFS AREA, EMERY, WAYNE AND GARFIELD COUNTIES, UTAH.

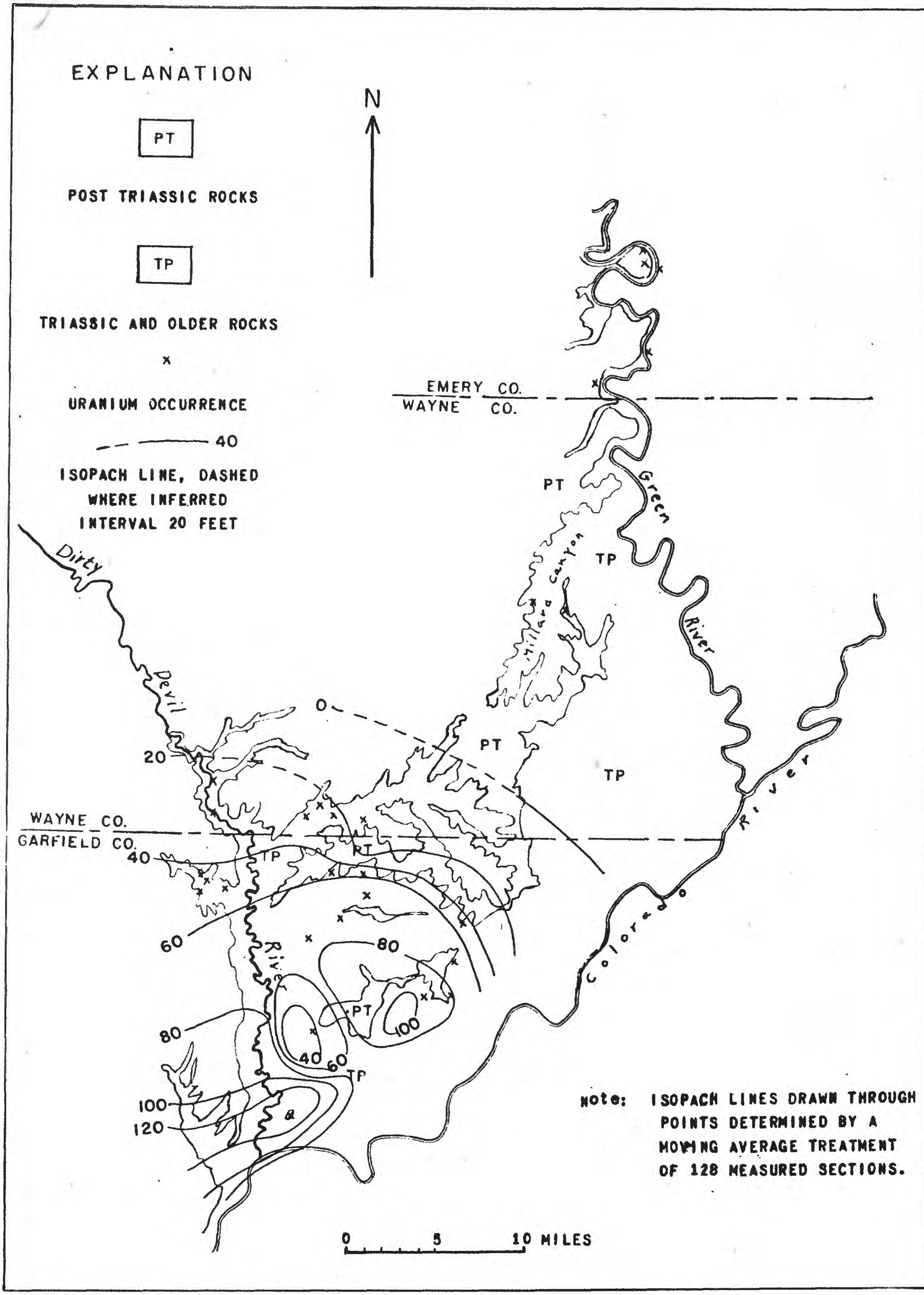


FIG. 22.--ISOPACH MAP OF THE MONITOR BUTTE MEMBER OF THE CHINLE FORMATION IN THE ORANGE CLIFFS AREA, EMERY, WAYNE AND GARFIELD CO NTIES, TAH.

The isopach maps support certain interpretations previously made regarding the sources and lateral variations of the rocks of the Chinle formation. Figure 20 indicates that the source of sediments of the Chinle formation was to the southeast, as the total thickness of the formation increases in that direction.

Figure 21 indicates that the Moss Back member of the Chinle formation thickens toward both the southeast and northwest. Measurements of the direction of cross-strata, however, show that streams that deposited the sediments of the Moss Back member generally flowed to the west or northwest in the Orange Cliffs area, indicating that the source of the Moss Back was to the southeast. The Monitor Butte member (fig. 22), however, increases in thickness to the southwest. Where the isopach lines of the Monitor Butte show a rapidly decreasing thickness (the 60- to 20-foot northernmost isopach lines on figure 22) the isopach lines of the Moss Back show a rapidly increasing thickness (fig. 21). In the same area the total thickness of the Chinle decreases to the north but increases again in the vicinity of the zero isopach line of the Monitor Butte. This variation in total thickness of the Chinle, therefore, may be independent of variations in the lower two members.

It can be inferred from these data that the pinchout of the Monitor Butte member may not be simply the result of onlap of the Chinle formation on the Moenkopi formation as suggested by Stewart and others (in preparation), but may represent a facies change in the lower part of the Chinle due to difference in source of the sediments in the areas underlain by the Moss Back and Monitor Butte members.

Field observations support this inference. In South Hatch Canyon and along the east side of North Block in the Orange Cliffs area, discontinuous lenses of sandstone grade laterally from Moss Back-type lithology to Monitor Butte-type lithology. An outcrop of a sequence of contorted interbedded rocks that has well-developed characteristics of both types of lithologies occurs in Happy Canyon.

These data and interpretations do not dispute the concept that some units of the Chinle formation are thinned or pinched out as the result of onlap on the Moenkopi formation. Within the Orange Cliffs area, however, the available evidence suggests a more complex history.

## San Rafael Swell, Utah

by

C. C. Hawley

The geologic environment and occurrence of uranium in the Temple Mountain district, Emery County, Utah, apparently differ in several respects from those of other uranium-vanadium deposits on the Colorado Plateau. The uranium deposits at Temple Mountain are chiefly in the Moss Back member of the Chinle formation, but mineralized rock (or ore) occurs in at least five other stratigraphic horizons. The deposits are spatially associated with collapse structures which are roughly elliptical masses of altered rock that have been warped and/or faulted below their normal stratigraphic position. The deposits differ from other deposits within the San Rafael Swell in metal content, associated alteration, and occurrence and form of the ore bodies, but are similar in gross mineralogy. The deposits at Temple Mountain are similar to the uranium-vanadium deposits in the Morrison formation of southwest Colorado in metal content, form and habit of ore bodies, distribution of elements within ore bodies, and associated alteration.

## General geology and collapse structures of the Temple Mountain district

Rocks of Permian to Jurassic age are exposed in the Temple Mountain district. The stratigraphic section in the immediate area of Temple Mountain (fig. 23) consists of the Moenkopi formation, the Chinle formation, the Wingate sandstone—all of Triassic age—and some of the Kayenta formation of Jurassic(?) age. The Coconino sandstone and Kaibab limestone of Permian age crop out in canyons north of Temple Mountain, and the Navajo sandstone (Jurassic and Jurassic(?)) and Carmel formation (Jurassic) crop out to the east.

The Moenkopi formation is divided into three members by the Sinbad limestone member which occurs about 120 feet above the base of the Moenkopi. Within the district, the Sinbad is a dolomite; in other parts of the San Rafael Swell it includes limestones. The Chinle formation is also divided into three units: (1) a lower unit that contains rocks of both the Monitor Butte and Temple Mountain members; (2) the Moss Back member; and (3) the Church Rock member. The Moss Back member may be further subdivided into four more or less distinct lithologic units. One of these, a mssive outcropping, fine- to medium-grained, clean, somewhat calcareous sandstone that is everywhere petroliferous, contains most of the ore deposits. This unit is typically underlain by conglomeratic sandstone and overlain by lime-pebble conglomerate and flaggy sandstone units. This subdivision of the Moss Back is approximately the same as recognized by Stokes (written communication, 1947) and Wyant (written communication, 1953).

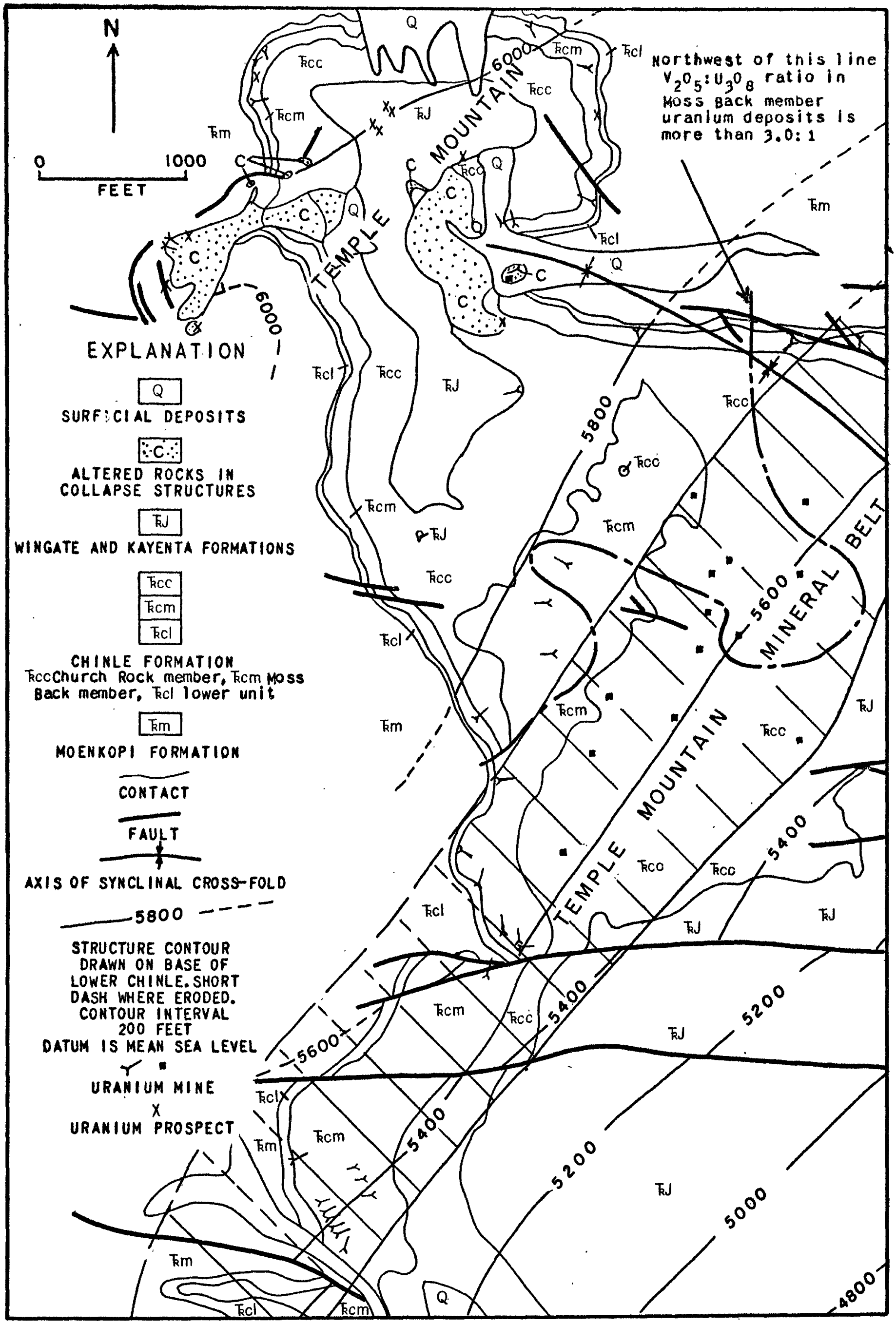


Fig. 23.---GENERALIZED GEOLOGIC MAP OF PART OF THE TEMPLE MOUNTAIN AREA, EMERY COUNTY, UTAH.

Rocks in all units from the Coconino sandstone to the Navajo sandstone are locally petroliferous. Petroleum is particularly abundant near the top of the Coconino sandstone, in the Kaibab limestone, in dolomite and sandstone of the Moenkopi formation, in the Moss Back member of the Chinle formation, and in the Wingate sandstone on Temple Mountain.

Several of the rock units are characteristically altered on a district-wide or larger scale. In the lower unit of the Chinle formation, ferric iron (in hematite) has been displaced from fractures and recrystallized; sulfide-bearing chert and carbonates have also formed in rocks of the lower Chinle. Practically all of the rocks of the Glen Canyon group—the Wingate sandstone, Kayenta formation, and Navajo sandstone—have been bleached; there are only minor remnants of pink to red Navajo. The bleached rocks of the Wingate contain secondary dolomite in replacement masses and micaceous silicates that are green in color. This alteration can be recognized throughout the San Rafael Swell, but it is more prevalent in the Temple Mountain district. To the south and north along the southeast flank of the San Rafael Swell the highest exposed rocks in the Glen Canyon group are shades of red. In general, the contact between the bleached and normal colored Glen Canyon rocks, in other parts of the San Rafael Swell, is a level plane crossing the bedding, showing that this alteration took place after uplift of the San Rafael anticline.

The district is on the southeast flank of the asymmetric, doubly plunging San Rafael anticline. It is crossed by northwest-trending cross folds and cut by westerly striking normal faults. The major faults strike west-northwest and have vertical displacements up to 200 feet.

There are also minor east-west and north-northwest striking faults that are apparently related to the major faults. The northwest-trending cross folds were apparently formed prior to the normal faulting.

Occurrences of minor intraformational fractures are confined to rocks in or near the collapse structures and to rocks in the lower part of the Chinle formation. The orientation of fractures in the lower Chinle suggests that they originated by slipping at the contact of the competent Moss Back sandstones and conglomerates and the less competent mudstones and siltstones of the lower Chinle during uplift of the San Rafael anticline.

There are five major collapse structures in the district, the largest of which is at Temple Mountain. The Temple Mountain collapse has two major and several minor surface expressions (fig. 23). The surrounding rocks dip into the collapse and the boundary of part of the collapse is a fault contact. The rocks within the structure are highly altered and the alteration extends into adjacent rocks for varying distances. The smaller collapse structures outside of the map area of figure 23 are similar. Downwarping, rather than faulting, is prominent in two collapse structures east of Flat Top Mesa; but there are small pluglike masses of downdropped rocks of the Moss Back in each. Probably the maximum amount of displacement in the structures is about 300 feet.

It has been suggested by Kerr and others (1955, p. 79) that removal of calcareous rocks from parts of the Kaibab limestone and Moenkopi formation plus outward flaring of the collapse structures at depth is adequate to account for this vertical displacement. Thinning of beds due to stretching during folding and collapse may contribute to the amount of apparent displacement.

Three of the collapse structures in the district, including the Temple Mountain collapse, are near the axis of a northwest-trending syncline. The two collapse structures east of Flat Top are in the same syncline, and it is inferred that the collapse structures and northwest-trending cross warps formed at about the same time.

Alteration accompanying collapse involved removal of carbonates in the rocks of the collapse structures and intense dolomitization of parts of the Wingate and other formations. Dolomite has replaced a zone at the upper Chinle and Wingate contact and has almost completely replaced large masses of sandstone in the Wingate. Some of the dolomite masses have very sharp contacts and occur in roll-like forms. The iron oxide masses found particularly in the upper Chinle, formerly thought to represent oxidation of pyrite (Hess, 1922, p. 274), were found by Keys and White (1956, p. 289) to probably represent oxidation of siderite.

Kelley (in Kerr and others, 1955, p. 31-42) found secondary kaolinite, sericite, and chalcedony in the altered rocks of the Temple Mountain collapse.

## Uranium deposits of the Temple Mountain district

Uranium deposits occur in all stratigraphic units from the Coconino sandstone to the Wingate sandstone. The most productive deposits are confined to the Moss Back and are more abundant and larger in an area called by Keys and White (1956, p. 296) the Temple Mountain mineral belt (fig. 23). Smaller deposits of commercial grade also occur in the Wingate sandstone and in the Temple Mountain collapse structure.

The gross mineralogy of the uranium deposits is rather simple. Asphaltite and pyrite are often the only introduced minerals (or mineraloids) identifiable megascopically. Montroseite and sphalerite are common in microscopic amounts in the ore; galena is abundant only at depth in deposits in the collapse structures. Uraninite, native arsenic, ferroselite, marcasite, and chalcopyrite are local constituents of the ore. The ferroselite occurs as disseminations in some ores and in the interstices of the sandstones in bands peripheral to ore. Gangue minerals are dolomite, siderite, chromium-bearing silicates, sericite, probably kaolinite, and quartz. Carbonaceous materials, other than asphaltite, are petroleum, asphalt, and various coaly materials. Vitrain is the most abundant of the coaly materials, but neither vitrain nor petroleum are particularly abundant in the ore. Coalified logs occur in abundance in the basal conglomeratic sandstone of the Moss Back member and small coalified fragments are found in mudstones of the same member. Petroleum, although not abundant in the ore, is distributed as a halo around ore bodies. There is a common gradation from disseminated ores into petroliferous rocks.

Vitrain, pyrite, and marcasite, occurring in cells and cell walls of carbonaceous materials, and minor sphalerite are commonly associated in the Moss Back near and away from ore bodies. In the disseminated ores asphaltite (with uraninite), zoned pyrite, minor ferroselite, montroseite, and sphalerite are closely associated. Uraniferous coalified wood--which is uncommon in the district--contains asphaltite (with uraninite), montroseite and a second generation of sphalerite in addition to the pyrite, marcasite, and sphalerite previously mentioned.

It appears that the pyrite and minor marcasite in the cells and cell walls of woody materials were the first metallic minerals deposited. Sphalerite and minor amounts of pyrite were deposited after this early pyrite, while the coaly materials were capable of deforming plastically. Closely associated sphalerite, montroseite, and asphaltite were introduced after the early sphalerite and occur in zones or fractures cross-cutting woody structure or early sphalerite bands. Asphaltite is generally later than the sulfides, uraninite, and montroseite, although it shows mutual boundary contacts with some montroseite; and is earlier than small amounts of pyrite, chalcopyrite, and sphalerite. An extremely fine-grained gray mineral that occurs in blebs, disseminated in the asphaltite, is probably post-asphaltite uraninite.

The ore deposits, when classified by bulk mineralogy, are asphaltite-type deposits, with the exception of some small deposits of oxidized uranium minerals and some small sulfide disseminations found at depth in the collapse structures. They are dominantly vanadium-uranium deposits; the average ratio of $V_2O_5$:$U_3O_8$ in the deposits in the Moss Back member is about 2.9:1.

Both tabular and roll-type deposits occur in the Moss Back member of the Chinle formation; most ore bodies have at least one roll-type contact with barren rock. Deposits in the Wingate sandstone are similar but the rolls are somewhat better defined. Ore in the collapse structures occurs in pipes, rolls, bedded deposits, and veins.

Most ore deposits in the Moss Back member of the Chinle are related obviously only to stratigraphic and sedimentary structures. The gross occurrence of most ore is controlled by favorable lithology; most of the ore occurs in the massive sandstone facies of the Moss Back member. The occurrence of ore in the host rocks is related to the shape and size of the sandstone hosts, minor intraformational scouring, the distribution of mudstones, and locally to the occurrence of coaly materials. Ore occurrences in the Wingate are in part related to crossbedding and major bedding planes.

There probably is some fracture control of mineral occurrences and alteration in the Moss Back and Church Rock members of the Chinle formation outside the collpase. Low-angle fractures with little displacement apparently control the occurrence of some ore at the Vanadium King 5 mine and possibly in the Camp Bird 7 mine. The high-angle normal faults in the area are post-ore.

The position of the Temple Mountain mineral belt with relation to structure contours suggests that it is related to folding and is later than the uplift of the San Rafael anticline (fig. 23). Reconstruction of the structure prior to normal faulting shows that all occurrences in the mineral belt are above the 5,440-foot structure contour drawn on the base of the Moss Back member of the Chinle formation.

Vanadium and uranium in deposits in the Moss Back member of the Chinle formation are zoned. The $V_2O_5:U_3O_8$ ratio ranges from 2.15:1 to 4.59:1; relatively vanadiferous ores occur in the north-central part of the mineral belt (fig. 23) and on North Temple Mountain. There is also zoning around the ore bodies; adjacent to uranium-vanadium asphaltite ores occur in rocks relatively rich in vanadium, selenium, nickel, cobalt, magnesium, and chromium.

Rock alteration spatially associated with ore deposits includes dolomitization, formation of chromium-bearing silicates, sericite-like minerals, and crystalline quartz overgrowths. Secondary kaolinite is abundant and widespread, but its relation to the deposits is not yet known. Decalcitization of the rocks containing ore deposits is suggested by zoning of the amount of calcite in the ores and by a comparison of the calcite content of similar rocks in the barren and mineralized ground. The relative amount of calcite in the ores increases southward in the mineral belt, from less than 1 percent in the northern part to more than 7 percent in the Black Beauty mine immediately south of the map area (fig. 23).

The history of the formation of ore minerals and associated minerals and mineraloids probably was long and complex, as indicated by relations between structures, alteration, and mineral paragenesis. Cementation by calcite, the formation of minor rounded quartz overgrowths, coalification with attendant pyritization, and the introduction of small amounts of sphalerite took place prior to the period of major uranium-vanadium mineralization. The spatial relation of collapse structures and northwest-trending cross folds suggests that these structures formed at about the same time. The uranium-vanadium mineralization is inferred to have taken place after formation of the collapse structures and apparently was related to the formation of dolomite, siderite, chromium-bearing silicates, minor sericite, and possibly kaolinite in the collapse structures and adjacent rocks. The similarity of this alteration and the regional alteration in rocks of the Glen Canyon group, which is more prevalent near Temple Mountain, suggests it may be related, in some way, to the intense alteration near the collapse structures. The characteristically altered rocks of the lower unit of the Chinle are more highly bleached and deformed adjacent to the collapse, suggesting that this regional alteration predated the uranium-vanadium mineralization.

The orientation of the Temple Mountain mineral belt suggests that the mineralization was post-uplift. If the alteration in the rocks of the Glen Canyon group is related to that adjacent to ore deposits, there is little doubt that the uranium-vanadium mineralization was later than the uplift of the San Rafael anticline. Petroleum was in the rocks prior to uranium-vanadium mineralization.

The ore deposits are believed to be the products of a reaction of introduced mineralizing fluids containing carbon dioxide with the petroliferous rocks. The petroliferous affiliation of the asphaltite is suggested by organic composition and trace element composition, but is best shown by gradational relations between petroleum and asphaltite. That the asphaltite was not derived from coal is suggested by the minor amount of woody material and the occurrence of asphaltite in non-coal-bearing formations. The occurrence of asphaltite, montroseite, and sphalerite in fractures cutting vitrain show that by the time of the main mineralization the coals did not deform plastically and it is inferred that they had nearly reached their present state of coalification.

The roll ore bodies are believed to have formed as a result of interface phenomena between two fluids as suggested by Shawe (1956, p. 241). The competency of carbonated solutions to redistribute oils is known as a result of secondary recovery work (cited by Garrels and Richter, 1955, p. 457).

The metallic elements present in the ores may have had several sources. Selenium, arsenic, and probably uranium are regarded as having been introduced into the rocks. The case for the introduction of selenium is particularly strong as shown by Coleman and Delevaux (written communication, 1956). Vanadium may have been introduced or contributed in part by petroleum or by the destruction of heavy minerals during alteration.

The alteration associated with the uranium deposits is similar in some respects to that associated with so-called mesothermal to telethermal ore deposits; however, the ultimate origin of the extrinsic fluids is open to conjecture.

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# Circle Cliffs, Utah

by

E. S. Davidson, L. D. Carswell, and G. A. Miller

Geologic mapping of eleven 7½-minute quadrangles in the Circle Cliffs area began in 1954 and is scheduled for completion in the summer of 1958. Detailed mapping of rocks of Triassic age in the Circle Cliffs area has yielded new information on several rock units, especially the Moenkopi formation of Early and Middle(?) Triassic age, and the Chinle formation of Late Triassic age.

A dolomite near the base of the Moenkopi formation probably correlates with both the Sinbad limestone member of the Moenkopi formation, which crops out in the Capitol Reef, and San Rafael Swell, and the Timpoweap member of the Moenkopi formation, which crops out in the Grand Canyon region. The Sinbad limestone in other areas contains the Meekoceras faunal zone, but diagnostic fossils have not yet been found in Circle Cliffs. The unit is considered to represent the middle of the Lower Triassic. The distribution of the Sinbad(?) member in the Circle Cliffs area is shown in figure 24. It is generally absent in the eastern part of the Circle Cliffs, is locally absent in a narrow zone bordering on the west, and is present in continuous outcrop in the remainder of the area. It is composed of sandy and conglomeratic dolomite in the east but is a relatively pure oolitic dolomite in the remainder of the area. The thickness ranges from about 15 to 40 feet over most of the area, increasing to a maximum of 80 feet in the northwest. In the northwest part of the Circle Cliffs area, the unit is underlain by 5 feet of greenish-gray siltstone which may correlate with the red siltstone underlying the Sinbad limestone member in the Capitol Reef area.

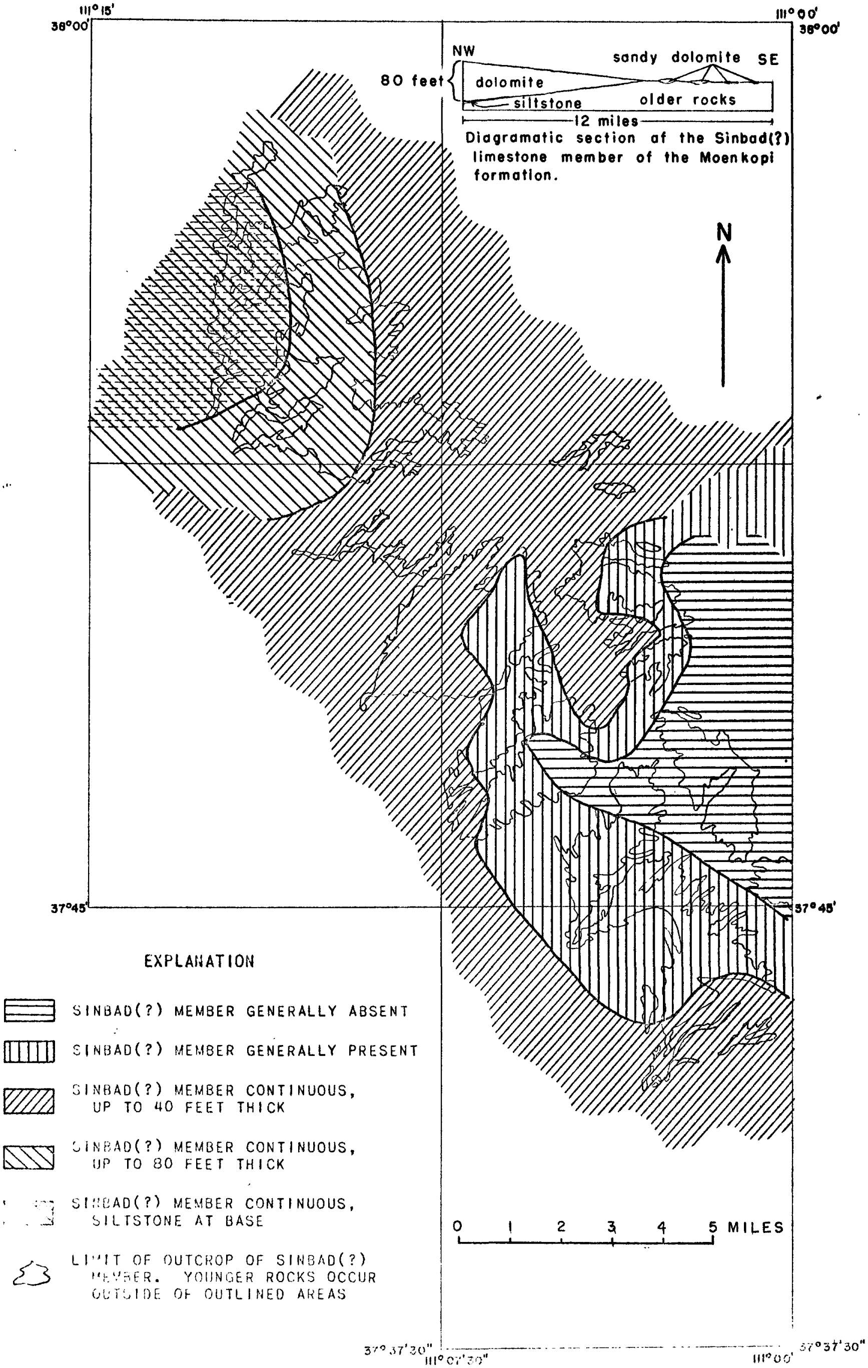


Fig. 24.--DISTRIBUTION OF THE SINBAD(?) LIMESTONE MEMBER OF THE MOENKOPI FORMATION IN THE CIRCLE CLIFFS AREA, GARFIELD COUNTY, UTAH.

The ledge-forming unit of the Moenkopi formation (TEI-640, p. 161) overlies the Sinbad(?) member and underlies the upper slope-forming unit of the Moenkopi formation in the Circle Cliffs. This ledge-forming unit is heavily asphaltic in a large area in the east, but is nonasphaltic a few miles north, west, and south of the heavily asphaltic area (fig. 25). The distribution of asphaltic rocks has no correlation with the position of the Circle Cliffs anticlinal structure, and contacts of asphaltic and nonasphaltic rocks are offset by faults. Presumably the asphaltic material was distributed before upwarping of the Circle Cliffs.

A mottled siltstone unit unconformably overlies the Moenkopi formation in parts of the Circle Cliffs area. This unit is in turn unconformably overlain by the Shinarump or Monitor Butte members of the Chinle formation. The siltstone unit is seen only in cliff exposures; and because its distribution behind the cliff face is not known, its occurrence is shown only in a narrow band along the contact of the Chinle and Moenkopi formations (fig. 26). This unit is predominantly a siltstone or very fine grained sandstone with a few coarse and very coarse sized grains of quartz. Most of the clastic material of silt size was probably derived from the Moenkopi formation. The color of the rock is purple, dark red, or mottled purple and white; locally, some of the rock is yellow. The cause of the mottled purple and white color is not known but the mottling does not appear to be related to the occurrence of uranium in the Circle Cliffs area.

All uranium occurrences in the Circle Cliffs area are associated with channels of Triassic age cut into the Moenkopi formation and filled with sandstone of the Shinarump member of the Chinle formation.

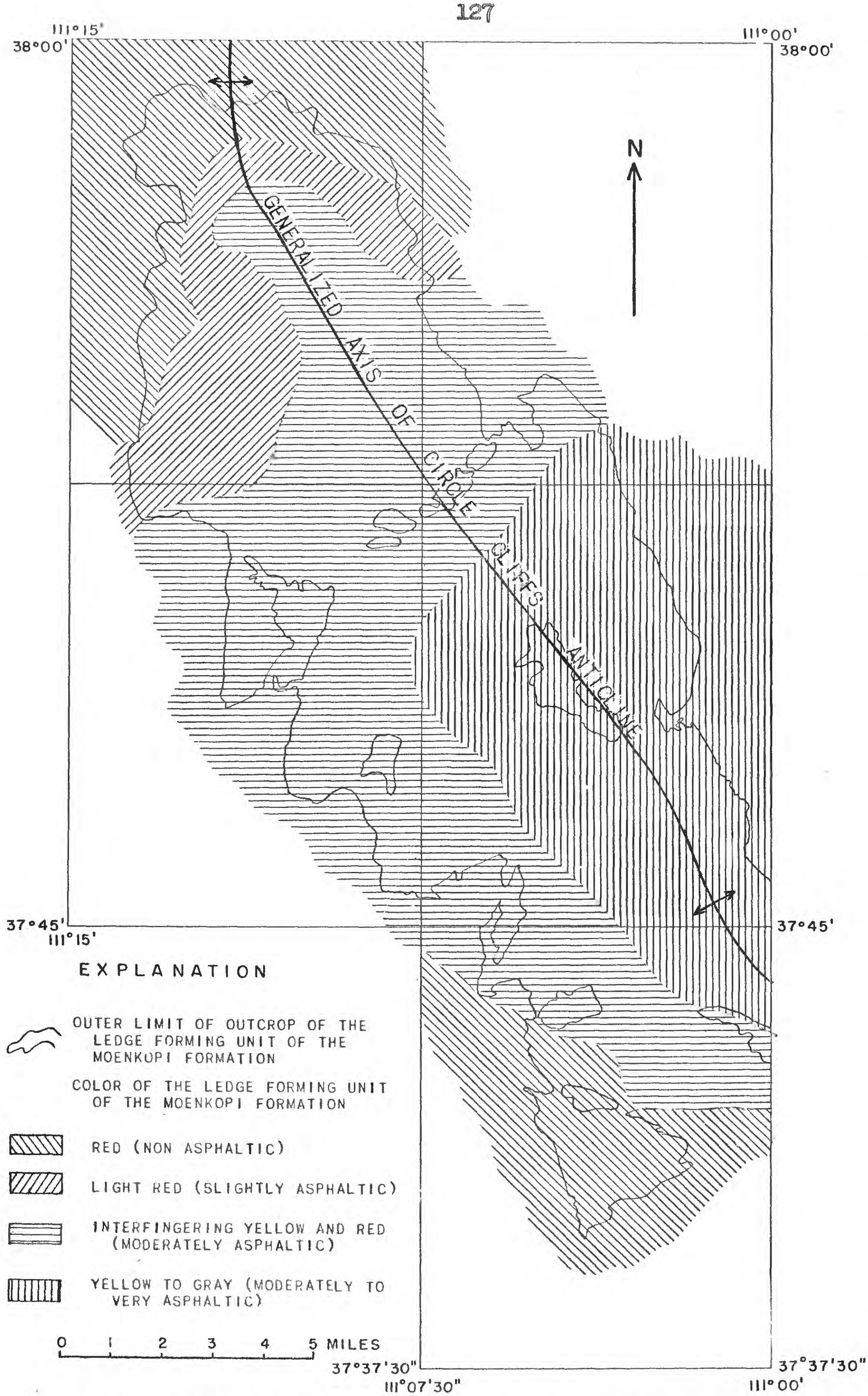


Fig. 25.--DISTRIBUTION OF ASPHALTIC ROCK IN THE LEDGE FORMING UNIT OF THE MOENKOPI FORMATION, CIRCLE CLIFFS AREA, GARFIELD COUNTY, UTAH.

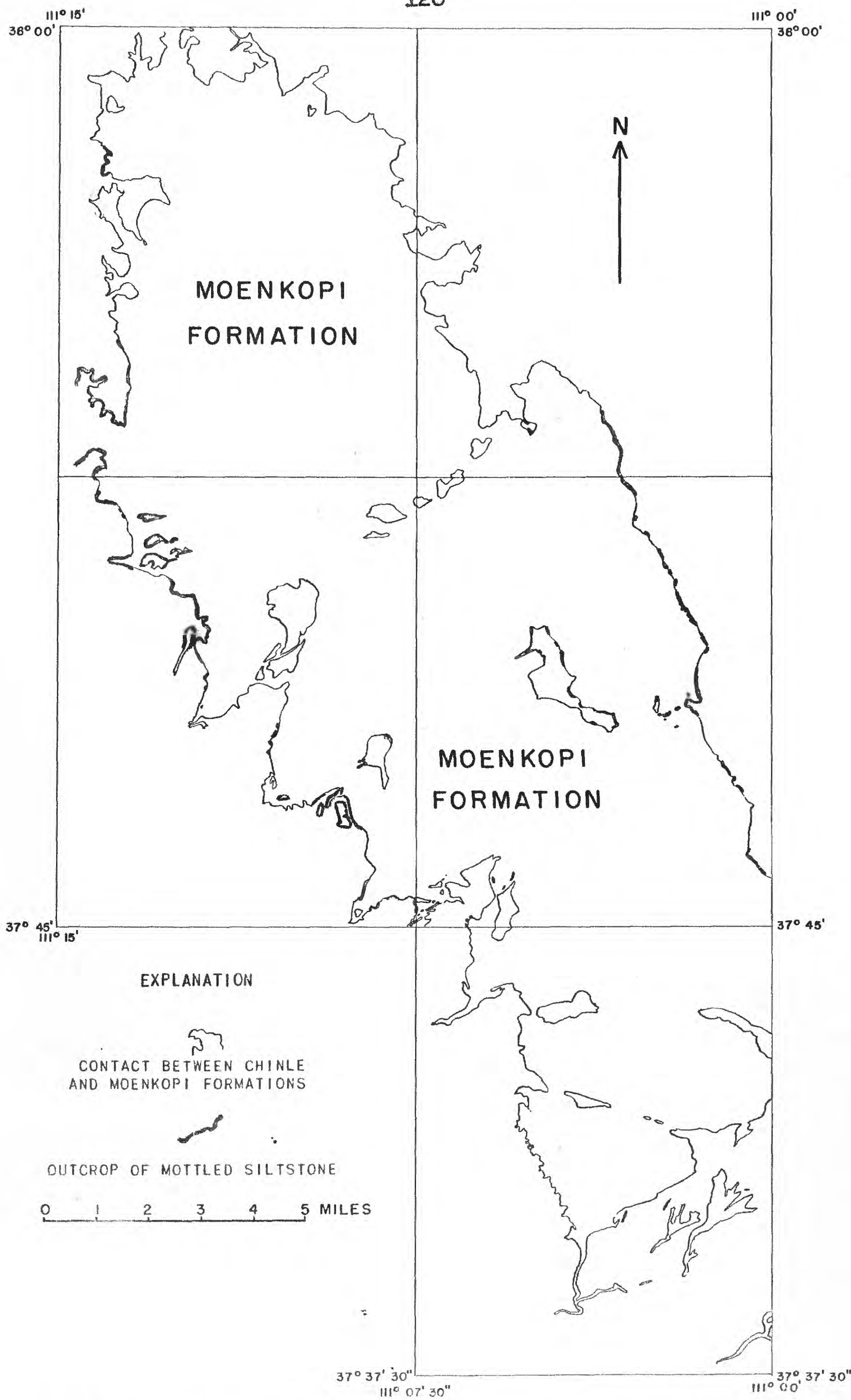


Fig. 26.--DISTRIBUTION OF MOTTLED SILTSTONE UNIT AT THE BASE OF THE CHINLE FORMATION, CIRCLE CLIFFS AREA, GARFIELD COUNTY, UTAH.

Figure 27 shows the distribution of the Shinarump member of the Chinle formation along its cliff outcrop and the inferred patterns of the channels at the base of the member. The channel winding through the central part of the Circle Cliffs area and trending northwest in the northern part of the area is thought to be a major channel. The smaller channels to the east are tributary to this main drainage.

The following report was published during the period:

Davidson, E. S., 1956, Rainy Day uranium deposit, Garfield County, Utah (abstract): Geol. Soc. America Bull., v. 67, p. 1685.

## Elk Ridge, Utah

by

R. Q. Lewis, Sr., and R. H. Campbell

The Elk Ridge mapping project covers an area of approximately 1,000 square miles in San Juan County, Utah. Mapping was started in May 1953, and continued through September 1956. The project is scheduled for completion in July 1957. The project area lies between the Abajo Mountains and the White Canyon area and covers Elk Ridge, the Needles, and the Beef Basin area (fig. 28). The crest of Elk Ridge ranges in elevation from 7,000 to 9,000 feet and forms a broad arched mesa bounded by steep-walled canyons. Physiographically the region can be divided into two general areas, the high mesa and surrounding lower mesas. Both are dissected by deep steep-walled canyons.

### Stratigraphy

Numerous drill holes in and near the project area have penetrated crystalline rocks beneath the thick sedimentary cover of Paleozoic rocks. These rocks are assumed to be of Precambrian age as they are unconformably overlain by Cambrian sediments.

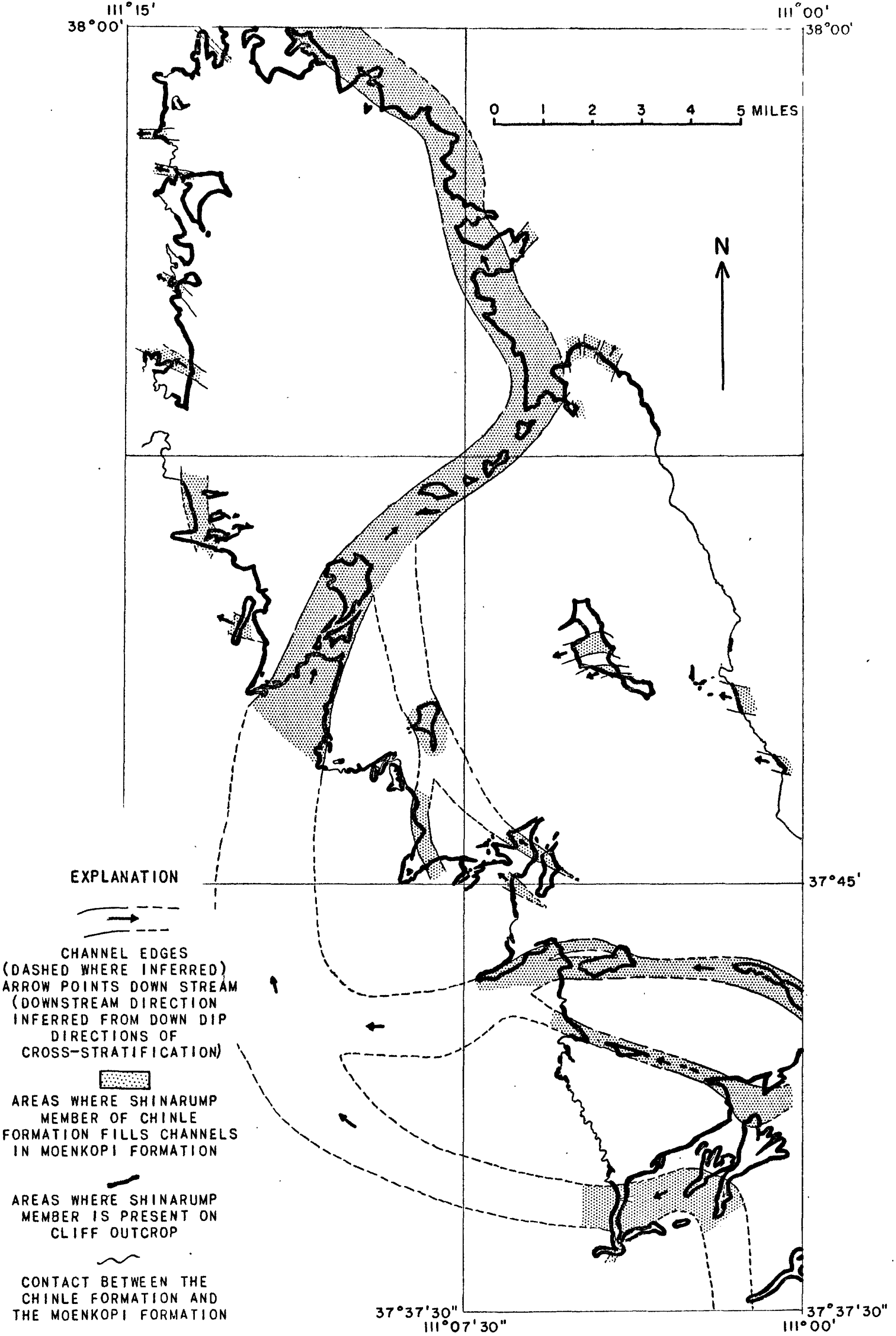


Fig.27 .--MAJOR CHANNEL PATTERNS AND DISTRIBUTION OF SHINARUMP MEMBER OF THE [illegible] AREA, GARFIELD COUNTY UTAH.

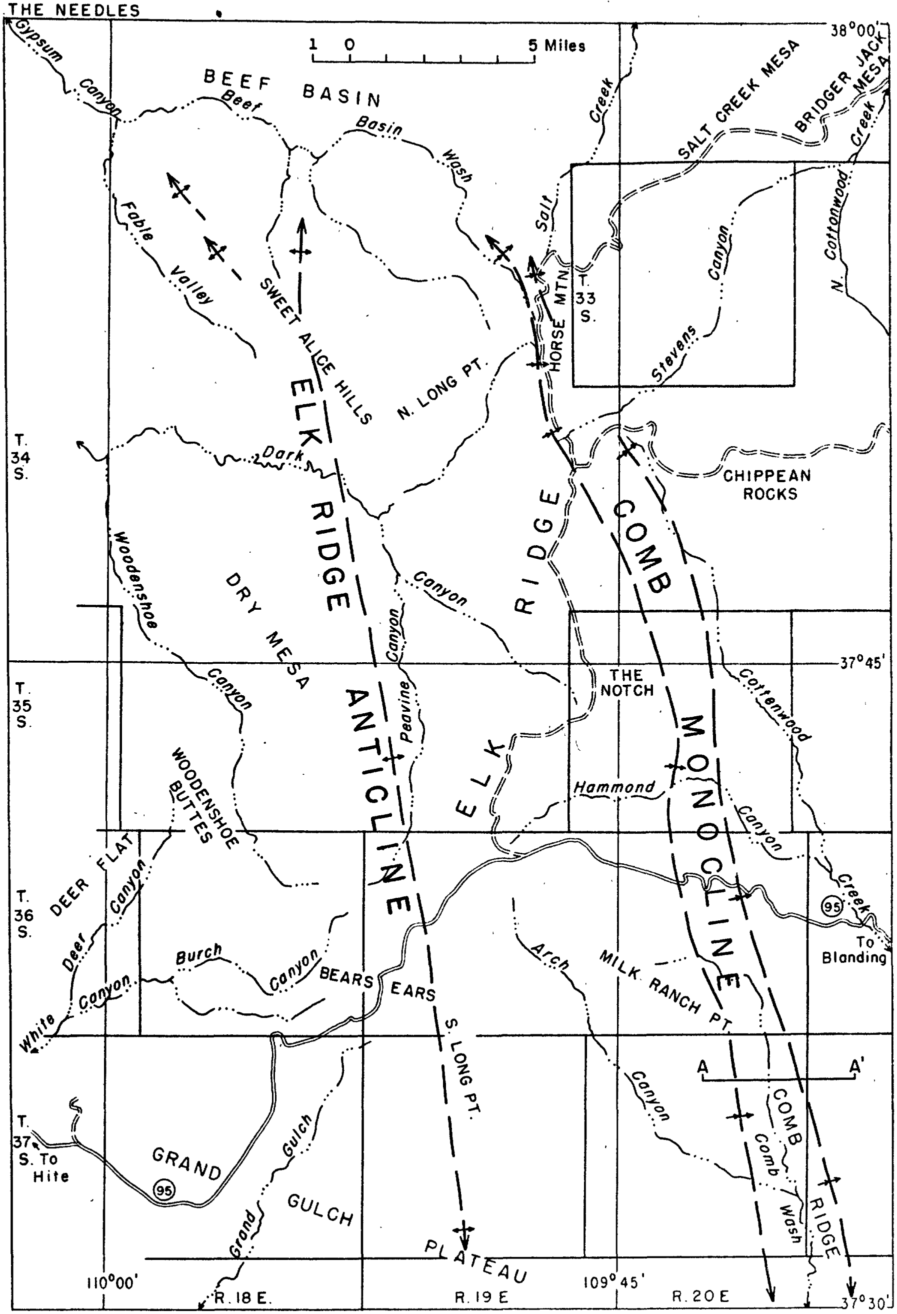


Fig. 28.--MAP SHOWING MAJOR STRUCTURAL FEATURES OF ELK RIDGE AREA, SAN JUAN COUNTY, UTAH.

Rocks of lower Cambrian age, known from well logs of holes both in the Elk Ridge area and to the east of the area beyond the Comb monocline, are chiefly coarse arkosic sandstone, conglomerate, and shales. The sequence is usually only a few hundred feet thick and is overlain by a thick dolomite which has been interpreted to be upper Cambrian. The top of the Cambrian is marked by an unconformity and no rocks of Ordovician, Devonian, or Silurian age are known in the area. The Mississippian rocks unconformably overlying the Cambrian rocks are possibly equivalent to the Leadville limestone of central Colorado, and are overlain unconformably by the Molas formation of Pennsylvanian age. The lower part of the Hermosa formation of Pennsylvanian age overlies the Molas formation and is overlain by the salt, gypsum, and black shale generally assigned to the Paradox member. The upper part of the Paradox is exposed in the deeper canyons; well-log data indicates that the unexposed section ranges between 4,000 and 5,000 feet in total thickness. The exposed sedimentary rocks in the area have an aggregate thickness of about 6,000 feet as shown in figure 29. The oldest rocks crop out in the deep canyons tributary to the Colorado River in the northwestern part of the area, and the younger rocks are exposed along the crest of the Elk Ridge anticline and in the Comb monocline along the eastern boundary of the area. The exposed rocks are marine, fluvial and eolian terrestial sediments.

## Structure

The Elk Ridge map area is on the northern end of the Monument upwarp, one of the major structural features of the Colorado Plateau. The crest of the Monument upwarp enters the area from the south and plunges out north of the Sweet Alice Hills (fig. 28). The major axis

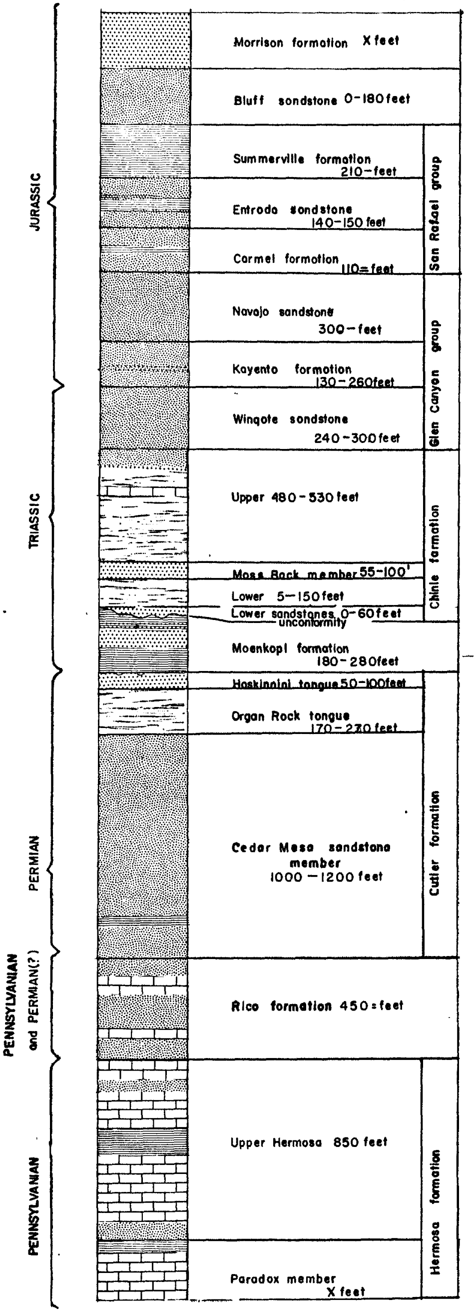


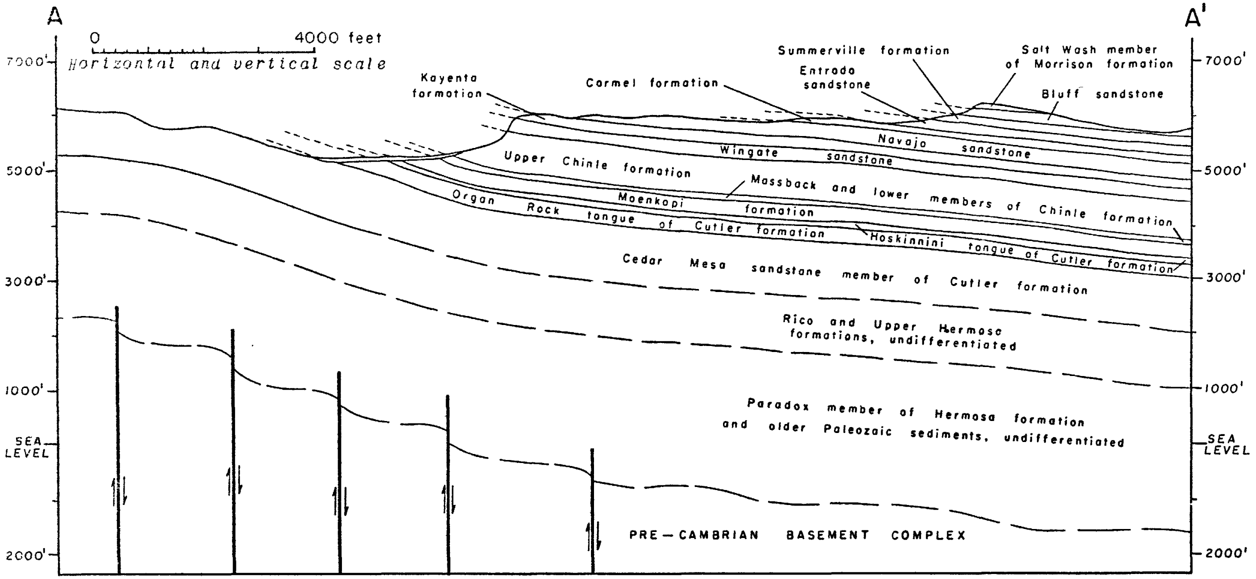
Fig. 29.--COLUMNAR SECTION OF CONSOLIDATED ROCKS EXPOSED IN THE ELK RIDGE AREA, SAN JUAN COUNTY, UTAH.

of the fold has been mapped on Elk Ridge as the Elk Ridge anticline--actually one of several asymmetrical anticlines superimposed on the major structure. It is probably continuous with the Mitten Butte anticline mapped by Baker (1936) in the Monument Valley area, Utah. Because of the broad, nearly flat, nature of the anticlinal crest and the associated minor parallel folds the exact position of the crest is difficult to locate, and representation by a single axis can only be an approximation.

The east limb of the anticline is, in part, much steeper than the west limb, as is characteristic of many of the major flexures of the Colorado Plateau (Kelly, 1956). Dips along The Comb--the east limb--generally exceed 10° and often are as great as 30°. The steep dips are, however, restricted to the lower part of the limb. Between the crest of the anticline and a point about halfway down the east limb the dips are similar in magnitude to those on the west limb--generally 2° or less. The inflection point, point of marked steepening, can be located quite closely in the field. The line of inflections has been mapped as an anticlinal-bend, and is indicated on the map as a line along which the dip abruptly steepens to the east. Thus in cross section the major fold is convex upward with a sharp, well-defined bend as noted on cross section A-A'; (fig. 30).

The minor folds on Elk Ridge appear to form two groups; those within the major upwarp and undoubtedly associated with it, and those transverse to the major fold axis north of the upwarp.

The major faults in the area are high-angle graben faults. The major grabens on Elk Ridge proper trend east or northeast and form an en echelon system with similar grabens in the Abajo Mountains and



Note: Thicknesses of pre-Cedar Mesa sandstone sediments extrapolated from reported information on nearby Shell Oil Co. Bluff unit No.1 well and Reynolds Mining Co. No.1 Fish Creek well.

Fig. 30.--GEOLOGIC CROSS SECTION A-A' THROUGH THE COMB MONOCLINE IN THE SOUTHWESTERN PART OF THE ELK RIDGE AREA, SAN JUAN COUNTY, UTAH. (See fig. 28)

Verdure areas to the east. The numerous grabens in the extreme northwestern part of the map are probably collapse structures associated with movement of salt in the Paradox member of the Hermosa formation. They apparently bear little or no relation to the major graben system.

Joints are well developed in all formations and are best exposed in the massive sandstone of the Cedar Mesa member of the Cutler formation and in the Wingate and Navajo sandstones. They appear to be closely related to the major upwarp, but in places are strongly influenced by local minor doming. Joints in many instances parallel the direction of the faulting in the northwestern part of the area where collapse structures are common.

## Ore deposits

Uranium ore has been produced from two parts of the Elk Ridge area. In the southwest, central, and east-central parts of the area, uranium ore has been mined from sandstone and conglomeratic sandstone at the base of the Chinle formation. The general limits of distribution of these sandstones of the lower Chinle define a belt (fig. 31) which is essentially an eastward extension of the White Canyon mining district to the west. In the northeast part of the area ore has been produced from a uranium deposit in basal sandstone and conglomeratic sandstone of the Moss Back member of the Chinle formation. The mine and prospects in the Moss Back are considered to be in a southwestern extension of the Indian Creek mining district.

A few hundred tons of uranium ore were produced from the Elk Ridge area prior to 1953. The rate of production has been greatest since 1955, and it may be expected to continue to increase in the near future. Production figures suggest that individual ore bodies range in size from

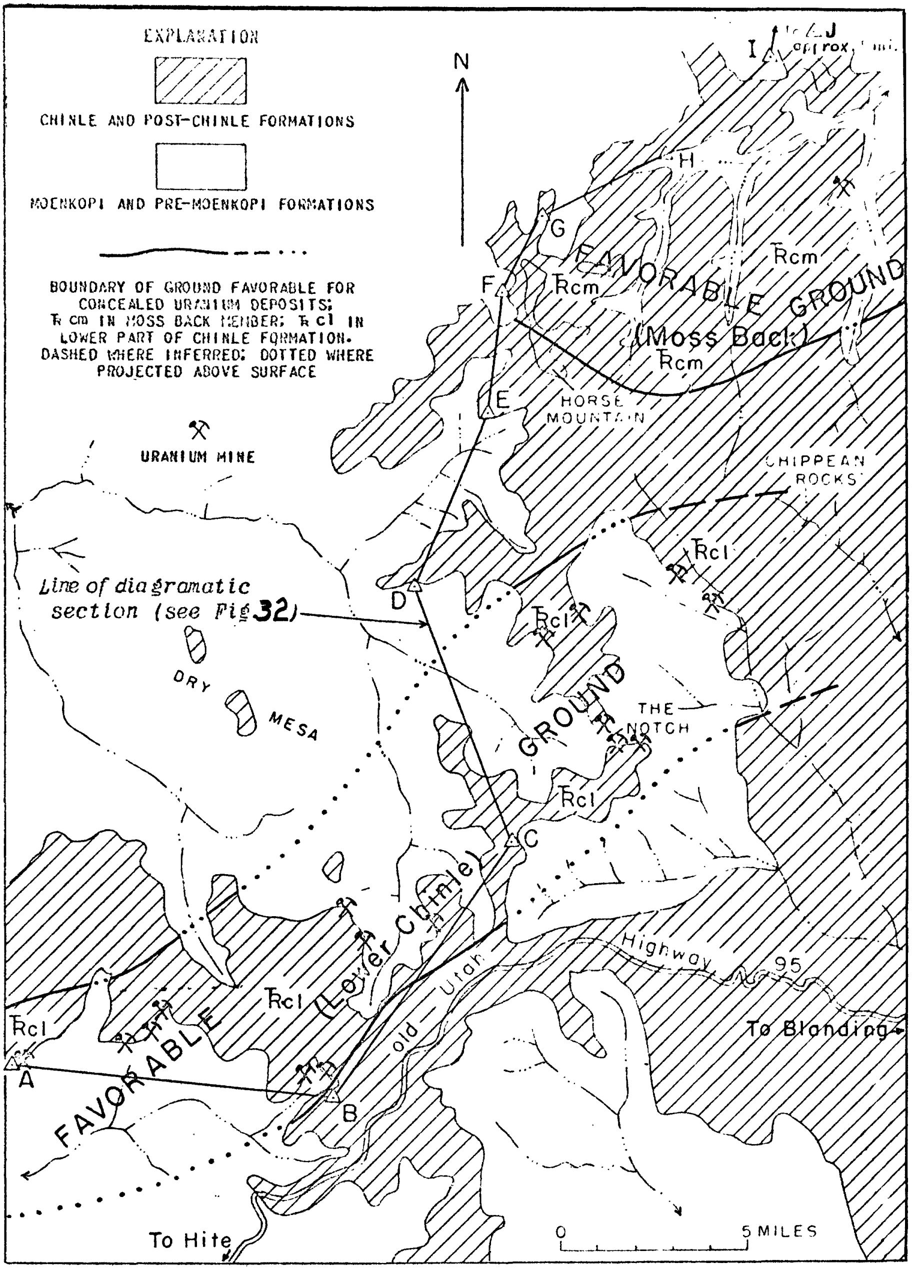


FIG. 31.--GROUND FAVORABLE FOR CONCEALED URANIUM DEPOSITS IN THE MOSS BACK MEMBER AND THE LOWER PART OF THE CHINLE FORMATION, ELK RIDGE AREA, SAN JUAN COUNTY, UTAH.

a few tons to more than 15,000 tons.

The ore deposits in both the lower Chinle and the overlying Moss Back member are in lenticular, lithologically similar sandstones and conglomeratic sandstones of the Chinle formation that were deposited in and built up above shallow channels cut into the top of the Moenkopi formation. The ore deposits are flat-lying lenticular bodies, elongated in the direction of the channels; they appear to thin laterally from the center toward both sides and longitudinally from the center toward both ends. There are many local variations in shape and dimension. Within the deposits, the grade of the mineralized rock is not uniform but varies greatly over short distances so that "run-of-mine" ore is a mixture of high-grade ore with low-grade ore, sub-ore grade material, and barren rock.

The distribution of the ore deposits appears to be controlled by the distribution of the channel sediments of the Chinle formation and their relationship to the contact of the Moenkopi and Chinle formations. The belt of deposits in the lower Chinle (fig. 31) outlines approximately the limits of distribution of basal channel sandstones in the unit. No ore deposits are known to occur in lenses that are not in contact with the Moenkopi formation, although some of the lenses are reported to contain small amounts of low-grade ore and sub-ore grade material. The area where the Moss Back member is "favorable" (fig. 31) is one in which the lower Chinle is greatly reduced in thickness. At the one mine known in the Moss Back, the mudstone in the lower Chinle is locally missing. Elsewhere in the "favorable" Moss Back a few prospects expose sub-ore grade mineralized material and uneconomic amounts of low-grade ore where only a few feet of mudstone in the lower

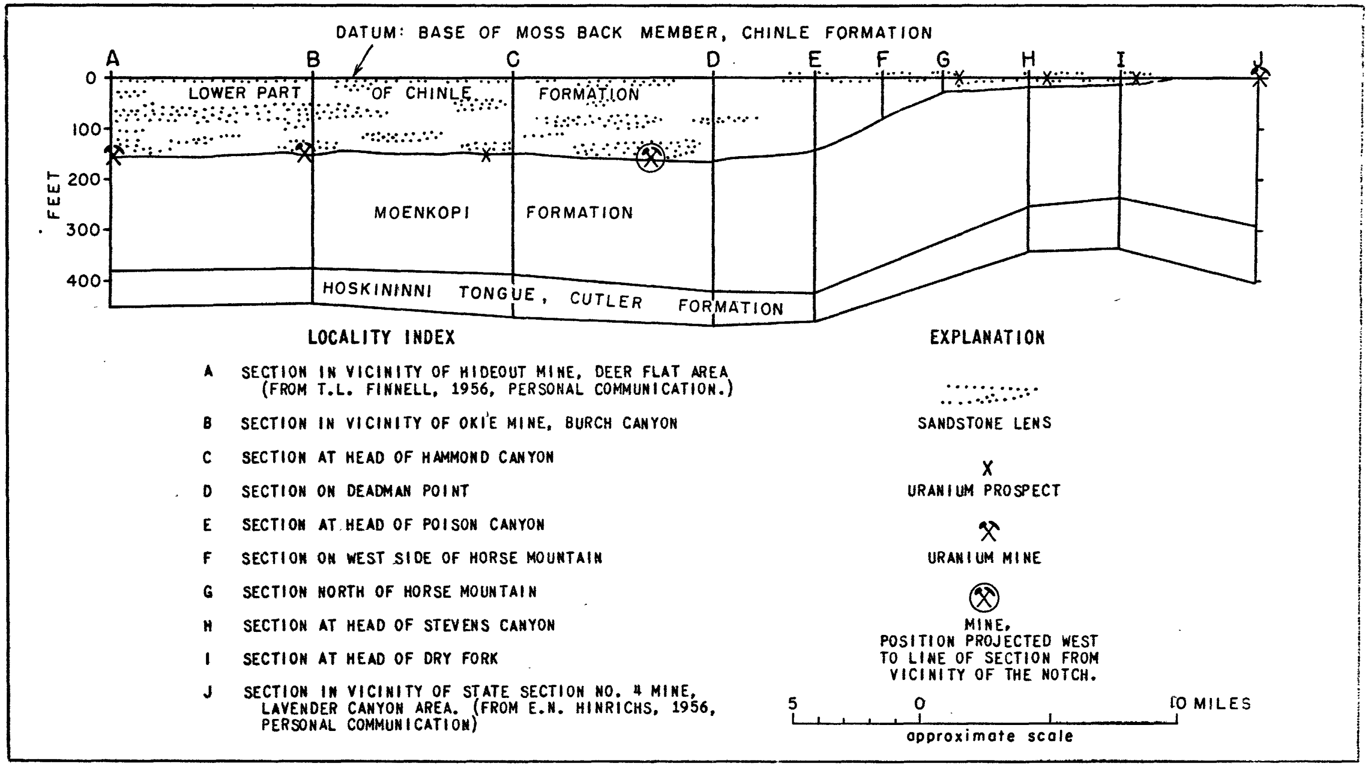
Chinle separate the Moss Back from the Moenkopi. Outside the area where the Moss Back is "favorable" no potentially economic uranium deposits are known in that unit, although minor amounts of low-grade and sub-ore grade material have been reported in drill holes.

Within the channel-filling lenses of sandstone in both the Moss Back and lower Chinle observations of detailed local stratigraphy indicate that the ore deposits almost invariably are immediately overlain by mudstone or very argillaceous sandstone lenses or splits having a lateral extent equal to or greater than that of the ore, which is in more permeable rocks below. The ore-bearing lenses also appear to grade longitudinally and laterally into less permeable argillaceous sandstone and mudstone. In some mines, ore minerals have been deposited in the lowermost parts of the channel, in some places extending a few inches to 2 feet (locally more along fractures) into the Moenkopi. The Notch No. 5 mine, where small amounts of ore have been found as much as 40 feet below the top of the Moenkopi, appears to be the only exception. In other mines (or more rarely, other ore bodies in the same mine) ore has been deposited as high as 20 feet above the top of the Moenkopi, and the basal parts of the sandstone are essentially barren.

As the ore deposits appear to have been formed before or during the earliest stages of the uplift that produced the Elk Ridge anticline and the Comb monocline, the only structural control indicated is that which controlled the deposition of the host rocks. Considering the shallow nature of the channel scours cut into the top of the Moenkopi (generally less than 10 feet deep), and considering the relatively uniform thickness of Moenkopi as opposed to the variations in thickness of the lower Chinle, the depositional basin that received the sediments of the lower Chinle appears to have been controlled by a structural trough of lower Chinle-post-Moenkopi age (fig. 32). It is believed that the outline of the "favorable" area of rocks of the lower Chinle probably represents the position of the deepest part of the inferred depositional basin.

Because of the regional and detailed stratigraphic associations of the ore deposits, the writers believe that the solutions from which the ore was deposited had an important ascending component to their direction of flow. The impounding nature of the detailed stratigraphic setting of the ore-bearing lenses suggests control by "impermeable barriers" (Lindgren, 1933, p. 200). The ascension and horizontal movement of dilute, essentially nonreactive, low temperature, ore solutions through the Moenkopi and, possibly, older rocks might leave little or no trace. Hypofiltration (Mackay, 1946) at mudstone-sandstone interfaces in the overlying Chinle formation could then have resulted in an increased concentration of the metallic solutes in the present site of the ore deposits by allowing the solvent to pass upward more readily than the solutes. It seems possible that such a mechanism might alone be responsible for the deposition of the ore minerals; however, the association of the minerals with organic material in many places suggests that the presence of organic matter facilitated deposition.

The suggested mode of deposition would account for several puzzling features: (1) the ore deposits are not restricted to the deepest parts of the channels; (2) the deposits are essentially restricted to sandstones of the Chinle that are in contact with the Moenkopi formation; (3) ore minerals are not found in sandstone lenses of the Chinle that are separated from the Moenkopi by mudstone of the lower Chinle;



**LOCALITY INDEX**

A SECTION IN VICINITY OF HIDEOUT MINE, DEER FLAT AREA (FROM T.L. FINNELL, 1956, PERSONAL COMMUNICATION.)

B SECTION IN VICINITY OF OKIE MINE, BURCH CANYON

C SECTION AT HEAD OF HAMMOND CANYON

D SECTION ON DEADMAN POINT

E SECTION AT HEAD OF POISON CANYON

F SECTION ON WEST SIDE OF HORSE MOUNTAIN

G SECTION NORTH OF HORSE MOUNTAIN

H SECTION AT HEAD OF STEVENS CANYON

I SECTION AT HEAD OF DRY FORK

J SECTION IN VICINITY OF STATE SECTION NO. 4 MINE, LAVENDER CANYON AREA. (FROM E.N. HINRICHS, 1956, PERSONAL COMMUNICATION)

Fig. 32.--DIAGRAMMATIC CROSS SECTION (located on fig. 31) SHOWING THINNING OF LOWER PART OF CHINLE FORMATION AND STRATIGRAPHIC POSITIONS OF URANIUM MINES AND PROSPECTS, ELK RIDGE AREA AND VIVINITY, SAN JUAN COUNTY, UTAH.

(4) there apparently are no permeability channelways, interconnecting ore-bearing basal sandstone lenses of the lower Chinle, that would allow widespread lateral migration through the lower Chinle; (5) there apparently is no ore in the Moss Back member of the Chinle where it is separated from the Moenkopi by mudstone (even though the Moss Back could provide permeable channelways for the lateral migration of ore solutions); (6) minor, but anomalously high radioactivity occurs at the contact of the Moenkopi with mudstone of the lower Chinle; and (7) there are no signs of strong alteration or other evidence of passage of concentrated ore solutions through the Moenkopi and older exposed rocks.

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# Abajo Mountains, Utah

by

I. J. Witkind

The major part of the Abajo Mountains area, San Juan County, Utah, is occupied by a laccolithic mountain mass similar in many respects to the Henry Mountains described by Hunt (1953).

The laccolithic mountains on the Colorado Plateau are characterized by groups of laccoliths radiating outward from a stock (Hunt, 1946, p. 16). This structural pattern is also present in the Abajo Mountains. As yet, no stock surrounded by a shatter zone has been found in the Abajo Mountains, though such zones are typical of the stocks in the Henry Mountains. The typical stock-laccolith relationship in the Abajos appears to be relatively simple. The stocks both cross-cut and are concordant with the adjacent sedimentary rocks. Extending outwards from the stocks are hugh tonguelike laccoliths. Some of these laccoliths form domes completely covered by sedimentary rocks and an igneous core must be surmised. Others have had part or all of their sedimentary cover removed, exposing the igneous core. Many of the laccoliths have been injected laterally either directly below the Burro Canyon formation of Lower Cretaceous age or directly above the overlying Dakota sandstone of Upper Cretaceous age. Consequently, in some places these formations form the roof of the laccoliths, and in others the floor. Where they form the laccolithic floor, the Mancos shale of Late Cretaceous age forms the roof.

The age of the intrusions is unknown, by it is suggested on tenuous evidence that they are Late Cretaceous or Early Paleocene in age.

Of the three differentiation stages recognized by Hunt (1954, p. 478) the magma that formed the Abajo Mountains apparently did not proceed beyond the initial, or diorite porphyry stage.

On the basis of the petrographic studies, the igneous rock in the Abajo Mountains is probably best classified as a hornblende andesite porphyry, rather than a diorite porphyry, a term used by Hunt (1953, 1954) in his petrographic description of the Henry and La Sal Mountains. Commonly it is a light-gray dull dense hard rock that weathers to form angular fragments a foot or two long and 2 to 3 inches wide. It is markedly porphyritic. Scattered through an aphanitic groundmass are large numbers of (1) more or less rectangular grayish-white andesine ($Ab_{58}An_{42}$) phenocrysts; (2) thin, elongate black shiny needles and prisms of hornblende; and (3) black, angular grains of magnetite. The groundmass is too fine grained to permit definite identification of its constituents, but it probably contains anhedral grains of quartz, orthoclase(?), plagioclase microlites, magnetite dust, and calcite.

Modal analyses of several selected rocks are shown in table 4.

For purposes of comparison, chemical analyses of several rock samples from the Abajo Mountains are shown in table 5. These analyses have been converted to normative minerals.

Commonly the phenocrysts are altered and the groundmass is unaltered. The andesine phenocrysts show the effects of alteration in rounded edges, embayed areas, and in patches in phenocryst centers. These altered patches contain opal, some calcite, sericite(?), and kaolin(?). The hornblende phenocrysts are the most altered of all. Generally they have altered to chlorite (penninite), magnetite, a

Table 4.--Modal analyses of thin sections prepared from rock chips collected in the Abajo Mountains, San Juan County, Utah

| Phenocrysts | Dike (percent) | Laccolith (percent) | Laccolith (percent) | Stock (percent) |
|---|---|---|---|---|
| Andesine ($Ab_{58}An_{42}$) | 17.78 | 32.88 | 28.31 | 30.72 |
| Hornblende (alters to penninite) | 12.50 | 14.70 | 9.76 | 13.01 |
| Magnetite | 1.62 | 2.12 | 1.78 | 2.98 |
| Calcite | -- | -- | -- | 0.31 |
| Quartz | -- | 1.82 | -- | 1.10 |
| Accessories (including sphene, apatite, zircon, augite) | 1.17 | 0.30 | -- | 0.47 |
|  | 33.07 | 51.82 | 39.85 | 48.59 |
| **Groundmass** |  |  |  |  |
| Includes quartz, orthoclase(?), plagioclase microclites, magnetite dust, and calcite | 66.91 | 48.18 | 60.15 | 51.41 |
| Total | 99.98 | 100.00 | 100.00 | 100.00 |

hydrated iron oxide, and calcite. Much of this alteration is probably deuteric.

On the basis of the absence of metamorphic effects on the intruded host sedimentary rocks, as well as on included xenoliths, it is suggested that the magma which formed the intrusives of the Abajo Mountains was viscous, had a low temperature, and probably contained only moderate amounts of volatiles. These volatiles, trapped by the impermeable Mancos shale, probably reacted with previously formed phenocrysts and altered them.

Some of the volatiles may have escaped along existing fractures to form the weakly mineralized sulfide veins common near the crest of

Table 5.--Chemical analyses and normative minerals for selected rock specimens from the Abajo Mountains, San Juan County, Utah

| Chemical analyses | | Dike (percent) | Laccolith (percent) | Stock (percent) |
|---|---|---|---|---|
| | $SiO_2$ | 60.87 | 61.85 | 58.05 |
| | $Al_2O_3$ | 16.37 | 17.46 | 16.74 |
| | $Fe_2O_3$ | 2.26 | 1.88 | 0.46 |
| | FeO | 4.13 | 4.19 | 7.50 |
| | MgO | 1.41 | 1.04 | 1.56 |
| | CaO | 4.36 | 5.12 | 5.34 |
| | $Na_2O$ | 4.28 | 4.70 | 3.72 |
| | $K_2O$ | 3.30 | 2.17 | 1.49 |
| | $TiO_2$ | 0.47 | 0.45 | 0.50 |
| | $P_2O_5$ | 0.34 | 0.29 | 0.39 |
| | MnO | 0.13 | 0.16 | 0.15 |
| Normative minerals | | | | |
| | Q | 11.28 | 12.66 | 12.24 |
| | or | 19.46 | 12.79 | 8.90 |
| | ab | 36.15 | 39.82 | 31.44 |
| | an | 15.85 | 20.29 | 23.91 |
| di | en | 0.80 | 0.50 | 3.90 |
| | fs | 1.06 | 0.92 | 12.80 |
| | wo | 1.86 | 3.34 | -- |
| hy | en | 2.70 | 2.10 | -- |
| | fs | 3.96 | 4.62 | -- |
| | mt | 3.25 | 2.78 | 0.70 |
| | ap | 0.67 | 0.67 | 1.01 |
| | il | 0.91 | 0.91 | 0.91 |

Analyzed by J. L. Theobald of the U. S. Geological Survey.

the Abajo Mountains, but it is doubtful whether sufficient mineralizers were available to form the uranium-vanadium deposits in and adjacent to the Abajo Mountains. It would appear that the source of the uranium-vanadium mineralizing solutions was not the magmas which form the laccolithic mountains.

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## East Vermilion Cliffs area, Arizona

Field work in the East Vermilion Cliffs began in 1955, and the study is scheduled for completion in July 1957. The area is located in north-central Coconino County, Ariz. (fig. 33). The structure of the area consists of the faulted East Kaibab monocline in the west and Echo Cliffs monocline in the east with a gently folded structural terrace between. Erosion in House Rock Valley and in the Colorado River Valley has exposed a section of sedimentary rocks more than a mile thick, including rocks from the Supai formation of Pennsylvanian and Permian age to the Entrada sandstone of Jurassic age (fig. 34).

Most of the uranium deposits in the East Vermilion Cliffs area occur in the Shinarump member of the Chinle formation in channel scours cut into the top of the Moenkopi formation. Small pockets of uranium minerals, however, occur in sandstone lenses in the Petrified Forest member of the Chinle. The known uranium deposits are located in the Lees Ferry and central East Vermilion Cliffs (fig. 33) areas. There are no known commercial deposits in the House Rock Valley area.

### The House Rock Valley area, by J. D. Wells

The sedimentary rocks that crop out in the House Rock Valley area are the Hermit, Toroweap, Kaibab, Moenkopi, Chinle, Moenave, Kayenta, Navajo, and Carmel formations (fig. 34). The rock units exposed are

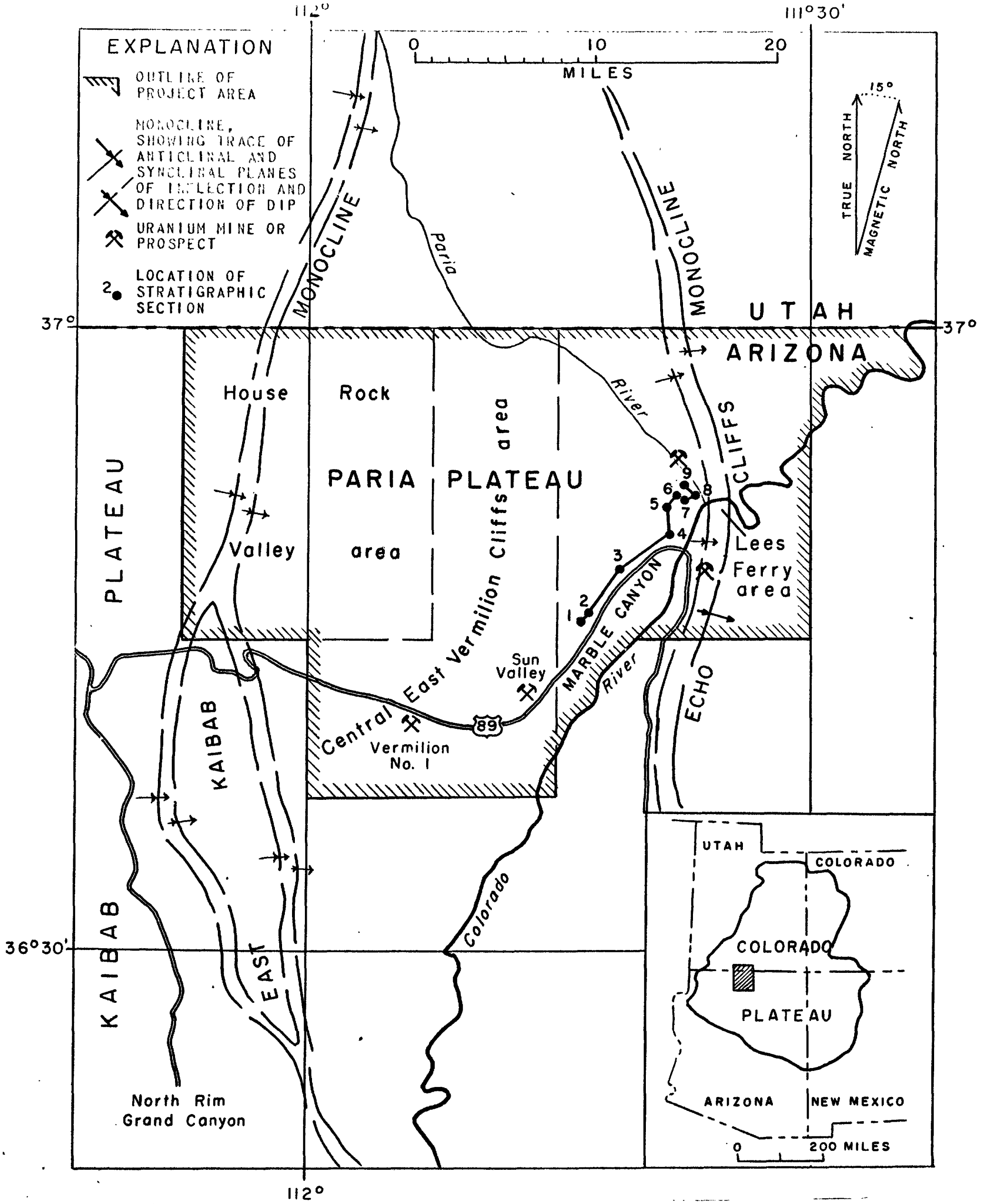

FIG. 33.— — INDEX MAP SHOWING LOCATION OF EAST VERMILION CLIFFS PROJECT AREA, COCONINO COUNTY, ARIZONA.

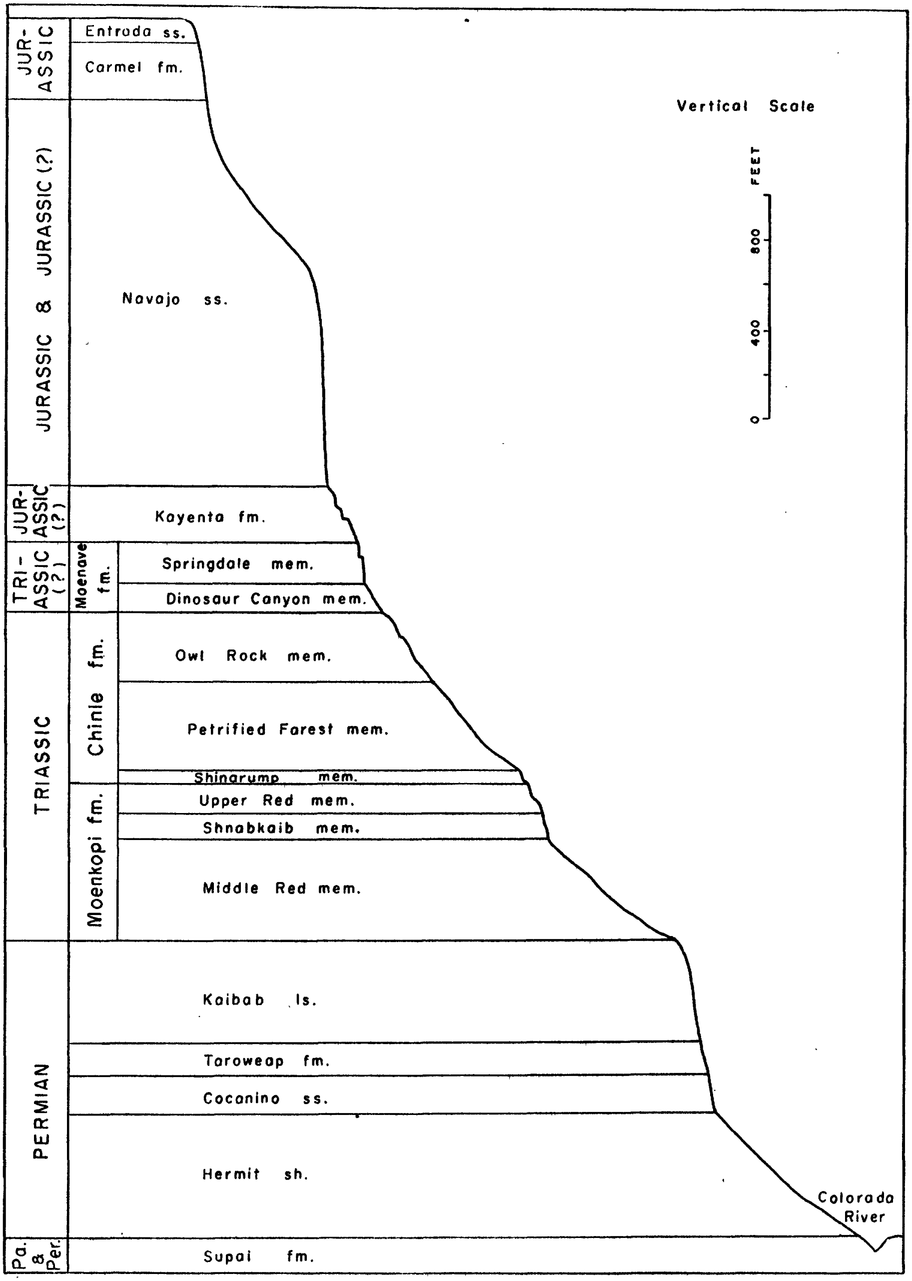

Fig. 34.--COLUMNAR SECTION ALONG EAST VERMILION CLIFFS, COCONINO COUNTY, ARIZONA

generally similar to the formations described in other areas of the Colorado Plateau. In this area the Coconino sandstone is not present; only a few rounded frosted quartz grains mark its probable lateral equivalent at the upper contact of the Hermit shale. The Shinarump member of the Chinle formation is absent in the southern part of the area and elsewhere ranges in thickness from a wedge edge to about 50 feet. The Shinarump is generally well consolidated, but locally in the central part of the area is unconsolidated. No paleostream channels were recognized in the member. The Carmel formation occurs as a bed about 70 feet thick on the tops of buttes on the Paria Plateau; this unit is a tongue of the Carmel and is overlain by a tongue of Navajo sandstone.

The tectonic structures present in this area--folds, faults, and joints--are typcial of the structures of the Colorado Plateau. The most prominent is the East Kaibab monocline which is a north-trending, north-plunging structure about 130 miles long. In the House Rock Valley area the monocline has a structural relief of about 3,500 feet; the eastward dips are generally 10° to 20° with a maximum of about 30°. The monocline has a major N. 10° E. trend with local trends of N. 20° E. to N. 20° W. Minor northwest-trending warps reflecting the changes in trend of the monocline occur in the steeply dipping part of the monocline. Other broad low amplitude anticlines and synclines are present east of the monocline; these generally trend parallel to the synclinal bend of the monocline. Sharp anticlines and synclines with limbs dipping up to 40° and which die out rapidly along strike occur in the Shinarump member of the Chinle formation in the northern half of the area.

Prominent high-angle faults with offsets of as much as 300 feet occur subparallel to the monoclinal trend; some of these have offsets that increase while others decrease the structural relief. High-angle faults with displacements of usually about 20 feet offset the Shinarump member in the northern part of the area and form horsts and grabens. Most of these faults are subparallel to the monocline but some strike at an angle to it. Northeast-trending faults with the south side downthrown about 200 feet exist west of the monocline. East of the monocline, in the northeast corner and in the central part of the area, faults trending northwest have displacements up to 150 feet with the southwest side downthrown. Associated with the major faults in the northeast are a series of faults with small displacements that form horsts and grabens which trend subparallel or nearly at right angles to the major faults.

Certain structural features are apparently associated with the synclinal bend of the monocline. Slickensides occur in the Chinle formation on fault planes that nearly parallel the axial plane of the synclinal fold. A series of small high-angle step faults cutting the lower contact of the Moenave formation in the locality of the slickensides strike near north-south and have displacements of about a foot with the west side upthrown. A shear zone consisting of many nearly vertical fractures has been formed in the Navajo sandstone and the Kayenta formation. Small low-angle faults with the east side thrust a few feet over the west occur in the Chinle formation. The slickensides, step faults, shear zone, and thrust faults occurring in the synclinal bend of the monocline are interpreted to have been formed by local compression on the inside of the fold.

No commercial ore deposits are known to exist in the House Rock Valley area, but two mineralized localities are present. Anomalous radioactivity was detected in a prospect adit located in the south-central part of the area. The radioactive material is around a small block of claystone in a sandstone bed in the Petrified Forest member of the Chinle formation. A channel sample from this material contained 0.018 percent uranium oxide, less than 0.5 percent vanadium oxide, and 0.069 percent copper.

In the northeast part of the area copper minerals cement parts of the Navajo sandstone near a fault. A sample of the sandstone contained 0.005 percent uranium oxide, less than 0.05 percent vanadium oxide, and 2.01 percent copper. Minerals present are pyrite, tetrahedrite, chalcocite, covellite, malachite, and cuprite.

### The Central East Vermilion Cliffs area, by R. G. Petersen

The central part of the East Vermilion Cliffs includes an area of about 240 square miles. The rocks range in age from Pennsylvanian and Permian (Supai formation) to Jurassic (Carmel formation) capping buttes on the Paria Plateau in the north. One minor but persistent fold, called the Soap Creek syncline, extends the entire length of the area. The axis of the syncline strikes about N. 15° E. and plunges about 2° to the north. All of the beds in the area are probably influenced by this fold and dip about 2°-3° in a northerly direction.

All of the known uranium mineral deposits in the area occur in the Shinarump member of the Chinle formation. The Shinarump is highly variable in thickness, areal extent, and composition. In channel scours the member attains a thickness up to 130 feet. In other places, perhaps only a few hundred feet from these scours, it is absent. Where persistent, the Shinarump usually ranges in thickness from 20 to 40 feet. It varies in composition from a hard, well-cemented conglomerate to a deposit of poorly sorted sand and gravel. In places it is a clay-cemented crossbedded sandstone.

Two uranium mines are located in the central area (fig. 33). One, the Vermilion No. 1 mine, has produced only a few tons of low-grade rock. The mine consists of an open pit in a small channel scour filled with the Shinarump member. The channel is about 10 to 20 feet deep, 30 to 50 feet wide, and about 300 feet long. The Shinarump in the channel is a poorly sorted mixture of clay, sand, and gravel. The uranium minerals occur in the Shinarump and in the Moenkopi, at or near the contact of the two units. The only uranium mineral identified is metatorbernite, which is found in the gravel in the Shinarump member and in the siltstones of the Moenkopi formation.

The second and most important uranium mine in the area is the Sun Valley mine. This mine is in a channel scour, filled with the Shinarump member, of greater dimensions than the scour at the Vermilion No. 1 mine. Surface and drill-hole data indicate that the deposit is in a U-shaped bend of a paleostream channel and is at least 1,000 feet long and 400 feet wide. In the deepest part of the channel the Shinarump is about 130 feet thick. About 400 feet of underground workings in this mine have produced several hundred tons of ore.

The only primary uranium ore mineral identified in the Shinarump member in the Sun Valley mine is uraninite, which occurs as interstitial material and as rounded grains (up to 1 mm. in diameter). Other minerals recognized are pyrite, sphalerite (light amber), hematite, galena (rare), and possibly jordisite. The cementing material is calcite with minor chalcedony. The probable paragenetic sequence is: (1) uraninite (interstitial type), (2) pyrite, and (3) sphalerite. The secondary uranium minerals found forming on the mine wall and on outcrops of the Shinarump are: zippeite, beta-zippeite, and an unnamed uranyl phosphate. In addition to these, the secondary molybdenum mineral ilsemanite is forming rapidly on the walls of the older mine workings.

Ten samples of uranium-bearing rock from the Shinarump member at the Sun Valley mine were found to contain an unusual amount (up to 0.07 percent) of rhenium. This metal, probably in the form of an oxide, was found to be concentrated in the water-soluble fraction of the samples. The soluble salt fraction of two samples assayed 1.5 percent rhenium.

## The Lees Ferry area, by D. A. Phoenix

The Lees Ferry area includes about 270 square miles of sparsely populated semiarid canyon and plateau country in Coconino County, Ariz. The historic ford of the Colorado River at Lees Ferry is situated in the geographic center of the region and the Glen Canyon dam site is on its eastern edge. Prominent land forms in the area are Marble Canyon and its upstream counterpart, Glen Canyon of the Colorado River; Marble Canyon is bordered by Vermilion Cliffs to the north and Echo Cliffs to the east (fig. 35).

The consolidated sedimentary rocks exposed in the Lees Ferry area have an aggregate thickness of about 4,500 feet and range in age from Permian to Upper Jurassic. The erosive characteristics of the rocks divide them into three broad groups: these are, in ascending

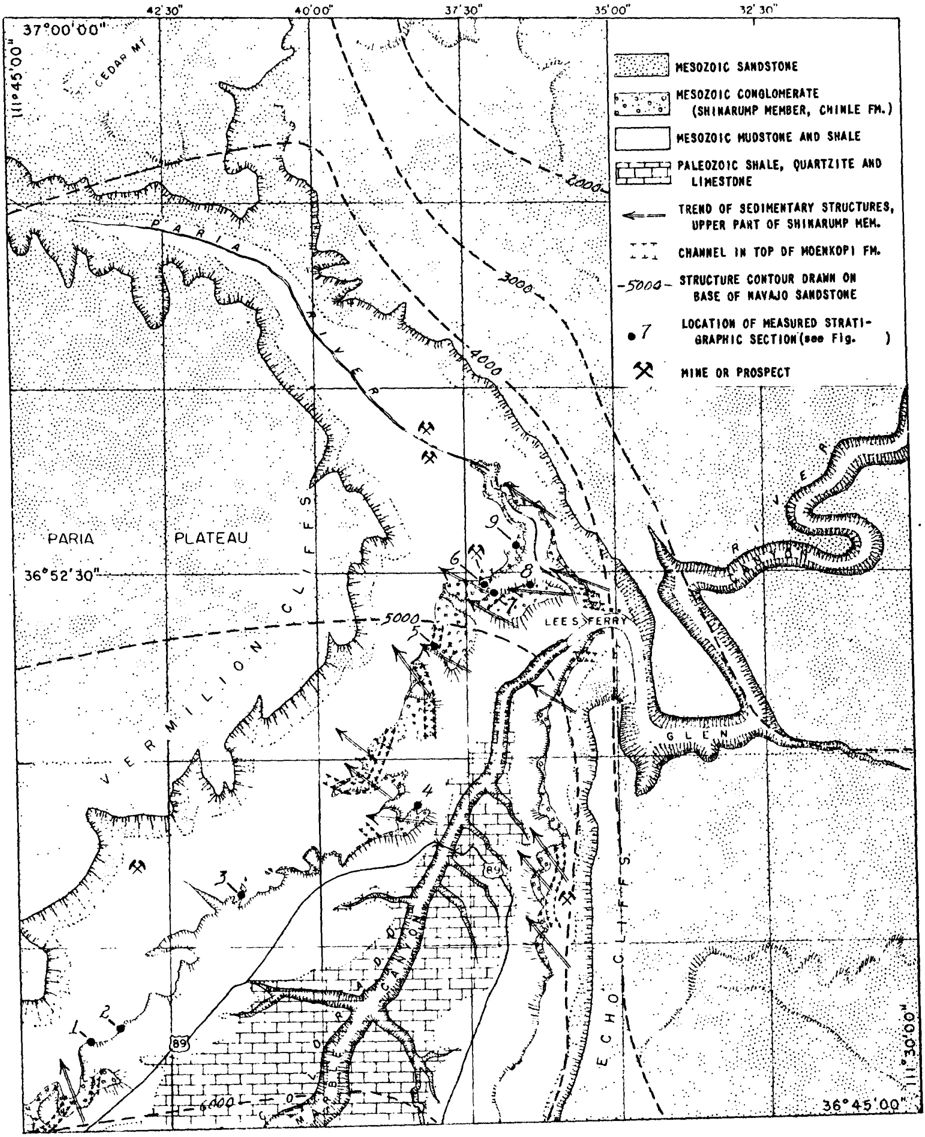

Fig. 35.--GEOLOGIC MAP SHOWING DISTRIBUTION AND TRENDS OF THE SHINARUMP MEMBER OF CHINLE FORMATION, LEES FERRY AREA, COCONINO COUNTY, ARIZONA.

order, about 800 feet of resistant shale, quartzite, and limestone of Paleozoic age that underlie the platform entrenched by Marble Canyon; about 1,600 feet of easily eroded clay and mudstone with subordinate but resistent strata of sandstone and conglomerate of Mesozoic age that support Vermilion and Echo Cliffs; and about 2,100 feet of resistant sandstones of Mesozoic age that compose the Vermilion and Echo Cliffs and underlie the plateaus of the region (fig. 35).

The rocks in the area are folded by the northward plunging Echo Cliffs monocline. This fold is about 40 miles long and like most of the monoclines in the Colorado Plateau displaces beds downwards to the east--the displacement in the area is about 2,000 feet. The formations on both sides of this fold have a regional dip of about 2° northward.

Structural details differ in the three major rock groups. The Paleozoic group of rocks are deformed locally by folds with as much as 100 feet of relief. These rocks are also cut by northwesterly trending high-angle faults with displacements ranging between 10 and 40 feet. Part of the deformation in these older rocks is localized near the Echo Cliffs monocline. Deformation in the youngest Mesozoic group of rocks is most severe along the steep limb of the Echo Cliffs monocline where the Navajo sandstone is cut by reefs and linear bodies of sheared and crushed sandstone. Elsewhere the sandstone strata are cut by high-angle faults with displacements of between 10 and 100 feet; local folds such as are found in the oldest group of strata do not occur in these rocks. The relatively plastic middle group of strata, including the Chinle and the Moenkopi formations, has absorbed much of the local folding and faulting in the resistant and more brittle strata above and below. Only locally do folds or faults connect between the two resistant groups of strata; so that the uranium-bearing Shinarump member of the Chinle formation is not deformed locally.

The Shinarump member of the Chinle formation consists of thin but resistant broad lenses of conglomerate and sandstone in the lower part of the nonresistant clay-rich group of rocks (fig. 35) and rests on the clay-rich Moenkopi formation. Where the Moenkopi formation is overlain by mudstone of the Chinle formation it is altered for several feet below the contact, but where the Moenkopi formation is overlain by the Shinarump member it is less altered.

The Shinarump member fills broad swales (Witkind, 1956) in the underlying Moenkopi formation (fig. 36) and locally it also fills deep sinuous channels in the Moenkopi formation. The member is believed to represent deposits left by streams, the flow of which shifted from place to place. Sedimentary structures in the upper part of the Shinarump member are mostly oriented northwest. The channels at the base of the member are oriented more or less at random, but the overall trend is about north-northwest.

Where the Shinarump member fills channels cut in the underlying Moenkopi formation it is locally uranium-bearing. Less important occurrences of uranium have also been found in other parts of the Chinle formation, but to date none have been economic.

The uranium-bearing Shinarump member of the Chinle formation is a thin lenticular aquifer probably elongate northwesterly, in which fluid movement during mineralization was in response to regional gradients and to physical characteristics of the aquifer. Fluid

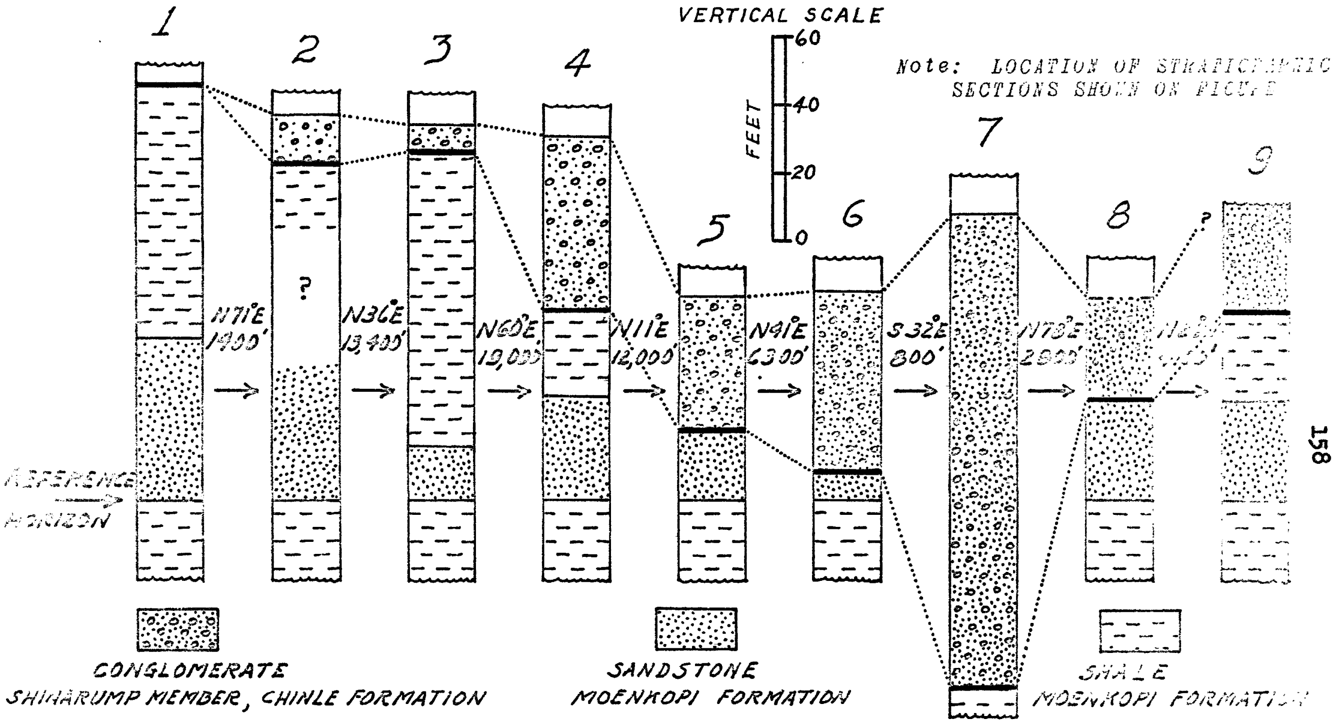

FIG. 36—STRATIGRAPHIC SECTIONS SHOWING CHANNELING OF THE SHINARUMP MEMBER OF THE CHINLE FORMATION INTO THE MOENKOPI FORMATION, LEES FERRY AREA, COCONINO COUNTY, ARIZONA.

movement from place to place was probably hindered by thin places in the member or by clay strata. Fluids probably became stagnant in the channels cut into the Moenkopi formation, particularly in those oriented at right angles to the regional hydraulic gradient; these places are also favorable to the localization of uranium. The origin of the uranium in the Shinarump member is not known but compaction of clay strata above the member probably yielded a more than ample supply of fluid to saturate these permeable sediments and it may be possible that the uranium was introduced in this way.

Reference

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## Grants area, New Mexico

by

R. E. Thaden and E. S. Santos

Pre-Dakota folding of sedimentary rocks in the Grants area is much less obvious and apparently less well developed than that reported in the Laguna area (TEI-640, p. 76-77); this lack of expression may be due to parallelism of exposures and the trends of folding. Minor northeast-trending folds in the Grants area and larger and more complicated folding have been described in earlier reports (TEI-620, p. 75-76; TEI-640, p. 75). Major folding in the Grants area trends south of east, and apparently developed as the sediments of the Morrison formation were being deposited (L. S. Hilpert and A. F. Corey, oral communication, 1957). There is little doubt that this folding is correlative with the major folding described in the Laguna area. Small folds in the Grants area, such as the one at the Poison Canyon mine, are probably of the same system as the large ones noted by Hilpert and Corey; this folding is probably synclinorial (TEI-620, p. 75; TEI-640, p. 77). That the syncline at Poison Canyon also developed contemporaneously with deposition of the Morrison sediments is indicated by thickening of the upper part of the Morrison formation in the syncline and thinning in the adjacent anticlinal areas. In addition, claystone units within the Westwater Canyon member of the Morrison are best developed in the syncline and are thinner and less numerous on the adjacent anticlinal highs. Uranium deposits tend to occur in the synclines; changes in thickness and persistence of claystone units in the Morrison formation may reveal the presence of folds even where vertical control is lacking and thus indicate areas where drilling for ore may prove successful,

New analytical data tend to confirm the concept of zoned ore deposits presented previously (TEI-620, p. 76). Chromium is apparently concentrated in a halo above the ore in the Westwater Canyon member of the Morrison formation, whereas molybdenum and selenium are apparently concentrated at the base of the ore. Where the ore occurs in multiple layers, the highest concentrations of these elements are above the uppermost layer and at the base of the lowermost layer, respectively. Knowledge of the range of concentration of these elements, combined with field testing, could conceivably save many feet of unnecessary exploratory drilling, particularly in areas where the lowest ore layer is a considerable stratigraphic interval above the base of the Westwater Canyon member.

## Laguna area, New Mexico
by
R. H. Moench and J. S. Schlee

The report period was devoted primarily to petrographic and mineralogic study of the ores and sedimentary rocks of the Laguna area. Most of the ores studied were from the Woodrow "pipe", the Sandy mine area, and the Crackpot and Chavez mines. The structural relationships of these mines and deposits have been described briefly in previous reports (TEI-590, p. 60; TEI-640, p. 79).

The mineralogy of the uranium ores studied is simple, consisting of one to three dominant minerals. On the basis of their dominant mineralogy the ores may be classified tentatively in four categories: (1) coffinite ores, which occur in the Jackpile mine; (2) coffinite-sulfide ores, which occur in the Woodrow mine; (3) coffinite(?)-roscoelite ores, which occur in the Chavez mine; and (4) uraninite-roscoelite ores, which occur in the several deposits of the Sandy mine area, and probably also in the Crackpot mine. Apparently coffinite is the dominant primary uranium mineral in deposits where the host rocks are noncalcareous or slightly calcareous, and uraninite is the most important uranium mineral in deposits where the host rocks are calcareous. Roscoelite is apparently an important ore mineral in those mines where the vanadium:uranium ratio is 1:2 or greater.

Sulfides are most abundant in the Woodrow mine but are present in all of the ore deposits. Pyrite is the most common sulfide mineral, but marcasite is abundant in the Woodrow mine, and minor amounts of chalcopyrite, galena, and sphalerite are present in most deposits. Small amounts of carbonate gangue--calcite, dolomite, and possibly rhodochrosite--are present in the Woodrow mine. Coffinite from the Jackpile and Woodrow mines and uraninite from the Sandy mine were identified in selected high-grade samples by Alice S. Corey of the U. S. Atomic Energy Commission (oral communication, 1957).

The sequence of deposition of the ore minerals is fairly consistent in all of the mines in the Laguna area. In general, the primary uranium minerals are later in the paragenetic sequence than the other minerals. In the vanadiferous ores, roscoelite is earlier in the paragenetic sequence than uraninite or coffinite. The sulfides--dominantly pyrite, with minor amounts of marcasite, chalcopyrite, galena, and sphalerite--are in general earlier than the uranium minerals, and probably younger than the roscoelite. Some pyrite was deposited later than uraninite. In the nonvanadiferous coffinite-sulfide ore of the Woodrow mine most of the pyrite, marcasite, and other sulfides and carbonate gangue are earlier in the sequence than coffinite. Minor amounts of pyrite, marcasite, quartz, and calcite are later than coffinite.

Replacement, rather than simple filling of open space, appears to have been a dominant process in the deposition of all the ores. In parts of the Woodrow mine the detrital constituents--quartz, feldspars, and rock fragments--have been completely replaced by pyrite and marcasite; forming a rock that consists of only sulfide minerals. In places both the sulfides and detrital constituents have been partly replaced by coffinite along close-spaced bedding planes and joints, resulting in "boxwork-type" ore. In the vanadiferous ores, roscoelite and uraninite have replaced much of the original clay and calcite cement, as well as the detrital constituents. In the higher grade parts of the sandstone ores the original cement is completely replaced, together with as much as 25 percent of the detrital quartz and feldspar, by ore minerals.

A sequence of eight samples taken vertically across a small roll-type ore body in the Sandy mine area was studied petrographically to determine the quantitative mineralogic differences between the barren host rock and the ore. From the sample sequence it is tentatively concluded that: (1) detrital quartz and feldspars have, to a great extent, been replaced by calcite and/or roscoelite within the ore zone, and, to a lesser extent, similarly replaced in the barren zone between the upper and lower parts of the ore roll; (2) calcite was not removed during mineralization, but was replaced by the ore minerals and redeposited in the lower grade parts of the ore and in the barren zone between the upper and lower parts of the ore roll; (3) some clay minerals may have been introduced at an early stage of mineralization; and (4) the roscoelite probably formed from materials derived from the replaced silicates, original clays, and introduced(?) clay, plus vanadium from the mineralizing solutions.

Preliminary petrographic study has been made of the color changes in the Entrada sandstone. Most of the unit is moderate orange pink; the uppermost 20 to 40 feet are mostly white to very pale orange, but a discontinuous mottled pale-red to grayish-red band as much as 5 feet thick is present near the base of the light-colored zone. The light-colored zone contains the uranium deposits in the Entrada in the Sandy mine area. The color changes transect sedimentary structures in the sandstone. From the petrographic work it is concluded tentatively that these color changes reflect the distribution of iron in the rocks. In the moderate orange-pink sandstone some of the detrital opaque minerals are altered to leucoxene or hematite or mixtures of both, but unaltered magnetite is also present; in addition, fine-grained hematite coats the detrital grains. In the white sandstone leucoxene is the only recognized relict detrital opaque mineral and hematite is absent; apparently, there is little or no iron-bearing mineral in the sandstone. In the grayish-red sandstone the detrital opaque minerals are present as in the moderate orange-pink sandstone and hematite is abundantly distributed in the interstices. It is suggested that moderate orange-pink sandstone represents the original rock, and that iron was leached from the original rock to form what is now the white zone, and at least partly reconcentrated in the grayish-red zone. Field relations indicate that the white and grayish-red color zones are as old as, or older than, the uranium deposits.

Another color change present in the Entrada sandstone is related to the diabasic dikes and sills. As the diabase is known to be younger than the uranium deposits, this color change is also younger. The color of the moderate orange-pink sandstone, described above, changes sharply to very pale orange to grayish-orange in zones 10 to 30 feet wide on either side of dikes, and in wide areal zones that are coextensive with sills. As in the white zone, leucoxene represents the only relict detrital opaque mineral in the very pale orange to grayish-orange sandstone. Hematite and limonite (goethite?) are disseminated throughout the rock as discrete pseudomorphs after pyrite. Some of the pseudomorphs contain traces of pyrite. It is suggested that the iron in the original moderate orange-pink sandstone was transformed to pyrite, and subsequently weathered to form hematite-limonite pseudomorphs.

In the Sandy mine area a number of small uranium-vanadium deposits cut by the diabasic sills are metamorphosed to lime-silicate rocks. As far as can be determined, the distribution and state of the primary uranium mineral, probably uraninite, is unchanged. Garnet, diopside, and vesuvianite have formed at the expense of detrital silicates, clay, and calcite. The garnet, not yet positively identified, is probably a member of the grossularite-andradite series. In some thin sections the garnet, which is nearly colorless in most of the rock, changes to deep brown or reddish brown in highly mineralized rock, especially where associated with roscoelite. Inasmuch as trivalent vanadium and iron have essentially the same ionic radii (0.65 and 0.67 kX respectively, Rankama and Sahama, 1949, p. 794) it is likely that vanadium may substitute for iron in andradite, and the garnet may have formed, in part, at the expense of roscoelite.

Petrographic examination of rocks of the Chinle, Summerville, and Bluff formations has revealed features which allow inferences regarding the paleogeography, depositional environment, and post-depositional history of these formations.

The Petrified Forest member of the Chinle formation consists mainly of shale, but to the north, in the vicinity of Mesa Gigante, sandstone and conglomerate beds are present at the top of the formation. The sandstones are arkoses, subarkoses, and protoquartzites (Pettijohn, 1957, p. 291); the texturally more immature sandstones occur toward the base of the sequence. Detrital constituents include quartz, feldspar, chert, rock fragments, muscovite, tourmaline, and zircon. Calcite cement commonly forms 15-20 percent, but locally as much as 50 percent, of the rock. Limestone conglomerates are interbedded with the arkosic sandstones. The limestone pebbles are set in a matrix of detrital quartz and calcite.

The Chinle sediments were probably derived from both igneous and sedimentary-metamorphic sources. The probable inability of the limestone to withstand the rigors of long transport suggests that the source was close, perhaps even within 100 miles. The high percentage of cement (as much as 40-50 percent) suggests that some of the sands may have been originally openwork, similar to the "clean" sands Lane (1938, p. 505-508) noted in a fluvial environment. Cross-bedding in the sandstone indicates a northwest direction of sediment transport.

The Summerville formation consists of alternating red coarse-grained siltstone and fine-grained sandstones. The sandstones are orthoquartzites, and the coarse-grained siltstones are, compositionally, feldspathic graywackes. The "graywacke" siltstones are marked by contorted bedding, poor sorting, and a clay-paste matrix. The orthoquartzites are well sorted, massive to flat bedded, and cemented by calcite. Mineralogic differences are not pronounced. Both types are rich in quartz (70 percent) with minor amounts of feldspar, chert, and assorted heavy minerals (tourmaline, zircon, ilmenite, monazite, and staurolite).

The interbedded orthoquartzites and "graywacke" siltstones are genetically incongruous, and yet they grade from one to the other over a vertical distance of a few inches. The siltstone has a "poured-in" look, due to the contorted bedding and incomplete separation of fine and coarse clastics. Periodic slumping and rapid influx of sediments into a shallow sea or lake followed by partial reworking of the slumped material by wave action is suggested as a possible mechanism to explain this sequence.

The Bluff sandstone is divided into a lower, festoon crossbedded sandstone and an upper, planar crossbedded sandstone. The lower Bluff sandstone is pale reddish brown to very pale orange, fine to medium grained, massive to festoon crossbedded, and friable. It is an orthoquartzite, and consists of quartz, feldspar, rock fragments, chert, and associated heavy minerals, and is cemented by hematite, clay, and calcite. The upper Bluff is a yellowish-gray to grayish-yellow, fine- to coarse-grained, friable, massive to planar crossbedded sandstone. It also is an orthoquartzite and is composed of quartz, feldspar, chert, and trace amounts of rock fragments, rutile, zircon, magnetite, and tourmaline, cemented by calcite or silica.

The sediments of lower Bluff sandstone are slightly finer grained, less well sorted, and less rounded than those of the upper Bluff sandstone.

The mineralogy of the detrital grains indicates that the Bluff sandstone was derived from an igneous, metamorphic, and sedimentary terrane. The combination of good sorting, low inclination of foreset crossbeds, and other features, suggest a fluvial origin for the lower Bluff sandstone. The upper Bluff sandstone, as suggested by the thickness of the crossbed sets (as much as 30 feet), and the steep inclination of the foreset crossbeds (average 24°), is probably aeolian in origin. Crossbedding studies indicate that the material was derived from the west.

A lateral color change (from pale reddish brown to yellowish gray) in part of the lower Bluff sandstone reflects a change in the kind and amount of iron oxide present. The cement in the pale reddish-brown sandstone is hematite and clay(?), whereas the equivalent yellowish-gray sandstone is cemented by calcite, secondary silica, and clay; goethite(?) is present, probably as an alteration product of pyrite.

Preliminary petrographic examination of the sandstones of the Morrison formation reveals a wide variation in composition--from feldspathic and lithic graywackes to orthoquartzites. Almost all of the sandstones have abundant quartz, feldspar, volcanic(?) debris, and clay matrix or calcite cement. Some of the volcanic fragments are fresh and consist of porphyritic and trachytic andesite.

Thin (less than 6 inches) fairly continuous, pale reddish-brown to moderate reddish-orange well-indurated massive tuff beds are present in the Brushy Basin member of the Morrison formation. Relic shard structure, extremely poor sorting, and angular mineral fragments typify these beds.

When contrasted with rocks of the Chinle, Summerville, and Bluff formations, the sandstones of the Morrison are notable for their higher content of labile constituents and clay matrix.

Preliminary petrographic investigation of the Mancos sandstones and shales reveals a range in composition and texture from massive orthoquartzites to poorly sorted clay-rich slump-bedded graywackes. Quartz is the dominant constituent, and other clastic fragments include feldspar, chert, rock fragments (metaquartzite, and shale), zircon, magnetite, and ilmenite. The cleaner sandstones of the Mancos are cemented by calcite or secondary silica. The less well-sorted indurated sandstones have a chlorite-sericite matrix.

## References

Lane, E. W., 1938, Notes on the formation of sand: Am. Geophys. Union Trans. 19th Ann. Mtg., p. 505-508.

Pettijohn, F. J., 1957, Sedimentary rocks: New York, Harper & Bros., 291 p.

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## Photogeologic mapping

by

W. A. Fischer

During the report period approximately 95 percent of the total photogeologic mapping effort was directed toward the compilation of maps at a scale of 1:62,500, for use in the Survey's 1:250,000-scale mapping program of the Colorado Plateau. High altitude photographs (approximate scale, 1:60,000) are used in conjunction with the radial planimetric plotter and the Zeiss stereotope. Part of the summer field season was spent in obtaining stratigraphic information preliminary to interpretation and compilation of geology for the 1:250,000 mapping program.

Two photogeology studies being carried out in close cooperation with field studies were continued throughout the report period. These studies are of the Orange Cliffs area, central Utah and part of the western Black Hills, Wyoming where the Inyan Kara group of Cretaceous age is being studied in detail. Kelsh plotter methods are being used in both of these projects.

During the report period maps at 1:62,500 scale of the equivalent of fifty-four 7½-minute quadrangles were completed. These maps were of parts of the Uncompahgre and Sage Plains areas, Colorado. In addition, six maps of 7½-minute quadrangles at a scale of 1:24,000 were published by the Geological Survey in the Miscellaneous Geologic Investigations map series. These are listed below by number and title:

I-196 - Lees Ferry NW, Coconino County, Arizona
I-221 - Navajo Mountain 8, San Juan County, Utah
I-222 - Lees Ferry NE, Coconino County, Arizona
I-229 - Navajo Mountain 1, San Juan County, Utah
I-233 - Navajo Mountain 10, San Juan County, Utah
I-238 - Navajo Mountain 14, San Juan County, Utah and Coconino County, Arizona

## Black Hills, South Dakota and Wyoming

Geologic mapping and related studies were started in the southern part of the Black Hills in 1952 with the objective of determining the lithologic, structural, and geochemical controls that influence the localization of uranium in the area. In 1955 the program was extended to the northern Black Hills, and somewhat later a program of combined geologic mapping and photogeologic interpretation was initated with the objective of filling in the gap between the southern and northwestern parts of the Hills. (See "Stratigraphy of the Inyan Kara group", under Geologic Topical Studies, this volume.) The area covered by the Black Hills studies is shown on figure 37.

Up to the summer of 1957 the Cascade Springs, Flint Hill, Minnekahta, Edgemont, Edgemont NE, Burdock, Jewell Cave, and Dewey 7½-minute quadrangles in South Dakota, and the Carlile and Storm Hill 7½-minute quadrangles have been mapped. Results of the investigations in the Black Hills, in addition to those in this volume, have been given in previous Semiannual reports, particularly TEI-620, p. 164-181, and TEI-640, p. 84-113.

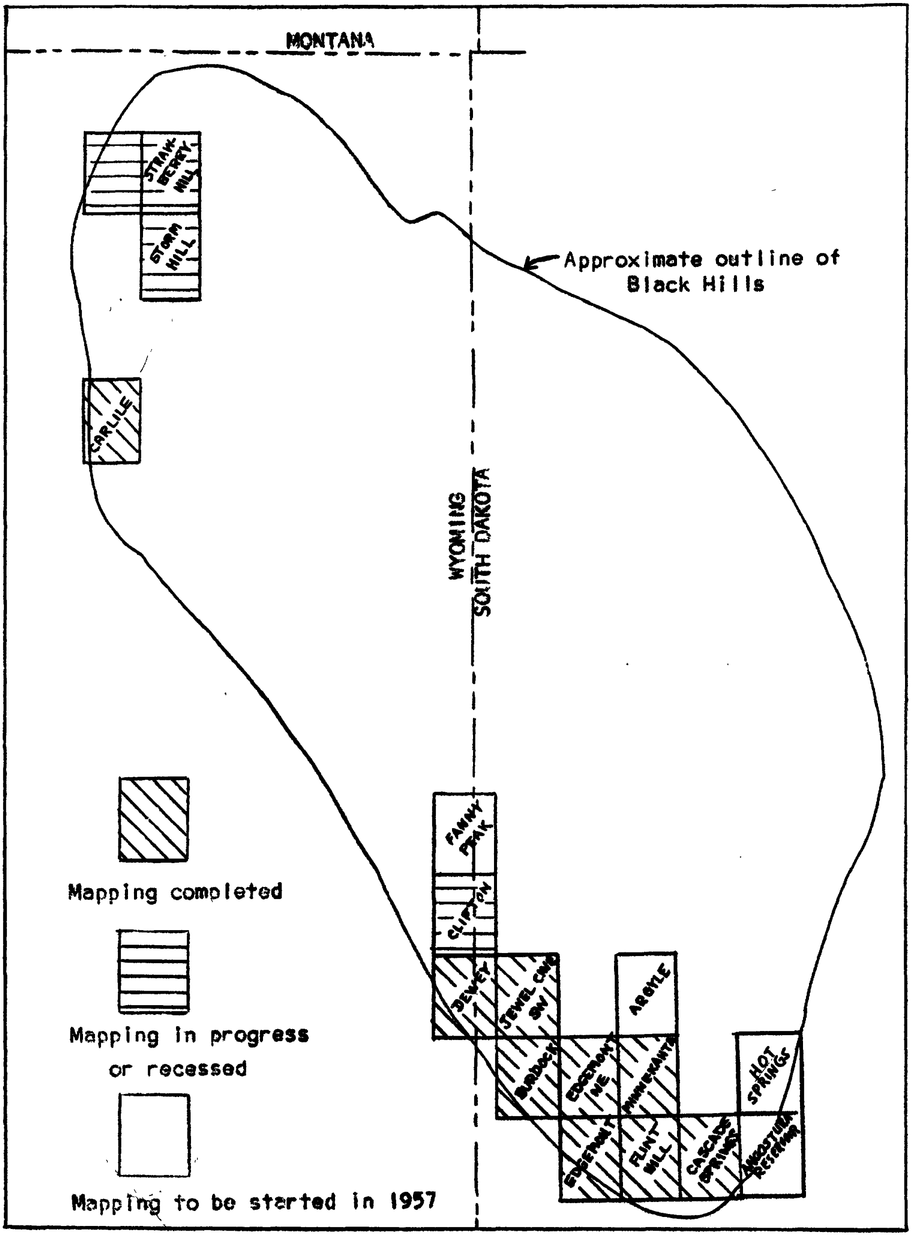


FIGURE 37. - PROGRESS OF GEOLOGIC MAPPING BY THE U. S. GEOLOGICAL SURVEY IN THE BLACK HILLS, SOUTH DAKOTA AND WYOMING.

During the report period the following MF maps of quadrangles in the Black Hills, all by G. B. Gott and R. W. Schnabel, were published:

MF-55. Preliminary geologic map of the northwest part of Edgemont NE quadrangle, Custer and Fall River Counties, South Dakota.
MF-56. Preliminary geologic map of the northeast part of Edgemont NE quadrangle, Custer and Fall River Counties, South Dakota.
MF-57. Preliminary geologic map of the east-central part of the Edgemont NE quadrangle, Fall River County, South Dakota.
MF-58. Preliminary geologic map of the west-central part of the Edgemont NE quadrangle, Fall River County, South Dakota.
MF-59. Preliminary geologic map of the southwest part of the Edgemont NE quadrangle, Fall River County, South Dakota.
MF-60. Preliminary geologic map of the southeast part of the Edgemont NE quadrangle, Fall River County, South Dakota.

## Edgemont NE quadrangle, South Dakota

by

G. B. Gott and R. W. Schnabel

The Edgemont NE quadrangle lies mostly within the Black Hills National Forest in Fall River and Custer Counties, South Dakota and includes part of the southwestern part of the Black Hills uplift. Geologic mapping of the quadrangle was begun in June 1954.

Sedimentary rocks of Permian, Triassic, Jurassic, Cretaceous, Tertiary(?), and Quaternary age are exposed with the quadrangle. The Permian and Triassic rocks consist of a sequence of about 725 feet of largely red or maroon fine-grained clastic rocks with some limestone and several marine evaporite facies; the formations are, in ascending order: the Opeche formation and the Minnekahta limestone of Permian age, and the Spearfish formation of Triassic age.

The rocks of Jurassic age exposed within the quadrangle are 400 to 450 feet thick and include marine sandstones and shales of the Sundance formation which are overlain by soft, fine-grained, non-marine calcareous rocks of the Morrison formation.

Lower Cretaceous rocks include, from oldest to youngest: the non-marine Inyan Kara group composed of the Lakota sandstone, Minnewaste limestone, Fuson formation, and Fall River sandstone; and the marine Skull Creek shale. The Minnewaste limestone is present in patches in the northwestern part of the quadrangle but evidently was not deposited elsewhere in the area. Where it is not present the contact between the Lakota sandstone and the Fuson formation is normally obscure or unrecognizable. For that reason the pre-Fall River Inyan Kara rocks are referred to in this report as the undivided Lakota-Fuson formations.

The Lakota-Fuson formations are composed of a crudely alternating sequence of rocks deposited in fluvial and quiet water environments (TEI-640, p. 106) and are 250 to 400 feet thick. The rocks deposited in quiet water probably accumulated as fine-grained material in lakes and marshes, although some of the fine-grained material may represent an accumulation of loess. As the lakes and marshes filled, dissection by northwestward-flowing streams began and later the erosional irregularities caused by this dissection were filled by a series of complex, channel-type crossbedding sandstones. Thus the lithologic characteristics of the Lakota-Fuson formations change radically from place to place, both laterally and vertically, depending on whether rocks of fluvial or non-fluvial origin predominate in a given locality.

The rocks that make up the Fall River sandstone are about 150 feet thick and are more uniform in composition and physical characteristics than are the pre-Fall River Inyan Kara rocks. The oldest Fall River rocks are fine-grained, thin-bedded, tabular sandstones alternating with carbonaceous siltstones that were evidently deposited in a swampy or marshy environment. These beds grade upward into a unit composed of thin, tabular brownish-gray ripple-marked sandstone beds that alternate with massive, gray, sparsely carbonaceous mudstones. A red mudstone near the top of this unit is locally useful as a marker bed. The upper contact of the Fall River sandstone appears to be gradational with the overlying Skull Creek shale and may indicate a gradational change from continental to marine sedimentation. During middle or late Fall River time the oldest Fall River rocks were, in places, partly or completely removed by erosion. The erosional irregularities were refilled with stream-laid sand and the resulting sandstone forms the canyon walls and rims of many of the present-day canyons.

Tertiary(?) and Quaternary rocks are represented in the Edgemont NE quadrangle mainly by terrace and alluvial deposits of unconsolidated sand and gravel. The division between Tertiary and Quaternary deposits is based mainly on the elevation of the several terrace levels.

The Edgemont NE quadrangle is along the slightly deformed southwest margin of the Black Hills uplift. The regional dip is about 3° to the southwest but on the westward-dipping monocline in the southeastern part of the quadrangle the maximum dips approach 20°. Small anticlinal folds are present in the northwestern and northeastern parts of the quadrangle. Elsewhere the structural irregularities consist of a step-like series of small structural terraces and monoclines. Several small faults exist; all have a displacement of less than 100 feet and many have a displacement of from 10 to 25 feet. Numerous structural sinks involving rocks ranging from the Minnekahta limestone to the Lakota sandstone are present. These structures evidently resulted from the removal in solution of either limestone or gypsum at depth.

Uranium deposits constitute the most economically important mineral resource in the Edgemont NE quadrangle but petroleum, gypsum, and sand and gravel deposits are also present.

To date exploration for economically minable uranium deposits has been largely restricted to the belt of outcrop. The deposits that have been found are relatively small but as yet none of the Inyan Kara rocks that are covered by the marine shales of Cretaceous age have been explored.

The uranium deposits occur in thick fluviatile sandstones of the Lakota, Fuson, and Fall River formations and in thin tabular sandstones that are interbedded with carbonaceous siltstones in the basal part of the Fall River sandstone. The fluviatile sandstones that have important production histories are: (1) the first thick sandstone above the Morrison formation in the Craven Canyon-Long Mountain-Red Canyon area (fig. 38); (2) a thick channel sandstone that is locally present directly below the base of the Fall River formation; and (3) the relatively thick Fall River rim-forming sandstone. The thick fluviatile sandstones are channel-like in shape, are approximately from 1 to 5 miles in width, and are at least several tens of miles in length. They are the sandstones through which the greatest volume of mineralizing solutions probably have moved.

The ore minerals occur in and around carbonaceous material, around grains and nodules of iron sulfide, adjacent to fine-grained facies of the sandstones, in association with calcium carbonate cement, and on structural irregularities, particularly on structural terraces and adjacent to monoclinal axes (fig. 39).

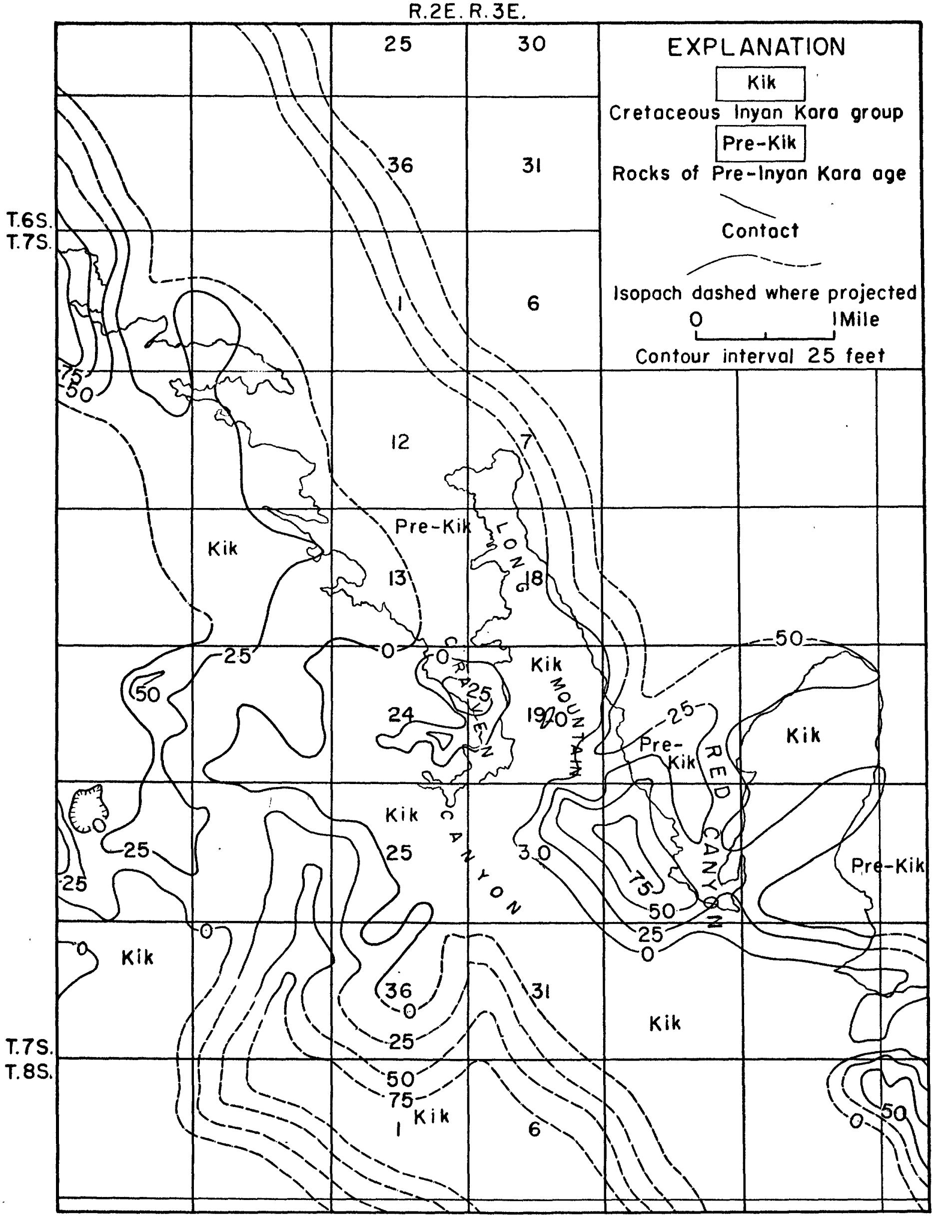


FIGURE 38 -ISOPACH MAP OF THE BASAL LAKOTA MUDSTONES AND SHALES, EDGEMONT NE QUADRANGLE

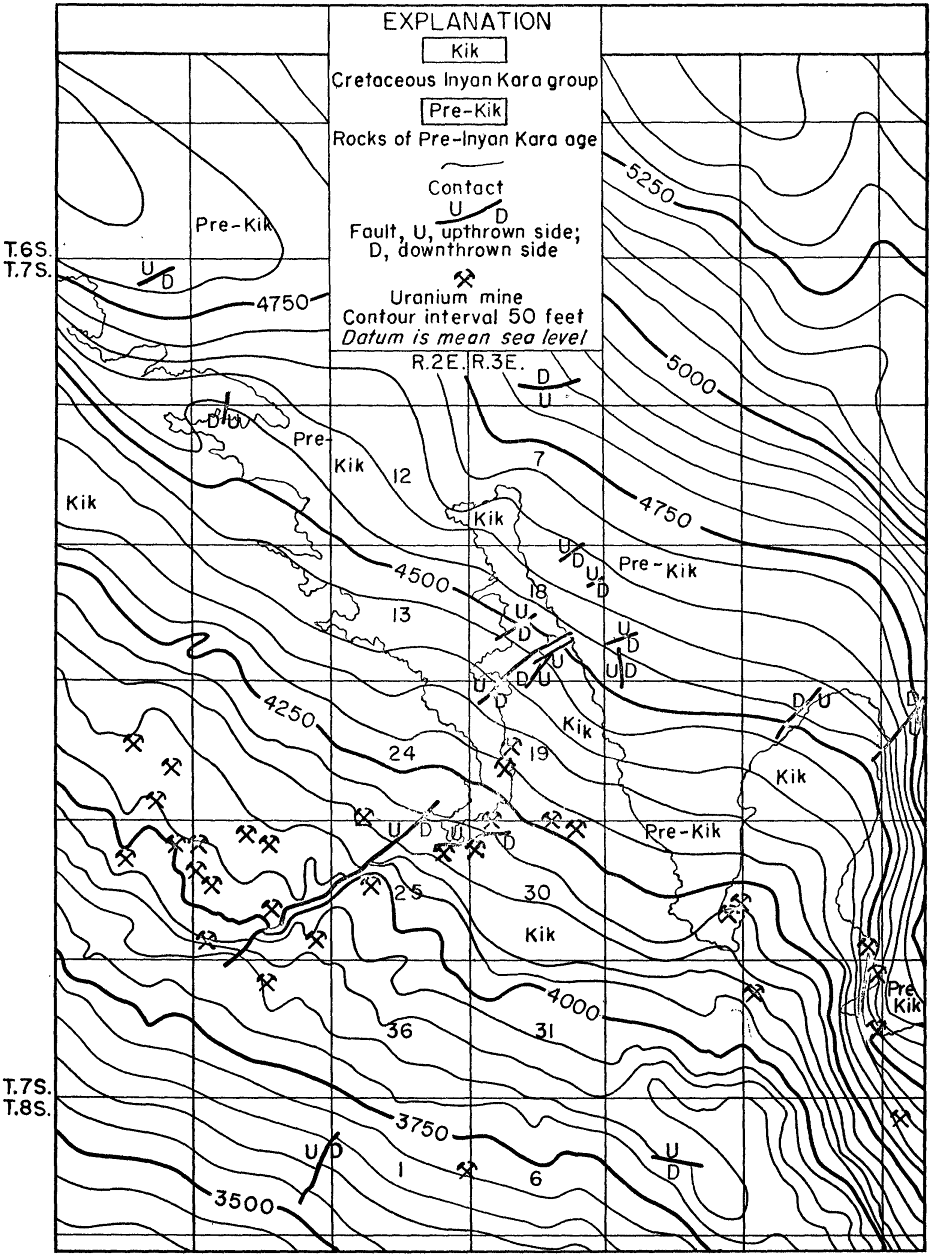


FIGURE 39 -STRUCTURE CONTOURS ON THE BASE OF THE FALL RIVER FORMATION, EDGEMONT NE QUADRANGLE

The ore deposits can be classified as highly oxidized, partly oxidized, and unoxidized deposits. Carnotite and tyuyamunite are the predominant uranium-vanadium minerals in the highly oxidized deposits. These deposits are generally low in vanadium and have a vanadium: uranium ratio that ranges from 0.25 to 0.68 and averages about 0.4 (table 6). All of the highly oxidized deposits are in the first thick sandstone ($S_1$) above the top of the Morrison formation. The distribution and thickness of this sandstone are shown on figure 40.

Garrels and Christ (TEI-640, p. 300) have suggested that the low vanadium content of the Wyoming-South Dakota ores indicates that some of the uranium may have been mobilized during the process of oxidation. If uranium is lost from low vanadium ores during the process of oxidation, it is probable that the highly oxidized carnotite-tyuyamunite ores were more affected than the other ores in the Edgemont NE quadrangle. The mineralogy of these deposits indicates that the vanadium is largely confined to the carnotite-tyuyamunite minerals and to the clays. As the vanadium in the clays would not have been available for the formation of stable uranium-vanadium minerals during the process of oxidation any excess uranium over that now present would have been lost in solution. If one or more large unoxidized deposits are postulated as the source from which the small oxidized deposits in the Cravan Canyon-Long Mountain-Red Canyon area were derived, then a considerable amount of uranium may have been carried away by ground water and deposited elsewhere below the zone of oxidation. Solutions moving through this area would probably have followed the thick permeable channel sandstone with thickness shown on figure 40. This sandstone evidently fills a scour in the underlying Lakota mudstones and shales (fig. 38). Solutions,

Table 6.--Vanadium:uranium ratios in the ores mined from the Edgemont NE quadrangle, Fall River County, South Dakota

| Highly oxidized ore Mine | Ratio V:U | | Partly oxidized ore Mine | Ratio V:U | |
|---|---|---|---|---|---|
| B and H No. 2 | .64 | Ores mined from Lakota formation | Coal Canyon Lode | 3.59 | Ores mined from Fall River sandstone |
| B and H No. 5 | .81 | | Coal Canyon No. 1 | 1.23 | |
| B and H No. 6 | .47 | | Coal Canyon No. 14 | 4.54 | |
| Clarabelle No. 1 | .40 | | Dakota Flats | .85 | |
| Clarabelle No. 2 | .68 | | Get Me Rich No. 1 | 2.10 | |
| Clarabelle No. 5 | .48 | | Get Me Rich Quick | 2.18 | |
| Flora | .34 | | King | 1.05 | |
| Green Acres No. 3 | .61 | | Luck No. 1 | 2.42 | |
| Green Acres No. 4 | .50 | | Lucky Strike | 1.08 | |
| Gertrude | .35 | | Pennywitt | 1.75 | |
| Hay and Fay | .42 | | Ridgerunner No. 3 | 2.80 | |
| Hay and Fay | .38 | | Ridgerunner No. 4 | 3.28 | |
| Hot Point No. 1 | .44 | | Road Hog 1 A | 1.84 | |
| Hot Point No. 2 | .34 | | Road Hog 3 A | 1.71 | |
| Hot Point No. 3 | .39 | | Southview No. 3 | 1.43 | |
| Little Annie | .29 | | Southview | 1.30 | |
| Lucky Toss | .33 | | Taylor | 1.31 | |
| Ophelia | .25 | | Trail Fraction | 1.40 | |
| Pictograph | .31 | | Verde | 1.80 | |
| Tess | .54 | | Virginia "C" | 1.95 | |
| Helen | .56 | | Wakan | 1.90 | |
| Too Lake | .56 | | Holdup No. 15 | 1.44 | Lakota formation |
| Western Edge | .31 | | Kados No. 3 | 1.33 | |
| Lakota No. 11 | .54 | | | | |

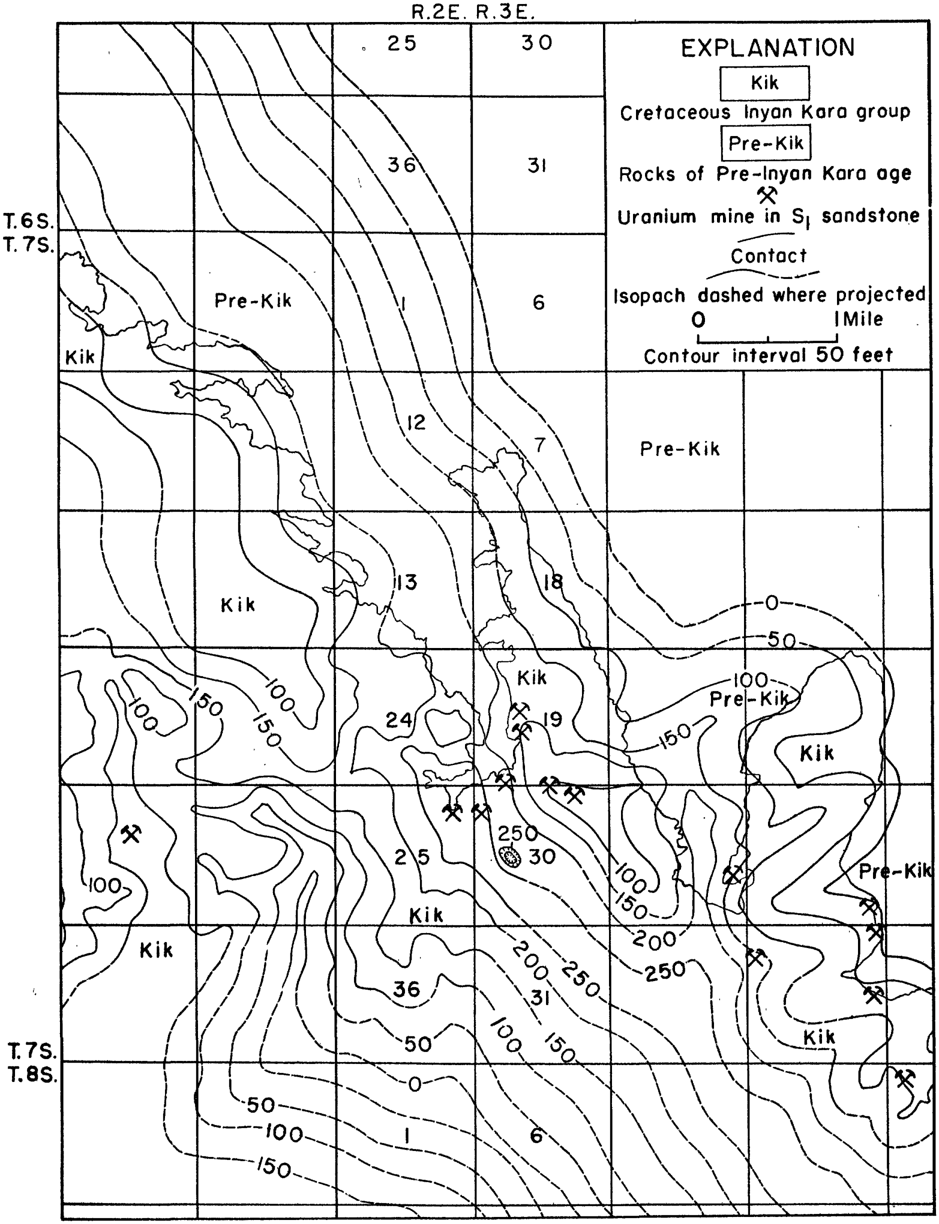


FIGURE 40 -ISOPACH MAP OF THE $S_1$ SANDSTONE OF THE LAKOTA FORMATION, EDGEMONT NE QUADRANGLE

therefore, probably would have moved along the bottom of the channel and if they encountered effective precipitating agents, such as carbonaceous material or pyrite, economically significant deposits may have formed.

The partly oxidized deposits contain both the yellow carnotite-tyuyamunite minerals and the dark corvusite-rauvite minerals. In contrast to the yellow ores these deposits have a vanadium:uranium ratio that ranges from 0.85 to 4.5 and averages 1.5 (table 6). With the exceptions of the Holdup No. 15-Kados No. 3 mine these deposits occur in highly carbonaceous rocks in the basal part of the Fall River formation.

One unoxidized deposit has been found near the base of a channel sandstone in the Fall River sandstone. The sandstone is in contact with and crosses an underlying channel sandstone. Ore is being mined from the overlying sandstone but mineralized rock is known to exist also in the lower channel sandstone. Uraninite, coffinite, and an unnamed low-valent black vanadium mineral are associated with pyrite, marcasite, and calcite cement. The deposit is adjacent to an area of intense calcite cementations and contains only a negligible amount of organic carbon.

## Mineralogy of the Runge mine, South Dakota

by

F. R. Shawe

The Runge mine, 7 miles north of Edgemont, South Dakota, is in the basal part of the Fall River sandstone. Epigenetic minerals that have been identified from the deposit are: quartz, calcite, clay, marcasite, pyrite, hematite, goethite, uraninite, mineral "A" ($V_2O_3 \cdot V_2O_4 \cdot 3H_2O$) (Evans and Mrose, 1956), coffinite, corvusite, carnotite, and tyuyamunite.

Metatyuyamunite is probably present also, but has not been positively identified. Coffinite and corvusite, detected by X-ray methods, have not been observed. Carnotite, tyuyamunite, metatyuyamunite(?), and corvusite are not important as ore minerals. The composition of the clay was not determined. The paragenetic sequence of these minerals is given in figure 41.

The quartz is present as interstitial cement and as overgrowths on quartz sand grains. Most of the overgrowths are in crystal continuity with the grain. Quartz as interstitial cement, once more abundant than at present, has been largely replaced by calcite and other later minerals. Replacement started at the juncture between quartz cement and sand grains and proceeded inward, leaving in many places small, irregular and isolated grains of quartz completely surrounded by calcite. The quartz is clear and well crystallized; no chalcodonic or opaline silica was observed. It is both very early and late in the paragenetic sequence.

Calcite is also mostly in the form of a cement. In many places it replaces earlier quartz cement, and in a few places, forms veinlets in sand grains, iron sulfides, and black uranium-vanadium minerals. It is mostly fairly coarsely crystalline ($\frac{1}{4}$-1 mm mean diameter); mosaics of fine crystals are rare. The crystals are untwinned and show no other evidence of strain. Calcite followed the quartz in the paragenetic order with a little, very questionable, overlap in time of deposition; it was also deposited in lesser amounts throughout much of the later deposition.

The iron sulfides were deposited in the order of: pyrite, pyrite, marcasite, pyrite, and marcasite; with considerable overlap in time between the second stage pyrite and the first stage marcasite, and with

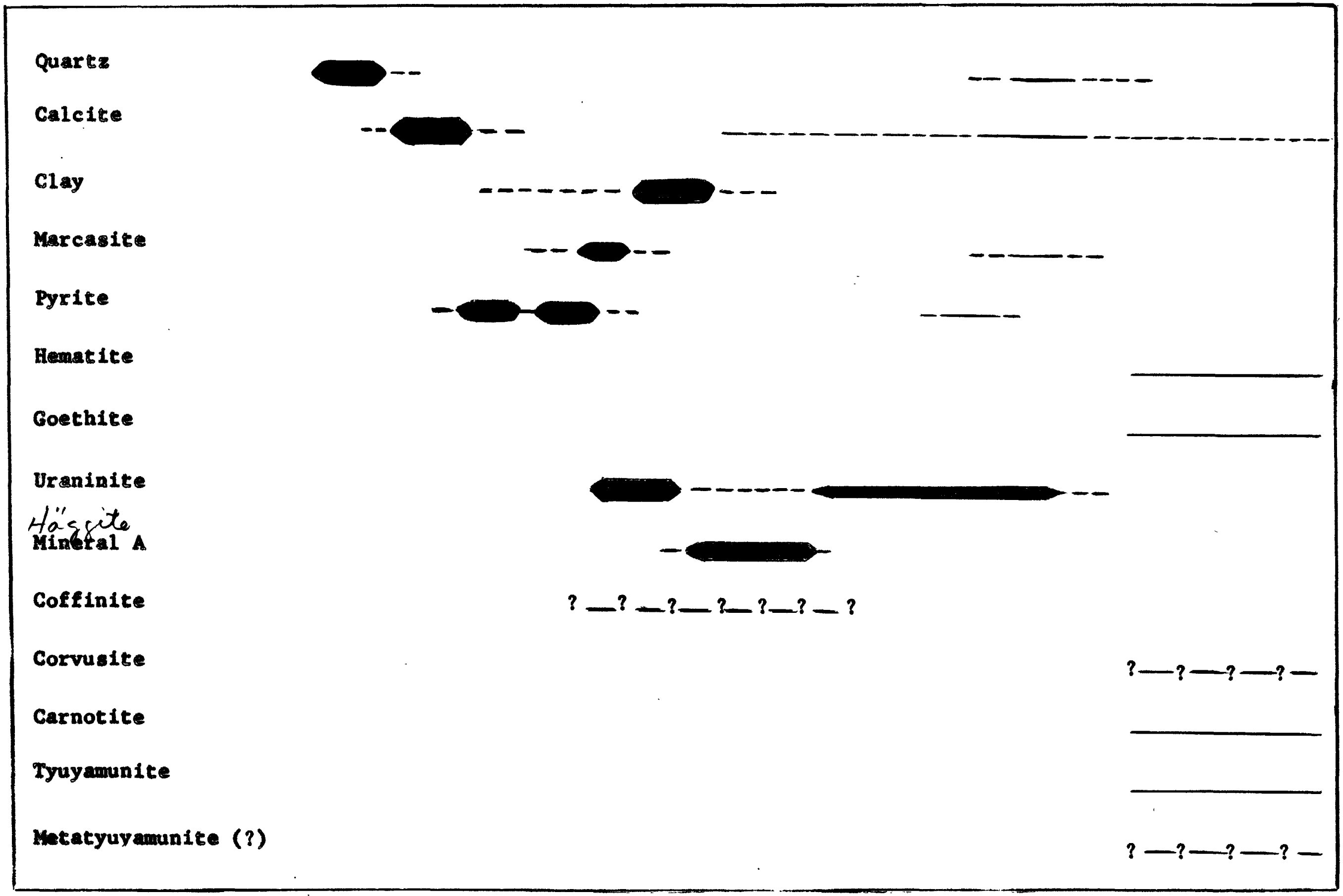


FIGURE 41.--PARAGENETIC SEQUENCE OF EPIGENETIC MINERALS, RUNGE MINE, FALL RIVER COUNTY, SOUTH DAKOTA.

some probable overlap in time between the last stage pyrite and the last stage marcasite. Uraninite deposition started almost simultaneously with the start of the first marcasite stage, and toward the end of this marcasite stage clays were deposited. After the first stage of uraninite, and overlapping the clay stage, mineral "A" was deposited. A second stage of uraninite followed the mineral "A". The earlier uraninite is a hard compact variety; the later uraninite is sooty and friable and is probably the result of a late stage reworking of the earlier variety. Both varieties of uraninite contain iron, the earlier stage having more than the later stage.

Although the formula for mineral "A" shows no metal other than vanadium, microchemical tests on hand-picked and washed grains of mineral "A" from the Runge mine show the presence of both iron and uranium.

Hematite, goethite, corvusite, carnotite, tyuyamunite, and metatyuyamunite are oxidation products of earlier formed minerals.

### Reference

Evans, H. T., and Mrose, M. E., 1956, Crystal chemical studies of low-valence vanadium oxide minerals from the Colorado Plateau (Abs.): Geol. Soc. America Bull., v. 67, no. 12 part 2, p. 1693.

## Burdock quadrangle, South Dakota

by

R. W. Schnabel

Mapping of the Burdock quadrangle, in the southwestern part of the Black Hills, was started in July 1955 and completed in November 1956. The rocks exposed in the quadrangle range in age from Late Jurassic to Quaternary. The pre-Quaternary rocks are about 1,400 feet thick and include marine shales and sandstones of the Sundance formation and non-marine shales of the Morrison formation of Late Jurassic age; non-marine sandstones and mudstones of the Inyan Kara group and marine shales of the Skull Creek shale and the Mowry shale of Early Cretaceous age; and marine shales of the Belle Fourche shale of Late Cretaceous age (fig. 42). Quaternary rocks include unconsolidated stream alluvium and terrace deposits. Most of the quadrangle is underlain by rocks of Cretaceous age but large areas of these are covered by Quaternary deposits.

About one square mile in the northeast part of the Burdock quadrangle is underlain by the Sundance formation of Late Jurassic age, a sequence of marine sandstones and shales. The Sundance formation has been divided into five members, the upper four of which are exposed in the Burdock quadrangle. These are, from bottom to top: the Stockade Beaver shale member, the Hulett sandstone member, the Lak member, and the Redwater shale member.

About ten feet of the upper part of the Stockade Beaver shale member is exposed in a small canyon in the northeast part of the quadrangle. Here the unit consists of a brownish-gray shale which grades upward through a series of interbedded sandstone and shale beds into the overlying Hulett sandstone member.

The Hulett sandstone is about 45 feet thick. It consists of fine- to medium-grained, thin-bedded ripple-marked, light yellowish gray sandstone. In the lower part the sandstone beds are separated by thin shale beds which look like the shale in the Stockade Beaver shale member. The upper contact of the Hulett sandstone is not exposed in the quadrangle but exposures in adjacent areas indicate that it is con-

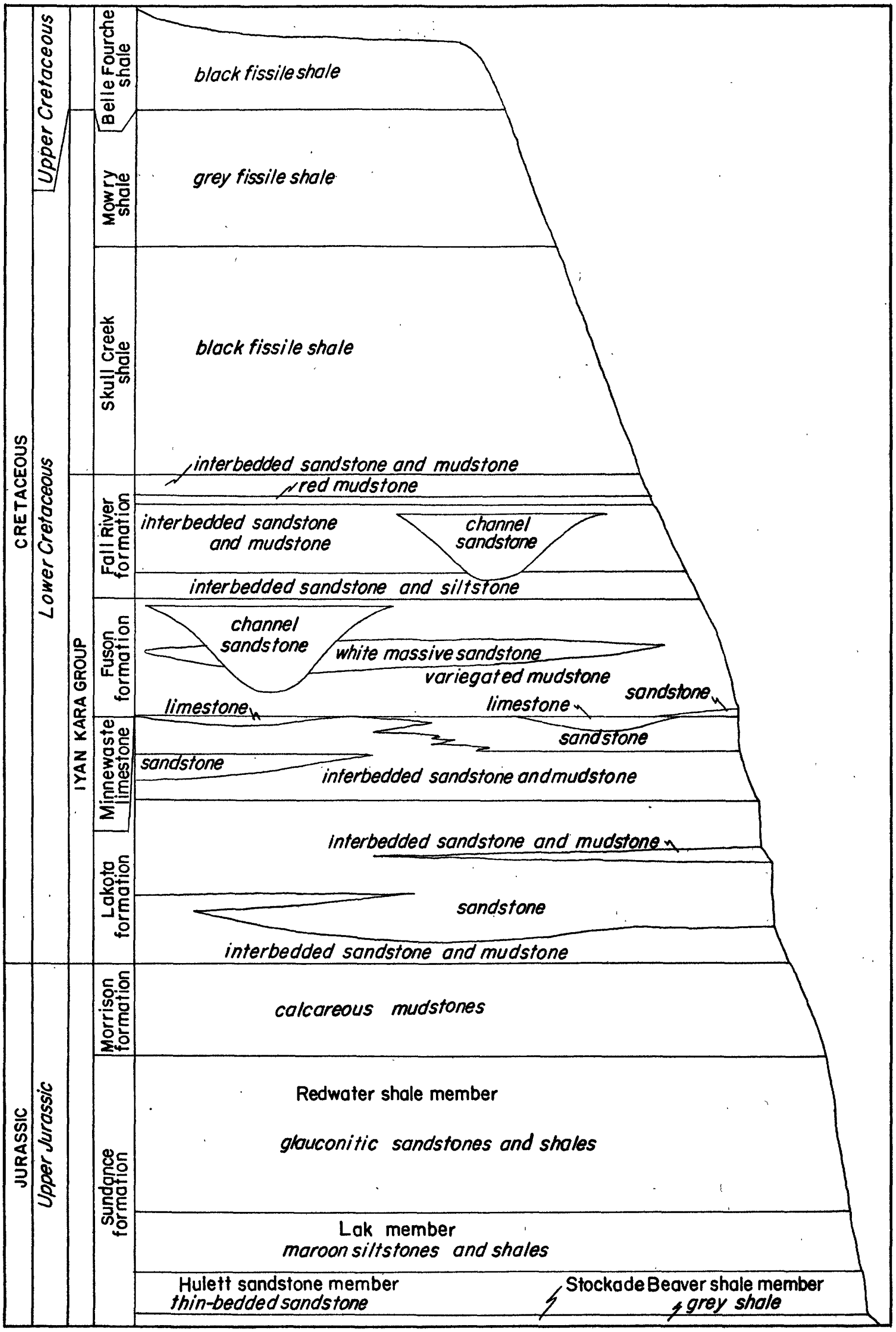


FIG. 42 —DIAGRAM SHOWING LITHOLOGY OF FORMATIONS IN THE BURDOCK QUADRANGLE,
[illegible] SOUTH DAKOTA

formable with the overlying Lak member.

The Lak member is poorly exposed in the Burdock quadrangle. Where it can be observed it consists of fine-grained sandstone or siltstone that is red or maroon in color. It generally imparts a red color to the soil. The upper contact of the Lak is not exposed within the area. The member is about 70 feet thick.

The Redwater shale member of the Sundance formation consists of a sequence of glauconitic shales and thin sandstone beds about 170 feet thick. This unit is not resistant to weathering and therefore is poorly exposed. The upper contact with the Morrison formation was not observed, but in view of the change in depositional environment it is probably disconformable.

The Morrison formation of Late Jurassic age is composed of a sequence of non-marine light-green to gray limy claystones. It underlies about one and one half square miles in the bottom of the canyons in the northeast part of the quadrangle. It is about 100 feet thick in this area, but at most places is covered by landslide debris derived from the overlying Inyan Kara rocks. Although the upper contact of the Morrison formation is covered nearly everywhere in the quadrangle, evidence from adjacent areas suggests that the contact is unconformable.

Darton (1904) mapped four formations in the sequence which Rubey (1931) later named the Inyan Kara group. They are from bottom to top the Lakota sandstone, the Minnewaste limestone, the Fuson shale, and the Fall River sandstone. Recent workers (TEI 590, p. 151-153) have found it impossible to define a consistent boundary between the Fuson formation and the Lakota sandstone in parts of the Black Hills. Where the Minnewaste limestone is present the division between the Fuson and the Lakota is marked by the limestone. Inasmuch as the Minnewaste limestone is present over most of the Burdock quadrangle it has been possible to separate the four formations with little difficulty.

The Lakota formation ranges from 200 to 350 feet in thickness in the Burdock quadrangle and consists of a complex series of thick channel-type crossbedded sandstones and thin sandstones interlaminated with carbonaceous mudstones. The nature of the rocks in this unit suggests that the thick sandstones probably were deposited in stream channels and the thin-bedded rocks in marshes and swamps. There are both downcutting and intertonguing relations between the rocks of fluvial and non-fluvial origin.

The Minnewaste limestone consists of a series of discontinuous lenses of limestone and calcareous sandstone. The maximum thickness of the limestone is about 30 feet. Locally the formation is a pure, almost lithographic limestone but it grades laterally in places into very sandy limestone and even calcareous sandstone. Sponge spicules and algae indicate a fresh-water depositional environment for the unit.

The Fuson formation ranges from about 50 feet to about 150 feet in thickness. It is a sequence of varicolored mudstones, the colors being mainly various shades of red and green; a thick white massive sandstone; and a thick crossbedded channel sandstone. Where the Minnewaste limestone is not present the lower contact of the formation has been mapped at the base of the varicolored mudstones. This contact seems to be the lateral equivalent of the Minnewaste horizon.

Little to no bedding is apparent in either the varicolored mudstone or the white massive sandstone. This probably means that they were deposited in quiet water, although the mudstone could have been deposited as a loess.

The Fall River sandstone is about 140 feet thick and is relatively consistent in lithology over most of the Burdock quadrangle. It consists, from bottom to top, of a series of thin-bedded highly carbonaceous interbedded sandstones, mudstones, and siltstones about 50 feet thick; a red and gray mudstone unit about 20 feet thick; and an upper unit of interbedded sandstone and mudstone that appears to grade into the overlying Skull Creek shale, although the contact between these units is obscure over most of the quadrangle. During middle or late Fall River time there were one or more periods of downcutting when some of the thin-bedded units below the red mudstone were removed by erosion. Later the channels thus formed were filled with thick, crossbedded sandstones. One such sandstone reaches a maximum thickness of about 80 feet along the north edge of the quadrangle and thinner approximate correlatives are present intermittently throughout the rest of the quadrangle. These thick channel-type sandstones are not generally as abundant in the Fall River sandstone in the Burdock quadrangle as they are in adjacent areas.

The Skull Creek shale, a black marine shale, conformably overlies the Fall River formation. The shale is covered in most places in the quadrangle by alluvial material and its thickness could not be reliably determined. In adjacent areas it is about 250 feet thick.

The Mowry shale is lighter in color than the Skull Creek shale which it overlies conformably, and is much sandier and contains more abundant fossil remains, mainly fish scales. The thickness could not be reliably determined because of heavy alluvial cover. It is about 150 feet thick in adjacent areas.

About 90 feet of the black marine Belle Fourche shale is exposed in the south-central part of the quadrangle. In general the unit is darker in color than the underlying Skull Creek and Mowry shales. It usually contains a large amount of bentonite in discrete layers in the lower part.

Alluvial deposits of unconsolidated sand and gravel cover large areas in the quadrangle, principally in the valleys of the present streams. Most of the material in the alluvium has been derived from rocks exposed in the central part of the Black Hills uplift and all the alluvial and terrace deposits appear to be associated with the present drainage system.

Uranium-vanadium deposits have been found in the thick sandstone beds of the Lakota formation, in the thin-bedded carbonaceous sandstone, siltstone, and mudstone units in the lower part of the Fall River formation. The deposits in the thick sandstones are small, and most are little more than mineral occurrences. Nearly all the production of uranium-vanadium ore has come from the thin-bedded units in the Fall River sandstone.

The uranium deposits in the thick channel sandstones are largely disseminations and fracture coatings of carnotite and tyuyamunite. These deposits resemble the highly oxidized deposits in the Lakota formation in the adjacent Edgemont NE quadrangle and may show the relations suggested in the report on the Edgemont NE quadrangle, this volume.

The uranium-vanadium deposits in the highly carbonaceous rocks of the Fall River sandstone are probably preserved in their present environment because of highly reducing conditions caused by the abundant carbonaceous material. Inasmuch as there seems to be no appreciable difference between the composition of the thin-bedded carbonaceous rocks that contain uranium-vanadium minerals and those that do not contain those minerals, it appears probable that the localization of uranium is the result of factors other than the composition of the rock. Most of the deposits in the thin-bedded rocks are adjacent to or very near to one or more of the thick channel sandstones. It is likely, therefore, that the thick sandstones served as aquifers which brought the uranium-bearing solutions into contact with the thin-bedded rocks where the geochemical environment was conducive to the precipitation of uranium compounds.

Detailed mapping in the Freezeout mine in sec. 36, T. 6 S., R. 1 E., the largest mine in the thin-bedded Fall River rocks, seems to indicate that permeability may have had an influence on the immediate localization of ore. In some places, the ore is localized at pinchouts of thin sandstone beds; in other places the ore is concentrated in places where a damp spot in the wall of the mine indicates a greater permeability of the rock.

## References

Darton, N. H., 1904, U. S. Geol. Survey Geol. Atlas, Edgemont folio (no. 108).

Rubey, W. W., 1931, Lithologic studies of fine-grained Upper Cretaceous sedimentary rocks of the Black Hills region: U. S. Geol. Survey Prof. Paper 165-A.

## Cascade Springs quadrangle, South Dakota

by

E. V. Post

The Cascade Springs quadrangle is at the extreme southern end of the Black Hills in Fall River County, South Dakota. Field work on the quadrangle was started in June 1955 and was completed in October 1956.

### Stratigraphy

Lithified sedimentary rocks ranging in age from Permian through Late Cretaceous with an aggregate thickness of about 2,800 feet crop out in the Cascade Springs quadrangle. These rocks are overlain in some places by unconsolidated sand, silt, and gravel of Quaternary age that comprise older terrace gravel deposits, older alluvium which has been surfically modified by prevailing northwest winds, and younger alluvium that fills the floors of many canyons.

Table 7 contains a list and description of all formations exposed in the quadrangle.

### Structure

The Cascade Springs quadrangle is at the extreme southern end of the Black Hills uplift. The general domal character of the uplift is modified in the southern Hills by two asymmetric south-plunging anticlines. The easternmost of these, the Cascade anticline, forms the major structural feature of the quadrangle (see fig. 43). The anticline has 1,635 feet of structural relief in the center of the quadrangle.

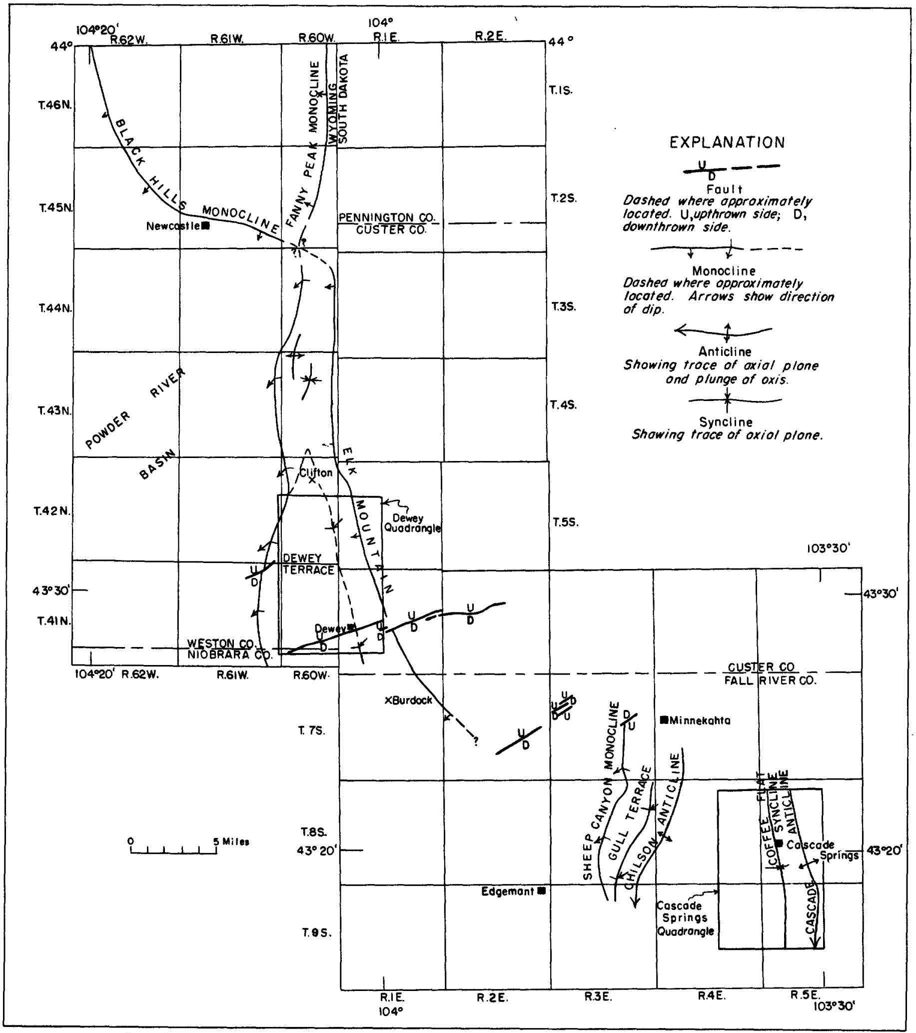


FIGURE 43 -GENERAL STRUCTURE MAP OF SOUTHWESTERN BLACK HILLS

Table 7.--Formations exposed in the Cascade Springs quadrangle

| System | Series | Group | Formation | Member | Thickness in feet | Description |
|---|---|---|---|---|---|---|
| Quaternary | | | Alluvium | | 0-50 (approx.) | Boulder gravel, sand, silt, clay. Thin discontinuous layers of calcareous tufa along Cascade Creek. |
| | | | Older alluvium | | 0-100 | Sand, silt, gravel. Surface modified by wind, forming blowouts, blowout dunes, northwest trending ridges, and in some instances cross-beds. Most deposits are on high interstream divides. |
| | | | Terrace gravel | | 0-50 (approx.) | Silty sand, and gravel containing pebbles, cobbles, and boulders of chert, quartz, quartzite, limestone feldspar, other igneous and metamorphic rock types. Most deposits are small isolated remnants of former extensive terrace deposits along Cheyene River and major tributaries. |
| | | | Landslide | | Variable 0-400(?) | Country rock, largely from Inyan Kara group and older rocks. Extensive in Falls Canyon in northwest corner of quadrangle. |

Table 7.—Continued

| System | Series | Group | Formation | Member | Thickness in feet | Description |
|---|---|---|---|---|---|---|
| Cretaceous | Upper Cretaceous | | Carlile shale | Sage Breaks | 57 | Poorly fissile brownish-gray shale with septarian limestone concretions. Basal contact indefinite. Concretions weather out conspicuously. |
| | | | | Turner sandy | 49 | Gray shale, 5 ft. thick platy sandstone at base. Mostly covered; sandstone forms low hogback. |
| | | | | Lower unnamed | 148 | Non-calcareous shale in upper part with silty limestone concretions containing *Inoceramus fragilis* Hall and Meek, *Collignoniceras woolgari* (Mantell), and *Scaphites larvaeformis* Meek and Hayden. Mostly covered. Fossils identified by W. A. Cobban. |
| | | | Greenhorn limestone | | 15-25 | Alternating 6 inch-thick beds of yellowish-gray limestone and calcareous laminated siltstone; contains abundant *Inoceramus labiatus*. Resistant ridge-forming limestone is only unit herein included in Greenhorn. Calcareous shales of indeterminate thickness above and below included in Carlile shale and Belle Fourche shale. |

Table 7 .—Continued

| System | Series | Group | Formation | Member | Thickness in feet | Description |
|---|---|---|---|---|---|---|
| Cretaceous | Upper Cretaceous | | Belle Fourche shale | | 425(av.) | Gray marine shale; upper 100 ft. (approx.) yellowish-brown and calcareous shale and mudstone with thin yellowish-gray fossiliferous sandy limestones. 70 ft.-thick manganosiderite concretion zone 10 ft. above base. Thin yellowish cone-in-cone limestone concretions 115 and 251 ft. above base. |
| | Lower Cretaceous | | Mowry shale | | 150(av.) | Medium light gray to silvery-gray marine shale; not characteristically siliceous; sandstone dikes and masses, indefinite. |
| | | | Skull Creek shale | | 250(av.) | Medium to dark gray marine shale with thin calcareous sandstone beds and lenses and yellowish cone-in-cone limestone concretions. |

Table 7.—Continued

| System | Series | Group | Formation | Member | Thickness in feet | Description |
|---|---|---|---|---|---|---|
|  |  | Inyan Kara | Fall River sandstone |  | 160(av.) | Lower 60 ft. interbedded thin-bedded sandstone and laminated carbonaceous siltstone; upper 100 ft. interbedded thin sandstone, gray locally carbonaceous mudstone and siltstone. Lower 2/3 of formation locally includes a thick yellowish-orange fine-grained cross-bedded cliff-forming sandstone labeled $S_5$ on preliminary maps. Lower unit contains uranium minerals in 2 localities. Finer-grained facies probably deposited in marsh or lagoonal environment. Thick cliff-forming sandstone probably deposited in stream channel or as offshore bar. Upper part of formation grades into marine Skull Creek shale. |
|  |  |  | Fuson formation |  | 75-100 | Mostly varicolored claystone locally containing white fine-grained argillaceous sandstone, limestone concretions in lower part, and polished siliceous pebbles. In west-central part of quadrangle includes at top as much as 60 ft. of fine-to medium-grained locally conglomerate cliff-forming channel-filling sandstone labeled $S_4$ on preliminary maps. Claystone probably lacustrine in origin; channel-sandstone fluviatile. |

Table 7.--Continued

| System | Series | Group | Formation | Member | Thickness in feet | Description |
|---|---|---|---|---|---|---|
| Cretaceous | Lower Cretaceous | Inyan Kara | Minnewaste limestone | | 0-80 normally less than 5 ft. | Medium gray sandy limestone, locally dense clean limestone. Where 80 ft. thick, top 30 ft. is limestone, lower 50 ft. is calcareous fine-grained thin-bedded pinkish-gray sandstone containing tabular lenses of sandy limestone. Maximum thickness obtained south of Angostura Reservoir in southeast corner of quadrangle. Not present in western third of quadrangle. Probably lacustrine in origin. |
| | | | Lakota sandstone | | 282-447 av. 300-350 | Fine-grained grayish-yellow to grayish-orange cliff-forming sandstone in large lenses locally separated by mudstone splits. Labeled $S_2$ on preliminary MF maps. Silicified logs common, but contains no appreciable carbonaceous material, in contrast to $S_1$, which is predominant Lakota sandstone to west. Thickest in center of quadrangle; fingers east and west into thin interbedded sandstone and mudstone. Top marked over much of the quadrangle by a prominent 5 ft.-thick red sandstone. Locally fills channels cut into underlying Unkpapa sandstone. Basal contact indefinite where lower Lakota and upper Unkpapa both are claystone. Sandstone probably |

Table 7.—Continued

| System | Series | Group | Formation | Member | Thickness in feet | Description |
|---|---|---|---|---|---|---|
| | | | | | | deposited in river channels; mudstone and interbedded facies probably deposited in interfluvial marshes and lakes. |
| Jurassic | Upper Jurassic | | Morrison formation | | 0-20 | Green sandy calcareous mudstone and thin limestones. Exposed only in Buck Canyon in northwest part of quadrangle where it pinches out. Probably of lacustrine origin. |
| | | | Unkpapa sandstone | | 50-230<br>av. 100-175 | White fine-grained cross-bedded locally calcareous sandstone. Where thickest includes as much as 15 ft. of varicolored claystone at top underlain by 100 ft. of red friable silty sandstone. Locally channeled and replaced by Lakota sandstone. Upper contact indefinite where top of Unkpapa and base of Lakota both are claystone. Depositional environment uncertain. Probably terrestrial - possibly aeolian. |

Table 7 .—Continued

| System | Series | Group | Formation | Member | Thickness in feet | Description |
|---|---|---|---|---|---|---|
| Jurassic | Upper Jurassic | | Sundance formation | | 328 - 372 | |
| | | | | Redwater shale | 128(av.) | Medium gray to olive gray marine shale, silty shale, thin fossiliferous limestones and limestone concretions. Platy glauconitic siltstone near top. |
| | | | | Lak member | 80(av.) | Moderate reddish-orange to reddish-brown massive siltstone and silty sandstone. |
| | | | | Hulett sandstone | 35(av.) | Pale grayish-orange fine-grained thin-bedded ripple-marked sandstone. Top 10 ft. gray shale and siltstone. |
| | | | | Stockade Beaver shale | 26-42 (av. 27) | Fossiliferous calcareous olive gray shale. |
| | | | | Canyon Springs sandstone | 54-98 | Lower 2/3 is pale yellowish-orange to moderate reddish-brown fine-grained friable calcareous honeycomb-weathering sandstone. Upper 1/3 is light brown to moderate orange pink, fine-grained, calcareous, laminated to thin-bedded sandstone. Appears to vary considerably in thickness over short distances. |

Table 7.—Continued

| System | Series | Group | Formation | Member | Thickness in feet | Description |
|---|---|---|---|---|---|---|
| Triassic(?) | | | Spearfish formation | Upper siltstone<br>Gypsiferous unit<br>Lower siltstone | 150<br>135<br>50 | Dark reddish-brown siltstone including in central part at least 4 gypsum beds ranging from 5 to 42 ft. in thickness. Olive gray carbonaceous 6 in. mudstone at base of gypsiferous unit is locally radioactive |
| Permian | | | Minnekahta limestone | | 50 | Grayish-red finely crystalline finely laminated limestone. Intricately folded and locally brecciated. |
| | | | Opeche formation | | 150 (approx.) | Dark reddish brown siltstone and thin-bedded fine-grained sandstone. Includes some yellow-orange sandstone beds in lower part and thin discontinuous gypsum at top. |

The axis of the anticline trends S. 10° E. in the northeastern quarter of the quadrangle, turns S. 40° E. for about 3 miles, then turns S. 7° W. in the southeastern part of the quadrangle. Dips on the east flank of the anticline average 5° SE. Immediately west of the axis it steepens rapidly and reaches a maximum of about 70° SW in the hogback ridge in the center of the quadrangle.

The westerly dip flattens abruptly in the extremely narrow trough of the Coffee Flat syncline, and averages about 3° SE on the east flank of the Chilson anticline in the western half of the quadrangle.

The more competent rocks, especially the thick sandstones of the Inyan Kara group, are in many places closely jointed. The prevailing joint direction, regardless of structural attitude, is N. 30°-40° W. A minor joint set trends N. 70° E. Most joints dip nearly vertically.

No faults have been noted in the quadrangle, though a fault of some magnitude relieving the stress along the western flank of the Cascade anticline might be expected. At several exposures in this area sandstone beds could be traced from a nearly horizontal position to a 60° westerly dip in less than 100 feet horizontally.

## Economic Geology

Uranium deposits:—Uranium minerals have been found in the Fall River sandstone at two localities in the Cascade Springs quadrangle. One of these occurrences is the Canyon Lode deposit on the east side of Cedar Canyon, in SE¼ sec. 25, T. 8 S., R. 4 E. Black highly radioactive uranium minerals are concentrated in a band two inches thick in a thin sandstone that is part of a sequence of thin sandstones, laminated carbonaceous siltstones, and mudstones, and containing abundant pyrite concretions. This sequence of rocks is about 75 feet thick and is the basal unit of the Fall River sandstone. Nine tons of ore-grade rock reportedly have been shipped from this deposit. A grab sample assayed 0.88 percent U and 0.49 percent V. A 2-foot channel sample across the "ore" zone assayed 0.075 percent U and 0.15 percent V.

The uranium at the Canyon Lode deposit appears to have been deposited in a small structural terrace that interrupts the general 3° southeast dip in the western part of the quadrangle. A local "channel" sandstone that cuts into the basal unit of the Fall River sandstone just down dip from the deposit may also have been effective in localizing the uranium minerals.

At the other uranium occurrence, yellow uranium minerals are present in a carbonaceous sandstone at the top of the basal unit of the Fall River sandstone at the top of the cliff south of Angostura Reservoir in the south center of sec. 10, T. 9 S., R. 5 E. A grab sample of mineralized rock assayed 0.33 percent U and 0.16 percent V. The limited extent of the radioactivity anomaly appears to indicate the deposit is of small size.

The Lakota sandstone ($S_2$ on preliminary MF maps) in the Cascade Springs quadrangle is apparently devoid of uranium deposits. This is in marked contrast to the Lakota sandstone ($S_1$) in the Flint Hill, Minnekahta, and Edgemont NE quadrangles to the west, where many small carnotite-type deposits are found. The absence of commercial uranium deposits in Lakota sandstone $S_2$ in this area is perhaps attributable to the general lack of significant quantities of carbonaceous debris and pyrite in this unit.

Several radioactivity anomalies are present in the Spearfish formation. (See TEI 640, p. 98). All are associated with a 1½ foot-thick dark-gray to black mudstone that is approximately 54 feet above the base of the formation. Highly radioactive fragments of this mudstone picked from a disturbed zone in the Spearfish on the south side of Highway 87 in the SW¼ sec. 20, T. 8 S., R. 5 E. assayed 0.10 percent U and less than 0.06 percent V. Samples of black mudstone containing a green copper-bearing mineral from the NW¼ SE¼ sec. 29, T. 8 S., R. 5 E., assayed 0.55 percent Cu.

Other economic resources.--Economic resources in the Cascade Springs quadrangle other than uranium include gypsum, which occurs in great abundance in the Spearfish formation; limestone from the Minnekahta limestone; sand and gravel from the Quaternary surficial deposits; ground water, especially that issuing from the Minnekahta limestone at Cascade Springs; and possibly oil and gas in the Minnelusa or Pahasapa formations. Darton (1904, p. 8) shows 500 feet of closure on the Cascade anticline just north of the Cascade Springs quadrangle. (On figure 43 the anticline has not been plotted beyond the quadrangle boundary). The present study has shown at least 50 feet of closure on the top of the Minnekahta limestone in the northeast part of the quadrangle. Possibly an additional 200 feet of closure could be demonstrated if structure contours were extended into the Minnekahta NE quadrangle to the north.

## Reference

Darton, N. H., 1904, Edgemont Folio, S. Dak.-Neb., U. S. Geol. Survey Geol. Atlas of the United States, Folio 108.

# Flint Hill quadrangle, South Dakota

by

Henry Bell and E. V. Post

The Flint Hill quadrangle is in the extreme southern part of the Black Hills, in Fall River County, South Dakota. Field work was started in June 1953 and was completed in October 1955.

The oldest rocks exposed in the quadrangle are part of the Lak member of the Sundance formation of Late Jurassic age. This member, a maroon silty sandstone, is exposed only in the deepest canyons. The Lak is overlain by the Redwater shale member of the Sundance formation. The Redwater shale is predominantly a greenish-gray glauconitic silty shale and mudstone containing thin beds of glauconitic sandstone and fossiliferous limestone.

Overlying the Dundance formation is the Unkapapa sandstone of Late Jurassic age, predominantly a very fine-grained crossbedded sandstone weathering to rounded cliffs and steep-gullied slopes. It is in most exposures a very homogeneous formation, but in some places includes red and gray siltstone. These siltstone beds may be associated with the western margin of the Unkpapa sandstone, which is present in the central part of the quadrangle. The crossbedding and homogeneous character of the Unkpapa sandstone suggest that it is of aeolian origin.

The Morrison formation, between 60 and 70 feet thick, is the uppermost formation of Jurassic age. This formation pinches out near the eastern margin of the quadrangle. It overlies the Unkpapa sandstone where that formation is present and is coextensive with the Unkpapa sandstone through a very narrow north-trending zone in the middle of the quadrangle. The Morrison consists of pale green-gray calcareous mudstone with numerous thin beds of light-gray argillaceous limestone or marl usually less than 5 feet thick. It contains a few thin beds of sandstone in the lower portion. The Morrison formation is a fresh-water deposit as indicated by the fossil ostracodes and charaphytes found in it.

Rocks of the Inyan Kara group of Early Cretaceous age crop out over the major part of the Flint Hill quadrangle. These rocks are subdivided into two units: Lakota-Minnewaste-Fuson formations undivided; and the Fall River sandstone. (See TEI-590, p. 151-153).

The Lakota-Minnewaste-Fuson formations undivided range in thickness from 310 feet to 485 feet, and comprise fine-grained to locally conglomeratic sandstone, mudstone, and minor amounts of limestone. These rocks are interbedded and abrupt facies changes are repeated many times in short distances. The cliff-forming sandstone beds are as much as 200 feet thick and are composed of numerous discrete cross-stratified lenses that overlap and truncate similar adjoining lenses. In the Flint Hill quadrangle three prominent cliff-forming sandstones have been mapped and can be traced northwestward and eastward as much as 20 miles. These are informally numbered $S_1$, $S_2$, and $S_4$ on preliminary MF maps (in press) of the Flint Hill quadrangle. The cliff-forming sandstones are light shades of brown, yellow, and orange; the quartz grains are well rounded, generally well sorted, and free of interstitial material or cement, but there is some conglomerate in sandstone $S_4$. Where the sandstones are interbedded with mudstones, the character of the sandstones changes, and they commonly are thinly bedded with much interstitial clay. The mudstones in the Lakota contain varied proportions of sand, carbonate, and organic material.

These rocks are various shades of greenish or yellowish gray, grayish red, and dark gray. The calcareous mudstones commonly contain abundant ostracodes with lesser amounts of gastropods, pelecypods, and charaphytes. The highly organic mudstones commonly yield a distillate when heated. The sandstones and mudstones are interbedded and grade laterally from one to the other. Mapping of the different lithologies has shown that the cliff-forming sandstones, probably river deposits, are bordered by areas of highly organic dark noncalcareous mudstones and sandstones that probably were deposited in a swamp environment. Adjacent to the dark organic mudstones and sandstones are light-colored calcareous mudstones containing abundant ostracodes and charaphytes. These rocks probably were deposited in a shallow pond or lake environment.

The Fall River sandstone is lithologically similar to the underlying Lakota sandstone. It is composed largely of cliff-forming sandstone but facies of interbedded thin sandstone, siltstone, and mudstone are common. The change from thick cliff-forming sandstone to the finer-grained facies is abrupt and usually obscure, but in some localities it appears that the sandstone lenses interfinger with siltstone and mudstone. At other localities the sandstone-mudstone relations suggest the large-scale truncation of siltstone and mudstone beds by the cliff-forming sandstones. A representative section of the Fall River sandstone includes, from the bottom to the top, as much as 50 feet of gray carbonaceous laminated siltstone; 80 to 100 feet of pale light-brown cliff-forming sandstone, informally numbered $S_6$ on preliminary maps; 10 feet of gray laminated siltstones containing thin discontinuous interbedded layers of very fine-grained sandstone;

10 feet of thin-bedded commonly micaceous sandstone; and 1 to 3 feet of dark-gray laminated mudstone and sandstone that are gradational into the overlying Skull Creek shale. In the Flint Hill quadrangle there are two areas of cliff-forming Fall River sandstone separated by an area of predominantly thin sandstone interbedded with siltstone and mudstone. The areas of cliff-forming sandstone trend north and northwest and can be traced into and through the adjoining quadrangles. The two areas of cliff-forming sandstone are nearly equivalent in stratigraphic position and age. The Fall River sandstone apparently was deposited by rivers in an environment similar to that in which the Lakota was deposited, but the lack of abundant calcareous ostracode-bearing mudstones suggests an area influenced by marine or brackish water. The orientation of cliff-forming sandstone masses and cross-stratification indicate a southeastern source for the sand in the Lakota and Fall River formations.

The Skull Creek shale, Newcastle sandstone, and Mowry shale of Early Cretaceous age, and the Belle Fourche shale and Greenhorn limestone of Late Cretaceous age crop out only in a small area along the southern and western margins of the quadrangle.

Rocks of Cenozoic age include terrace gravel deposits along the major streams, older silty and sandy alluvial deposits that have been surfically modified by the wind, and younger alluvial deposits of sand, silt, and gravel in the valley bottoms.

The rocks in the Flint Hill quadrangle were deformed during Laramide time as part of the general doming of the Black Hills. Interrupting the regional structure are the south-plunging asymmetrical Chilson anticline and the west-dipping Sheep Canyon monocline. (See fig. 43). A structural terrace separates the monocline on the west from the more steeply dipping west limb of the anticline. Commonly the rocks dip two or three degrees to the south and southeast, but there are dips of 14 and 20 degrees on the west limb of the Chilson anticline and the Sheep Canyon monocline. The rocks are thoroughly jointed, but faults are not common and have only minor displacement.

Uranium has been produced from several deposits in the Flint Hill quadrangle. The deposits are of two general types and are restricted to two major rock types within the Inyan Kara group. In the more highly oxidized type of deposit carnotite and tyuyamunite are the predominant uranium minerals. In the less highly oxidized deposits corvusite and rauvite are more common. Uraninite has been identified in small amounts at one deposit. Iron oxides, pyrite, carbonaceous material, and calcium carbonate are commonly associated with the uranium deposits.

The more highly oxidized uranium deposits are commonly found in the thick rim-forming sandstones ($S_1$, $S_4$, and $S_6$). Ore from these deposits has an average grade of about 0.25 percent $U_3O_8$ and 0.30 percent $V_2O_5$.

The less highly oxidized deposits are found in thin sandstones interbedded with siltstones and mudstones marginal to the thick cliff-forming sandstones of $S_1$ and $S_6$. Ore from these deposits may have a grade of as much as 0.40 percent $U_3O_8$ and 1.4 percent $V_2O_5$. These deposits commonly contain a larger proportion of the dark minerals corvusite and rauvite accompanied by a resulting increase in the vanadium/uranium ratio.

The known distribution of uranium deposits in the Edgemont mining district, which includes the Flint Hill quadrangle, suggests that the deposits are more common near the change from thick cliff-forming sandstone to the interbedded facies. The proximity of calcium carbonate-cemented sandstone to uranium deposits in the Runge mine (See chapter on Runge mine in this report, and Gott, G. B., U. S. G. S. Bull. 1046-A, 1956) and in the Gould mine suggests that sandstone $S_4$ may be a favorable unit for prospecting in the vicinity of an area of carbonate cement in the south-central part of the Flint Hill quadrangle. Prospecting along extensions of favorable lithologic and structural trends under the cover of overlying formations may lead to the discovery of unoxidized deposits of the uraninite-coffinite type.

## Jewel Cave SW quadrangle, South Dakota

by

W. A. Braddock

The Jewel Cave SW quadrangle is in the southwest rim of the Black Hills, and is about 25 miles southeast of Newcastle, Wyoming. Field work was started in June 1955 and completed in September 1956.

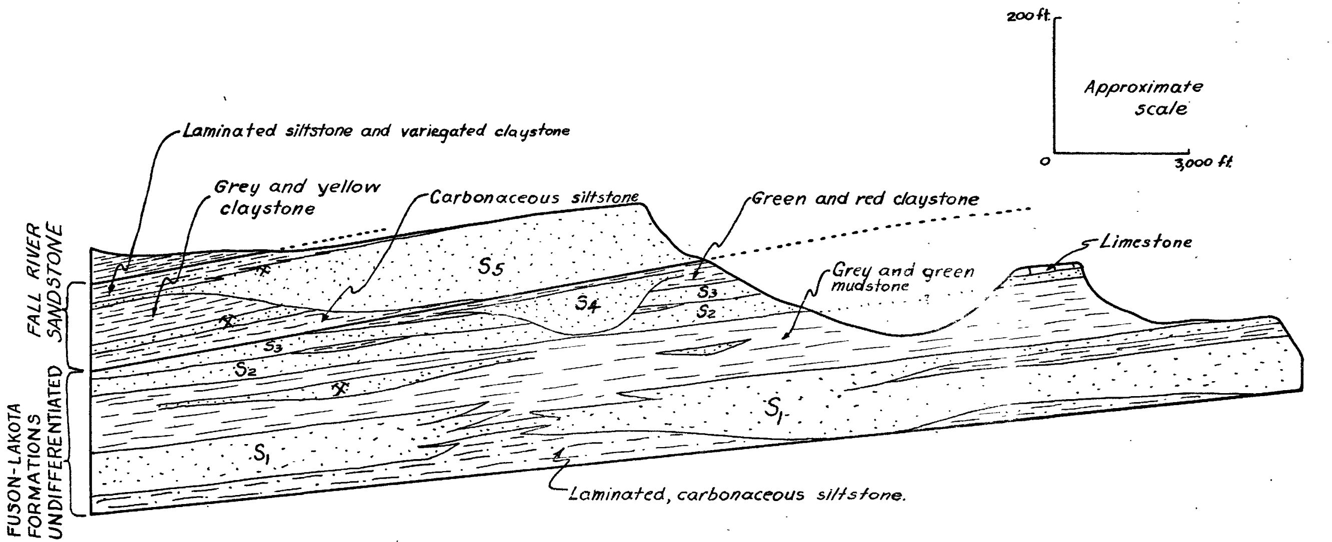
Sedimentary rocks ranging in age from Pennsylvanian to Quaternary crop out within the quadrangle. The Paleozoic and lower Mesozoic rocks were deposited predominantly in shallow marine water. The upper portion of the Minnelusa sandstone of Pennsylvanian age is composed of red and yellow crossbedded sandstone with some gypsum and thin limestone beds. The Opeche formation of Permian age consists predominantly of red siltstone with several thin beds of gypsum. The Permian Minnekahta limestone is thinly bedded limestone and dolomite and grades upward into gypsum in the central part of the quadrangle. The Spearfish formation of Triassic age consists of laminated red siltstone, fine sandstone, and beds of laminated dolomite and gypsum. The Sundance formation of Late Jurassic age consists of a lower member of aeolian and marine sandstone, overlain by green to gray laminated shale, thin-bedded sandstone, red siltstone, and thin-bedded glauconitic shale and sandstone.

The Morrison formation of Late Jurassic age is dominantly greenish-gray mudstone with marlstone and rare thin channel sandstones. These rocks probably were deposited in shallow lakes and along stream channels. The Lower Cretaceous Inyan Kara group consists of irregularly interbedded sandstone, mudstone, conglomerate, and minor amounts of limestone (fig. 44). The Fuson-Lakota formations undifferentiated (TEI 590, p. 151) were deposited in stream channels, on flood plains, and possibly in lakes. The Fall River sandstone may be in part stream channel and flood-plain deposits, and in part deltaic or shoreline deposits.

Black shales of the marine Lower Cretaceous Skull Creek and Mowry shales crop out in the southwest corner of the quadrangle.

Quaternary deposits in the quadrangle include unconsolidated alluvial deposits and terrace gravels.

The rocks in the Jewel Cave SW quadrangle dip gently to the southwest. The Dewey fault strikes about N. 70° W. across the quadrangle; the south block of the fault has apparently been downthrown about 300 feet. A gentle northwest-trending anticline extends from the Edgemont NE quadrangle two-thirds of the way across the Jewel Cave SW quadrangle. An elongate northwest-trending dome is limited to the northeast corner of the quadrangle.



S5 ; Medium- to fine-grained, crossbedded sandstone. Trends northwest.
S4 ; Coarse- to fine-grained channel sandstone. Trends northwest.
S3 ; Fine-grained, white, massive sandstone.
S2 ; Coarse- to fine-grained, locally conglomeratic sandstone.
S1 ; Crossbedded sandstone with interbedded mudstone. Individual channels trend northwest.

⚒ Stratigraphic position of small uranium deposits.

Figure 44.– Diagram showing the variation of the Inyan Kara Group across the southern part of the Jewel Cave S.W. Quadrangle.

Within the quadrangle there is evidence to suggest that solution of soluble rocks at depth, with the resulting collapse of overlying rocks, has occurred. The evidence is: (1) The upper part of the Minnelusa formation is extensively and intensely brecciated in the areas where no gypsum beds are present. A gypsum bed over 40 feet thick at the stratigraphic position of the lowest brecciation is known to be down-dip from the area of most heavily brecciated rocks. Where the gypsum is present the overlying rocks are relatively undisturbed. This suggests that in places the gypsum has been completely removed in solution and the overlying rocks have been brecciated through subsidence (TEI-640, p. 111-112). (2) Thin strata of brecciated and vuggy dolomite occupy the stratigraphic position of nearby gypsum beds in the Spearfish formation. This suggests that the brecciated and vuggy dolomite is the residual remnant of a gypsum bed that has largely been removed in solution. (3) Small near-vertical down-dropped breccia pipes a few feet to a few tens of feet in diameter have been observed in the Minnelusa, Opeche, Minnekahta, Spearfish, Sundance, and Lakota formations.

Other structural features are small, nearly isoclinal folds in the Minnekahta limestone with amplitudes of several feet. The fold axes are oriented northwest, parallel to the regional dip and to the two major anticlines in the quadrangle. It is probable that these folds resulted from pre-consolidation sliding in the direction of the regional dip although some of the folding may have resulted from collapse of underlying rocks.

A number of small bodies of secondary uranium minerals occur in the Inyan Kara rocks in the southwest corner of the quadrangle. These deposits are most abundant along the southwest margin of a thick channel sandstone ($S_5$) in the Fall River sandstone (fig. 44). Several deposits occur in a thin sandstone in the lower part of the Fall River southwest of the channel margin. One occurrence of uranium minerals has been found in a channel sandstone near the middle of the Lakota-Fuson interval.

## Dewey quadrangle, Wyoming - South Dakota

by

D. A. Brobst

The Dewey quadrangle is on the southwest flank of the Black Hills about 20 miles southeast of Newcastle, Wyoming. The northeastern third of the quadrangle is occupied by Elk Mountain, a hogback on which the rocks dip 3° to 13° to the west. West and southwest of the ridge are rounded hills of low relief on a structural terrace known as the Dewey terrace (fig. 43). The altitude ranges from 4,967 feet on Elk Mountain to 3,620 feet at the lowest place on the Dewey terrace.

About 2,100 feet of consolidated sedimentary rocks of Triassic (?) to Cretaceous age are exposed in the quadrangle. Some of the stratigraphic data are summarized in table 8. The Inyan Kara group and older rocks are exposed on the Elk Mountain hogback. The Fall River sandstone forms the cap of this hogback. The Skull Creek shale, Newcastle sandstone, Mowry and Belle Fourche shales are exposed on the Dewey terrace west of Elk Mountain. The Greenhorn limestone and the Carlile shale are exposed in a small hogback 40 to 100 feet high on the west side of the Dewey terrace.

### Inyan Kara group

The Inyan Kara group of Early Cretaceous age is exposed over an area of about 16 square miles on Elk Mountain. The group has an average thickness of 350 feet and consists of two major units: the Fall River sandstone and the Lakota-Fuson formations undivided. The rocks are of terrestrial origin and are principally mudstones, siltstones, and sandstones. Some of the sandstones locally contain uranium minerals.

Fall River sandstone.--The Fall River sandstone has an average thickness of 125 feet and includes three lithologic units. The upper unit is exposed on the western foot of Elk Mountain along the margin of the Dewey terrace where it averages 75 feet in thickness and is composed of interlayered mudstone, siltstone, and sandstone in thin beds ranging from a few inches to 5 feet thick. The mudstones are yellow, gray, red, and black. The siltstones are generally buff to gray. The sandstones are white to red and medium to fine-grained; some are crossbedded. The contact with the overlying Skull Creek shale appears to be gradational. In a contact zone about 5 feet thick, thin-bedded black mudstones increase in abundance and thin-bedded sandstones decrease in the Fall River giving way to the black Skull Creek shale above.

The middle lithologic unit is a crossbedded, light-brown to red quartzose sandstone of coarse to fine grain size that is exposed on the dip slope over about two-thirds of Elk Mountain. In the canyons and on the east face of Elk Mountain it forms a prominent cliff. The average thickness is about 30 feet, but it ranges from 5 feet to more than 80 feet thick (fig. 45). The sandstone contains scattered irregular pods of red clay and clay gall conglomerate two to three inches thick and several feet in diameter and rounded white calcareous concretions as great as six feet in diameter. On weathered surfaces, the concretions are dark brown. Carbonaceous matter is common. (See TEI 640, p. 108.)

Table 8.--Formations exposed in the Dewey quadrangle, Wyoming - South Dakota

| Age | Unit | Average thickness in feet | Characteristics |
|---|---|---|---|
| Recent | Loess | 5 | Wind-deposited fine sand and silt in the southwest part of the quadrangle. |
| Quaternary | Alluvium | 10 | Mixed boulders, sand and clay in the stream valleys. |
| Late Cretaceous | Carlile shale | 200+ | Gray shale with thin sandstone. Top not exposed. |
| | Greenhorn limestone | 75 | Thin-bedded fossiliferous limestone interbedded with calcareous shale. |
| | Belle Fourche shale | 600 | Black shale with ferruginous concretions and some beds of bentonite, especially in the lower 50 ft. |
| Early Cretaceous | Mowry shale | 130 | Gray siliceous shale and thin sandstone. A 5-ft. zone of sandstone forms a horizon marker 50 ft. above the base. |
| | Newcastle sandstone | 0-10 | Scattered irregular lenses of brown sandstone. |
| | Skull Creek shale | 250 | Black shale and some scattered dikes of sandstone in the upper part. |
| | Inyan Kara group* | 350 | |
| | Fall River sandstone | 125 | Mudstones, siltstones, and sandstones. |
| | Fuson-Lakota formations undivided | 225 | Mostly mudstones and sandstones, some conglomeratic. |

Table 8 .—Continued

| Age | Unit | Average thickness in feet | Characteristics |
|---|---|---|---|
| Late Jurassic | Morrison formation* | 0-100 | Green mudstone and shale with thin beds of gray lithographic limestone. |
|  | Sundance formation | 320 |  |
|  | Redwater shale member | 150 | Green shale with some thin beds of gray to yellow sandstone and limestone. |
|  | Lak member* | 70 | Mostly red siltstone with some thin beds of red sandstone. |
|  | Hulett sandstone member | 50 | Yellow to gray calcareous sandstone in thin to thick beds. |
|  | Stockade Beaver shale member | 50 | Mostly green shale with thin beds of siltstone and sandstone near the top. |
| Triassic(?) | Spearfish formation | 50+ | Red siltstone and sandstone, some gypsum. Only the upper 50 ft. exposed in the quadrangle. |
|  | Total | 2,100 + |  |

*Terrestrial rock units; all others are marine units.

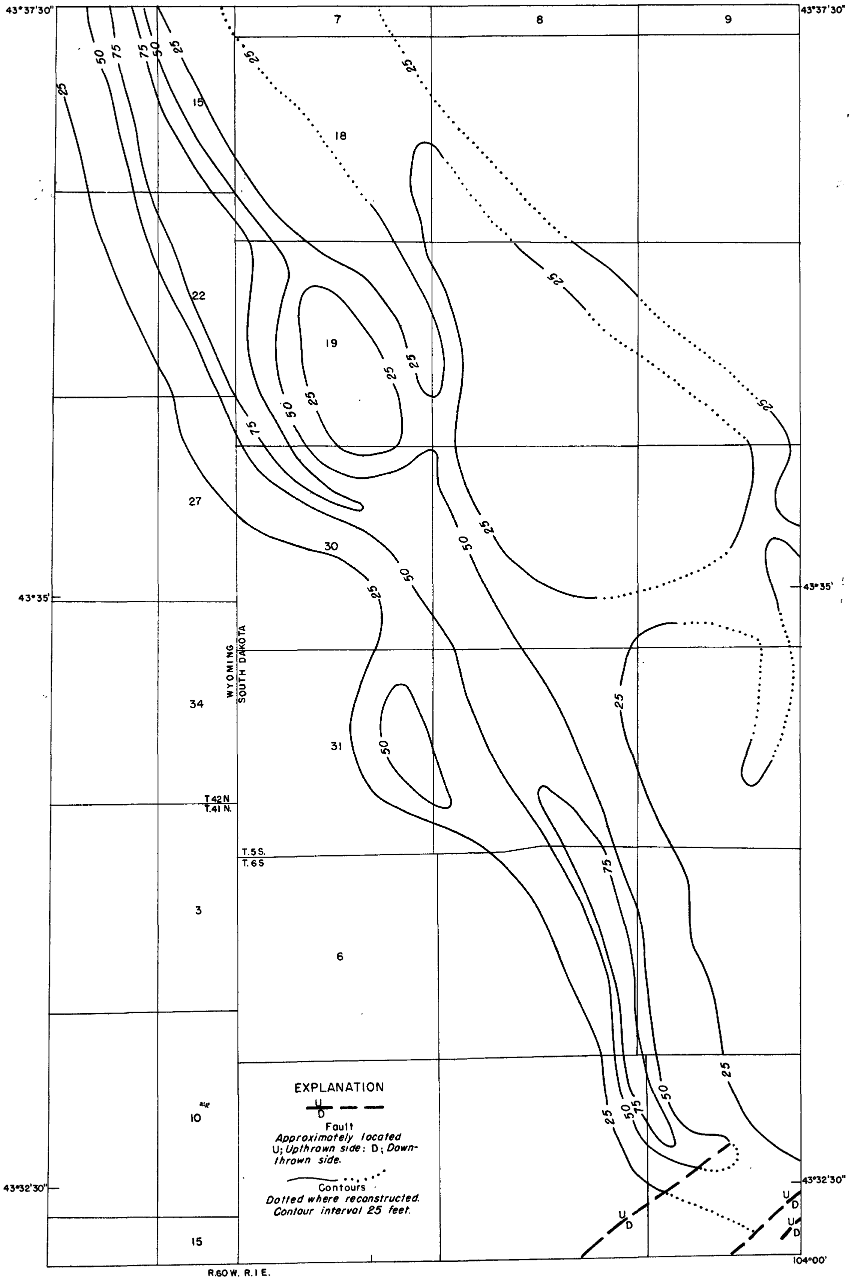


FIGURE 45.- ISOPACH MAP OF A SANDSTONE IN THE FALL RIVER SANDSTONE IN THE NORTHEAST PART OF THE DEWEY QUADRANGLE, WYOMING - SOUTH DAKOTA.

This sandstone is considered to be of channel origin because of the elongate character of the thickest parts of the unit (fig. 45), the apparent thinning of the unit laterally, the variation in grain-size and included materials, and the irregular configuration of its contact with underlying units. In many places the underlying carbonaceous siltstones have been removed entirely. Fragments of underlying rocks also are included in the basal parts of the sandstone. The crossbeds indicate a northwest direction of flow.

The lowest unit consists of carbonaceous siltstones that are as much as 40 feet thick. The siltstones average about 20 feet thick, but they are absent at places because of channeling by the overlying sandstone as described previously. The unit is gray and thinly bedded. The carbonaceous matter occurs as black laminae generally less than one-quarter inch thick.

Lakota-Fuson formations undivided.--The Lakota-Fuson formations undivided have an average thickness of 225 feet and include three major lithologic units that are exposed in the canyons and along the east side of Elk Mountain. The upper unit ranges in thickness from less than 100 feet to more than 250 feet (fig. 46). This is a heterogeneous unit containing chiefly varicolored mudstones, gray siltstones, and white to yellow sandstones, some locally conglomeratic. Compositional gradations among these rock types are common. The unit also contains some channel sandstones such as the 8-Ball channel sandstone (See TEI 640, p. 105, 108). Individual beds generally are difficult to trace because of insufficient and poor exposures.

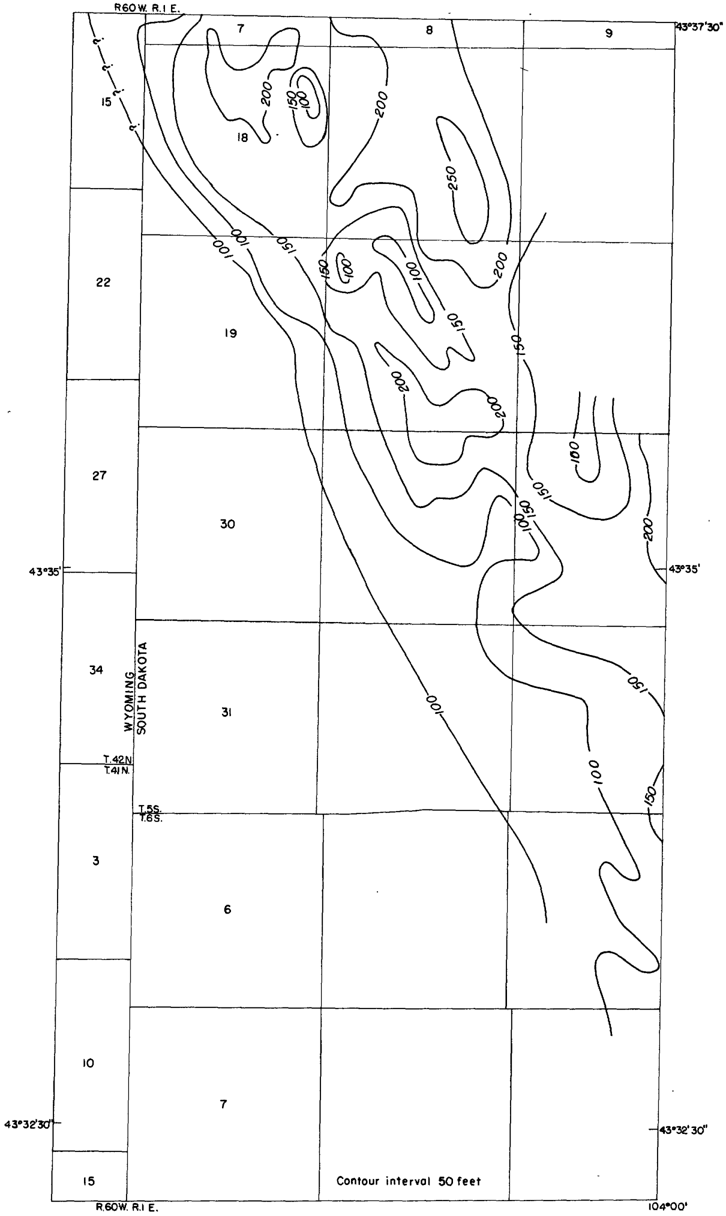


FIGURE 46 .- ISOPACH MAP OF THE INTERVAL BETWEEN THE TOP OF A SANDSTONE IN THE FUSON FORMATION - LAKOTA SANDSTONE UNDIVIDED AND THE BASE OF THE FALL RIVER SANDSTONE, NORTHEAST PART OF DEWEY QUADRANGLE, WYOMING-SOUTH DAKOTA.

The middle unit is a fine- to coarse-grained and locally conglomeratic red to yellow, quartzose sandstone that ranges in thickness from 20 to 120 feet with an average thickness of about 50 feet. This unit also appears to be of channel origin. Crossbedding is common, and it indicates a generally northwestward direction of flow.

On the north end of Elk Mountain, a conglomeratic facies of this sandstone that contains well-rounded gray pebbles of chert lies directly on the Redwater shale member of the Sundance formation. The lowest lithologic unit of the undivided Lakota-Fuson formations and the Morrison formation are absent. This absence may be the result of the removal of these two units by channeling before the sandstone was deposited.

The lower unit is a dark-brown silty carbonaceous mudstone that is as much as 40 feet thick and averages 25 feet. At places it is absent, probably from channeling before deposition of the overlying sandstone. The contact of the brown mudstone with the underlying green Morrison formation is exposed in only a few places but is marked by a sharp color change below which carbonaceous material is absent and silt is nearly absent.

## Structure

The major structural features of the quadrangle are the monocline that forms the Elk Mountain hogback, the Dewey structural terrace, the monocline on the west side of the terrace that forms the structural boundary between the Powder River Basin on the west and the Black Hills uplift on the east, and the northeast-trending Dewey fault in the southern part of the quadrangle. These structures and their relationships to others in the southern Black Hills are shown in figure 43.

The Elk Mountain hogback occupies the northeastern third of the quadrangle. The attitudes of the rocks on the hogback are shown on figure 47, by structure contours at the base of the Fall River sandstone. The east face of the hogback is an escarpment 300 to 800 feet high.

The rocks on the Dewey terrace dip 1° to 2° west and are broken by many small faults with vertical displacements of one to 20 feet. The trend of these faults varies greatly.

The low hogback on the west side of the terrace passes through the northwest corner of the quadrangle where the beds dip between 25° and 30° to the west.

The Dewey fault has been traced for nearly 7 miles from the southern end of Elk Mountain to the southwestern corner of the quadrangle. The direction of movement is mostly vertical; the maximum throw is about 200 feet. The south side is downthrown. This fault is part of an en echelon series that extends to the northeast on the same trend for at least 10 miles.

The competent beds in the quadrangle are cut by two sets of vertical to steeply dipping joints. The most prominent set strikes N. 30° - 45° E., and the other set strikes N. 30° - 45° W.

## Economic geology

Scattered radioactivity anomalies and occurrence of secondary uranium minerals have been found in the Fall River sandstone on Elk Mountain. Of these, only the Wicker-Baldwin property in the NW$\frac{1}{4}$ sec. 16, T. 42 N., R. 60 W., Weston County, Wyoming, has been developed. This property is at the foot of the Elk Mountain hogback close to the east side of the Dewey terrace. Underground workings totaling 340 feet are in the channel

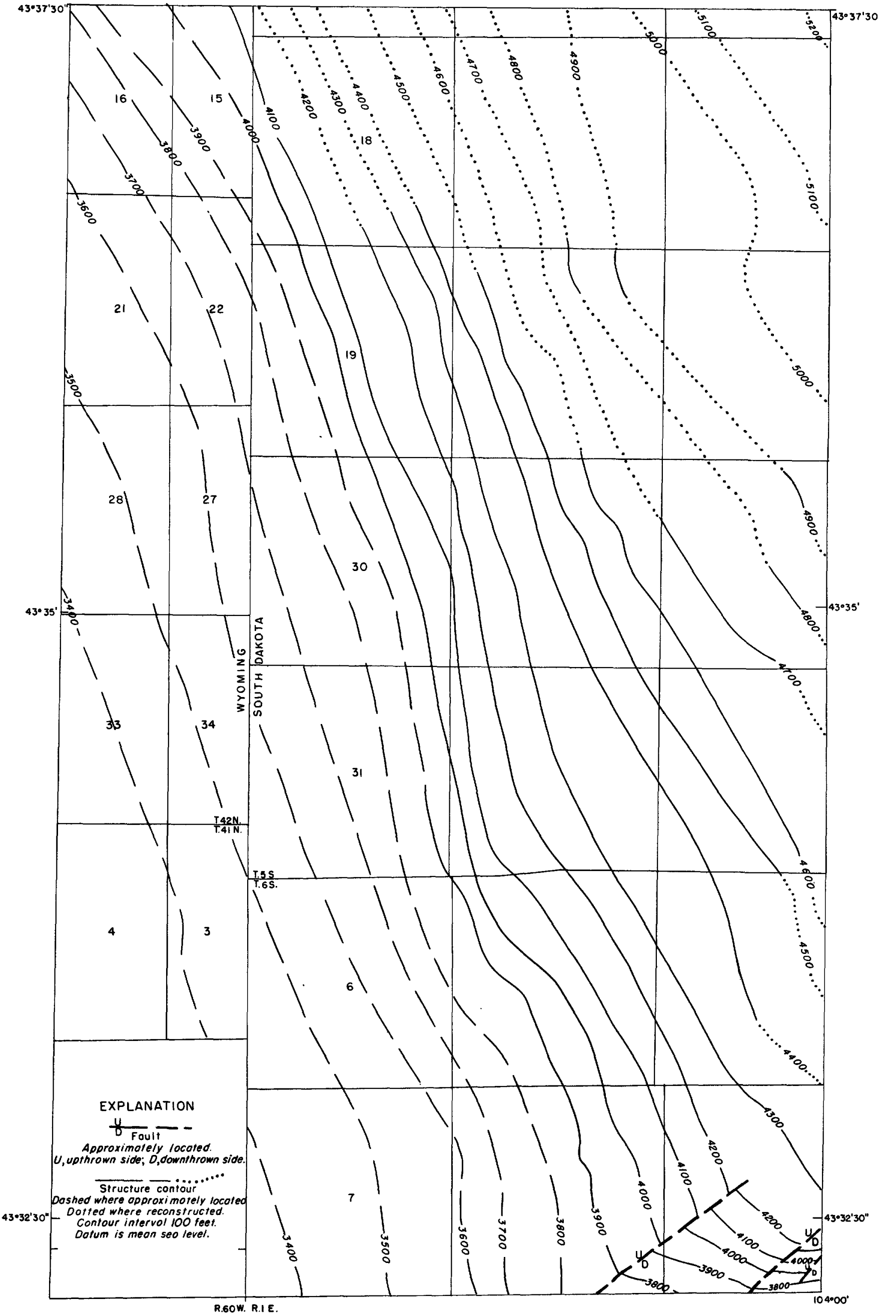


FIGURE 47.—STRUCTURE CONTOUR MAP ON THE BASE OF THE FALL RIVER SANDSTONE IN THE NORTHEAST PART OF THE DEWEY QUADRANGLE, WYOMING—SOUTH DAKOTA

sandstone unit of the Fall River sandstone. Carnotite-type minerals are associated principally with pods of lignitic material, pyrite, and marcasite. The great variation and irregularity of the lithology at the mine and the local trends of the enclosing sandstone suggest that these sediments were deposited on the fill-side of a bend in the channel. At the mine the sandstone strikes N. 32° W. and dips 8° SW and is at least 60 feet thick (See TEI 620, p. 172-173; TEI 640, p. 110-111).

Bentonite beds from a few inches to 2 feet thick are interlayered in the black shales of the Dewey terrace, especially in the upper part of the Mowry shale and the lower part of the Belle Fourche shale. The beds have been extensively prospected and they probably are not of commercial value under current economic conditions, chiefly because of their thinness and the large amount of overburden.

Sand and gravel is available in the area from terraces along the valley of Line Creek at the western foot of Elk Mountain and from cappings on the tops of the low hills on the Dewey terrace.

Several wells were drilled for oil on the Dewey terrace. One well near the center of sec. 7, T. 41 N., R. 60 W., Weston County, Wyo., produced some oil from the Minnelusa formation of Pennsylvanian age. Several small structural closures on the Dewey terrace suggest that there might be some possible future production of oil and gas in the area. Some of the abandoned wells are now yielding artesian water.

# Clifton quadrangle, Wyoming
by
N. P. Cuppels

Field work on the Clifton quadrangle began in June 1956 and will be completed at the end of the 1957 field season. A summary of the geology of the part of the quadrangle mapped in 1956 was included in TEI-640, p. 99-101.

All the uranium produced in the Black Hills has been mined from rocks of the Lower Cretaceous Inyan Kara group. Despite active prospecting of extensive outcrops of these rocks in the Clifton quadrangle, no minable deposits of uranium have been found. The most favorable lithologic unit in the southern part of the quadrangle appears to be a rim-forming sandstone near the base of the Fall River sandstone of the Inyan Kara group. Most radioactivity anomalies found in the area are in this rim sandstone.

The rim sandstone is a light-gray to yellow, fine- to medium-grained, thick-bedded unit with distinctive variations in its color and cement. A color boundary within the sandstone trends northward for 6,000 feet from the Alray mine (fig. 48); the sandstone is yellow east of the boundary and light gray west of the boundary. A uniform distribution of siliceous cement in the light-gray sandstone contrasts sharply with the irregular distribution of the siliceous and calcareous cement of the yellow sandstone. Nodules cemented with calcium carbonate and silica are common in the yellow sandstone and, locally, ferruginous nodules are abundant.

The thickness of the rim sandstone varies, as shown in figure 49. Some of the northeastward thinning is the result of erosional truncation but much of the thinning is probably a sedimentary feature. The southwestward

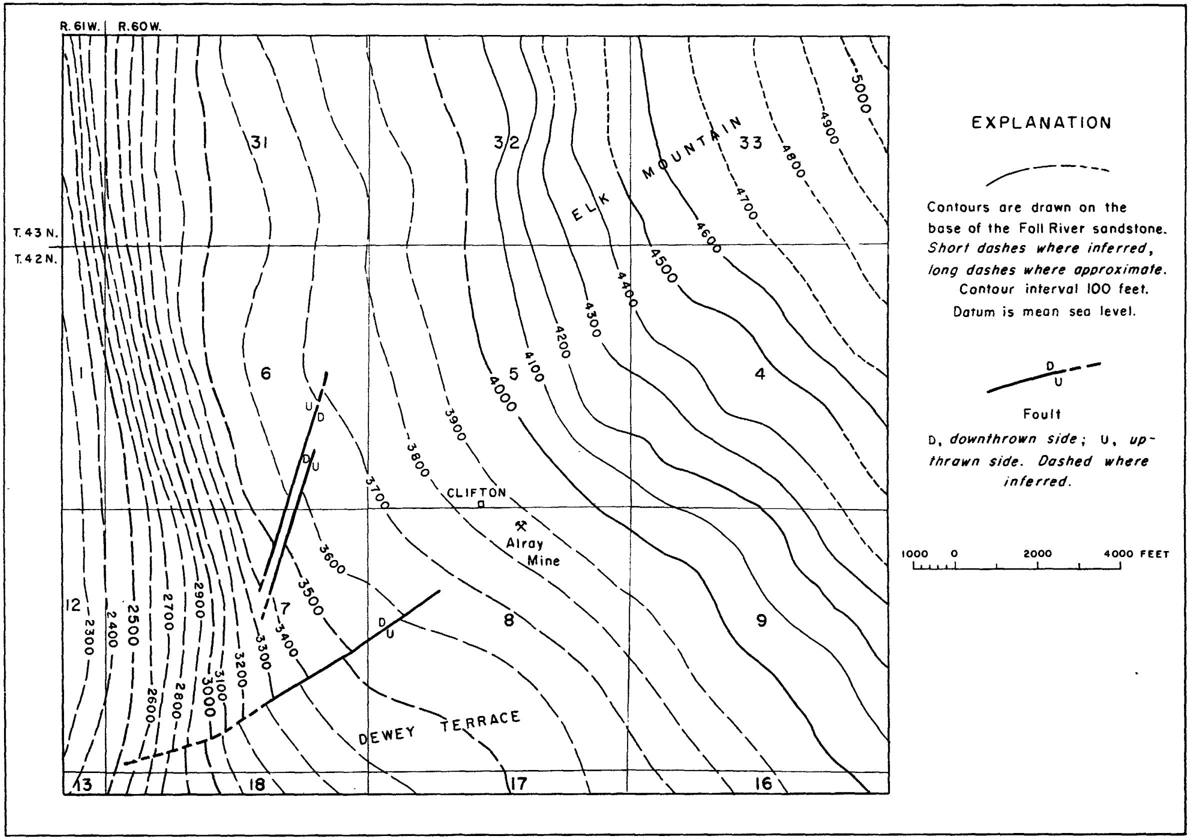
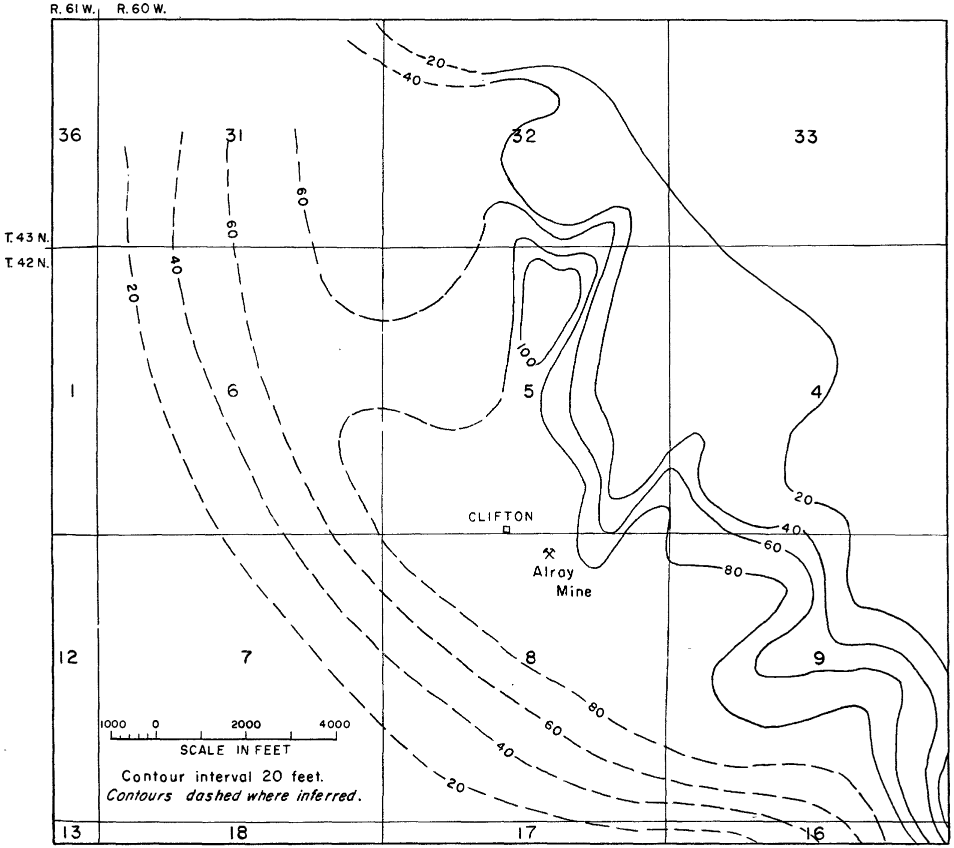


FIGURE 48. STRUCTURE CONTOUR MAP OF THE FALL RIVER RIM SANDSTONE IN THE SOUTHWEST PART OF THE CLIFTON QUADRANGLE, WESTON COUNTY, WYOMING.

thinning is inferred from data in the Dewey quadrangle and the log of a well northwest of Clifton. The thickness of the rim sandstone varies inversely with the thickness of an overlying, thin-bedded sandstone and siltstone unit. Two miles north of Clifton, the rim sandstone pinches out and its stratigraphic interval is occupied by thin-bedded sandstone and siltstone. A carbonaceous siltstone, 20 to 30 feet thick, which underlies the rim sandstone is the basal unit of the Fall River formation. The bottom of this unit has been used as a datum for the structure contours shown in figure 48. In the southwestern part of the quadrangle, Inyan Kara rocks have a regional southwestward dip of 7 to 8 degrees. The regional dip is interrupted by the Dewey terrace (fig. 48) where dips flatten from 15 to 3 degrees at the head of the terrace and steepen from 3 to 25 degrees at the foot. Most of the terrace is underlain by marine shales of the Skull Creek and Mowry formations, with the Fall River-Skull Creek boundary being covered by alluvium and colluvium near the eastern margin of the terrace.

All radioactivity anomalies found on the dip slope of Elk Mountain (fig. 48) are at the same stratigraphic interval, near the base of the Fall River rim sandstone. One of these anomalies has been explored by means of a tunnel at the Alray mine. The rim sandstone at the mine is irregularly mineralized in a zone several feet thick extending from the color boundary eastward into the yellow sandstone. A secondary yellow uranium-bearing material having a pale yellow fluorescence is concentrated in bands peripheral to siliceous nodules and as tabular bodies near a thin bed of fragmented, pyritiferous, carbonaceous siltstone. Black uraniferous material irregularly distributed in the siltstone may have



Contour interval 20 feet.
*Contours dashed where inferred.*

FIGURE 49 . ISOPACH MAP OF THE FALL RIVER RIM SANDSTONE IN THE SOUTHWEST PART OF THE CLIFTON QUADRANGLE, WESTON COUNTY, WYOMING.

been the source of the yellow material. No uraniferous minerals have been identified but the results of chemical analyses shown in table 9 and the fluorescence suggest that the yellow material is a combination of uranium phosphates and vanadates.

Table 9. Analyses of five samples collected at the Alray mine, Weston County, Wyoming

| Sample No. | Lithology of Sample | U ppm | eU ppm | V ppm | As ppm | P ppm |
|---|---|---|---|---|---|---|
| 94 | Quartz sandstone | 1200 | 1200 | 500 | 22 | 1700 |
| 95 | Quartz sandstone | 800 | 610 | 700 | 14 | 500 |
| 97 | Carbonaceous Pyritiferous siltstone | 650 | 690 | <300 | 14 | 5200 |
| 100 | Gypsiferous siltstone | 30 | 70 | <300 | 14 | <200 |
| 92 | Calcareous sandstone | 10 | 10 | <300 | 6 | <200 |

Mineralized rocks at the Alray mine could be interpreted as evidence for the movement of uranium-bearing, ground water solutions through the rocks. If movement occurred in a favorable geochemical environment subsequent to the Black Hills uplift, substantial quantities of uranium could have been carried to the Dewey terrace (fig. 48) and concentrated at or near the water table. Work by Garrels and Christ has outlined some of the features of an environment favorable for the migration and precipitation of uranium in ground water solutions. When tetravalent uranium is oxidized to the hexavalent state, it is "fixed" in stable compounds of vanadium, arsenic, and phosphorus; in the absence of these elements, the hexavalent ion will tend to migrate with ground water until it is precipitated in a reducing environment. Carbonaceous material at the Alray mine probably localized the uranium which was subsequently stabilized by phosphorus and vanadium. The high concentration of phosphorus in the black, pyritiferous, carbonaceous siltstone (table 9) indicates that this unit may have been the source of stabilizing as well as localizing agents. The siltstone is quantitatively inadequate, however, to form a significantly extensive chemical barrier to the migration of uranium in solution. In the absence of other localizing agents, migrating solutions should have reached the water table on the Dewey terrace where a change from oxidizing to reducing conditions could have precipitated uranium in significant quantities.

## Carlile quadrangle, Wyoming

by

M. H. Bergendahl and G. A. Izett

Mapping of the Carlile 7½-minute quadrangle, which occupies about 50 square miles in southwestern Crook County, Wyoming, was started in July 1955 and is scheduled for completion in June 1957.

### Stratigraphy

All rocks exposed in the Carlile quadrangle are sedimentary and range in age from Late Jurassic to Recent. The distribution of the units, which have an average total thickness of about 1,800 feet, is shown on the geologic map (fig. 50). The upper Jurassic sequence in the quadrangle is 265 feet thick and consists of the marine Redwater shale member of the Sundance formation and the overlying lacustrine variegated

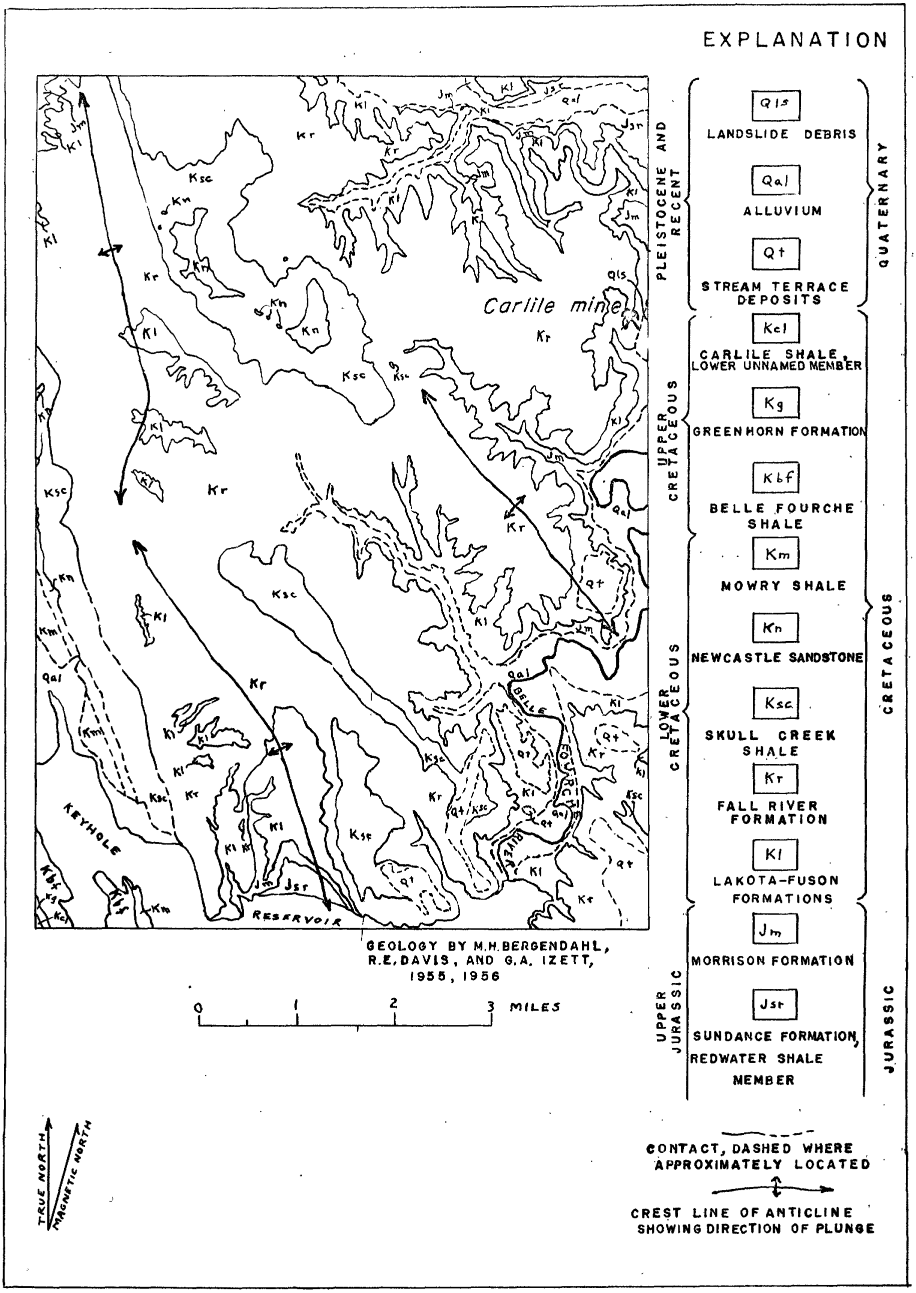


FIG. 50–GEOLOGIC MAP OF THE CARLILE QUADRANGLE, CROOK COUNTY, WYO.

claystones and thin mudstones of the Morrison formation. The basal Lower Cretaceous rocks are the Lakota-Fuson formations undifferentiated and the superjacent Fall River sandstone, which make up the Inyan Kara group; The Inyan Kara is about 260 feet thick and consists of interfingering and lenticular sandstones, claystones and mudstones of continental or fluvio-marine origin (fig. 51). Overlying the Fall River sandstone is a thick sequence of marine sediments consisting, in ascending order, of the black Skull Creek shale, 250 feet in thickness; the Newcastle sandstone, a sequence of lenticular sandstones, carbonaceous claystone, bentonite, and siltstone; and the gray siliceous Mowry shale, 180 feet thick. Overlying the Mowry shale is the lowermost formation of the Upper Cretaceous series, the Belle Fourche shale, which is a black marine shale about 700 feet thick containing abundant ferruginous and calcareous concretions. The Greenhorn formation, 70 to 80 feet thick, composed of thin limestone beds, shale, and layers of concretions, overlies the Belle Fourche shale. Overlying the Greenhorn formation is the youngest of the Upper Cretaceous rocks exposed in the quadrangle, the lower unnamed member of the Carlile shale, which is dark-gray, non-calcareous marine shale, 50 feet thick. The sediments of Pleistocene and Recent age consist of unconsolidated stream terrace deposits, alluvium, and landslide debris.

## Structure

The Carlile quadrangle lies along the periphery of the upwarped rocks bordering the Black Hills uplift. Part of the monocline that extends along the western flank of the Black Hills uplift crosses the southwest corner of the quadrangle. Superimposed along the upper part of this monocline are two northwest-trending doubly-plunging anticlines that form

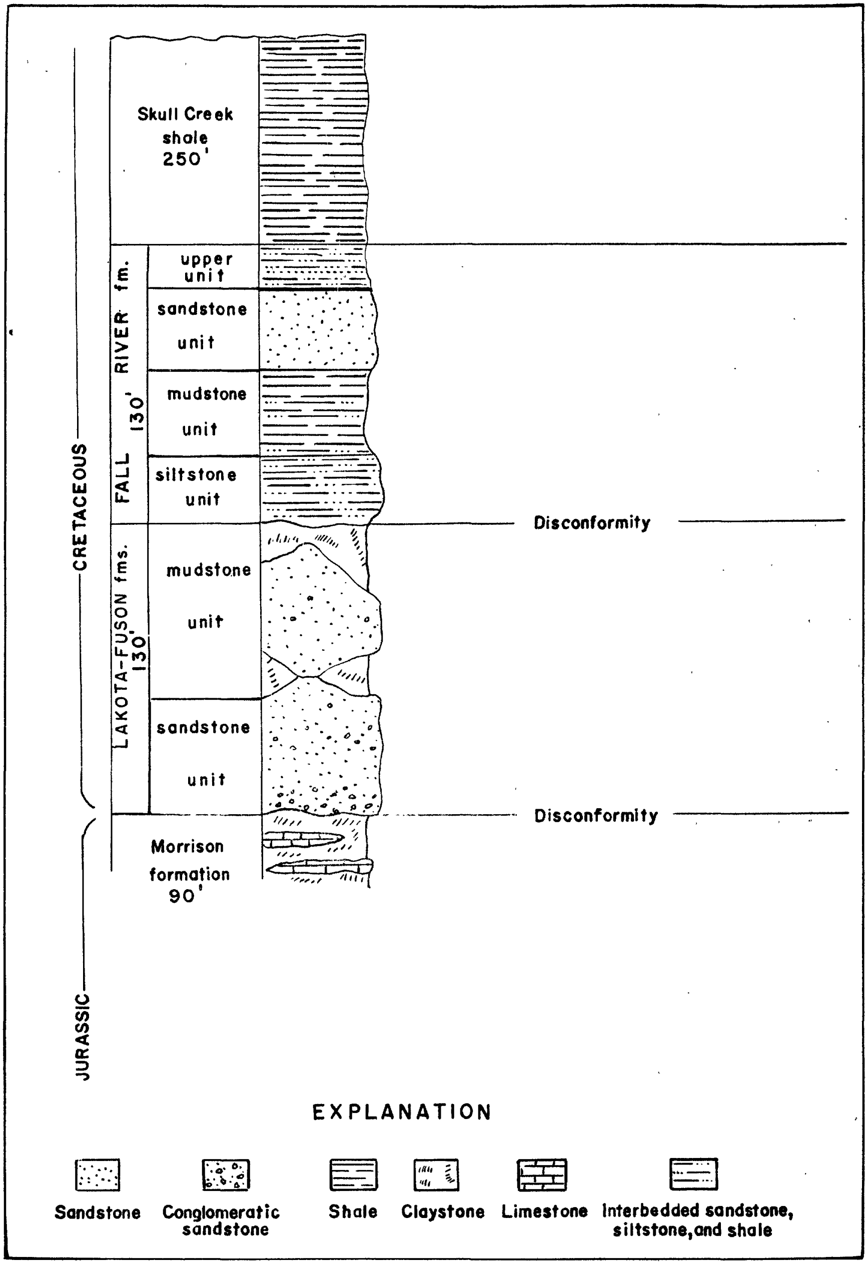


FIGURE 51 -COMPOSITE SECTION OF LAKOTA-FUSON FORMATIONS UNDIVIDED AND FALL RIVER FORMATION SHOWING LITHOLOGIC CHARACTERISTICS OF THE UNITS, CARLILE QUADRANGLE, WYO.

prominent topographic features in the western part of the quadrangle (fig. 50). Throughout the remainder of the quadrangle, the beds dip gently westward and are locally warped into minor terraces, domes, and basins. Only three faults were mapped. These are normal, have nearly vertical dips, and have displacements of 30 feet or less. None of the faults could be traced for more than a mile.

## Petrographic studies

Results of mechanical analyses show that the Lakota-Fuson and Fall River sandstones and siltstones are well sorted, but that the Lakota-Fuson is somewhat less well sorted than the Fall River. The median diameters of the sand grains in all samples ranged from .042 to .25 millimeters.

Studies of heavy minerals from samples of the Fall River and Lakota-Fuson formations show that in general the two formations contain small suites of similar species that were probably derived from a pre-existing sedimentary or metasedimentary terrane. Figure 52 shows the distribution and relative abundance of the heavy minerals. It will be noted that chloritoid is present in the Fall River samples, but not in the Lakota-Fuson samples. Chlorite is also restricted to the Fall River, but is a minor constituent.

Microscopic examination of thin sections from the Lakota-Fuson formations undivided and the Fall River sandstone reveals that both units contain detrital grains of quartz and chert as major constituents and feldspar and white mica as minor constituents. Clay and iron oxides commonly are the cementing materials.

| | LAKOTA-FUSON fms. sandstones | | | | FALL RIVER fm. | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | *siltstone unit* | *sandstone unit* | | | *upper unit* |
| | G-29 | G-30 | G-31 | G-32 | G-6 | G-17 | B-100 | B-122 | G-44 |
| **ANATASE** | | VR | | | | | | | VR |
| **BROOKITE** | VR | | | | | R | | | |
| **CHLORITE** | | | | | VR | VR | VR | | VR |
| **CHLORITOID** | | | | | R | C | C | R | R |
| **EPIDOTE** | | | | | | | | | VR |
| **GARNET** | VR | R | VR | VR | R | R | R | VR | R |
| **RUTILE** | R | R | C | C | C | C | C | C | R |
| **SILLIMANITE** | | | | | | | | | VR |
| **STAUROLITE** | R | C | R | R | R | VR | VR | VR | C |
| **TOURMALINE** | C | C | C | C | C | C | A | C | VA |
| **ZIRCON** | VA | A | VA | VA | A | C | A | VA | C |

EXPLANATION

VA — Very Abundant > 60 %
A — Abundant 41-60 %
C — Common 6-40 %
R — Rare 1-5 %
VR — Very Rare < 1 %

G-29 Sample Number

FIGURE 52 —DISTRIBUTION OF HEAVY MINERALS IN THE LAKOTA-FUSON AND FALL RIVER FORMATIONS

## Uranium deposits

Throughout the northern Black Hills concentrations of uranium minerals have been found in sandstone beds in the Lakota-Fuson formations undivided and in the Fall River sandstone; consequently these units have been mapped in more detail and studied more thoroughly than the remainder of the stratigraphic section. It has been found possible to divide the formations into mappable lithologic units; the subdivisions within the Fall River are more consistent in thickness and lateral extent than the units within the Lakota-Fuson formations undivided.

Carlile mine.--Uranium has been mined from the Carlile mine, near the western edge of the quadrangle (fig. 50). The surface workings of the Carlile mine have been mapped at a scale of 1:1200 and the underground workings at a scale of 1:240. The uranium deposits occur in a sandstone lens in the upper unit of the Lakota-Fuson formations undivided; the lens, which is from 20 to 40 feet in thickness, is enclosed within two relatively thick and impermeable clayey beds. Before mining began, four ore bodies were present; three on a long narrow southward-trending promontory, and one on a landslide block.

The predominant ore minerals at the Carlile mine are carnotite and tyuyamunite, which occur as yellow fine-grained aggregates coating sand grains and fragments of carbonized wood, and filling interstices between sand grains. An unidentified black vanadium mineral is also present. Calcite and gypsum are closely associated with the uranium minerals, as shown in figure 53. Seams of carbonized wood and silty clay are abundant in the ore-bearing sandstone; where these seams thicken, or where several seams coalesce, uranium minerals are present.

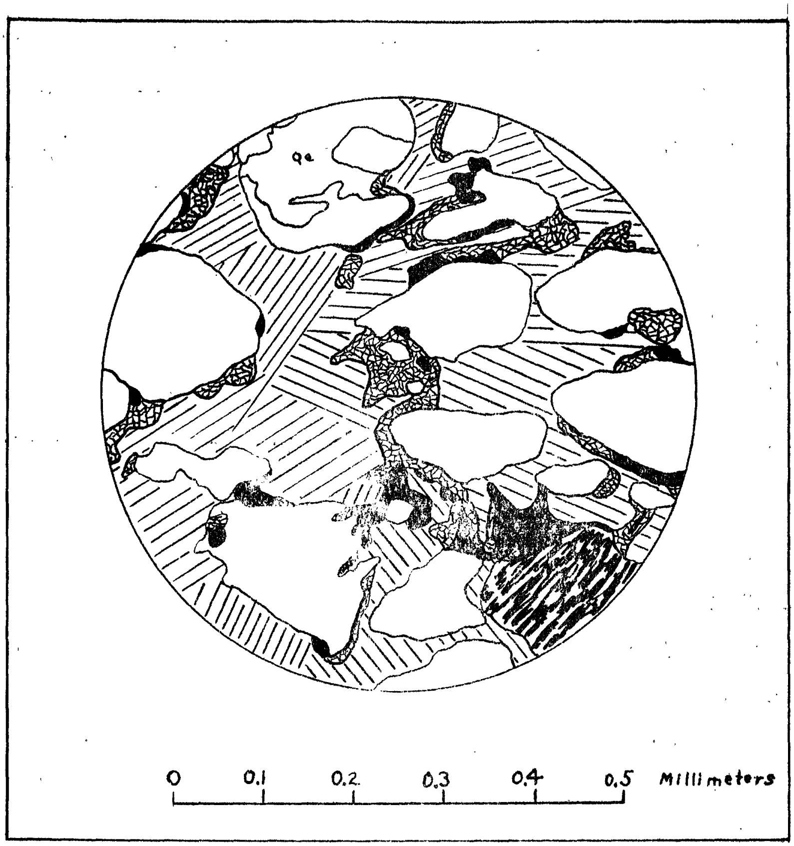


Fig. 53 —Uranium ore from Carlile mine. Unpatterned grains are quartz, Qe is quartzite grain, diagonal line pattern is mixture of cryptocrystalline gypsum and calcite, mottled grain is chalcedony, mosaic patterned areas are aggregates of carnotite and tyuyamunite, black areas are opaque black vanadium mineral; quartz grains are etched and corroded.

The grade of mineralized rock remaining in the underground workings of the Carlile mine in 1955, when the mine became inactive, as determined from 45 samples, ranged from trace amounts to 1.93 percent uranium and from less than 0.1 percent to 3.37 percent $V_2O_5$. Mineralized rock from the surface workings, as determined from nine samples, ranged from 0.005 percent to 0.34 percent uranium and from less than 0.1 percent to 0.62 percent $V_2O_5$.

Samples from the areas that are high in uranium are also high in selenium and arsenic. Radioactivity and chemical analyses for uranium correspond very closely, indicating that only minor solution or migration of the present suite of minerals has taken place.

## Thorn Divide

Concentrations of a sooty black uranium mineral were encountered and roughly outlined in several holes recently drilled about one mile west of the Carlile mine on Thorn Divide. The uranium occurs at two intervals in the Lakota-Fuson formation undivided and is associated with abundant pyrite. The upper uraniferous zone is in the same sandstone lens that contains the Carlile ore bodies; the lower uraniferous zone is in a conglomeratic sandstone near the base of the Lakota-Fuson formations undivided. The Thorn Divide deposit is near the center of a structural basin less than a mile in diameter with a closure of 30 feet. No mining has been attempted because the deposits lie at depths of 175 to 275 feet below the ground surface.

Ore controls.--Though the controls for the concentration of ore in the Carlile quadrangle are not yet clear, it is believed that a combination of the following factors provided a favorable environment for precipitating uranium from aqueous solutions that were probably of carbonate or sulfate composition: (1) abundant carbonaceous material and pyrite in a thin lens of permeable sandstone enclosed in relatively thick impermeable clays, (2) local structural basins, and (3) a regional structure consisting of a broad syncline between two anticlines. The structural features are believed to have controlled the regional flow of groundwater, and the lithologic features controlled the local rate of flow. A combination of these factors provided a favorable chemical environment for uranium deposition.

## Hulett Creek area, Crook County, Wyoming

by

C. S. Robinson and H. D. Goode

The stratigraphy, structure, and ore deposits of the Hulett Creek mining area were discussed in TEI 640, p. 85-91. This report covers the map compilation, laboratory work, and analysis of field and laboratory work done since November 1956.

A structure contour map (fig. 54) of the base of the ore-bearing upper unit of the Fall River sandstone (fig. 55) and a map (fig. 56) showing the thickness of the same unit confirm earlier observations that the ore occurs near the base or along the edges of a lens within the upper unit, and that in general the mineralized zones are elongate parallel to the margins of this lens. The structure contour map shows that the greatest known mineralization within the area is localized in a synclinal trough that abuts against and dips toward a normal fault, and that the other deposits probably are related to small synclinal troughs at the margins of the lens.

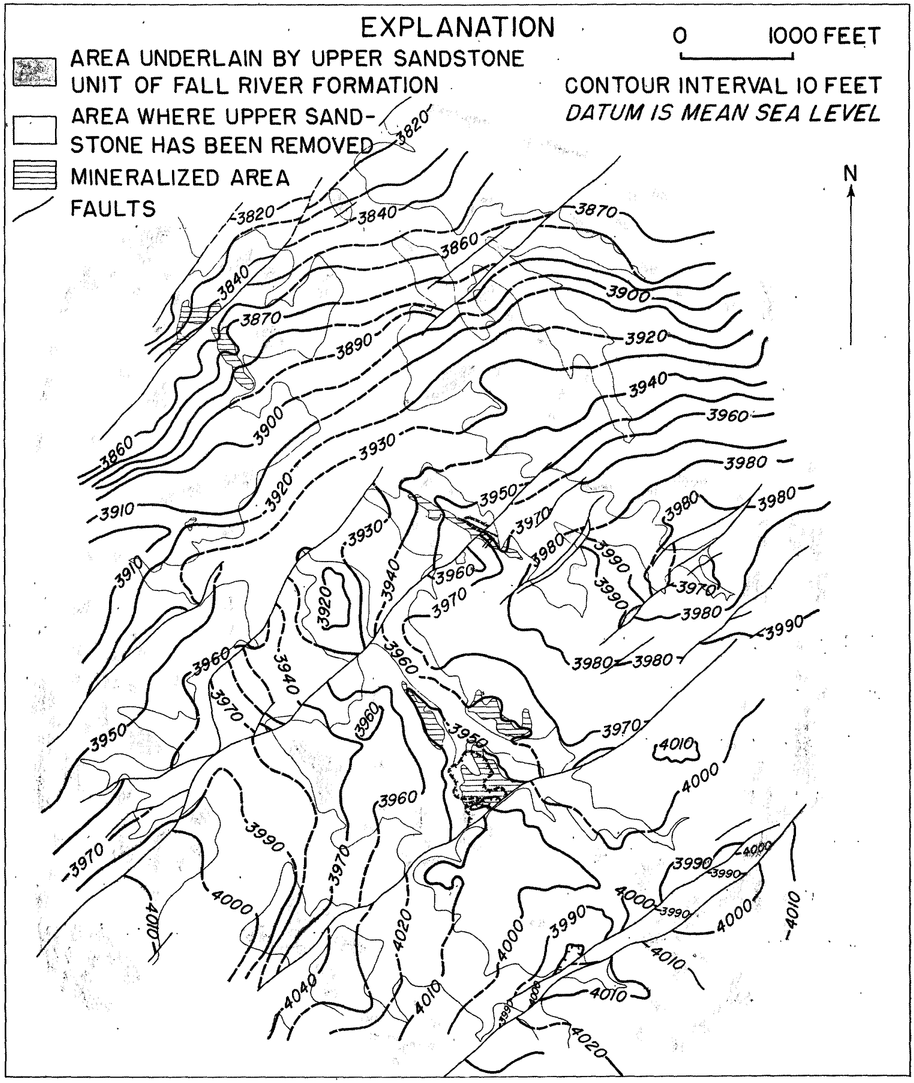
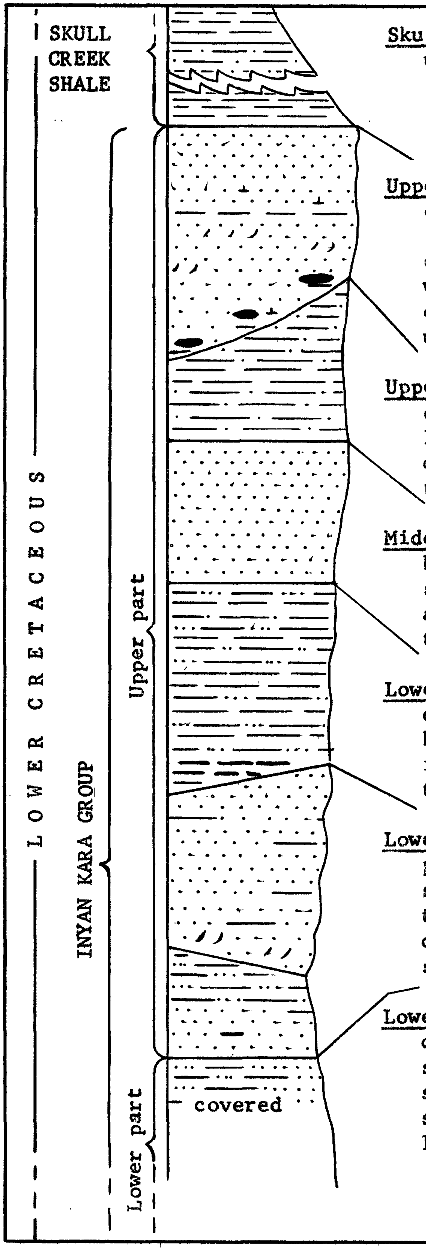


FIGURE 54 -MAP SHOWING STRUCTURE AT THE BASE OF THE UPPER SANDSTONE UNIT OF THE FALL RIVER FORMATION



__Skull Creek shale__: Lower silty shale unit is gray to black silty shale interbedded with ferruginous siltstone. Upper non-silty shale unit is dark-gray to black. 250 feet max.

__Upper sandstone__: Inter-tonguing lenses of very fine grained, micaceous sandstone; locally carbonaceous, calcareous, and quartzitic. Ore occurs within 10 feet of base of unit, commonly above shale of underlying unit. 15 to 45 feet thick.

__Upper shale and siltstone__: Light-gray or brownish-gray siltstone with light- to dark-gray shale and carbonaceous shale. 3 to 28 feet thick.

__Middle sandstone__: Light-gray to light-brownish-gray very fine-grained sandstone; massive with fine laminae and cross-laminae. 18 to 20 feet thick.

__Lower shale and siltstone__: Thin beds of dark- to light-gray shale interbedded with siltstone; carbonaceous in lower part, micaceous near the top. 20 to 40 feet thick.

__Lower sandstone and siltstone__: Lower part dark-gray carbonaceous siltstone, locally shaly. Upper part thin bedded very fine-grained silty, clayey, micaceous, and carbonaceous sandstone. 30 to 50 feet thick.

__Lower part__: Clayey sandstone and sandy claystone exposed at top. Drill logs show covered part to be sandy claystone, interbedded poorly sorted sandstone with conglomerate at base. 150 to 200 feet thick.

FIGURE 55.--GENERALIZED SECTION IN THE HULETT CREEK MINING AREA, CROOK COUNTY, WYOMING, SHOWING STRATIGRAPHIC LOCATION OF MINED ORE.

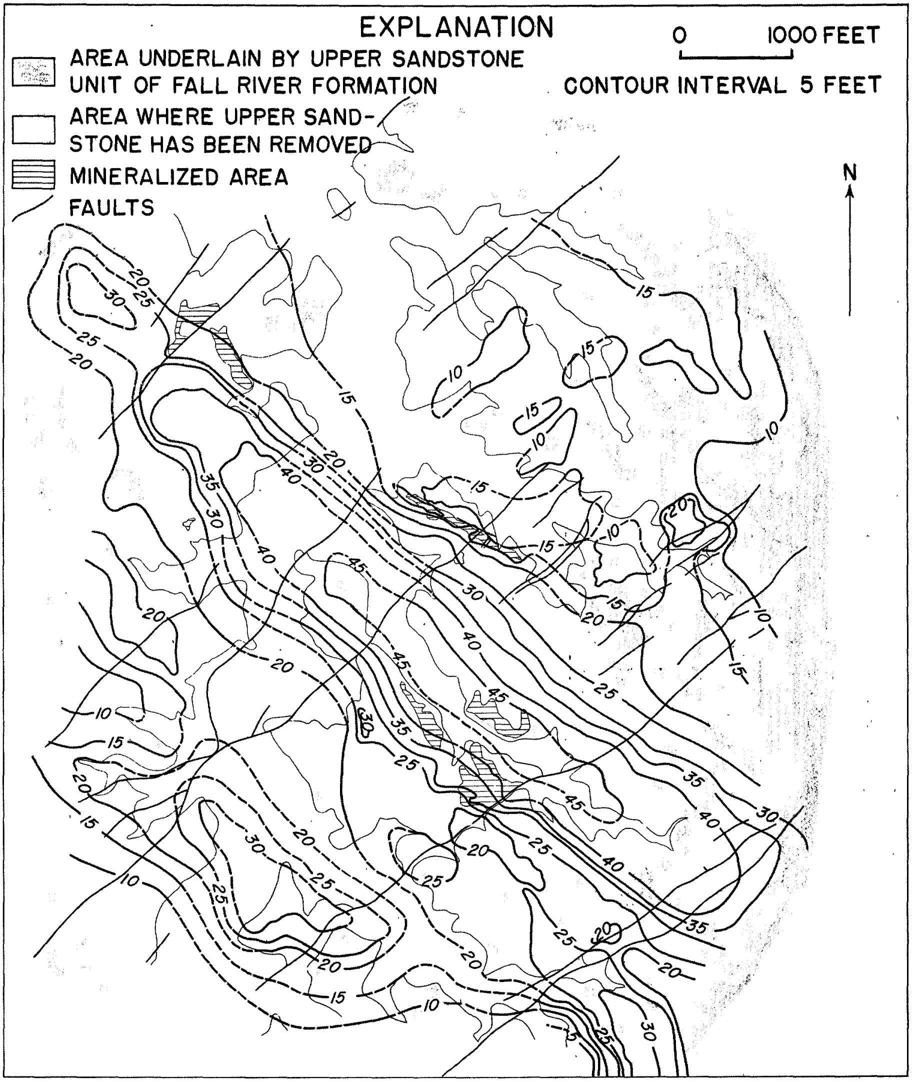


FIGURE 56.—MAP SHOWING THICKNESS OF UPPER SANDSTONE UNIT OF THE FALL RIVER FORMATION

A series of mechanical and heavy mineral analyses is being made of the units in the Fall River sandstone (fig. 55). Results to date indicate that the sandstones are for the most part fine to very fine-grained, and are very similar in their mineral content. The middle sandstone (fig. 55) probably is uniform in lithology along its strike but shows a decrease in grain size from top to bottom (table 10). The unit is a very fine-grained sandstone at the top, becomes a silty very fine-grained sandstone in the middle, and is a slightly sandy siltstone at the base. This lithology is similar to that of a sandstone in a similar stratigraphic position in the Carlile quadrangle, about 25 miles to the south (G. A. Izett, 1957, oral communication).

The upper unit, which contains the ore deposits, shows a marked variation in grain size along the strike and a lesser variation vertically within the lens. Beyond the limits of the sandstone lens, this unit is a sandy siltstone (table 11). Within the lens, the unit is a very fine-grained sandstone that, in general, shows an increase in grain size towards the bottom (table 11). This is significant because the ore deposits occur near the bottom and at the margins of the lens where the grains are coarsest.

## Strawberry Hill quadrangle, Wyoming

by

R. E. Davis

Mapping of the Strawberry Hill 7½-minute quadrangle, Crook County, Wyo., was started in the 1956 field season. The Busfield and Vickers mines were mapped in detail, and a brief account of the geology and occurrence of uranium deposits in the mine area was presented in TEI-640, p. 92-95.

Table 10.--Mechanical analyses of channel sandstone samples from the middle sandstone unit of the Fall River sandstone, Hulett Creek area, Wyo.

| | Top of unit | | Middle | | Bottom of unit | |
|---|---|---|---|---|---|---|
| Sample Number | $117a_1$ | $117a_2$ | $117b_1$ | $117b_2$ | $117c_1$ | $117c_2$ |
| | percent | percent | percent | percent | percent | percent |
| Coarser than 65 mesh (medium grained) | 0 | 0 | 0 (trace) | 0 | 0 (trace) | 0 |
| 65 to 100 mesh (about fine-grained size) | .5 | .3 | 2 | 0 | 0 (trace) | 0 |
| 100 to 270 mesh (about very fine-grained size) | 76.5 | 75.7 | 63 | 66 | 29 | 20 |
| Smaller than 270 mesh (silt and clay size) | 23 | 24 | 35 | 34 | 71 | 80 |

Table 11.—Mechanical analyses of sandstone samples from the upper sandstone unit of the Fall River formation

| | Away from lens | In lens away from ore | | | | Ore | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Top of lens | | Bottom | | Mostly near bottom of lens | | | | | |
| Sample Number | 118 | 119a | 119b | 119c | 119d | 80 | 81 | 89 | 90 | 97 | 98 |
| | % | % | % | % | % | % | % | % | % | % | % |
| Coarser than 65 mesh (medium-grained) | .1 | 0 | .3 | 16 | 14 | 2.5 | 5.5 | 18.5 | 7.5 | 35 | 20 |
| 65 to 100 mesh (about fine-grained size) | 2.1 | 4 | 3.2 | 44 | 26 | 54.5 | 59.5 | 33.5 | 11.5 | 32 | 45 |
| 100 to 270 mesh (about very-fine grained size) | 47.3 | 65 | 70.5 | 26 | 42 | 28 | 23 | 34 | 59 | 19 | 22 |
| Smaller than 270 mesh (silt and clay size) | 50.5 | 31 | 26 | 14 | 18 | 15 | 12 | 14 | 22 | 14 | 13 |
| | | Approximate averages of two determinations on each sample | | | | One determination on each sample | | | | | |

Work during the report period has consisted largely of laboratory work and the compilation of reports and maps of the mine area and of the individual mines. Preliminary results of chemical analyses for certain elements run on a number of samples from the mines strongly suggest that the arsenic content increases downward from the oxidized zone into the unoxidized zone and is coincident with an increase in uranium content, although the As:U ratios are quite inconsistent. Analyses of a limited number of samples show that ore from the Vickers mine contains more than twice as much arsenic as ore samples from the Busfield mine taken at approximately the same distance below the zone of oxidation. The analyses also show that the content of selenium apparently bears little relationship to that of uranium. Results of other chemical and spectrographic analyses are pending.

## Central region exclusive of the Black Hills

### Southern Powder River Basin, Wyoming

by
W. N. Sharp and A. B. Gibbons

Field work in the southern Powder River Basin, Wyoming, started in July 1955 and was completed in October 1956. Detailed geologic mapping and study of the deposits were carried on in areas in which exploration and mining were being done, and geologic reconnaissance mapping of the southern part of the Powder Basin was done to integrate the detailed geologic data into a basin-wide picture. As a result of this program, a relationship between the color of the host rocks and the uranium deposits, which can be used as a good basic guide for prospecting and exploration, has been established.

The uranium deposits in the Wasatch formation in the southern Powder River Basin are limited to a central part of the area of Wasatch outcrop, where the sandstone lenses in the Wasatch formation are reddish and pink to partly reddish in color. The largest deposits are near the boundary of this "red sandstone zone" (see fig. 57). The distinctive red coloration of these sandstone lenses represents a post-depositional change within the lenses, and the relation of uranium concentration to this change is thought to be the result of a single sequence of physical-chemical events. Recognition of the relationship between red sandstone and uranium and the demarcation of the "red sandstone zone" effectively direct prospecting activities toward an area less than one-tenth the size of the Wasatch outcrop.

## Geologic setting

The Powder River Basin in northeastern Wyoming is a physiographic as well as a structural basin which is bounded on the west and south by the Bighorn Mountains and the Laramie Range, and on the east by the Black Hills and the Hartville uplift. The basin is underlain predominantly by rocks of the Wasatch formation of Eocene age. The Wasatch is underlain by the Fort Union formation of Paleocene age, which crops out around the edges of the basin. Younger rocks of the White River group of Oligocene age cap Pumpkin Buttes in the central part of the basin and overlie upturned Fort Union beds along the southern edge of the basin.

Fort Union formation.--The Fort Union formation in the southern part of the basin is a sequence about 3,000 to 4,000 feet thick of thin-bedded clastic sedimentary rocks. The formation is divided into two distinct

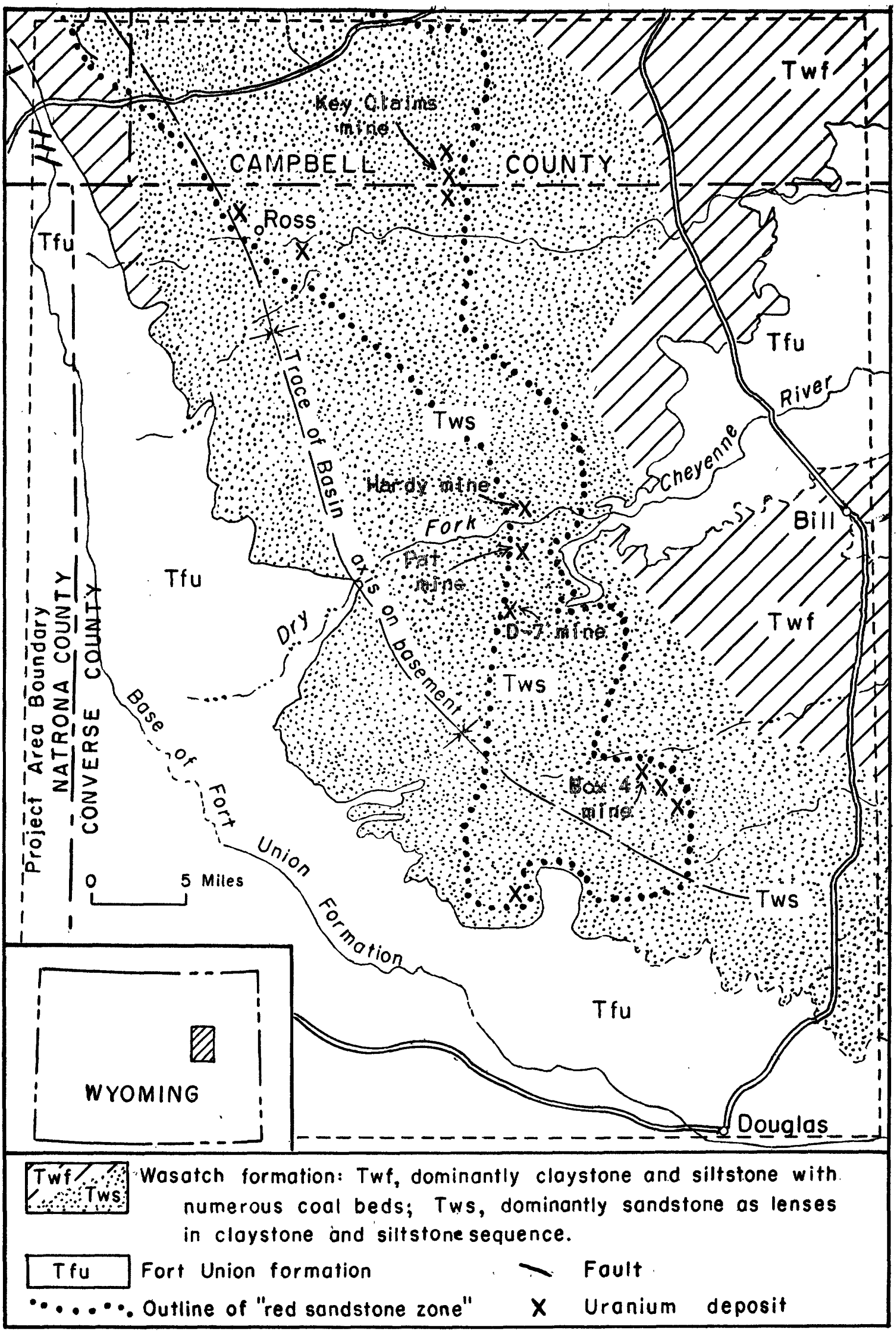


FIGURE 57.-LITHOFACIES AND COLOR IN SANDSTONE AS RELATED TO

lithologic units. The lower unit is characterized by siltstone, claystone, carbonaceous shale, and coal beds interbedded with conspicuous varicolored sandstone lenses. The upper unit is characterized by white-weathering thin-bedded claystone, siltstone and silty sandstone interbedded with coal and numerous layers of brown "ironstone." Sandstone is not a conspicuous component of the upper unit.

Wasatch formation.--The Wasatch formation is a sequence 500 to 1,000 feet thick in the southern part of the basin, and is composed of flat-lying claystone and siltstone beds interbedded with irregularly spaced sandstone lenses. Coal and carbonaceous shale beds are also numerous.

The amount of sandstone in the formation is much greater in the center of the basin than at the margins, and conversely the amount of carbonaceous material is much greater in the marginal zones. The change in lithology from the center to the margin makes it possible to divide the formation into two facies. Around the margin the formation is characterized by gray claystone and siltstone and numerous beds of coal and carbonaceous shale. Sandstone lenses are few and generally inconspicuous. In the central part of the basin the Wasatch is characterized by much sandstone in the form of broad lenses and narrow channel fillings; in this facies sandstone constitutes as much as one-third of the formation.

Throughout the basin the sandstone is generally slightly calcareous, and locally highly calcareous and tightly cemented concretionary masses are common. The sandstone is typically medium- to coarse-grained, but in places in the southern part of the area near the Laramie Range it is conglomeratic. Also in the southern part of the basin, some sandstone lenses contain abundant interstitial white montmorillonite.

The color of the sandstone is generally drab, yellowish-gray to yellowish brown, but some sandstone units in a zone along the axis of the basin are reddish, pink, or grayish-red. The red tint affects large continuous masses of the rock and does not occur as isolated splotches of color. The contact between the red colored and the drab colored sandstone is generally very sharp, but is irregular in plan and cross section. The contacts are generally convex into the drab sandstone, and lobes and long arms of red coloring extending into drab sandstone are common.

Neither position nor extent of red color within individual sandstone lenses is controlled by any apparent feature of the rock itself. Color contacts cut across grain-size changes and crossbedding; red color may be in the upper part of some lenses and in the lower part of others, or the position may range from the upper part to the lower part of a lens.

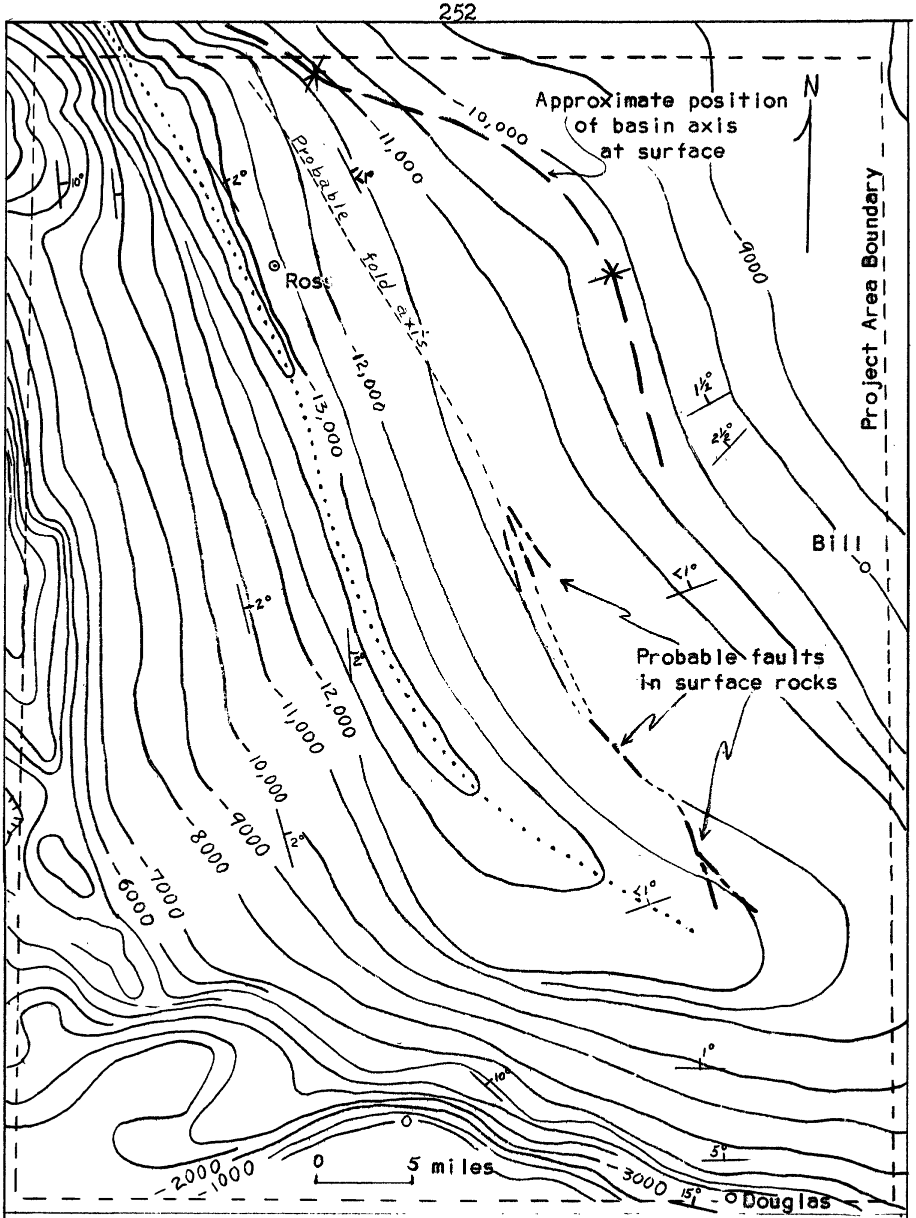
The iron contents of the red and drab sandstones are similar, and commonly range from 1 to 3 percent. The red sandstone contains hematite, whereas the drab sandstone contains mostly limonite.

The "red sandstone zone" described above is about 70 miles long and 5 to 20 miles wide. The long axis of the "zone" closely parallels the axis of the Powder River Basin, and extends from near Douglas, at the southern edge of the basin, to several miles north of Pumpkin Buttes in the central part of the basin (see fig. 57). The boundary of the "red sandstone zone" is delimited more easily in some areas than in others. Color changes in the sandstone are generally more distinct in the central part of the basin around Pumpkin Buttes than farther south in Converse County. Further, gently rolling topography in Converse County provides few and poor exposures, and a fairly widespread bleaching of both drab and red sandstone to white or grayish-white makes delineation of the boundary less exact. Bleaching of the sandstone is accompanied by formation of abundant white clay, which apparently is a product of the chemical breakdown of volcanic ash deposited with the sand grains. This alteration of ash and bleaching of the sandstone, however, has spared enough of the original color, in small patches and small areas, to permit the color contact to be drawn.

## Structural features

Structural features in the Southern Powder River Basin are inconspicuous. The region appears to have been relatively stable during and after Eocene time, although the presence of a significant structural element is suggested by several linear surface features which have been mapped as probable faults. Differences in the altitudes of rock units throughout the southern basin also suggest the existence of this structural element. Probable faults have been mapped at three widely separated places (see fig. 58). All of these "faults" trend northwest, and the "faulted" areas lie across a common northwest line which parallels the structure contours drawn on the Precambrian floor of the basin. It is possible that these "faults" are merely fissures or fractures formed as a result of incipient folding parallel to the basin axis. The inferred structure must be more prominent at depth than the structure contour map (fig. 58) shows.

Northwestward extension of the line joining the "faults" traverses an area east of Ross in which a slight anticlinal fold or terrace may exist in the gently-east-dipping strata. Though surface expression of folding is slight, it is believed that the structure is more prominent at depth than



Contoured on top of Precambrian rocks
Interval 1,000 feet (500 ft. interval used locally)
Structure contours after Osterwald, U.S.G.S.

FIGURE 58.

SURFACE STRUCTURAL FEATURES SUPERIMPOSED ON STRUCTURE CONTOUR MAP OF SOUTHERN POWDER RIVER BASIN at the surface. This idea is bolstered by data obtained from oil exploration in the area.

A second structural feature is indicated in the area southwest of Pumpkin Buttes and north of the project area. The line that marks the approximate position of the basin axis at the surface is subparallel to and near the trace of the basement trough (see fig. 58). This displacement results in a curving of the axis around the locality of inferred positive structure. The surface structural features of the southern Powder River Basin, considered together, suggest that rocks have been folded along a line parallel to the basin axis. This folding is in part post-Tertiary in age.

### Ore deposits

The uranium deposits of the Wasatch formation are in sandstone units in the "red sandstone zone." They are mostly in units that are only partly red because most of the uranium in the deposits is concentrated in the drab sandstone at and close to the contact with the red color, and appear to form larger concentrations where the color contact is highly irregular. Without exception, the major uranium deposits that have been mined in the Powder River Basin are not only along a color change within a sandstone unit, but are also very near the boundary of the red sandstone zone (see fig. 57). Certain of the larger mines in the southern Powder River Basin are located at the "red sandstone zone" boundary in the area of clay alteration. Several hundred smaller occurrences are known throughout the zone of red sandstone.

The deposits consist largely of yellow uranium minerals: tyuyamunite, carnotite, uranophane, and locally liebigite. The minerals are disseminated in the sandstone. At places the deposits contain small masses of uraninite and pyrite-cemented sandstone; these are commonly rimmed by thick halos of yellow oxidized minerals. The pyrite and uraninite appear to have been localized by coalified wood fragments. Black nodules with a sub-metallic luster, and irregular masses of manganese oxides occur near and at the surface of many deposits. Some of these masses also contain yellow uranium minerals, and a few small deposits consist almost entirely of such uraniferous magnanese-oxide concretions. Joints and small iron-oxide lined fissures in sandstones of the deposits are commonly coated or speckled with light-yellow, yellow-orange and green secondary minerals; these minerals are uranophane, liebigite, sparse autunite (only in clay glll inclusions) and several unidentified minerals.

The geologic features of the deposits are strikingly similar throughout the Powder River Basin. The mineralogy and paragenetic sequence are the same from mine to mine, and a close relationship of uranium minerals to red color contacts exists at almost every deposit. Nevertheless, mineralogic features peculiar to local places in a deposit are found.

Three of the mines (shown on figure 57) have been selected as showing the variation in the uranium deposits of the southern Powder River Basin, although similarities far outweigh dissimilarities. The southernmost mine, the Box no. 4 mine, in sec. 1, T. 35 N., R. 73 W., in Converse County, typifies deposits which have not been affected by clay alteration and the coincident bleaching of the sandstone. At this mine the medium-coarse to conglomeratic sandstone is relatively free from interstitial clay. The uranium minerals follow a highly lobate contact between red to pink sandstone and grayish-brown sandstone. Uranium minerals are visible in the drab sandstone within a few inches to a few feet of the color contact, whereas the red sandstone itself is generally barren. Particularly rich ore was found in a drab ferruginous basal zone of the sandstone at places where the color contact approaches the zone at a low angle.

The Pat mine in sec. 3, T. 37 N., R. 73 W., Converse County, is typical of the mines within the zone of clay alteration. The principal ore-bearing unit is the lower of two sandstones exposed in the mine workings. This unit is a calcareous grit at least 20 feet thick, that contains abundant interstitial clay. Most of the ore has come from an irregular zone about 10 feet thick near the middle of the unit. Carnotite and tyuyamunite are disseminated unevenly throughout the ore zone. Apple-green liebigite fills shrinkage cracks in coalified wood and incipient fractures in localized calcareous sandstone. Masses of uraninite and pyrite up to 2 feet in greatest dimension also occur around coaly material. The ore is in yellowish-gray and tan sandstone and grit, but red color appears in the grayish-white, clay-rich, bleached, barren rock immediately adjacent. The change from drab to reddish sandstone follows an irregular line. The Pat mine is near the western limit of the "red sandstone zone" of the southern Powder River Basin.

The Key Claims mine is in sec. 20, T. 41 N., R. 73 W., Campbell County. The mine workings expose a crossbedded, variably coarse-grained sandstone in contact with an underlying clay bed. A color contact between drab and red sandstone similar to that at the Box no. 4 mine appears in the trench walls, and along the contact there are local concentrations of yellow uranium minerals. Ore produced from the Key Claims mine, however, has come entirely from a hard, dark-gray, calcareous layer at the base of the sandstone. This layer, 8 to 12 inches thick, consists of coarse- to fine-grained sand cemented predominantly by a dark fibrous mineral which has the X-ray pattern of chrysotile. Other cementing minerals of the basal layer include calcite, minor pyrite, uraninite, and hydrous iron oxides. Radially growing chrysotile (?) coats the sand grains and completely fills much of the interstitial space. Calcite fills the core of the larger spaces. Pyrite and uraninite occur together in the interstices as small blebs coated with chrysotile (?). At some places uraninite coats sand grains, and uraninite with pyrite fills interstices. In such local spots rich in uraninite, chrysotile (?) coats the outer surface of the uraninite and pyrite. Further study will be made of this unusual occurrence of chrysotile (?) in Tertiary sedimentary rocks.

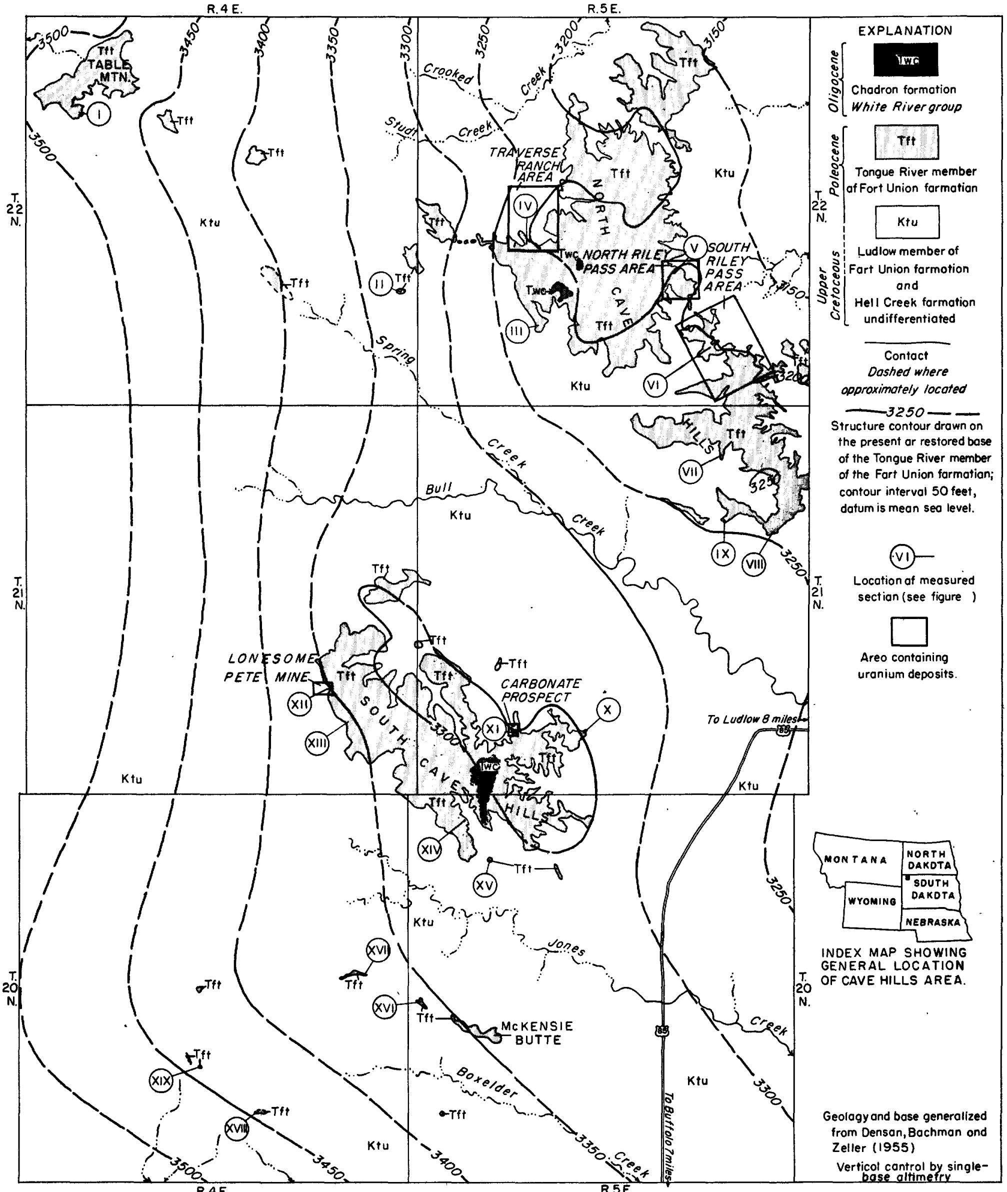
The uranium deposits in the Wasatch formation in the southern Powder River Basin and the red color of the "red sandstone zone" are thought to be related. No addition of material to the Basin is necessary to explain either the development of the "red sandstone zone" or the concentration of the deposits. All the necessary components were available in disseminated form within the sandstone units, and the deposits were formed by some process of accretion of these components around favorable centers. The redistribution and concentration of uranium, vanadium, and manganese seem to have been controlled within the sandstone lenses by the same factors that controlled the solution and concentration of calcite within the sandstone. One of the controlling factors is considered to have been the partial pressure of $CO_2$ in ore-bearing solutions as a determinant of the $HCO_3$ concentration. The concentration of these components together provided a means for the solution and migration of the economically important metals as complex ions.

## Cave Hills, Harding County, South Dakota
by
G. N. Pipiringos

The general geology of the Cave Hills area was investigated by reconnaissance methods in 1950. In the summer of 1954 uranium deposits of ore grade were discovered in the E coal bed in the North Cave Hills, and in carbonaceous siltstone and phosphatic claystone in the South Cave Hills. Detailed studies in the area, consisting of sampling and mapping of uraniferous rocks throughout the Cave Hills, with particular emphasis on the deposits in the North and South Riley Pass areas of the North Cave hills, the Carbonate prospect and the Lonesome Pete mine in the South Cave Hills, and the Traverse Ranch area in the North Cave Hills (see fig. 59), were started in 1955, and a report on the first year's work was included in TEI-620, p. 243-254. The program will be completed in the summer of 1957.

### Stratigraphy

Rocks exposed in the Cave Hills include the Hell Creek formation of Upper Cretaceous age, the Fort Union formation of Paleocene age, and the Chadron formation of Oligocene age. In addition, a small remnant of gravel seen only on McKensie Butte (fig. 59) is considered to be of Pliocene or Pleistocene age; it consists mostly of reworked fragments of rocks common in the Arikaree formation of Miocene age, which may at one time have covered the entire region.



G.N.Pipiringos, W.A.Chisholm and R.C.Kepferle 1955–56

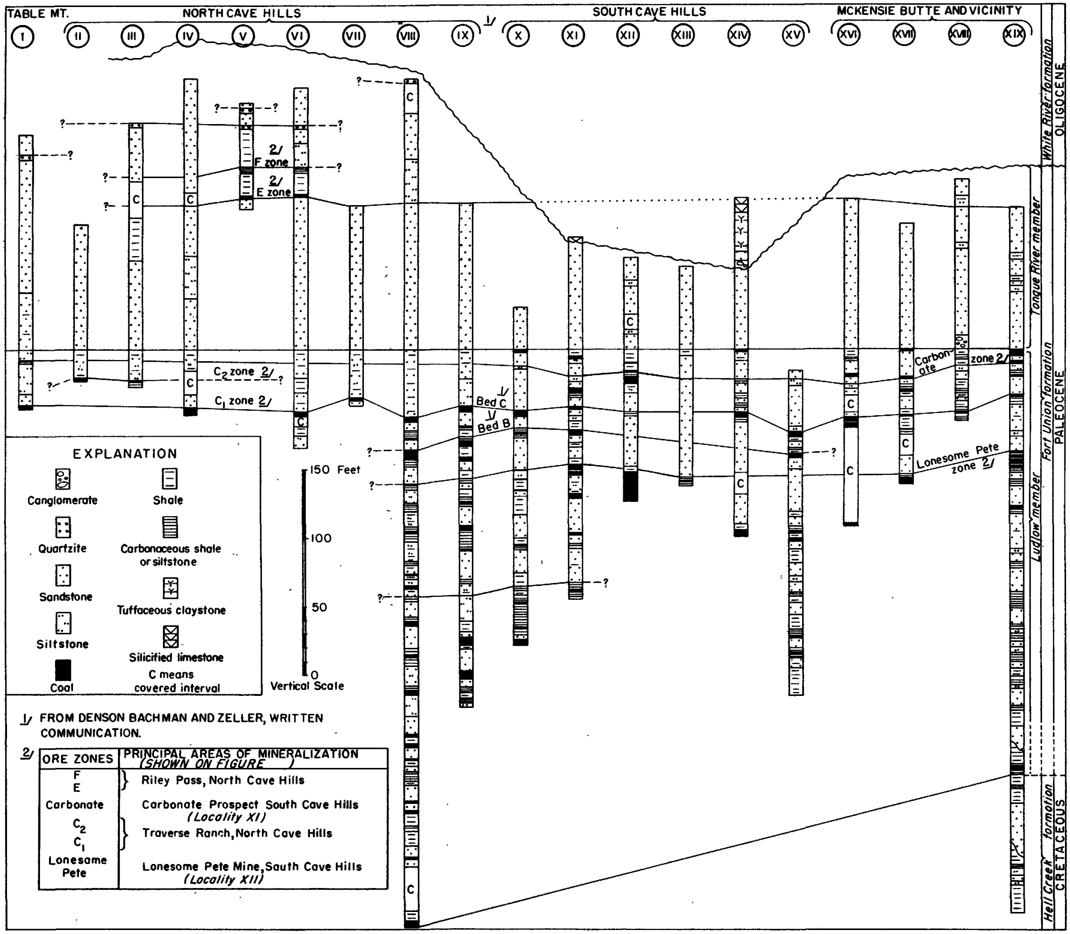
FIG. 59–GEOLOGIC MAP OF CAVE HILLS AREA, HARDING COUNTY, SOUTH DAKOTA.

0 1 2 3 4 5 Miles

The Hell Creek formation consists principally of gray to nearly black claystone and clay shale with lesser amounts of gray fine-grained sandstone, thin carbonaceous shale, and siltstone. The formation ranges from 360 to 460 feet in thickness and appears to have been deposited in a fluviatile or lacustrine environment not conducive to the formation of coal beds. It rests conformably on the Fox Hills sandstone of Upper Cretaceous age and grades into the overlying Ludlow member of the Fort Union formation. The Hell Creek is not differentiated from the Ludlow member of the Fort Union formation on the geologic map, but is shown separately on the chart (fig. 60).

The Fort Union formation in the Cave Hills area consists of two members: the Ludlow and the Tongue River. The Ludlow member consists of gray clay shale, greenish-gray siltstone, and gray fine-grained sandstone that weathers to a distinctive yellowish color. Locally some of the sandstone beds are well indurated and form slabby ledges. The thickness of the member ranges from 310 to 420 feet and averages about 365 feet. The Ludlow member consists of fluviatile, lacustrine, and paludal sediments, a possible exception being the uranium-bearing phosphatic claystone beds at the Lonesome Pete mine. As it intertongues with the marine Cannonball member of the Fort Union approroximately 10 miles northeast of the mapped area (Winchester and others, 1916), these phosphatic rocks at the Lonesome ore zone may represent a wedge-edge of the Cannonball. Analcite occurs sporadically throughout the Ludlow member, but is abundant only in the upper 100 feet, and there locally.

The Ludlow member is conformable with and grades into the underlying Hell Creek formation. The contact with the overlying Tongue River member



1/ FROM DENSON BACHMAN AND ZELLER, WRITTEN COMMUNICATION.

2/

| ORE ZONES | PRINCIPAL AREAS OF MINERALIZATION (SHOWN ON FIGURE) |
|---|---|
| F<br>E | Riley Pass, North Cave Hills |
| Carbonate | Carbonate Prospect South Cave Hills (*Locality XI*) |
| $C_2$<br>$C_1$ | Traverse Ranch, North Cave Hills |
| Lonesome Pete | Lonesome Pete Mine, South Cave Hills (*Locality XII*) |

FIGURE 60-CHART SHOWING CORRELATION OF URANIUM ORE ZONES AND ASSOCIATED ROCKS IN THE CAVE-HILLS AREA, HARDING COUNTY, SOUTH DAKOTA.

of the Fort Union formation is marked by a sharp change in lithology from the soft slope-forming interbedded shale, siltstone, and sandstone of the Ludlow to the nearly homogeneous, generally cliff-forming, sandstone of the Tongue River member.

In the Cave Hills area the Tongue River consists predominantly of gray-white medium- to coarse-grained sandstone cemented principally by analcite and calcite. The sandstone weathers yellow-buff. The lower part of the member forms sheer cliffs as much as 110 feet high. Marine vertebrate fossils collected in 1955 from the cliff maker at three localities show that at least the basal 110 feet of the Tongue River member is of marine origin.

The original thickness of the Tongue River member cannot be determined in this area because of erosion. A maximum thickness of 260 feet was measured in the South Riley Pass area.

The member includes quartzite beds as much as 3 feet thick that are lenticular but persistent over large areas. The most prominent of these quartzite beds (see top of section VIII, fig. 60) caps several buttes east of the North Riley Pass area, among which are Kalisthet, Flint, and Teepee Buttes.

The Chadron formation consists of a basal conglomerate overlain by gray to greenish-white interbedded tuffaceous claystone and silicified limestone. Two small remnants of this formation occur in the North Cave Hills, and two in the South Cave Hills. One of the South Cave Hills remnants is very small, while the other remnant is large and thick. A maximum thickness of 50 feet was measured at the west central edge of the latter which is also the place where fossil vertebrates of Chadron age were collected.

Local relief of the Chadron-Fort Union unconformity at the remnants does not exceed 5 feet, but total relief in the area on this surface may have been as much as 170 feet. The Chadron in adjacent areas ranges in thickness from a wedge-edge to 160 feet and is overlain by the Brule formation of Oligocene age or by the Arikaree formation of Miocene age (J. R. Gill, personal communication).

## Structure

The structure of the area is shown in figure 59 by contours drawn on the base of the Tongue River member of the Fort Union formation. The rocks strike northwest to north and dip northeast to east at an average rate of about 25 feet per mile.

## Coal beds

All of the thick, relatively pure coal beds of this area are in the Ludlow member of the Fort Union formation. The coal is of lignite rank. A few thin impure coal and carbonaceous shale beds occur in a zone about 110 feet to 140 feet above the base of the Tongue River member of the Fort Union formation. The Tongue River coal beds in the Cave Hills area are too thin and too poor in quality for use as fuel except the E bed southeast of the Traverse Ranch area, which attains a thickness of about four feet and is of a quality comparable to the coal beds in the Ludlow member. A general idea of the number of coal beds and their thickness, areal distribution and correlation may be obtained from figure 60.

## Uranium deposits

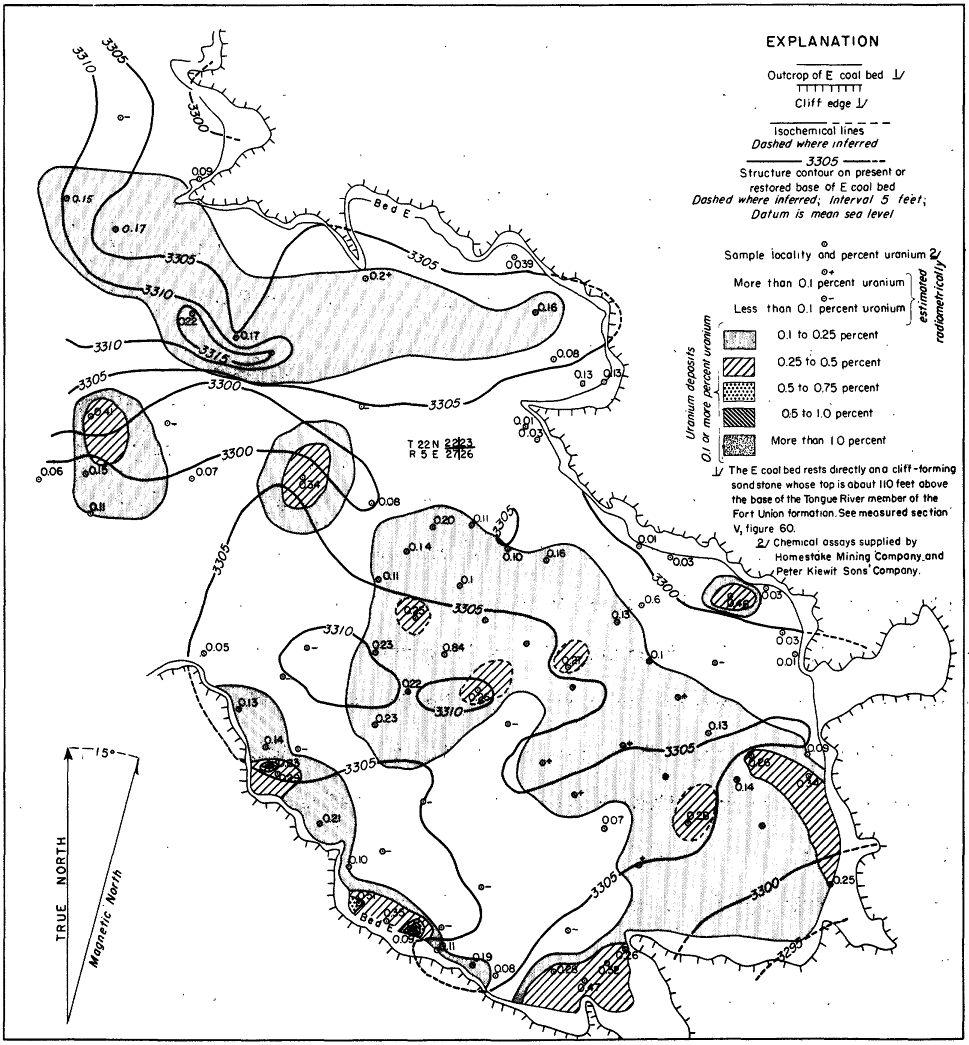
Uranium deposits occur in: (1) the C, E, and F coal beds of the Riley Pass and Traverse Ranch areas in the central and northwestern parts of the North Cave Hills; (2) carbonaceous clayey siltstone (locally a coal, designated the Carbonate no. 1 bed) at the Carbonate prospect in the South Cave Hills; and (3) phosphatic silty claystone at the Lonesome Pete mine in the South Cave Hills. The Riley Pass deposits have the largest and the Carbonate prospect deposits the smallest areal extent. The principal deposits of uranium in coal are in the E bed of the Riley Pass areas. Mineralization of the C and F coal beds is spotty.

The uranium occurrences are distributed through a stratigraphic interval of about 240 feet extending from the Lonesome Pete zone about 100 feet below the base of the Tongue River member to the F zone about 140 feet above the base of the Tongue River member.

Uranium in coal.--The most important deposits of ore-grade uranium deposits in coal in the North Cave Hills are in the North and South Riley Pass areas (figs. 61 and 62). Though the Traverse Ranch area was not studied in detail, grab sampling of the C coal bed in that locality shows that it contains sporadic occurrences of ore-grade material. The E bed just beyond the southeast corner of the Traverse Ranch area likewise contains ore-grade uranium occurrences. The Traverse Ranch area however, seems unlikely to become as important as either of the Riley Pass areas.

To date it appears that degrees of mineralization of coal were determined by: (1) permeability of the coal bed itself and of the underlying and overlying rocks; and (2) regional and local structure of the associated rocks.

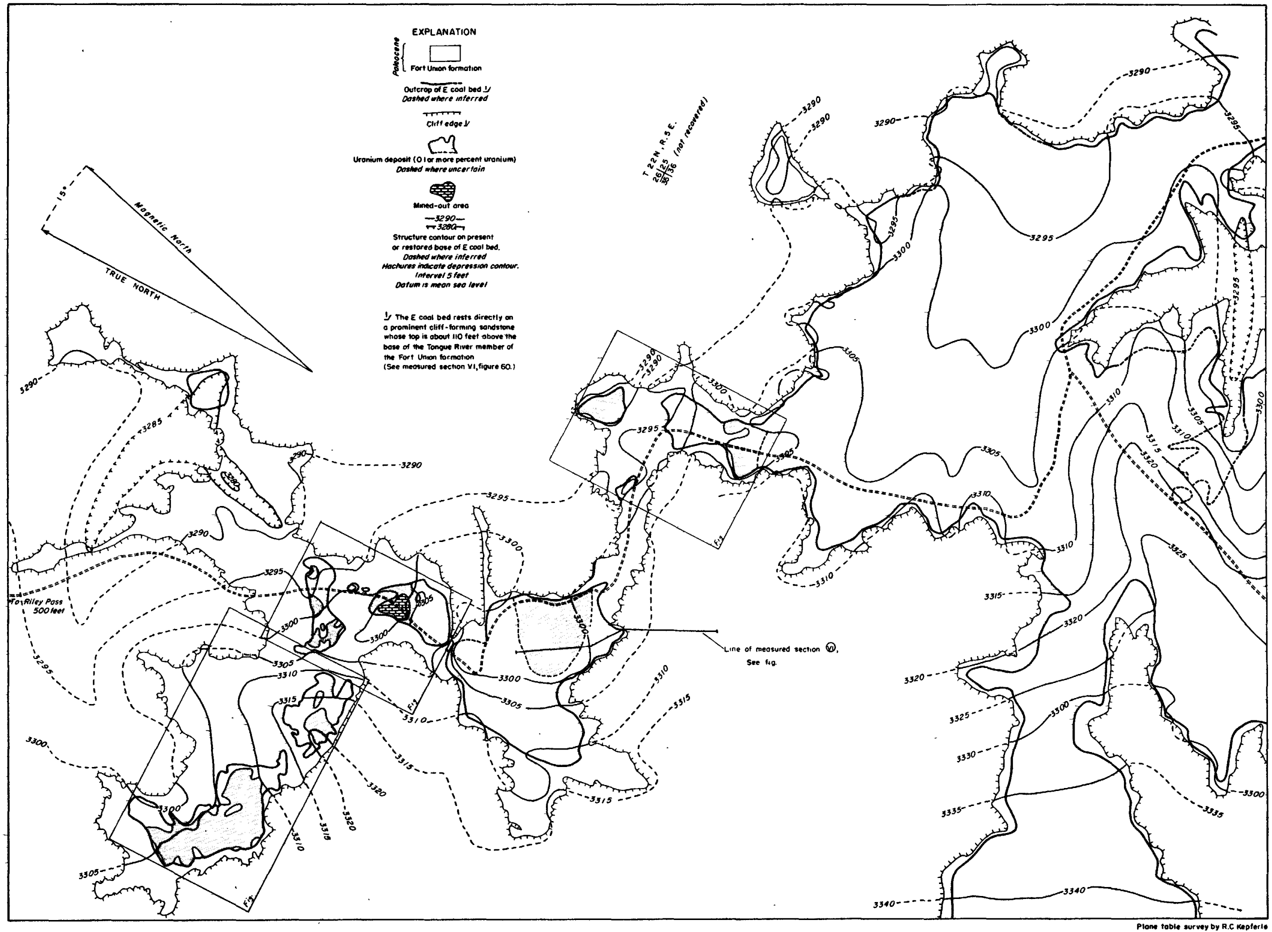
Detailed mapping suggests that locally water moving through sandstone overburden met impermeable shale and was forced to pass through the coal bed itself, mineralizing it to a greater extent than where the E bed is overlain by sandstone.



Plane table survey by R.C. Kepferle and W.A. Chisholm, 1955.

FIGURE 61.—STRUCTURE MAP SHOWING VARIATION IN GRADE OF URANIUM DEPOSITS IN THE E COAL BED, NORTH RILEY PASS AREA, HARDING COUNTY, SOUTH DAKOTA.

0 100 200 300 600 900 Feet



Plane table survey by R.C Kepferle and W.A Chisholm, 1955

FIGURE 62—STRUCTURE MAP SHOWING URANIUM DEPOSITS IN THE E COAL BED, SOUTH RILEY PASS AREA, HARDING COUNTY, SOUTH DAKOTA.

0 100 200 300 600 900 Feet

Most of the coal beds of the Ludlow member generally contain less than 0.005 percent uranium, affording further evidence that the Tongue River sandstone was the principal aquifer for mineralizing solutions in this area. The only coal beds in the Ludlow member that show anomalously high uranium concentrations are those stratigraphically closest to the base of the Tongue River. Examples of this are mineralization in the Carbonate coal zone at localities XI and XII (fig. 60) and in the C coal zone of the Traverse Ranch area. The stratigraphically lowest occurrence of relatively high uranium concentration in coal is represented by the thick coal bed a few feet below the phosphatic ore zone of the Lonesome Pete area (fig. 63). There the topmost few feet of the coal bed contains from 0.012 to .030 percent uranium. This occurrence coincides with a local, nearly homogeneous sandstone facies of the Ludlow which resembles the sandstone of the Tongue River and even makes cliffs similar to those of the Tongue River.

In general the areas containing uranium deposits are associated with structural lows rather than with highs. This general relationship appears to be true even in detail. The detailed structure maps in figures 61 and 62 show this relation of mineralized areas to structure.

Uranium in carbonaceous siltstone.--At the Carbonate prospect in the northcentral part of the Cave Hills (figs. 59, 64) uranium occurs in a carbonaceous siltstone in the Ludlow member of the Fort Union formation that grades locally into coal. This siltstone bed has been informally designated the Carbonate no. 1 bed to distinguish it from the previously known Carbonate no. 2 coal bed, which is 8 to 21 feet above the Carbonate no. 1 bed throughout most of the area and is directly overlain by the Tongue River member of the Fort Union formation.

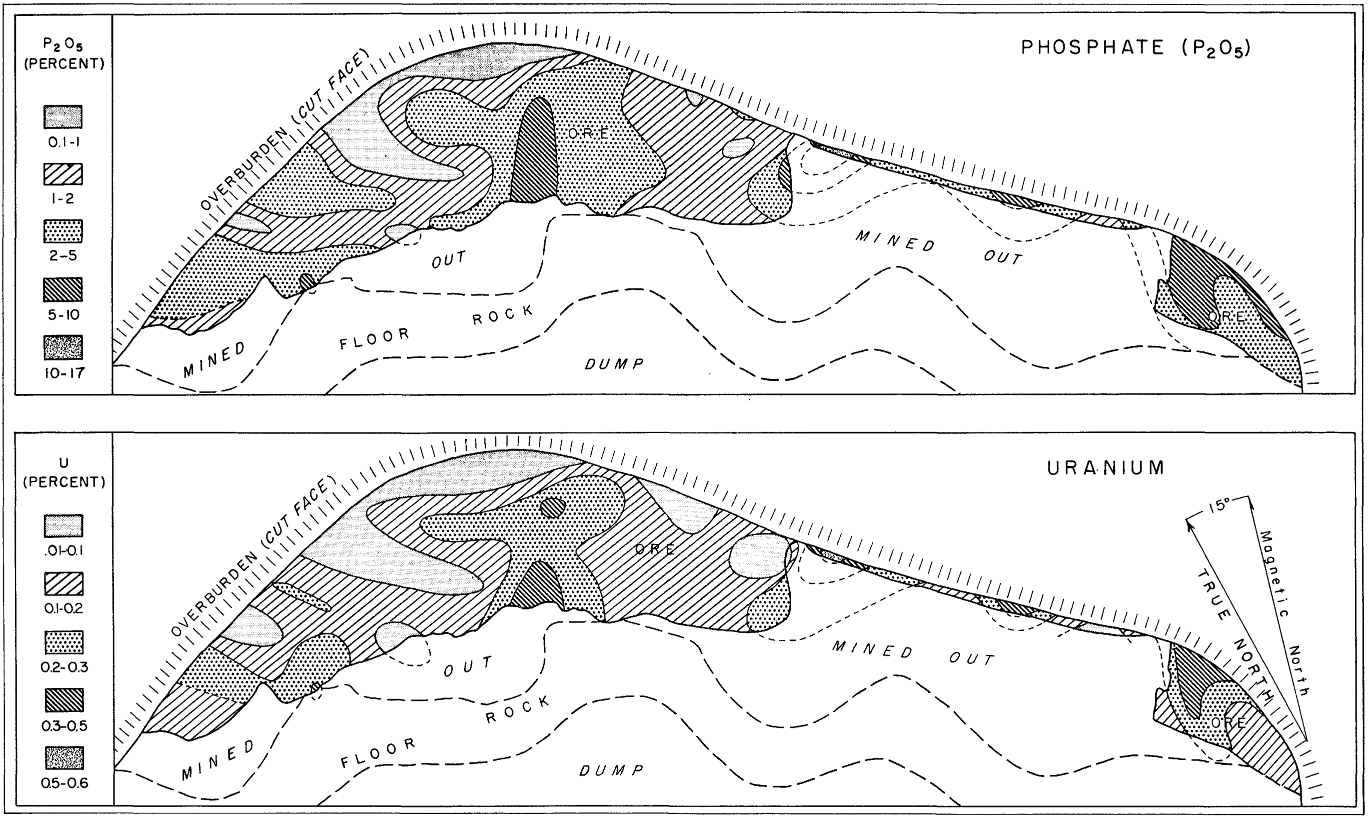
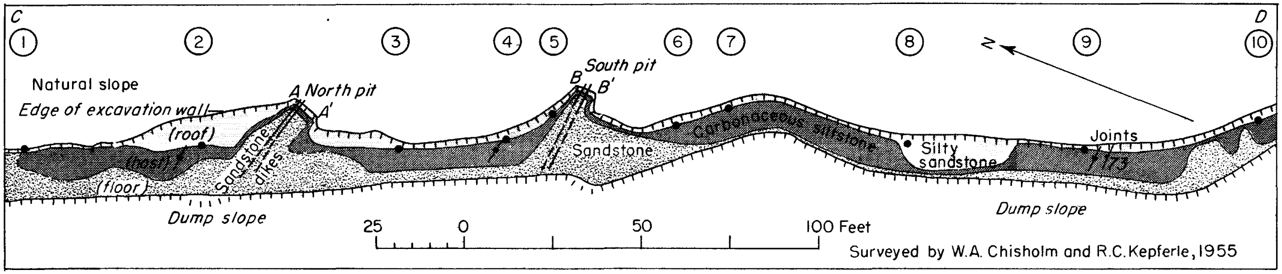
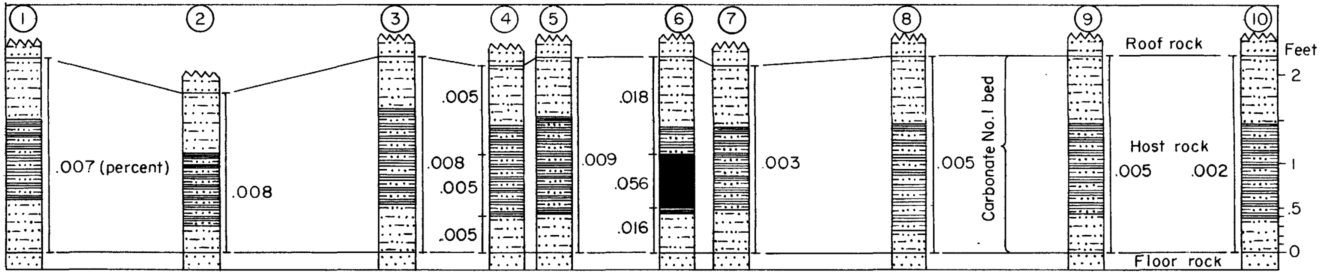


FIGURE 63.–MAPS SHOWING DISTRIBUTION OF URANIUM AND PHOSPHATE AT THE LONESOME PETE MINE.



Surveyed by W.A. Chisholm and R.C. Kepferle, 1955

PLAN VIEW OF EXCAVATION ALONG OUTCROP OF CARBONACEOUS HOST ROCK AT THE CARBONATE PROSPECT.



COLUMNAR SECTIONS SHOWING URANIUM CONTENT OF CHANNEL SAMPLES AT LOCALITIES SHOWN ON PLAN VIEW.
FIGURE 64.

At the Carbonate prospect, ore-grade material occurs in two prospect pits where the ore is associated with generally vertical sandstone dikes (fig. 65). That the dikes were the determining factors in concentration of uranium in this area is indicated by the fact that channel samples of the Carbonate no. 1 bed, collected on either side of the pits exposing the dikes, show relatively low concentrations of uranium (fig. 64). Isochemical contouring of arsenic, molybdenum, vanadium, and iron (the last is not shown on fig. 64) show similar relations to the dikes. It seems likely that the permeable sandstone dikes served as passageways for mineralizing ground waters.

Clastic dikes are rare in this area and it does not seem likely that uranium occurrences of this type will become important.

Uranium in phosphatic claystone.--Uranium occurs in phosphatic, very silty claystone in the Lonesome Pete area (fig. 59). The host rock has a $P_2O_5$ content ranging from 0.1 to 17 percent and a uranium content ranging from 0.01 to 0.6 percent. The similarity of distribution of the uranium and the phosphate is shown by isochemical contouring (fig. 63) of the data presented in figure 48, p. 250, of TEI-620.

Origin of the uranium deposits.--The uranium deposits in the Cave Hills area seem to have similar origins differing only in detail of geologic setting. The deposits probably were formed by absorption by the host rock of uranium borne by percolating ground water whose direction of flow was determined by differential permeability and structural attitude of the host rock and the rocks associated with it.

The distribution of uranium in the E coal bed of the Riley Pass area seems to have been determined primarily by differential permeability and

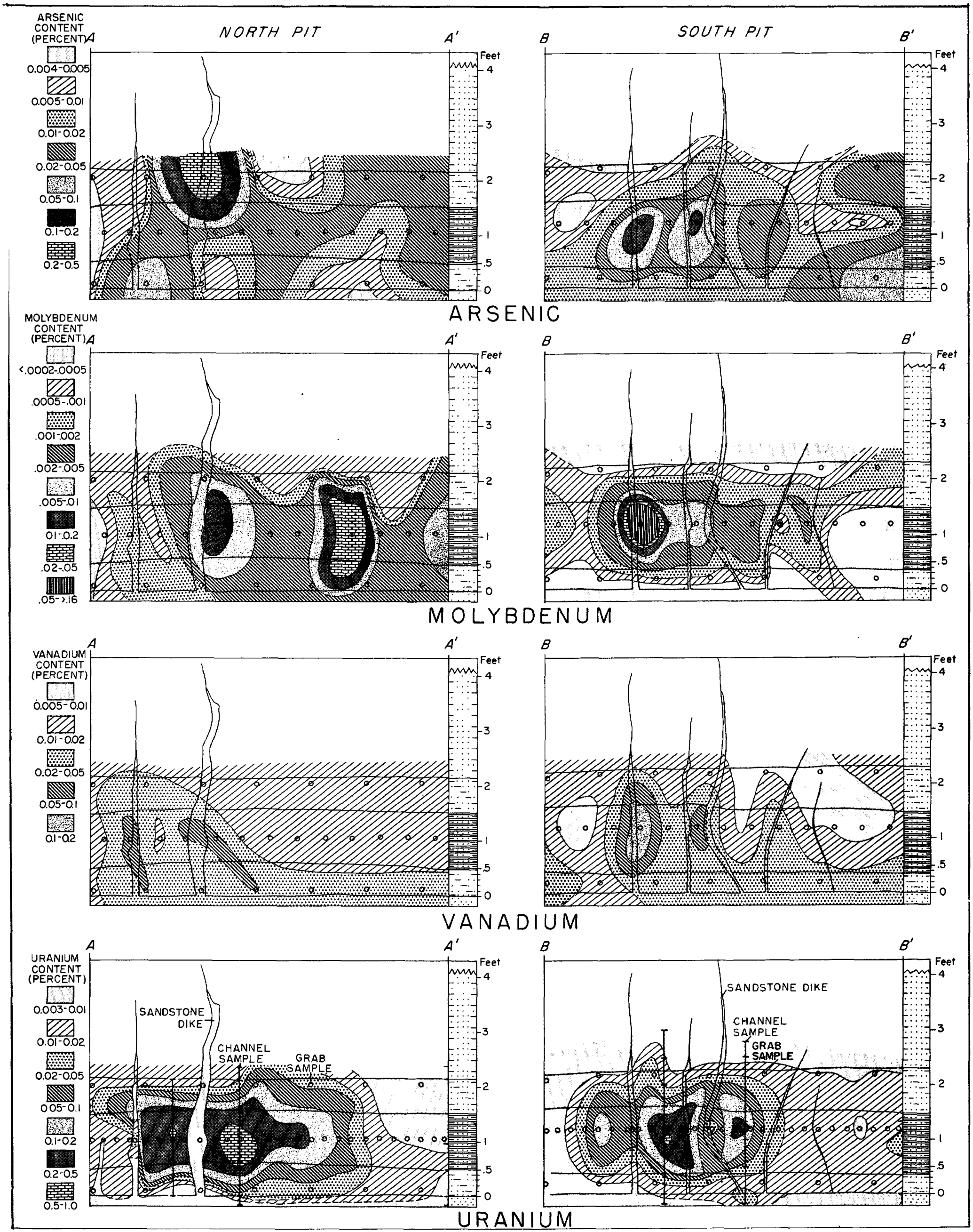


FIGURE 65. CROSS SECTIONS SHOWING RELATION BETWEEN SANDSTONE DIKES AND ELEMENTS ASSOCIATED WITH URANIUM AT THE CARBONATE PROSPECT.

structure of the coal bed and the overlying and underlying rocks. The distribution of uranium in the Carbonate prospect was determined primarily by sandstone dikes which offered access to mineralizing solutions not available to the potential host rock elsewhere. The relatively low stratigraphic occurrences of high grade uranium deposits at the Lonesome Pete mine probably owe their existence to the fact that there the overlying part of the Ludlow consists of a nearly homogeneous sandstone very similar to the massive sandstone of the Tongue River member.

That the area contains ore-grade uranium occurrences sporadically distributed through a stratigraphic interval of about 240 feet (from the Lonesome Pete zone in the Ludlow member to the F bed of the Tongue River member) in contrast to occurrences in surrounding areas where the richest concentrations are clustered close to the Oligocene-Paleocene contact, is probably due to the fact that the basal part of the Tongue River member, and locally the upper part of the Ludlow member in the southern part of the area, consists of massive medium- to coarse-grained sandstone that makes an excellent aquifer.

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# Gas Hills area, Wyoming
by
H. D. Zeller

Geological investigations in the Gas Hills area, Fremont and Natrona Counties, Wyoming, began in 1954 and will continue in 1957 and 1958. Results of field mapping to date were incorporated in the last semiannual report (TEI-640, p. 115-116). The two generalized geologic maps in this report (figs. 66 and 67) show the locations of the uranium mines and some of the many occurrences and prospects in the area, which is an increasingly important producer of uranium ores.

Radiochemical studies made by J. N. Rosholt of the U. S. Geological Survey on samples collected by the U. S. Atomic Energy Commission give a possible age of 11,000 years for the mineralization in the lignitic coal (TEI-640, p. 116) at the Lucky Mc mine. Unoxidized ore from the Vitro mine (fig. 66) showed a possible age of 170,000 years (Pleistocene ?). This supports field evidence which indicates that at least some of the uranium deposits in the Gas Hills area are very young and are related to post-Miocene to Pleistocene regional tilting to the south which may have had the effect of stopping or reversing the ground water movement from a northward (basinward) direvtion. (TEI-640, p. 124). The introduction of uranium into the district appears to have been by alkaline ground waters rich in carbonate (Coleman, R. G., personal communication, 1957). Where these waters came in contact with favorable reducing environments, the uranium was precipitated. In the Gas Hills district the abundance of pyrite in sandstones and mudstones, the presence of some carbonaceous material, and the hydrogen sulfide associated with present natural gas seeps (Grutt, 1957) separately or in combination provided local

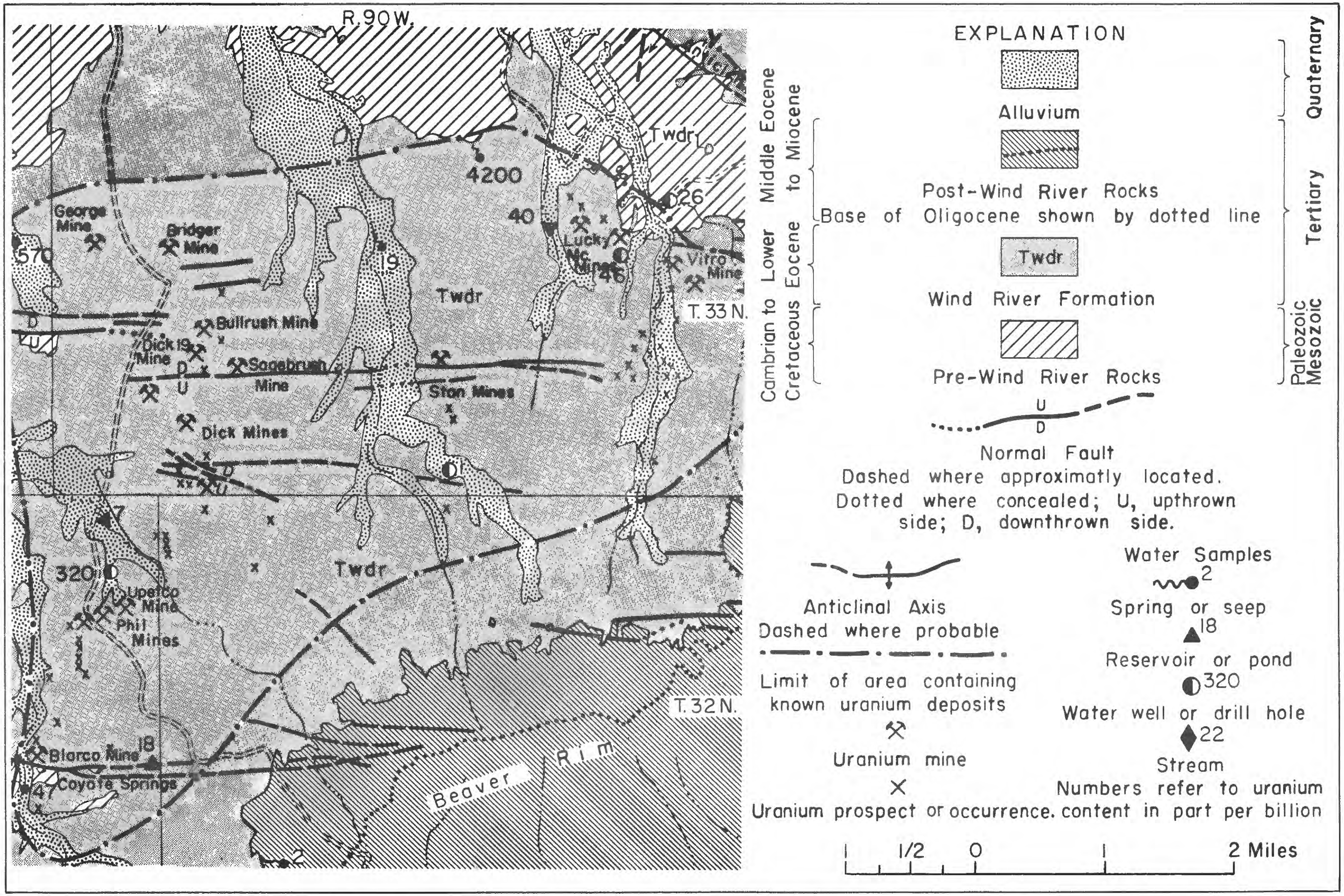
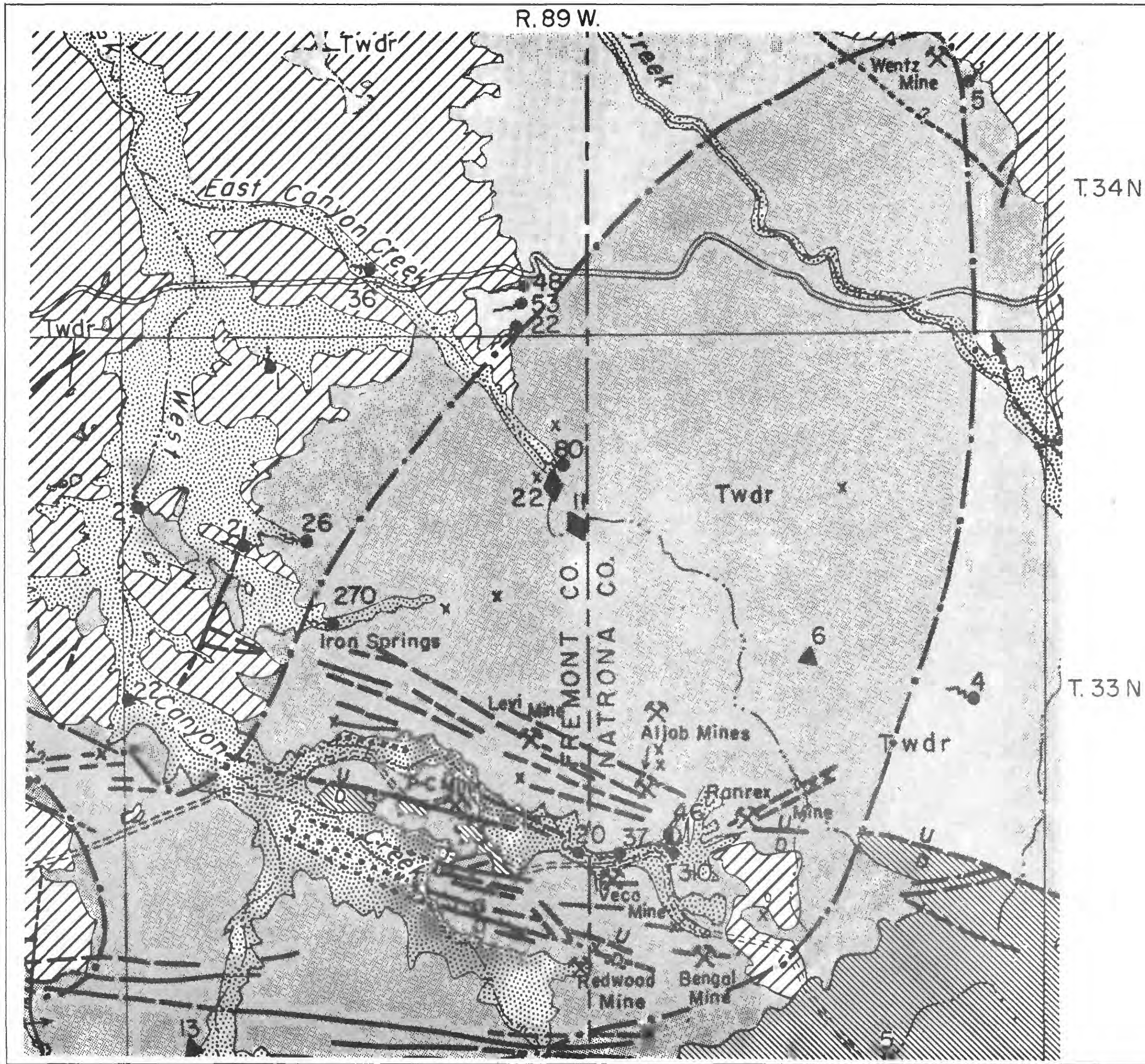


FIG. 66-GENERALIZED GEOLOGIC MAP, WESTERN GAS HILLS AREA



FOR EXPLANATION
SEE FIG. 66

FIG. 67–GENERALIZED GEOLOGIC MAP, EASTERN GAS HILLS AREA

favorable environments for precipitation.

A mile south of Iron Springs (fig. 67) there is evidence that faulting displaces a boulder- and cobble-covered pediment surface of probable Pleistocene age composed of round stones derived from Middle and Upper Eocene rocks. This apparent faulting of a pediment, coupled with only slight erosion of a fault scarp visible northwest of the Redwood mine (fig. 67) is evidence that movement along faults associated with the collapse of the Granite Mountain fault block to the south continued in Pleistocene time. Evidence in the Levi mine (fig. 67) indicates that movement along some of the faults is even more recent than ore deposition, because the contact of the oxidized and unoxidized mineralized sandstone is faulted. Similar evidence is apparent at the Vitro mine.

Post-Miocene to Pleistocene normal faulting related to the collapse of the Granite Mountain fault block is controlling in part the present ground water movement in the Gas Hills district. Impermeable fault gouge and barriers formed by coarse-grained sandstone in fault contact with mudstones control the position of ground water tables in the vicinity of the P-C and Ranrex mines (fig. 67).

The graben south of the P-C mine (TEI-640, p. 116) has a vertical displacement of over 300 feet as evidenced by remnants of Middle and Upper Eocene rocks exposed within the structure. Drilling information indicates that the depth of the water table in the graben is over 160 feet from the surface. The P-C mine, north of the graben, is located in a horst-like structure where the top of a perched water table about 60 feet below the gravel surface coincides with the top of the ore deposit. This perched water table is confined to the horst by the fault gouge and mudstone contact to the south.

At the Ranrex mine two faults of Lower Eocene age trend in a northeasterly direction. The ore is restricted to a coarse-grained sandstone in a small horst-like structure between these faults. The top of the ore is about 30 feet below the present surface and coincides with the top of a perched water table that is supported by a mudstone which underlies the ore-bearing sandstone. The perched ground water is confined on the north by a fault contact with mudstone and on the south by clayey fault gouge.

A mile south of the Lucky Mc and Vitro mines uranium mineralized rock has been found in zones 4 to 20 feet thick that lie at depths ranging from 60 to 250 feet below the surface. These occurrences appear to be related to a pre-Wind River valley which trends southeast from the Vitro mine (TEI-590, p. 167, fig. 30).

For a discussion of the mineralogy of the Gas Hills area, see R. G. Coleman, "Mineralogy and geochemistry of the uranium deposits in the Gas Hills," this volume.

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## Hiland-Clarkson Hill Area, Wyoming

by

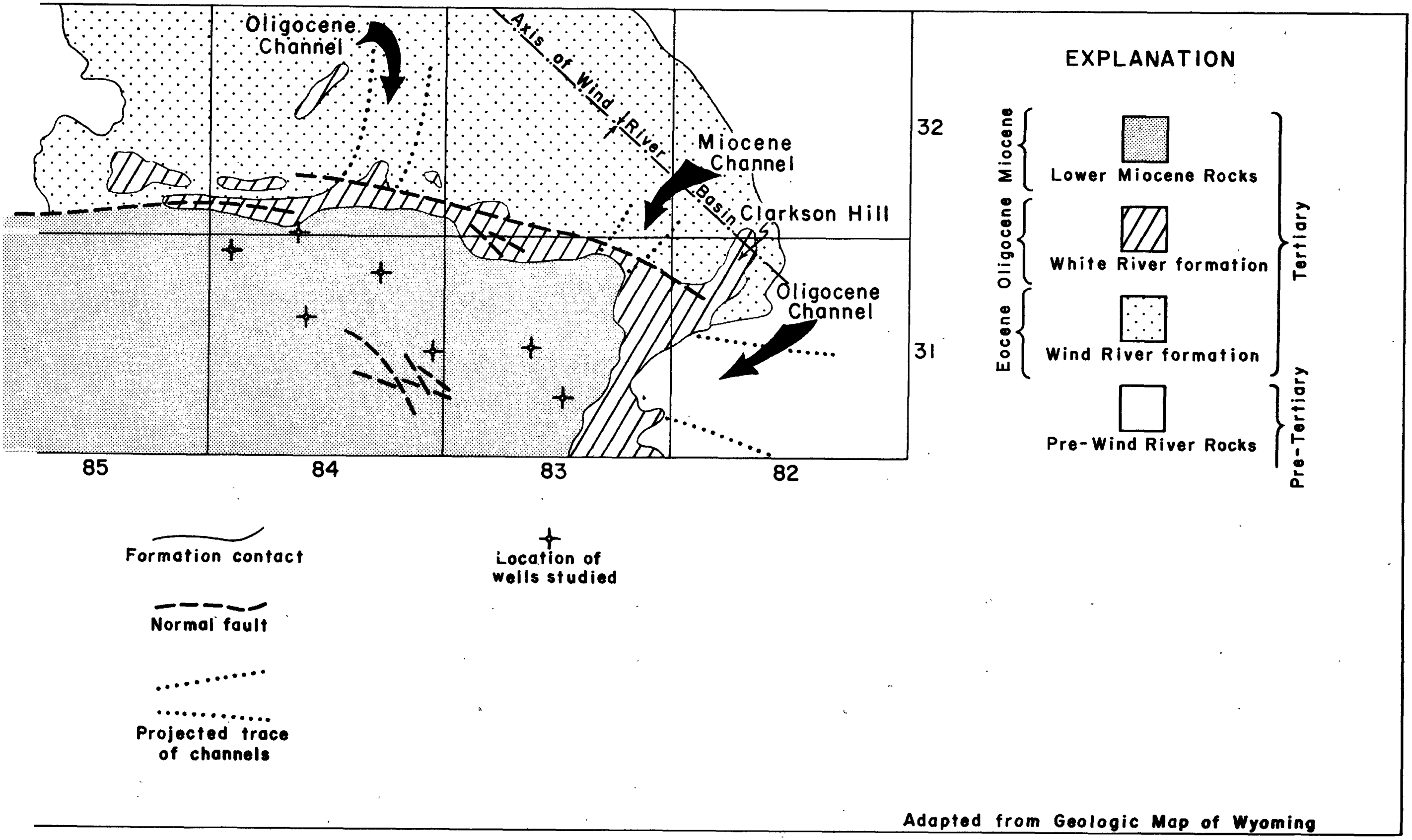
E. I. Rich

Post-Miocene southward regional tilting in the Clarkson Hill area is thought to have materially affected the movements of ground water within the Wind River formation. Because of differences in the magnitude of tilting, the original northward dip of the Wind River formation was reversed by regional tilting in the Gas Hills area but not in the Clarkson Hill area. The attendant adjustments of ground water movement may, to some degree, explain why commercial quantities of uranium accumulated in the Gas Hills, but not in the Clarkson Hill area. (See TEI-640, p. 121-125).

During the present report period electric logs and well cuttings from several wells along the southeastern margin of the basin were examined in order to determine the southward extent of the Wind River formation, to determine the characteristics of the faulting in the major east-west fault zone along the southern margin of the basin, and to relate this subsurface information to the deposition and accumulation of uranium in the area (Fig. 68).

The subsurface studies indicate that the Wind River formation is confined to the north side of the east-west fault zone. South of the fault zone strata of the White River formation rest with erosional unconformity on Cretaceous rocks with no intervening lower, middle, or upper Eocene rocks such as are present in the Gas Hills area. Since the principal source area for the rocks of the Wind River formation was probably the Granite Mountains, about 10 miles to the south, it is logical to assume that the area of Wind River deposition originally extended from the Granite Mountains northward across the southern end of the Wind River Basin. The Wind River rocks south of the fault zone were later removed by post-Wind River, pre-White River erosion.

Subsurface information also indicates that the displacement in the Cretaceous rocks along the fault zone is possibly as much as 5,000 feet. The fault planes are nearly vertical or dip slightly southward with



Adapted from Geologic Map of Wyoming

ig. 68–Generalized Geologic Map of Clarkson Hill area showing location of oil wells studied.

the downthrown sides on the north. These faults which involve the Tertiary rocks, on the other hand, are nearly everywhere normal and the maximum displacement in surface exposures is 170 feet. The faulting in the Tertiary rocks is therefore interpreted as minor adjustment along the pre-existing fault zone or as due to differential compaction or slumping along the zone of faulting.

Preliminary isopach maps of the Tertiary rocks suggest that faulting influenced the major lines of drainage during post-Wind River - pre-White River time inasmuch as White River rocks in the southeastern part of the area (Fig. 68) fill a channel trending eastward, roughly parallel to the trend of the fault zone.

From the structural and stratigraphic relationships which have been outlined above, several tentative conclusions may be drawn to explain why large uranium deposits have not been found in Clarkson Hill area: (1) The fault zone may have prevented northward moving ore solutions from reaching favorable areas of concentration in the Wind River formation to the north, except very locally; (2) The deep channels trending eastward, parallel with the basin margin, may have diverted ore solutions to the east or northeast; (3) There are no recognized favorable host rocks for uranium concentration south of the fault zone; and (4) Post-Miocene regional tilting was not of sufficient magnitude in most places to reverse the original northward or basinward movement of ground water in the Wind River formation.

# Maybell-Lay area, Colorado

by

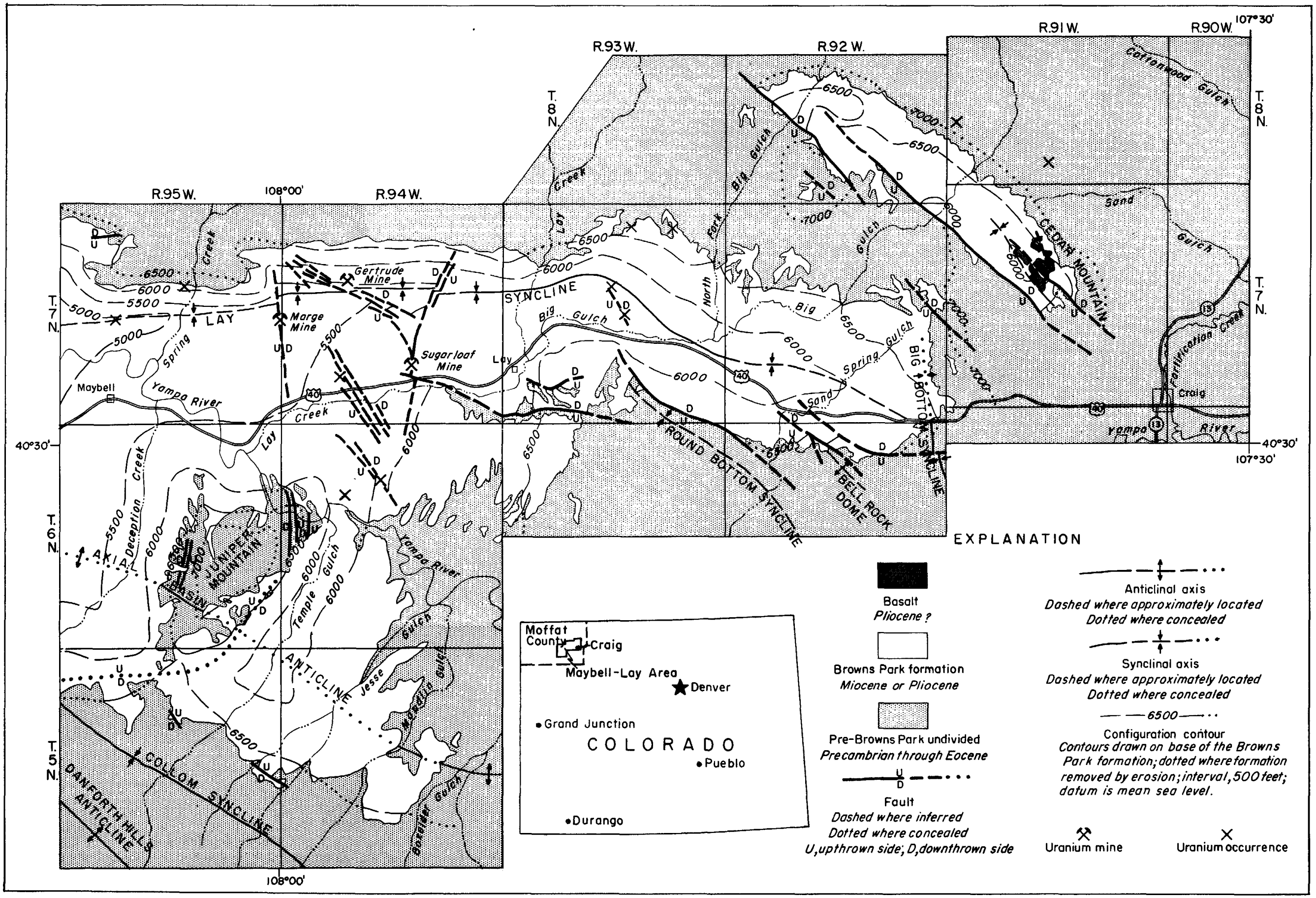
M. J. Bergin

Radioactivity anomalies in the Browns Park formation of Miocene or Pliocene age were discovered in the Maybell-Lay area, Moffat County, Colorado, in March 1954. The Geological Survey began geologic mapping and related studies in the area in 1955, and the present program will be completed in the summer of 1957. Preliminary results of the investigations were reported in TEI-590, p. 176-179; TEI-620, p. 190-199; and TEI-640, p. 138-143.

## Stratigraphy

A generalized geologic map of the Maybell-Lay area is shown in figure 69, and Table 12 gives a generalized section of rocks present in the area. In addition to field observations, data has been incorporated from Sears (1924), Hancock (1925), Thomas, McCann and Raman (1945) and Abrassart and Clough (1955).

The Browns Park formation, which overlies unconformably all older rocks in the Maybell-Lay area, has a minimum thickness of 1,800 feet. Two lithologic units can be recognized in the formation; (1) an upper sandstone sequence which contains all the known commercial uranium deposits, and (2) a basal conglomerate in which minor uranium mineralization occurs. Preliminary results of petrographic studies by W. A. Chisholm of the Geological Survey demonstrate that there are also two lithologic facies in the upper sandstone sequence which probably are related to separate source areas. These facies are (1) a non-tuffaceous facies which thickens to the east and probably is derived from the Sierra Madre-Park Range; and (2) a tuffaceous, or pyroclastic, facies which thickens to



Geology by: M.J.Bergin and J.J.Musser, 1955
M.J.Bergin and D.E. McGannon, Jr., 1956

FIGURE 69.-GENERALIZED GEOLOGIC MAP SHOWING RELATIONSHIP OF URANIUM OCCURRENCES TO REGIONAL STRUCTURE, MAYBELL-LAY AREA, MOFFAT COUNTY, COLORADO.

0 1 2 3 4 5 10 Miles
1957

Table 12.--Generalized section of rocks present in the Maybell-Lay area.

| System | Series | Group and formation | Thickness (feet) | Characteristics |
|---|---|---|---|---|
| Quaternary | Recent and Pleistocene |  | 0-100 | Silt, sand, and gravel in flood plain and terrace deposits along major stream channels. |
| Tertiary | Miocene or Pliocene | Browns Park formation | 1800+ | Massive buff to light gray sandstone, siltstone, and tuffaceous sandstone with few thin beds of volcanic ash and bentonitic? claystone or shale. Basal conglomerate. Contains all known commercial uranium deposits. |
|  | Eocene | Wasatch formation | 3000+ | Variegated clay shale, gray and buff sandstone, greenish-gray conglomeratic arkosic sandstone, thin carbonaceous shale and coal beds. Contains uranium mineral meta-autunite in T. 8 N., R. 91 W. Exposed along northern map border. |
|  | Paleocene | Fort Union formation | 800-1100 | Gray and brown sandstone, drab shale, thin carbonaceous shale and coal beds; basal conglomerate. Exposed east and west of Cedar Mountain. |
| Cretaceous |  | Lance formation | 1300 | Predominantly gray and brown massive cliff forming sandstone with thin gray shale, carbonaceous shale and coal beds. Exposed south and west of Cedar Mountain and along axis of Round Bottom syncline. |
|  |  | Lewis shale | 600-1000 | Gray marine shale with thin calcareous sandstone beds. Exposed in vicinity of Craig and on flanks of Round Bottom syncline. |
|  |  | Mesaverde group: Williams Fork formation | 3000 | Predominantly gray and brown sandstone with thinner gray shale, carbonaceous shale and minable coal beds. Extensive exposures on Danforth Hills anticline, Collom syncline, Round Bottom syncline, and Bell Rock dome. |
|  |  | Mesaverde group: Iles formation | 1350 |  |
|  |  | Mancos shale | 5000 | Predominantly gray marine shale with thick sandstone beds near top and base. Extensive exposures along axis of Axial Basin anticline. |
|  |  | Dakota sandstone | 150 | Gray quartzitic sandstone, gray and green shale, quartz and black chert pebble conglomerate. Limited exposures along Yampa River east of Juniper Mountain. |
| Jurassic |  | Morrison formation | 500 | Variegated clay shale, platy and massive white and buff sandstone, thin chert conglomerate lenses. Limited exposures along Yampa River east of Juniper Mountain. |
|  |  | Curtis formation | 50 | Green, well bedded, sandy shale and sandy limestone, fossiliferous. Limited exposures along Yampa River east of Juniper Mountain. |
|  |  | Navajo? sandstone | 200 + | White to brown well crossbedded sandstone. Limited exposures along Yampa River east of Juniper Mountain. Base not exposed. |
| Triassic |  | Chinle formation | 40-200? | Not exposed in area. Well cuttings and outcrops in nearby areas are red mudstone, calcareous shale, and few fine-grained sandstone beds. |
|  |  | Shinarump conglomerate | 0-50? | Not exposed in area. Well cuttings and outcrops in nearby areas are crossbedded sandstone and conglomerate. |
|  |  | Moenkopi formation | 600? | Not exposed in area. Well cuttings and outcrops in nearby areas are gray and red shale, siltstone, and sandstone with thin stringers of gypsum in lower part. |
| Permian |  | Park City formation | 100-150? | Not exposed in area. Well cuttings and outcrops in nearby areas are dolomitic siltstone and sandstone. |
|  |  | Weber sandstone | 300-500? | Not exposed in area. Well cuttings and outcrops in nearby areas are buff to light-gray, fine grained calcareous sandstone. |
| Pennsylvanian |  | Morgan formation | 1000 | White to buff crossbedded sandstone, thick gray limestone, variegated shale, and limestone conglomerate. Exposed only on flanks of Juniper Mountain. |
| Mississippian |  | Madison limestone | 450 | Gray limestone, dolomitic limestone, limy dolomite, and dolomite with chert lenses. Exposed only on Juniper Mountain. |
| Cambrian? |  | Unnamed | 50-200 | Predominantly conglomeratic sandstone and quartzite with thin bedded variegated shales at base. Exposed only on Juniper Mountain. |
| Precambrian |  | Uinta Mountain group | 1000+ | Massive red quartzite and sandstone. Base not exposed. Limited exposures on Juniper Mountain. |

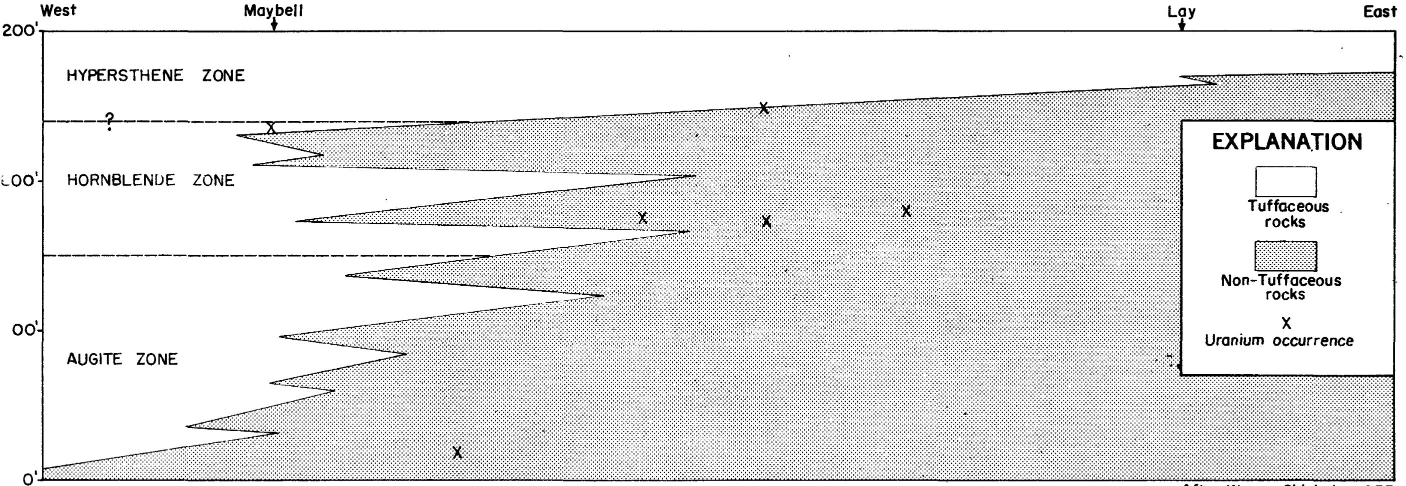
the west and probably was derived from some westerly source. Sandstones of the two facies are not distinguishable in field mapping. Most uranium deposits in the area occur in sandstone near the upper or western margin of the non-tuffaceous facies (fig. 70).

Rocks making up the non-tuffaceous facies are predominantly light gray to white, very fine- to medium-grained sandstone and siltstone composed principally of quartz grains, lesser amounts of white and pink feldspar, and minor amounts of black, red, and green accessory minerals. This facies also contains a few lenticular beds of conglomeratic sandstone and intraformational conglomerate up to 5 feet thick and greenish to reddish gray claystone or shale up to 2 feet thick. A few beds of white volcanic ash up to 2 feet thick which are probably interbedded from the tuffaceous facies are also present.

Rock types making up the tuffaceous facies are the same as those in the non-tuffaceous facies except that the rocks contain minor to abundant amounts of volcanic glass and ash beds are more common.

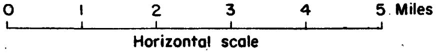
A basalt flow 15 to 30 feet thick which caps Cedar Mountain (fig. 69) is probably a part of the formation because at one locality it is overlain by sandstone similar to Browns Park sandstone below.

Cementing materials of the Browns Park formation are clay and calcium carbonate. Bedding is well developed locally, but the formation as a whole is massive and poorly bedded. At numerous localities sandstone exhibits cross bedding. For the most part the formation is soft and friable and weathers to sand that effectively masks outcrops,and the lack of persistent beds makes lateral correlations difficult.



After Wayne Chisholm 1955

FIGURE 70.-PRELIMINARY CROSS SECTION SHOWING RELATIONSHIP OF URANIUM OCCURRENCES TO PYROCLASTIC FACIES IN THE BROWNS PARK FORMATION, MAYBELL-LAY AREA, MOFFAT COUNTY, COLORADO.



Field relationships show that the basal conglomerate of the Browns Park formation contains two facies related to separate source areas. In the Maybell-Lay area the basal conglomerate, ranging from a knife edge to at least 120 feet in thickness, is composed of rounded pebbles and cobbles of granite, gneiss, schist, green and gray quartzite, chert, and vein quartz up to 6 inches in diameter in a matrix of poorly sorted sandstone. The source of the material is probably the Sierra Madre-Park Range some 45 miles to the east. A western source area, probably the Uinta Mountains, may be inferred for the conglomerate west of the Maybell-Lay area, where Sears (1924, p. 295) reports that it consists predominantly of red quartzite boulders.

Oxidation of the Browns Park formation extends to depths of from 40 to 100 feet below the surface. The color of the oxidized sediments is white, light gray, buff, and brown; the color of unoxidized sandstone is medium bluish-gray to dark gray. The ground water table does not coincide with the depth of oxidation, but is usually 50 to 100 feet lower.

## Structure

Structural features in pre-Browns Park sediments in the area are a series of northwestward-trending synclines and anticlines, the largest of which is the Axial Basin anticline (fig. 69). The conformable relationship of the Wasatch formation to older sediments on the north flank of the Axial Basin anticline indicates that the folds were formed in post-Eocene - pre-Miocene time.

The most prominent structural feature in the Browns Park formation is the east-southeast-trending Lay syncline (fig. 69). This syncline is strongly asymmetric with a steeply dipping northern flank and a more gently dipping southern flank. A similar, less pronounced synclinal trend is also present in the vicinity of Cedar Mountain.

Numerous high-angle normal and reverse faults with as much as 500 feet of known displacement cut the Browns Park formation. Several of the faults place the Browns Park formation against older sediments. These faults and synclinal folds may have been factors in the preservation of the easily eroded Browns Park formation. Most faults were mapped or inferred from poor surface exposures, but many more were inferred from seismic refraction surveys. Two fault trends appear to be present in the Browns Park formation, one trending northerly, the other northwesterly. Seismic information south of the Sugarloaf mine indicates that the north-trending faults are earlier, as they are offset by the northwest-trending faults. Uranium deposits are associated with both trends.

## Uranium occurrences

Occurrences in the Browns Park formation:--The first mineralization discovered in the Maybell-Lay area was at the sites of the present Gertrude and Marge mines (fig. 69). Subsequent extensive prospecting in the area resulted in the discovery of numerous mineralized areas but only one other commercial deposit, the Sugarloaf mine, has been developed. Continued commercial development outlined mineralized areas and open-pit mining was started in 1955.

Uranium minerals identified from oxidized deposits in the area include meta-autunite, uranophane, liebigite, tyuyamunite, an unnamed uranyl phosphate, torbernite, zeunerite, and carnotite. No identification of uranium minerals in unoxidized sandstone has been made; the radioactivity has been traced to black "sooty" coatings of possible uraninite or coffinite on pyrite grains.

Detailed mine studies demonstrate that similar lithologic conditions exist at the Gertrude and Marge mines. At these localities uranium occurs as disseminated material in soft, porous, very fine- to medium-grained, massive to crossbedded sandstone beds ranging from 5 to 30 feet in thickness and separated by beds of claystone or shale and hard calcareous sandstone 1 to 5 feet thick. Analyses as high as 1.0 percent U have been obtained in selected samples from the ore zones. The uraniferous zones are irregularly shaped elongate bodies ranging from 1 to 19 feet in thickness; the largest is reported to be about 1,000 feet long and 200 to 300 feet wide. The zones are generally concordant to the bedding of the host rock, but are not usually as thick as the sandstone interval containing them. Large quantities of limonite, jarosite, and gypsum are associated with the mineralized as well as with barren rock at both mines. Pyrite is abundant in unoxidized sandstone at the Marge mine.

At the Marge mine ore bodies occur in both blocks of a high-angle, west-dipping reverse fault of unknown displacement (fig. 69). Relationships are not clear, but the fault is thought to be pre-ore. No fault is present in the Gertrude mine, but surface exposures and seismic studies indicate that at least one high-angle fault crosses about 1,000 feet south of the mine.

At the Sugarloaf mine (fig. 69) small tonnages of uranium ore were mined in a clayey sandstone gouge zone 2 to 6 feet wide along a north-trending, almost vertical, normal fault of unknown displacement. Meta-autunite occurs disseminated and as fracture coatings in the gouge zone. Analyses only as high as 0.21 percent U were obtained in selected samples from the mine. Abundant limonite, jarosite, and gypsum and small quantities of marcasite occur in the gouge zone.

Relationships and their probable influence on the distribution and localization of uranium deposits in the area are summarized below:

(1) The larger uranium deposits and most uranium occurrences are restricted to the Browns Park formation, indicating that favorable conditions for uranium deposition occur in this formation and not in older rocks, or that uranium-bearing solutions were restricted to the Browns Park formation.

(2) Uranium usually occurs in soft, porous sandstone or siltstone beds rather than in hard relatively impervious calcareous sandstone or claystone beds, indicating that uranium-bearing solutions moved in porous zones and may have been trapped by the impervious beds.

(3) No significant differences, except the presence of uranium minerals, can be seen in a megascopic comparison of mineralized and barren sandstone samples, indicating that uranium-bearing solutions did not physically alter the host rock.

(4) Chemical analyses of ore-grade sandstone samples show that most are out of equilibrium in favor of chemical uranium, indicating a relatively young age for the deposits. Determinations from radioactive barite in the uranium deposits of the Browns Park formation in the Baggs area about 40 miles to the north indicate an age Of 5,000 years (Prichard, G. E., personal communication).

(5) Semiquantitative spectrographic analyses of both barren and mineralized samples show no apparent correlation of uranium with other elements. A slight positive correlation with barium, copper,

and rare earths, exists in selected high-grade ore samples.

(6) Most uranium deposits occur in a non-tuffaceous facies near the margin on a westward thickening and eastward-overlapping tuffaceous facies. This association is interpreted to mean that the areal distribution of these facies may have controlled the area of localization of uranium ores.

(7) Uranium occurrences are related to structure in the Browns Park formation. Deposits occur near the axis of an asymmetrical syncline or in less well defined structural depressions, and along or in proximity to high-angle faults of post-Browns Park age. These structural features which are interpreted to be pre-ore are believed to have influenced the flow of mineralizing solutions.

Occurrences in older rocks.--Uranium occurs as disseminated meta-autunite in conglomeratic sandstone of the Wasatch formation of Eocene age at two places in the southern part of T. 8 N., R. 91 W. (fig. 69). Both localities lie within 250 feet below the restored Wasatch-Browns Park contact. The occurrences are significant because they show that the Wasatch formation, which has great areal extent in northwest Colorado and southwest Wyoming, contains favorable environments for deposition of uranium deposits.

A selected sample of coal one foot in thickness in the Lance formation in sec. 4, T. 7 N., R. 93 W., contains 0.22 percent U and 0.44 percent U in the ash. At this locality the coal is directly overlain by basal conglomerate of the Browns Park formation. No high radioactivity was detected in the coal bed along outcrop where Lance shale and sandstone are present between the coal bed and the basal conglomerate of the Browns Park formation.

## Source of uranium and origin of deposits

Conclusive evidence for determining the source of the uranium and the origin of uranium deposits has not been found in the area.

Though deep-seated source and deposition by hydrothermal solutions cannot be ruled out, the lack of altered zones in the host rock, lack of increased mineralization at depth along faults, lack of equilibrium of U and eU at depth, and lack of significant deposits in older rocks would tend to discount this theory.

A source of the uranium in the Browns Park formation and localization of deposits by circulating round water solutions is proposed. Uranium in water solutions could be obtained by: (1) leaching from igneous and metamorphic source rocks from which the non-tuffaceous facies of the Browns Park formation was derived; and (2) leaching during devitrification of tuffaceous rocks in the formation. Water percolating down dip in porous beds could become enriched in uranium and add to the uranium present in circulating ground water. Large amounts of uranium would be concentrated in structurally low areas, where ground water circulation is restricted, near impervious fault zones serving as groundwater dams such as at the Marge mine, or in local traps along pervious faults serving as conduits for ground-water circulation such as at the Sugarloaf mine. Possible uranium precipitating agents may have been calcium carbonate, iron sulfides, or hydrogen sulphide in natural gas rising from buried older sediments.

## References

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Thomas, C. R., McCann, F. T., and Raman, N. D., 1945, Mesozoic and Paleozoic stratigraphy in northwestern Colorado and northeastern Utah: U. S. Geol. Survey Oil and Gas Investigations Preliminary Chart 16, sheet 2.

## Ralston Buttes, Colorado
by
D. M. Sheridan

A complete summary of the general geology of the Ralston Buttes district and the economic geology of the uranium deposits was given in TEI-640, p. 125-137. Field work has been completed, laboratory studies and the compilation of final maps are now nearly complete, and the project will terminate in June 1957.

## Colorado Front Range
by
P. K. Sims and others

Geologic mapping and related studies were begun in the Colorado Front Range in the summer of 1952. Most of the work was done in five mining districts - Central City, Idaho Springs, Lawson-Dumont-Fall River, Freeland-Lamartine, and Chicago Creek - in Gilpin and Clear Creek Counties, Colorado. The program was completed during fiscal year 1957, and the present report is a summary of the more significant results.

The Central City district and adjoining mining areas in the central part of the Front Range mineral belt have supplied small quantities of uranium ore intermittently since the discovery of uraninite at Central City in 1871. During the early years of development the uranium production from the region was of national importance, and until 1951 the region was this country's principal domestic source of uraninite, which occurs as a local minor constituent of base-metal sulfide veins, chiefly valuable for their gold content. In recent years the production of uranium has been insignificant, although the search for the metal has been far greater than at any previous time.

The mining districts of the central part of the Front Range mineral belt are in a terrane of complexly folded Precambrain crystalline rocks which constitute the core of the Front Range, and are located near intrusive centers of porphyritic igneous rocks of early Tertiary age. The Precambrian rocks are an interlayered and generally conformable sequence of gneissic, granitic, and pegmatitic units. The Tertiary intrusive rocks include a wide variety of rocks ranging in composition from granodiorite to alaskite. Thirteen distinct petrographic varieties of intrusive rocks are recognized, and can be classified into four groups--hornblende granodiorite, leucocratic granodiorite, quartz monzonite, and bostonite. In general, the older Tertiary intrusive rocks occur as small irregular-shaped plutons, whereas the younger rocks form long narrow dikes.

Although most of the Precambrian rocks have a low natural radioactivity, biotite-muscovite granite and two varieties of pegmatite are abnormally radioactive. The biotite-muscovite granite contains thorium-bearing monazite and is 2 to 6 times as radioactive as other Precambrian granites and gneisses in the region. The radioactive pegmatites are of two types, one containing mainly thorium-bearing monazite and the other containing uraninite. Analyses of the thorium-bearing pegmatite, which typically forms migmatite, indicate .023-.055 percent equivalent uranium and .008-.012 percent uranium. The uranium-bearing pegmatite occurs as discrete, generally conformable bodies that appear to contain (bulk grade) from about .01 percent to as much as .06 percent uranium, but selected parts of the pegmatite bodies contain more than .1 percent uranium.

The Tertiary igneous sequence is one of the most radioactive groups of intrusive rocks in the world. The radioactivity of quartz bostonite--the most radioactive rock of the sequence--is 15 to 25 times as great as the average granitic rock, and results from both thorium and uranium, which, according to George Phair of the Geological Survey, occur largely in primary zircon.

The structural features of the region are of Precambrian and Laramide age. The Precambrian rocks are complexly folded as a result of two periods of Precambrian deformation. The dominant folds trend north-northeast and northeast and were formed during an early period of plastic deformation, which was accompanied by the development of mignatites and the intrusion of granodiorite. Minor folds that trend about N. 60° E. and which are particularly abundant in the southeastern part of the region were formed by a later deformation, largely cataclastic, that occurred after the formation of the youngest Precambrian rocks.

The dominant Laramide structures are faults. Early Laramide faults that trend northwest and north-northeast, and which are locally marked by siliceous breccias known in the Front Range as breccia "reefs" formed before the emplacement of the Tertiary igneous sequence; and later Laramide faults that trend northeast, east-northeast, and east developed after the emplacement of all the intrusive rocks except the youngest, biotite-quartz latite. With few exceptions the faults dip steeply and have a dominant horizontal relative motion of one block to the other. Displacements are small except along some of the persistent early Laramide northwest-trending faults.

The ore deposits in the mining districts of the region are gold-, silver-, copper-, lead-, zinc-, and uranium-bearing veins that formed as hydrothermal fissure fillings in the Laramide faults. The structure, mineralogy, and texture of the veins are similar to those described by Lindgren as mesothermal. The veins range from single, well-defined filled fissures to complex, branching lodes consisting of subparallel fractures, loops, and "horsetailing" fractures; in general they are 1 to 2 feet in width, the lower figure being the more common. The principal ore minerals are sulfides and sulfosalts of iron, copper, lead, and zinc; uraninite is a local constituent. Quartz is the dominant gangue mineral, but carbonates of the calcite group, fluorite, and barite are present in some veins.

The veins in the region differ in quantitative mineralogy and can be classified into two main types, one characterized by dominant pyrite and the other by galena and sphalerite. The distribution of veins of the two contrasting types indicates a regional concentric zonal arrangement of the ores around a major center of mineralization. A large irregular core area (central zone) of pyrite type veins is surrounded by a broad outer area (peripheral zone) of galena-sphalerite type veins; transitional veins containing both pyrite and galena -sphalerite as well as copper minerals occur within an intermediate zone.

Uranium occurs locally in veins of different mineralogic types throughout much of the region, but it is abundant in only a few veins. Of a total of 141 localities known to contain concentrations of uranium, 53 mines including 16 that have produced uranium ore contain selected material that assays .10 percent or better. The remainder of the localities are not known to contain material of ore grade. Although uranium-bearing veins are widely scattered, a large proportion of the occurrences and most of the minable deposits are in the Central City district. With few exceptions, the principal groups of deposits occur in clusters a square mile or less in size.

Uraninite is the primary uranium mineral in the veins. Oxidation of the uraninite has yielded a limited variety of hexavalent uranium minerals, which are hydrous uranium phosphates, silicates, sulfates, and carbonates. The most abundant of these secondary minerals are torbernite, autunite, and kasolite.

The uraninite varies from a hard black dense material with a pitchy luster to soft porous sooty material with a dull luster, and all gradations between these extreme types exist. The hard uraninite appears massive but characteristically has a colloform texture, occurring as spheroidal forms, pellets, and rarely "cellular" or dendritic forms. The sooty uraninite is loosely aggregated and little is known of its texture. The change from a hard dense mineral to a sooty material is the result of oxidation, and is accompanied by a decrease in the unit cell size of uraninite and a loss of definition of X-ray diffraction powder patterns.

The uraninite contains, in addition to its essential constituents uranium and oxygen, a distinctive suite of minor elements which can reasonably be inferred to occur in the mineral structure. Spectrographic analyses indicate that the uraninite from the Central City district and the Lawson area generally contains several percent of zirconium and some contains substantial molybdenum and tungsten; all uraninites contain yttrium and many also contain other rare earth elements. The uraninite from Fall River is devoid of zirconium but contains substantial nickel and some cobalt. The nickel and cobalt in this uraninite appear to occur in inclusions of foreign minerals.

The uraninite was deposited early in the sequence of vein filling, essentially contemporaneous with quartz and sparse early pyrite and before the deposition of base-metal sulfides and sulfosalts. In the Central City district uraninite was deposited during the first of three distinct states of mineralization, and preceded a pyrite stage and base-metal stage mineralization; but at Fall River it appears to have been an early local variant of pyrite stage mineralization.

The uraninite occurs locally in several sets of vein-fissures as small lenses, pods, or stringers, or rarely as larger ore shoots. The margins of the ore bodies are sharp, and the intervening vein material commonly is nearly devoid of uranium. Most ore bodies contain only a few tens to a few hundred pounds of ore, but some of the larger shoots contain as much as 50 tons of ore. The bodies commonly are high in grade but much narrower than mining widths, and accordingly the grade of the shipping ore depends upon the care taken in mining and sorting.

As the uraninite was deposited as fillings of open spaces, its localization depended largely upon structural features which produced openings along the fissures; but a factor of equal importance was proximity of the openings to the source of the ore-forming fluids. Hard brittle rocks are the common wall rocks of most ore shoots, whereas soft plastic rocks rarely form the walls of large ore bodies. Other ore shoots are related to the structure of the wall rocks, to the amount and direction of the fault movement, or to irregularities in the fissures themselves.

In contrast to the more abundant gold- and silver-bearing sulfide ores, the uraninite deposits do not appear to extend over long vertical depths, and rarely can be mined profitably over a vertical range of more than 500 feet. At Central City most of the valuable deposits have been mined within 500 feet of the surface.

The upper parts of uraninite-bearing veins have been altered by surficial waters and atmospheric gases. Uranium was leached from pyrite type veins; but an assemblage of hexavalent secondary uranium minerals was formed by the oxidization and solution of uranium in the primary pitchblende from galena-sphalerite type veins. The secondary uranium minerals occur in the original vein with limonite and as disseminations and fracture coatings in wall rock adjacent to the originating vein. Sooty uraninite occurs at the interface between the unoxidized and the oxidized parts of veins. At most localities secondary uranium minerals do not extend below a depth of 150 feet.

The uranium deposits at Central City, near Lawson, and locally elsewhere in the region are closely related geographically to quartz bostonite, and this relationship together with mineralogical and chemical data is interpreted to indicate that the uranium in these deposits was derived directly from quartz bostonite magma. Uranium and thorium were progressively enriched during differentiation in successively younger magmatic phases of the Tertiary magma sequence, and enrichment culminated in the magma that consolidated to form quartz bostonite. Uraninite was deposited in vein-fissures adjacent to dikes of the quartz bostonite when reducing conditions developed, probably as a result of cooling of the derived hydrothermal fluid.

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

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Sims, P. K., 1956, Paragenesis and structure of pitchblende-bearing veins, Central City district, Colorado: Econ. Geology, v. 51, p. 739-756.

Tooker, E. W., 1956, Altered wall rocks along vein deposits in the Central City-Idaho Springs region, Colo.: Nat. Res. Council Pub. 456, p. 348-361.

## Thomas Range, Utah

by

M. H. Staatz

The area covered by the Thomas Range studies comprises the Dugway Range 15-minute quadrangle and the northern one-third of the Topaz Mountain 15-minute quadrangle in Juab and Tooele Counties, Utah. The geologic studies have been largely concentrated in the mountainous parts of the area, the Thomas and Dugway Ranges, which consist of Paleozoic sedimentary rocks and Tertiary volcanics, the latter underlying a little over 50 percent of the total area. The basins surrounding the ranges are filled chiefly with Lake Bonneville gravels and marls of Pleistocene age. Mapping and related geologic studies were started in the area in 1954; field work has been completed, and the final report on the project is in preparation.

The Paleozoic sedimentary rocks consist of 26 formations ranging in age from Early Cambrian to late Mississippian, and have a total thickness of at least 30,000 feet, of which the Prospect Mountain quartzite makes up at least 12,000 feet. The other Paleozoic rocks consist chiefly of limestones and dolomites with lesser amounts of quartzite, siltstone, and shale.

Rocks of Paleozoic age in the Thomas and Dugway Ranges in general strike north and dip moderately to the west, although the ranges as a whole have a northwesterly trend. Most areas of Paleozoic rocks are highly faulted, particularly on Spor Mountain in the western part of the Thomas Range and in the western Dugway Range. Folding is unimportant, although one gentle syncline is present in the northeast part of the Dugway Range. Three general groups of faults can be distinguished: (1) thrust faults, which are few in number and are probably the oldest; (2) numerous normal and a few reverse faults of diverse trends and generally of relatively small displacement; and (3) large north- and northwest-trending Basin and Range-type faults, which are probably the youngest.

The Tertiary volcanic rocks are made up of an older and a younger group. The older volcanic group is exposed chiefly in low-lying hills adjacent to the main volcanic mass and as intrusives into the Paleozoic sedimentary rocks of the main ranges. In this older volcanic group 11 units have been distinguished: enstatite-augite latite; hypersthene-augite latite; latite breccia and associated tuffs; plagioclase crystal tuff; black glass welded tuff; sanidine crystal tuff; quartz-sanidine crystal tuff; vitric tuff; red vitric tuff, conglomerate, and sandstone; porphyritic rhyolite; and intrusive breccia.

The younger volcanic rocks make up the greater part of the volcanic rocks exposed in the area, and consist of at least five overlapping series containing vitric tuff, breccia, obsidian, and rhyolite, of which rhyolite makes up more than 95 percent of the total. These four rocks are cut by a green glass unit, which probably represents rocks found in and near volcanic vents.

The Tertiary volcanic rocks are younger than most of the faulting in the area, and although the younger group of these rocks are cut by a few small faults, it is essentially flat-lying and was deposited on a surface eroded across the tilted Paleozoic rocks and the older group of volcanic rocks.

Three small sandstone units of varying composition interbedded with the volcanic rocks appear to be deposits formed in small lakes.

The mineral deposits in the Thomas and Dugway Ranges are of three main types: (1) uraniferous fluorspar pipes, (2) uranium, and (3) lead-zinc-silver-copper with minor gold. The uraniferous fluorspar deposits occur throughout Spor Mountain in dolomite, as pipes and veins, and consist chiefly of fluorspar with minor silica and clay minerals. More than 98 percent of the fluorspar mined comes from the pipes, which are as large as 180 feet in diameter. All these fluorspar pipes contain some uranium, and the grade of the ore ranges from about 0.008 to 0.23 percent uranium. These ore bodies have been described in considerable detail (Thurston, Staatz, Cox, and others, 1954, p. 24-45; Staatz and Osterwald, 1956, p. 131-136).

The uranium deposits occur on the east and west flanks at the southern end of the main part of the Thomas Range, and consist of two types: (1) veinlets in rhyolite and tuff, and (2) replacement bodies in tuffaceous sandstone and conglomerate. The first type consists of numerous veinlets made up chiefly of opal but with lesser amounts of calcite and fluorite; yellow uranium minerals are visible rarely. Uranium content of these veinlets ranges from 0.009 to 0.026 percent. The small size as well as the low grade of these deposits makes them of little economic interest. The second type of deposit, found only on the Good Will property, consists of an unknown yellow uranium silicate replacing parts of limestone pebbles in a conglomerate and of betauranophane filling the pore spaces in a porous sandstone. The replacement type deposits are now being mined on the Good Will property.

The source of the uranium in both the uraniferous fluorspar and uranium deposits is believed to have been the magma which formed the younger volcanic group. The uranium content of these rhyolitic rocks is approximately three times that of the uranium content of the average rhyolitic rock in western United States.

The lead-zinc-silver-copper deposits occur in the northern part of the Dugway Range in limestone, dolomite, and quartzite, chiefly as veins and containing mainly galena, sphalerite, fluorite, barite, quartz, pyrite, chalcopyrite and their alteration products. Deposits are small and many ore bodies do not exceed 40 feet in length. The largest production has come from the Four Metals mine whose main vein sequence is about 200 feet long. This deposit is being mined to a reported depth of 400 feet, which is by far the deepest in the district. On many properties only the oxidized material has been mined. No abnormal radiation has been noted anywhere in this district.

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## Tucumcari-Sabinoso area, New Mexico

by

R. L. Griggs

Mapping of thirteen 15-minute quadrangles in the Tucumcari-Sabinoso area, New Mexico, was begun in 1955 and was completed early in 1957. Uranium minerals were discovered in the area in 1954, in the Dockum group of Upper Triassic age and the Morrison formation of Upper Jurassic age. The occurrences in the Dockum group are in conglomeratic sandstone beds that are similar to and occupy approximately the same stratigraphic position as the Shinarump member of the Chinle formation occupies in the Colorado Plateau.

Resumes of the geology and uranium occurrences in the Tucumcari-Sabinoso area have been reported in TEI-590, p. 191-195; TEI-620, p. 209-212;

and TEI-640, p. 144-145. Work during this report period has consisted of compilation of the final map and preparation of the final report.

## Pacific region

### Turtle Lake quadrangle, Washington
by
G. E. Becraft

Geologic mapping of the Turtle Lake quadrangle, Washington, was begun in 1955, and slightly more than one half of the quadrangle has been mapped. The general geologic setting was given in the preceding semiannual report TEI-640, p. 146-150.

Field work was resumed on the Turtle Lake quadrangle in May 1957, and the project will be completed in the summer of 1958.

### Jarbidge quadrangle, Nevada
by
R. R. Coats

The Jarbidge quadrangle covers an area of about 220 square miles in northeastern Nevada, just south of the Idaho border. Field work was begun in 1954, and is essentially completed, and a map on the scale of 1:48,000 is being prepared for submission for publication in the MF series.

In the Jarbidge quadrangle, Paleozoic(?) limestone, phyllite, and quartzite have been intruded by Cretaceous(?) granodiorite. These rocks are unconformably overlain by six different sequences of silicic volcanics, all apparently of Pliocene age. The silicic volcanic rocks are overlain by the Snake River basalt and associated sediments probably of Pliocene age. The silicic formations, in order of decreasing age, are referred to here as the Deadhorse tuff, the Jarbidge rhyolite, the God's Pocket dacite, the Pole Creek vitrophyre, the Robinson Creek vitrophyre, and the pyroxene rhyolite welded tuff. All of these except the Deadhorse tuff show petrographic characteristics indicating their general consanguinity; all except the God's Pocket dacite have furnished glassy phases sufficiently fresh to permit an estimate of the original content of trace elements that is regarded as being close to that obtaining at the time of eruption.

The total thickness of the Deadhorse tuff is about 5,000 feet, but poor exposures and the massive character of the rock render this estimate rather uncertain. The tuff rests upon Paleozoic limestone south of the Jarbidge quadrangle. Most of the rock throughout the total thickness is massive, dull green to reddish- and pinkish-gray biotite quartz-latite welded tuff. Pumiceous phases are common, but well-bedded tuffs are very scarce. Just within the border of the quadrangle a thin lenticle of chocolate brown, white-weathering well-bedded tuffs has furnished an abundant flora regarded by D. A. Axelrod (personal communication) as Mio-Pliocene. The upper part of the formation is predominantly massive white biotite quartz-latite welded tuff. The formation contains small amounts of sedimentary rock fragments, commonly quartzite and chert. The tuff grades upward into a coarse conglomerate. In a few places a short distance south of the quadrangle, thin layers of black glassy biotite vitrophyre, showing well-developed collapsed shard structure, have been found. This rock contains abundant phenocrysts of brown biotite, and less common ones of green hornblende, rare hypersthene, and plagioclase ($An_{52-35}$). Zircon and ilmenite are also present in the matrix of brown glass, which has a refractive index $n = 1.50$.

The Deadhorse tuff and the overlying conglomerate have been faulted, tilted, and a surface of low relief was cut across them. On this surface was deposited a sequence of quartz-rich rhyolitic rocks, herein called the Jarbidge rhyolite.

The total thickness of the Jarbidge rhyolite has not been determined precisely, because it is sliced into a number of fault blocks, and reliable stratigraphic markers have not been recognized within it, but it is at least two thousand feet thick. In part, it was erupted through fissures, now occupied by dikes, examples of which have been recognized in the Jarbidge area, and in part through small, sub-circular necklike bodies. In some places, there is definite textural evidence that at least part of the Jarbidge rhyolite was erupted as a welded tuff, but recyrstallization has destroyed most of the pertinent evidence.

The fresher phases range in color from pale bluish gray to yellowish gray; glassy phases are black. Where altered or oxidized it is brownish to reddish, locally green or purplish. Thin layers of light gray to dark brown ash-fall tuffs are present locally. The lower parts of some of the welded tuffs, as well as the necks, may be vitrophyric in texture.

In some of the mines near Jarbidge, thin layers of coal and well-bedded white tuff have been found. Miss Estella B. Leopold reported (written communication, 1957) that no pollen, and only a few unidentifiable spores could be found in it. In specimens from the dump of the Legitimate Mine of a thicker coal bed containing recognizable coalified wood, Miss Leopold reported finding too few pollen grains for quantitative analysis, but representatives of "the following plant groups: Pinus, Abies, Juniperus, Juglans, Aceraceae, Compositae (long-spined), Artemisia, Chenopodiaceae, and Graminae. The presence of members of the Compositae (including Artemisia) and Chenopodiaceae ascertains a Miocene or younger age for the material." Richard A. Scott reported (written communication, 1956) that the structural features of the woody fragments were too far obliterated for identification.

The volcanic rocks proper of the Jarbidge rhyolite are characterized by a large proportion of quartz phenocrysts up to 5 millimeters in diameter, many of which are broken, whereas others are rounded; a few are euhedral. They commonly carry sanidine crystals, which are smaller and less numerous than those of quartz, and rarer oligoclase-andesine. Clinopyroxene is very rare, but bastite pseudomorphs that may have replaced it are somewhat more common. Accessories include zircon, apatite, ilmenite and magnetite.

Locally, in the southeastern quarter of the quadrangle, a sequence about 700 feet thick of dacitic flow material, here called the God's Pocket dacite, overlies the Jarbidge rhyolite disconformably. Locally, 30 to 50 feet of pale gray vitric tuff separate the two formations. The dacite is a pale gray dense lithic rock which locally contains black vitrophyric phases. It is characterized by relatively large sanidine and andesine phenocrysts, and smaller and sparser ones of quartz and pigeonite. The accessory minerals include magnetite, apatite and zircon.

Near the eastern border of the quadrangle, near the contact between the Jarbidge rhyolite and the pyroxene rhyolite welded tuff, there are a number of small domical protrusions of medium gray to black vitrophyre, probably of dacitic composition. The maximum thickness is as much as 900 feet, and the maximum exposed length about a mile and a half, but parts of the masses are concealed by the gravels deposited around them by streams whose drainage was interrupted by the extrusion. These rocks are characterized by numerous oligoclase xenocrysts, each of which has a spongy, more calcic rim. Sparse quartz and pigeonite phenocrysts are also present. Accessories include magnetite, ilmenite, apatite and zircon. These rocks are mapped as the Pole Creek vitrophyre.

On the same contact in the central part of the quadrangle, there are several smaller gray vitrophyric perlite domes, characterized by labradorite, hypersthene, augite, magnetite, and apatite. The maximum exposed thickness of any of them is about 200 feet, and the greatest length about three-fourths of a mile, but generally the bases on which they were extruded are not visible, and the original outer surfaces have been removed. These rocks are mapped as the Robinson Creek vitrophyre.

The northern third of the Jarbidge quadrangle is a dissected tableland, tilted gently northward, underlain by a series of pyroxene rhyolitic welded tuffs. These welded tuffs are reddish brown, yellowish brown, or brownish gray in color where they are holocrystalline, but glassy phases are black or gray to orange-red depending on the degree of oxidation. The sequence is made up of a number of flows lapping on the erosion surface cut across the flows of Jarbidge rhyolite, so that the highest of the flows exposed in the quadrangle extends farthest to the south. The total thickness is unknown, but the maximum exposed thickness is about 1,150 feet. The thicker flows are generally lithic and microcrystalline, and form crudely columnar cliffs as much as 150 feet high; the highest of such cliffs represent the combined thicknesses of several successive flows. The glassier phases of the flows are more closely fractured and are commonly obscured by slope wash. Many flows have vitrophyric basal phases that grade upward into dense rocks of lithoidal appearance. Much of the welded tuff is vesicular; the ellipsoidal vesicles may be nearly equidimensional, or flattened and slightly elongate, or much elongate but only slightly flattened. The flattening is generally in the plane of the textural layering, and elongate vesicles display a marked parallelism. In some places, the thicker welded tuffs show signs of deformation subsequent to extrusion, in the form of sharp anticlinal folds, which, on the average, tend to have a northeastward trend. Younger welded tuffs pass undisturbed across the crests of these folds; in some places, folds die out downward within the thickness of a single flow. The anticlinal folds are unaccompanied by any adjacent synclinal flexure.

Petrographically, the pyroxene rhyolite welded tuffs are characterized by the sparseness of the phenocrysts; the phenocrysts everywhere make up less than 10 percent, and generally, less than 2 percent of the rock. The phenocrysts are quartz, sanidine, oligoclase-andesine, pigeonite, with accessory zircon, magnetite, and apatite. Proportions of the various minerals differ from flow to flow. In the thicker flows, recrystallization of the glassy phase to sanidine and tridymite is complete. Small vesicles may also be filled with tridymite, indicating probable gas-phase transport. This is also true for spherulites inclosed within glassy phases of the welded tuffs.

Variation in trace elements:—Fluorimetric analyses for uranium, chemical analyses for fluorine, and spectrographic determinations of tin, beryllium, niobium, lanthanum, lead, zirconium, lithium, and boron were made of a number of wholly or partly glassy samples selected for freshness. The number of analyses ranged from six for the pyroxene rhyolite welded tuff, to one for the Deadhorse tuff. Most of the determinations were made in the laboratories of the Geological Survey in Denver. The results are depicted in figure 71, as ratios of the average contents to the mean contents of each of the elements in 116 analyzed dacitic and rhyolitic rocks from the Cordilleran region. These regional means are:

| | ppm |
|---|---|
| Uranium | 5 |
| Boron | 32 |
| Tin | 5 |
| Beryllium | 5 |
| Lanthanum | 40 |
| Niobium | 22 |
| Lead | 24 |
| Zirconium | 139 |
| Fluorine | 655 |

It should be noted that the values plotted in figure 71 are on a logarithmic scale; those values that fall along the central horizontal line are equal to the regional mean; the ratio to the mean of values that fall a given distance below the line is the reciprocal of the ratio to the mean of a value falling the same distance above the line. The advantage of this type of chart is that it permits the comparison of, in a single diagram, the results for elements having a wide range of actual values. The values of the various rock series are represented by symbols of different shapes, arranged in vertical columns, each column representing a single element; the order and spacing of the columns have no significance.

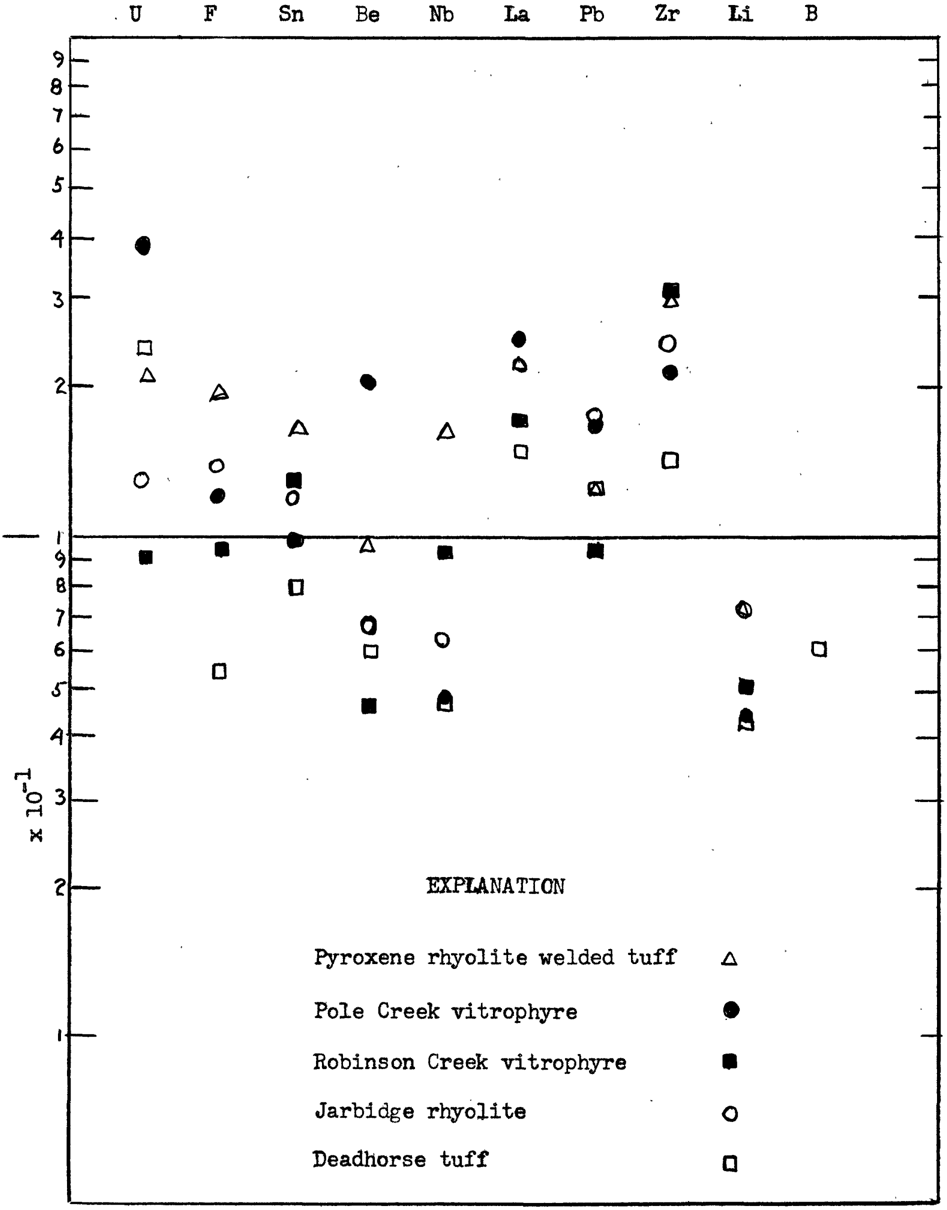

Fig. 71.--Ratios of contents of some trace elements in five sequences of silicic volcanic rocks from the Jarbidge area, Nev. to the mean content in 116 analyzed rhyolitic and dacitic rocks from the Cordilleran region.

The extreme right hand column, that for boron, has but one symbol, that for the Deadhorse tuff. Boron was looked for, but not found, in the rocks of all the other series. It is evident from the distribution of the symbols that each of these rock series has a distinct pattern of distribution of trace elements; the reliability of this conclusion may be vitiated for some series by the small number of samples. In general, the contents of uranium, fluorine, lanthanum and zirconium are significantly above the regional mean, taking all the series together; those of beryllium, lithium, and boron are markedly below the regional means. Zirconium is the only one of these elements that is commonly found in an independent mineral; zircon is unusually common in all these volcanic rocks. The low content of beryllium is unusual for the rocks of the comagmatic province from which these rocks come (TEI-159, p. 34).

Lack of accessible openings cutting the volcanic rocks where the vein structures were simple and clearly exposed made difficult any study of the effect of hydrothermal alteration on the distribution of uranium. Near the northern edge of the town of Jarbidge, the Hayden tunnel cuts several hundred feet through barren Jarbidge rhyolite to intersect a small, unproductive vein. Lack of structural complications makes it evident that the alteration of the wall rocks is related to the vein fracture. Examination of the radioactivity of the rocks underground suggested a perceptible decrease as the vein is approached. Sampling and assay of the samples for eU, U, and K, by C. Angelo, H. Lipp, and E. Fennelly, in the Denver laboratories of the Geological Survey, gave the following results:

| Location | eU percent | U percent | K percent |
|---|---|---|---|
| Lode material | 0.001 | 0.0005 | 0.28 |
| Adjacent to lode | 0.001 | 0.0005 | 0.47 |
| 1 foot from lode | 0.002 | 0.0005 | 1.10 |
| 6 feet from lode | 0.003 | 0.0005 | 2.80 |
| 38 feet from lode | 0.003 | 0.0005 | 2.91 |

The material most remote from the lode is a somewhat adularized and argillized rhyolite with a micropegmatitic groundmass. Argillization increases as the lode is approached; the lode itself appears to contain some vein silica and a clay mineral, possibly kimolite, differing from the one commonly found in the walls which appears to be kaolinite; neither has been definitely identified. It is evident that the diminished radioactivity is caused by the removal of potassium consequent on argillization. The uranium remains untouched; perhaps in these rocks most of it is in the accessory zircon, which is unaffected by the hydrothermal alteration.

### Reference

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## Eastern Region

### Mauch Chunk, Pennsylvania

by

Harry Klemic and J. C. Warman

Geologic mapping of the Mauch Chunk district, Pennsylvania, which comprises the northern half of the Mauch Chunk 15-minute quadrangle and the easternmost portions of the adjoining Nesquehoning and Weatherly

$7\frac{1}{2}$-minute quadrangles, was started in 1955. A partial description of the rock units in the area was given in TEI-620, p. 212-214, and a preliminary geologic map and a description of the geologic section was given in TEI-640, p. 151-156. The past report period has been spent in laboratory work, particularly petrographic studies of rock samples from the area. Results of these studies are summarized below.

### Clay mineral studies

X-ray studies of the clay size mineral components of the sandstones have been made to supplement the thin-section studies of the coarser-grained components. A fine particle fraction (less than 2 micron diameter) was separated from the rock samples and analyzed on the X-ray spectrometer. A list of the minerals in the clay size fraction of these rocks is given in table 13.

Of the units shown in table 13, the Hamilton formation and Portage group are marine deposits; the others are continental sedimentary rocks. At least two samples from each of the units listed were X-rayed. Minerals other than those indicated may be present in small amounts, but their X-ray patterns were not recognizable. Minerals indicated by a question mark on the list were tentatively identified on the basis of poorly developed powder patterns. Chlorite and illite are the principal constituents of the clay size fraction of all samples. The term illite as used here describes the sericite, hydromica, and muscovite fraction of the rocks. In all of the samples that give good illite powder patterns the illite is of the 2 M muscovite type (Yoder and Eugster, 1955).

$Fe_2O_3$ is abundant in the red shales. In the X-ray trace of one sample of the Damascus red shale and one sample of the Portage shale

Table 13. Minerals identified in clay size fractions of rocks from the Mauch Chunk district, Pennsylvania.

| Mineral | Group or formation | | | | | | |
|---|---|---|---|---|---|---|---|
| | Hamilton 1/ | Portage 1/ | Damascus 1/ | Cherry Ridge 2/ | Pocono 3/ | Mauch Chunk 3/ | Potts-ville 4/ |
| Quartz | X | X | X | X | X | X | X |
| Chlorite | X | X | X | X | X | X | X |
| Illite $M_2$ | X | X | X | X | X | X | X |
| Illite $M_1$ | | ? | ? | | | | |
| Kaolinite | | | | | ? | | |
| $Fe_2O_3$ | X | | X | X | X | X | |
| Lepido-chrosite | | | | | | | ? |
| Calcite | | | ? | | ? | X | X |
| Dolomite | ? | ? | ? | | | | |
| Siderite | | ? | ? | | ? | | |
| Feldspar | | | | X | | | |

1/ Devonian age
2/ Upper Devonian or Mississippian age
3/ Mississippian age
4/ Pennsylvanian age

small peaks suggestive of 1 M type muscovite were noted in addition to peaks of the abundant 2 M type muscovite.

If the 1 M type muscovite is present it must be of minor abundance. The scarcity or absence of 1 M type muscovite may be due to metamorphism of the micaceous minerals to the 2 M type structure. The rocks in this area have been sufficiently metamorphosed to convert the coaly materials to anthracite and to impart a slaty character to some of the Devonian shales.

### Thin-section studies

Damascus red shale:-- Samples of sandstone from the Damascus red shale of Devonian age contain about 50 to 77 percent granular detrital material composed principally of quartz, quartzite fragments, and chert. Fresh or slightly sericitized feldspar makes up less than 3 percent of the rock, but highly altered fragments that probably were feldspar grains constitute about 5 percent of two samples and almost 17 percent of one sample. Magnetite, leucoxene, sphene, apatite, and pyrite (?) are accessory minerals. Micaceous minerals and clay size material are abundant. Heavy silica overgrowths on quartz grains are common. One specimen contains black, possibly carbonaceous, interstitial material.

Much of the Damascus red shale consists of red shale, siltstone, and sandstone. The minerals of the clay-sized material of the shales are listed in table 13.

Uraniferous rock in Catskill formation.--Petrographic studies of a sample of uraniferous fine-grained graywacke sandstone from the Penn Haven Junction uranium occurrence show that the rock consists of about 65 percent granular detrital material which is about two-thirds quartz and about one-third rock fragments and a few percent chert. Feldspar grains are rare. Layers of the heavy minerals magnetite, allanite (?), zircon, ilmenite (?) and leucoxene, tourmaline, apatite, sphene, hornblende and garnet make up a few percent of the rock. Interstitial uraninite is in a zone that includes some of the heavy mineral layers.

The uraninite is abundant between some of the heavy mineral layers and is relatively disseminated in the adjoining part of the rock. Clausthalite occurs in about the same range as the uraninite and is most abundant in layers rich in uraninite. However, in the layer containing the greatest concentration of uraninite the clausthalite is scarce or absent, although uranium-rich layers above and below this layer contain abundant clausthalite. The clausthalite in this rock, in its present form, is epigenetic. Some of the rock appears to have been partially desilicified and the space between the remnants of the quartz grains is filled with holocrystalline and euhedral chlorite and with clausthalite and calcite. Further study of this material is planned.

## Analysis of galena from Carbon County, Pennsylvania

A specimen of galena from the Portage formation of Devonian age has been analyzed spectrographically by K. V. Hazel and H. W. Worthing of the Geological Survey. The results of the semiquantitative analysis are as follows:

| element | percent | looked for but not detected |
|---|---|---|
| Pb | major | Na, K, Ti, P, As, Au, B, Be, |
| Si | .1 | Cd, Ce, Co, Cs, Dy, Er, Eu, |
| Al | .03 | Ga, Gd, Ge, Hf, Hg, Ho, In, |
| Fe | .3 | Ir, La, Li, Lu, Mo, Nb, Nd, Ni, |
| Mg | .001 | Os, Pd, Pr, Pt, Rb, Re, Rh, Ru, |
| Ca | .01 | Sb, Sc, Sn, Sm, Ta, Tb, Te, Th, |
| Mn | .001 | Te, Tm, U, V, W, Y, Yb, Zr. |
| Ag | .003 | |
| Ba | .0003 | |
| Bi | .003 | |
| Cr | .0003 | |
| Cu | .0003 | |
| Sr | .003 | |
| Zn | .01 | |
| Se | less than .01 | |

The purity of the galena suggests that it crystallized at low temperatures.

## Spore studies

An attempt was made to extract spores from the rocks (Norem, 1956) for use in correlation and geologic dating. The initial experiment included four samples: (1) Upper Devonian Portage sandstone with abundant plant impressions; (2) Upper Devonian Catskill sandstone from the Penn Haven Junction uranium occurrence; (3) Mississippian Pocono coaly zone; and (4) Pennsylvanian Pottsville uraniferous conglomeratic sandstone. Spores were recovered only from the Pottsville. They are somewhat overmacerated, either naturally or artificially or both; however, they appear similar to *Cirratriradites*, a spore that has a wide stratigraphic distribution.

It is hoped that other spore types which will be of assistance in defining the Mississippian-Pennsylvanian contact may be recovered.

## References

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Yoder, H. S., and Eugster, H. P., 1955, Synthetic and natural muscovites: Geochemica et Cosmochemica Acta, v. 8, p. 225-280, Pergamon Press Ltd., London.

# Phosphate deposits and their "leached zones" in northern Florida:

by

G. H. Espenshade

## 1956 drilling program in the Hawthorn formation

*Lithology and stratigraphy*.--Preliminary lithologic logs and a brief discussion of the stratigraphy were given in TEI-620, p. 271-278. Paleontological studies are still in progress, and the upper contact of the

Hawthorne formation in these drill holes cannot yet be defined closely, and the sequence is here referred to as Hawthorn (?). Chemical analyses and x-ray studies of numerous samples have shown the following facts about the lithology of these beds:

| Lithologic zone | Significant minerals |
|---|---|
| (Top) | |
| 1. Clayey sandy zone | 1. Clay mineral is kaolinite |
| 2. Zone of claysy sand with fine to coarse phosphate, and interbedded clay locally. | 2. Clay mineral is montmorillonite, and is generally accompanied by clay-size apatite. |
| 3. Sandy phosphatic dolomite with interbedded clay and sandy clay. | 3. Dominant clay mineral is attapulgite, usually accompanied by variable amounts of montmorillonite; clay-size apatite is locally present. Dolomite is the carbonate; practically no calcite is present. |

A similar vertical distribution of clay minerals occurs in the land-pebble district, except that attapulgite is apparently restricted to the upper part of the Hawthorn, and montmorillonite occurs again at depth. Altschuler et al (1956, p. 497) believe that the montmorillonite has been altered to attapulgite, and that the weathered limestone in the Hawthorn has been dolomitized by marine transgression. Cathcart (1956, p. 490) indicates that attapulgite is present in weathered material but not in unweathered. In the 1956 drill hole samples from northern Florida, both dolomite and attapulgite are quite fresh and unweathered, and not associated with limestone; attapulgite occurs at least 150 feet below the top of the dolomite zone in drill hole 45. It seems most probable that dolomite and attapulgite were formed here as original marine sediments or in a very early state of diagenesis.

Results of the 1956 drilling show that the thickness of the zone of phosphatic dolomite in the Hawthorn (?) formation is quite variable, and is thickest (93 to 247 feet) in those holes (36, 39, 42, and 44) where the contact between the Ocala limestone and the Hawthorn (?) is deepest (93 to 218 feet below sea level); in this north-trending line of drill holes, dolomite thickens from south to north. The dolomite zone is much thinner (17 to 55 feet) in those holes (32, 33, 35, and 37) where its contact with the Ocala limestone is shallow (10 above to 24 feet below sea level). This "high" on the Ocala surface is southeast of the "low" mentioned above (TEI-620, figs. 53-77). These relations suggest that the pre-Hawthorn surface had considerable relief, possibly with northerly-trending ridges and valleys, and that dolomite deposition in Hawthorn time was thicker in the basins than in the shallow areas.

Phosphorus and uranium distribution:--Drill samples of the clayey-sandy phosphorite have been separated into size fractions by screening, and the fractions analyzed; analyses of a few samples are not yet completed. Information on the available analyses of clayey-sandy phosphorite, whose lithology is somewhat similar to the Bone Valley phosphorite, is summarized in table 14.

## Exposures of Hawthorn (?) phosphorite in northern Florida

Four well-exposed sections of Hawthorn (?) phosphorite in northern Florida were measured and sampled; stratigraphic and analytical information are summarized below.

Ditch north of Gainesville airport, Alachua Co.:--Six feet of coarse, clayey-sandy phosphorite are exposed beneath a cover of 21.6 feet of coarse

Table 14. Drill samples with significant content of phosphorus and uranium in the Hawthorn formation

| Drill holes | Sample interval (feet) | Percent $P_2O_5$ | Percent U | Phosphate mineral |
|---|---|---|---|---|
| 32 | 28.0 - 32.0 | 10.8 | .015 | |
| | 36.0 - 38.2 | 9.4 | .011 | |
| | 38.2 - 39.5 | 20.5 | .029 | apatite |
| 37 | 61.5 - 65.5 | 16.7 | .010 | apatite |
| 40 | 37.0 - 40.0 | 6.2 | .013 | apatite and wavellite |
| | 40.0 - 46.0 | 10.0 | .004 | |
| 41 | 17.0 - 20.5 | 6.1 | .016 | |
| | 20.5 - 22.0 | 14.3 | .027 | apatite and wavellite |
| | 22.0 - 24.0 | 15.9 | .009 | apatite |
| 46 | 29.5 - 32.8 | 10.1 | .003 | apatite |

In the two samples above that contain wavellite with apatite, the uranium content of the minus 150 mesh fraction is high: D. H. 40, (37.0' - 40.0')-.041% U; D. H. 41 (20.5' - 22.0')-.059% U.

Other samples of clayey-sandy phosphorite have lower contents of phosphorus or uranium, as shown by the following data for 22 samples;

| | Sample length (feet) | Percent $P_2O_5$ | Percent U |
|---|---|---|---|
| Range | 1.0 to 10.0 | 1.8 to 7.9 | .001 to .006 |
| Weighted average | 4.1 | 4.9 | .003 |

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clayey sand in the deep diversion ditch just north of the Gainesville airport, NW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 24, T. 9 S., R. 20 E. Two samples from the exposed phosphorite average 16.5% $P_2O_5$ and .012% U; the plus 14 mesh fraction (35.6% of total) contains 26.7% $P_2O_5$, .019% U, 17.35% insoluble, and 1.9% $Al_2O_3$.

Brooks Sink, Bradford Co.--Phosphatic dolomite and interbedded clayey-sandy phosphorite are excellently exposed over a vertical distance of about 40 feet in Brooks Sink (Pirkle, 1956, p. 207-215). Analyses of clayey-sandy phosphorite beds are as follows:

| Sample interval (feet above water level) | Percent $P_2O_5$ | Percent U |
|---|---|---|
| 30.5 - 40.6 | 5.8 | .004 |
| 25.0 - 29.5 | 5.1 | .001 |
| 20.5 - 24.2 | 4.7 | .001 |
| 11.0 - 12.8 | 11.8 | .004 |
| 5.5 - 7.6 | 10.2 | .003 |

SW$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 31, T. 1 N., R. 17 E., Hamilton Co.:--On the west bank of the Suwannee River, 100 yards below the Benton bridge, about 18 feet of clayey-sandy phosphorite (with coarse phosphate in the lower beds and fine phosphate in the upper) is exposed; poorly preserved pelecypods occur at the base. Samples from this interval average 4.5% $P_2O_5$ and .001% U.

SE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 20, T. 2 N., R. 13 E., Hamilton Co.:--The following section is very well exposed in a bluff on the west side of the Alapaha River:

| Height above river (feet) | Lithology | Percent $P_2O_5$ | Percent U |
|---|---|---|---|
| 48 - 63 | Loose, loamy, brown sand | | |
| 39 48 | Tan and gray clayey sand | 3.7 | .003 |
| 32.5 - 39 | Fine clayey sand with fine phosphate; poorly preserved fossils | 3.5 | 0 |
| 29 - 32.5 | Tan clayey sand with much phosphate | 9.9 | .001 |
| 27 - 29 | Sandy marl and dolomite with pelecypods | | |
| 0 - 27 | Interbedded dolomite and light green clay | | |

## Outliers of Hawthorn formation in central Marion County

Outliers of the Hawthorn formation of Miocene age make low hills, 100 to 200 feet above sea level, in central Marion County; Ocala limestone of Eocene age lies beneath the Hawthorn and is exposed in the surrounding low land (Cooke, 1945, pl. 1; p. 158-159). Sandy and clayey-sandy phosphorite are interbedded with clay here; a few feet of phosphatic dolomite occurs locally at the base of the Miocene beds. The lithology and thickness of units change abruptly; clay seems to be more abundant, and phosphate less abundant in the outliers to the north of Ocala than in those to the south of Ocala. In many places the phosphorite has been highly weathered to very porous phosphatic sand rock composed mainly of quartz, kaolinite, wavellite, and crandallite, and which resembles the "leached zone" rock of the Bone Valley formation in the land-pebble district.

Radioactivity anomalies in the Hawthorn outliers south of Ocala that had been outlined several years ago by aerial survey (Moxham, 1954) were investigated and explored at several places (mainly in the large area of abnormal radioactivity west of Belleview) by jeep-mounted auger. Clayey-sandy phosphorite with pellet apatite was found in beds ranging from several feet to 14.5 feet in thickness; $P_2O_5$ content ranges from 3.1 to 20.8 percent, and U from .004 to .022 percent. Samples of leached sandy phosphorite range from 12.7 to 16.8 percent $P_2O_5$, .019 to .023 percent U, 14.7 percent $Al_2O_3$, and 40.1 to 54.1 percent quartz.

## Hardrock phosphate district

Geology:--Irregular deposits of secondary phosphate are found in the northerly-trending hardrock phosphate district, about 90 miles long, that lies west of the areas of Hawthorn outliers (Mansfield, 1942, pl. 8).

Pieces of hard, dense apatite occur in mixtures of soft clay-like apatite, and clay and sand. Some earlier geologists have held the opinion that these deposits were formed by groundwater leaching of Hawthorn phosphorite beds, and redeposition of the phosphate by replacement or filling of solution cavities in the underlying Eocene limestone. Results of the present study support this view of origin. The principal items of evidence are a rather uniform stratigraphic order of lithologic units throughout the district, and the occurrence of fine to coarse phosphate pellets (resembling those in the Hawthorn formation) in sand, sandy clay, or clay in practically every deposit. The generalized stratigraphic order is as follows:

| Unit | Lithology (top) | Thickness (feet) |
|---|---|---|
| 6 | Loose sand | 0 - 25; usually under 10 |
| 5 | Bedded sand | 0 - 10 |
| 4 | Phosphatic sand, usually with abundant fine phosphate grains at base | 0 - 30 |
| 3 | Clay | 0 - 5; usually under 2 |
| 2 | Sandy clay with coarse phosphate pellets | 0 - 5 |
| 1 | Secondary phosphate | 0 - 60; usually under 30 |
| 0 | Limestone | |

Units 2, 3, and 4 are believed to have originally been Miocene marine phosphatic sediments that were equivalent to the Hawthorn. After uplift, the secondary phosphate deposits of unit 1 were formed by groundwater leaching and redeposition during a long period of erosion (Pliocene ?). The bedded sands of unit 5 may be of marine origin (Pleistocene ?); the loose, surficial sands of unit 6 are partly wind blown (Pleistocene to Recent).

If this interpretation is correct, it appears that the lithologic facies of the Miocene phosphorite beds changes from west to east from dominantly sandy in the hardrock district, to sandy beds with considerable clay in the center (central Marion and Alachua Counties), to sand and clay with much dolomite farther east (in the area of the 1956 drill holes).

Distribution of phosphorus and uranium in the hardrock district.--The phosphatic sands (unit 4) are widely distributed and have been considered as a potential source of phosphorus, uranium, and aluminum. These sands consist roughly of 80 percent quartz and 20 percent clay-size material that is mostly kaolinite, crandallite, and "millisite" (possibly not a single mineral, but a mixture of crandallite, wardite, and apatite). Analyses of channel samples of phosphatic sands from exposures in abandoned phosphate pits are summarized below:

| | Thickness (feet) | Percent $P_2O_5$ | Percent U | Percent Quartz | Percent $P_2O_5$ in non-quartz material (calc.) | Percent U in non-quartz material (calc.) |
|---|---|---|---|---|---|---|
| Samples from 5 pits in northern part of district (T. 6 S. to T. 15 S.): | | | | | | |
| Range | 10 - 25 | 0.5 - 6.1 | .001 - .003 | 68.5 - 90.4 | 2.2 - 27.1 | .010 - .021 |
| Average | 15.6 | 1.8 | .002 | 81.8 | 8.9 | .014 |
| Samples from 5 pits in central part of district (T. 16 S. to T. 18 S.): | | | | | | |
| Range | 8 - 15 | 4.4 - 6.6 | .002 - .004 | 75.8 - 81.2 | 22.8 - 27.8 | .014 - .022 |
| Average | 10.8 | 5.5 | .004 | 78.9 | 25.3 | .017 |
| Samples from 4 pits in southern part of district (T. 18 S., to T. 20 S.): | | | | | | |
| Range | 7 - 24 | 2.7 - 4.1 | .002 - .003 | 79.1 - 85.4 | 13.9 - 24.1 | .010 - .018 |
| Average | 15.1 | 3.1 | .002 | 82.0 | 17.6 | .014 |

The last group of samples was also analyzed for CaO, total $Al_2O_3$, and soluble $Al_2O_3$, as follows:

| | Content of total sample | | | Content in non-quartz material (calculated) | | |
|---|---|---|---|---|---|---|
| | Percent CaO | Percent total $Al_2O_3$ | Percent soluble $Al_2O_3$ | Percent CaO | Percent total $Al_2O_3$ | Percent soluble $Al_2O_3$ |
| Range | .82 - 1.37 | 4.5 - 5.7 | 3.2 - 4.4 | 4.93 - 8.06 | 27.3 - 32.1 | 20.6 - 25.9 |
| Average | 1.01 | 5.3 | 3.9 | 5.70 | 29.9 | 22.0 |

The content of uranium relative to phosphate is less in the secondary apatite of unit 1 than in the clay-size phosphate minerals of the phosphatic sand (unit 4). Samples of plus 20 mesh secondary apatite from four hard-rock phosphate mines contain from 32.6 to 35.5 percent $P_2O_5$, and from .003 to .011 percent U. Samples of slimes ("soft or colloidal phosphate") from four tailings ponds contain from 18.0 to 23.0 percent $P_2O_5$, .004 to .008 percent U, 18.5 to 23.9 percent CaO, 13.8 to 15.9 percent total $Al_2O_3$, and 12.6 to 13.8 percent soluble $Al_2O_3$. Mineral constituents of the slimes were determined by x-ray to be quartz, apatite, crandallite, a kaolin group mineral (halloysite ?), and possibly a montmorillonite mineral.

Mining and prospecting:--Most mining and prospecting of hardrock phosphate deposits have been in two areas: (1) at the northern end of the district in a belt about 15 miles long between the Santa Fe River and Newberry, and (2) near the center of the district in another belt about 15 miles long lying between Dunnellon and a few miles south of Hernando (Mansfield, 1942, pl. 8). In the Newberry area, many of the deposits are east of the main area of thick sand cover, and have only a thin, discontinuous mantle of sand; these deposits were probably found because of surface exposures, or by shallow drilling near exposed deposits. In the

Dunnellon area nearly all deposits are under a thick sand cover; close, systematic drilling is necessary for prospecting.

Reliable guides to ore in the district have not been found, and the exploration practice has been to drill systematically in the vicinity of, or in the ground between, old mines. The location and distribution of the secondary phosphate deposits must be dependent mainly upon two factors: (1) the original sedimentary distribution (which may have been largely restricted to the eastern part of the sand covered area), and (2) redistribution of phosphate by ground waters (which may have involved considerable lateral movement of phosphate in some places). Some deposits are in sink holes which lie along abandoned stream channels; there is no surface drainage now in the district, except for the Withlacoochee River. These old stream channels and sink holes must have been the sites of ground water solution, and appear to be favorable areas for prospecting. They are well shown on the Geological Survey's new 7½-minute topographic maps that cover much of the district, and can be readily picked out by tracing out the 50-foot and 100-foot contours.

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# EXPLORATION DRILLING ON THE COLORADO PLATEAU, 1947 - 1956

## Summary of drilling and analysis of ore reserves discovered

From 1947 until 1956 the Geological Survey conducted exploration drilling to search for and appraise uranium deposits in 30 areas in nine districts in Colorado, Utah, and Arizona. Investigative drilling for geologic information was done in five areas which included three areas drilled for reserve appraisal. This work was done on 56 drilling contracts at a contractual cost of \$8,736,199.58, or an average cost per foot of \$2.94. Government operating costs for personnel, equipment, and supplies, in conjunction with the drilling program, total \$3,639,764.62. Total cost to the Government for all exploration was \$12,375,964.20, or an average of \$4.16 per foot drilled.

Estimated Class I indicated and inferred reserves discovered by drilling total 2,273,400 short tons averaging 0.34 percent $U_3O_8$ and 2.12 percent $V_2O_5$. These reserves have a gross value of \$96,483,500 and a per-ton value of \$42.44 based on the AEC uranium price schedule of June 21, 1951, and 31 cents a pound for vanadium and excluding the initial production bonus on the first 10,000 pounds produced from new discoveries. Value of these reserves for $U_3O_8$ content along based on the same price schedule for uranium is \$66,610,900 or \$29.30 per ton.

Summary of costs and value of ore discovered
November 1947 - April 30, 1956

| | Footage drilled | Contractual cost | Salaries-expenses | Total cost |
|---|---|---|---|---|
| | 2,973,068 | $8,736,199.58 | $3,639,764.62 | $12,375,964.20 |
| Cost per foot drilled | | 2.94 | 1.22 | 4.16 |

| Tons of ore discovered | Tons ore discovered per foot drilled | Exploration cost per ton ore discovered |
|---|---|---|
| 2,273,410 | 0.764 | $5.44 |

| Average grade of ore discovered | Value per ton | Value of ore discovered |
|---|---|---|
| 0.34 percent $U_3O_8$ | $29.30 $U_3O_8$ | $66,610,900 |
| 2.12 percent $V_2O_5$ | 13.14 $V_2O_5$ | 29,872,600 |
| Total | $42.44 | $96,483,500 |

A summary of drilling and a compilation of Class I indicated and inferred reserves attributable to the drilling is shown on table 15. Indicated reserves are those for which the grade is computed from drill-hole samples and for which the tonnage is computed by projections for a reasonable distance on geologic evidence from drill holes. Inferred reserves are those for which quantitative estimates are based on broad knowledge of the geologic character of the deposits and for which there are few, if any, samples or measurements.

Figures showing pounds of contained $U_3O_8$ and $V_2O_5$ on table 15 were obtained from the summary table of reserves in the various TEI reports cited, from interim reports, file reports, or computed from the average grade of the reserves.

Approximately 300 reserve blocks or individual deposits ranging from 10 tons to 96,500 tons and averaging 7,500 tons in size are included in the tonnage figures reported in the grade classification tables, table nos. 16 and 17. Class I reserves on Atkinson Mesa are reported in TEI-290 in three reserve blocks, one containing 331,000 tons of reserves in 27 deposits ranging in size from 500 to 74,000 tons. Because a large tonnage reported as one block of a certain grade would disproportionately influence one grade range of the total reserves, the tonnages for each of the 29 deposits containing the Atkinson Mesa reserves were classified by grade.

Grade and tonnage distribution of Class I $U_3O_8$ and $V_2O_5$ reserves derived from the grade classification tables is shown graphically on figures 72 and 73. Percentage distribution of $U_3O_8$ and $V_2O_5$ reserves by grade classes is shown graphically on figures 74 and 75.

The average grade of ore reserves in each area drilled, the weighted average grade of reserves in all areas, and the average grade of ore produced in each area drilled is shown graphically on figure 76. Grade of ore mined was obtained either from shipment records compiled by AEC or from production data reported in the more recent TEI reports.

TABLE 1 COLORADO PLATEAU EXPLORATION PROGRAM, November 1947 - April 1956

Drilling summary and compilation of indicated and inferred Class I* ore reserves

| Location | Number holes drilled | Footage drilled | Average depth of hole (feet) | Tons ore discovered per foot drilled | Total reserves discovered (short tons) | Grade | | Pounds contained | | References | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Percent $U_3O_8$ | Percent $V_2O_5$ | $U_3O_8$ | $V_2O_5$ | Rept. No. (In preparation) | Date |
| Drilling to search for and appraiee deposits: | | | | | | | | | | | |
| Thompson district, Grand County, Utah: | | | | | | | | | | | |
| Yellow Cat area | 1,721 | 220,478 | 128 | 0.26 | 56,850 | 0.24 | 1.47 | 272,880 | 1,671,390 | (TEI-448) | |
| Gateway district, Grand County, Utah, and Mesa County, Colorado: | | | | | | | | | | | |
| Beaver Mesa | 212 | 101,202 | 477 | 0.35 | 34,245 | 0.46 | 1.88 | 317,375 | 1,294,075 | (TEI-449) | |
| Blue Mesa | 284 | 31,374 | 111 | 0.16 | 5,000 | 0.19 | 1.50 | 19,200 | 154,000 | TEI-154 | 2/52 |
| Calamity Mesa | 622 | 41,296 | 66 | 1.14 | 47,100 | 0.33 | 1.52 | 309,500 | 1,433,000 | TEI-146 | 6/51 |
| Maverick Mesa | 107 | 5,726 | 54 | 3.91 | 22,370 | 0.40 | 2.93 | 180,000 | 1,312,000 | TEI-117 | 6/50 |
| Moon Mesa-Horse Mesa | 324 | 55,846 | 172 | 0.02 | 870 | 0.09 | 1.30 | 1,600 | 27,000 | TEI-165 | 3/53 |
| Outlaw Mesa | 1,302 | 222,150 | 171 | 1.21 | 268,300 | 0.33 | 1.45 | 1,774,500 | 7,791,500 | TEI-163 | 11/52 |
| Paradox dietrict, San Juan County, Utah, and Montrose County, Colorado: | | | | | | | | | | | |
| La Sal Creek | 505 | 123,371 | 244 | 0.93 | 115,240 | 0.26 | 2.08 | 609,780 | 4,791,480 | TEM-716 | 12/54 |
| Uravan district, Montrose County, Colorado: | | | | | | | | | | | |
| Atkinson Mesa | 405 | 266,001 | 657 | 1.24 | 328,900 | 0.40 | 2.80 | 2,631,200 | 18,420,600 | TEI-290<br>TEM-801 | 5/54<br>11/54 |
| Club Mesa | 662 | 170,095 | 257 | 1.16 | 198,000 | 0.35 | 1.80 | 1,372,000 | 7,260,000 | TEI-147 | 11/52 |
| Dolores Bench | 190 | 56,838 | 299 | 1.58 | 90,100 | 0.33 | 2.11 | 595,000 | 3,802,000 | TEI-214 | 11/53 |
| Long Park | 1,373 | 480,774 | 350 | 0.52 | 250,800 | 0.31 | 2.04 | 1,538,500 | 10,222,100 | (TEI-550) | |
| San Miguel Bench | 309 | 92,116 | 298 | 0.46 | 43,000 | 0.42 | 1.98 | 362,000 | 1,705,000 | TEI-289 | 9/55 |
| Spring Creek Mesa | 280 | 180,287 | 644 | 0.27 | 50,400 | 0.26 | 1.16 | 260,500 | 1,171,500 | TEI-343 | 12/54 |
| Uravan district (Second and Third Parks) | 29 | 8,793 | 303 | ---- | -- | -- | -- | --- | --- | TEM-885 | 11/55 |
| Bull Canyon district, Montrose and San Miguel Cos., Colorado: | | | | | | | | | | | |
| Jo Dandy | 459 | 195,865 | 427 | 2.80 | 548,300 | 0.35 | 2.39 | 3,860,000 | 26,208,550 | GJ file | 3/55 |
| Monogram Mesa | 260 | 194,595 | 748 | 0.09 | 17,000 | 0.40 | 2.70 | 136,000 | 918,000 | TEM-804<br>Monthly Summary | 10/54<br>4/56 |
| Gypsum Valley district, Montrose and San Miguel Counties, Colorado: | | | | | | | | | | | |
| Gypsum Valley | 485 | 76,140 | 157 | 0.49 | 37,400 | 0.19 | 2.18 | 142,120 | 1,630,640 | (TEM-830) | |
| Slick Rock district, San Miguel County, Colorado: | | | | | | | | | | | |
| Charles T | 741 | 40,989 | 55 | 0.44 | 18,000 | 0.17 | 1.79 | 62,400 | 644,000 | TEI-112 | 3/50 |
| Disappointment Valley | 138 | 108,454 | 786 | 0.06 | 6,700 | 0.34 | 2.12 | 45,560 | 284,080 | (TEM-881)<br>Mo. Sum. | 3/56 |
| Ellison | 46 | 7,747 | 168 | 0.35 | 2,700 | 0.25 | 1.50 | 13,500 | 82,000 | TEI-115 | 4/50 |
| Georgetown | 80 | 8,173 | 102 | 0.77 | 8,300 | 0.42 | 2.33 | 63,660 | 373,160 | TEI-116 | 6/50 |
| Hawkeye | 6 | 1,422 | 237 | ---- | -- | -- | -- | --- | --- | TEM-687 | 10/53 |
| Legin group | 450 | 70,935 | 158 | 0.81 | 57,300 | 0.32 | 2.10 | 363,000 | 2,451,000 | TEI-164<br>TEM-833 | 7/52<br>12/54 |
| Lower group | 115 | 8,606 | 75 | 2.02 | 17,400 | 0.30 | 2.00 | 102,000 | 692,000 | TEI-114 | 4/50 |
| Radium-Summit | 433 | 40,564 | 94 | 0.29 | 11,735 | 0.56 | 2.22 | 131,000 | 521,000 | TEI-113 | 4/50 |
| Spud Patch | 436 | 78,591 | 180 | 0.26 | 20,500 | 0.28 | 2.10 | 114,500 | 861,000 | TEM-833<br>TEI-286 | 12/54<br>8/53 |
| Upper group | 200 | 15,207 | 76 | 0.56 | 8,500 | 0.20 | 1.64 | 34,400 | 279,000 | TEI-145 | 7/51 |
| White Canyon district, San Juan County, Utah: | | | | | | | | | | | |
| Deer Flat | 265 | 49,585 | 187 | 0.17 | 8,300 | 0.56 | (1.91% Cu) | 92,960 | --- | (TEI-545)<br>TEM-579<br>Mo. Sum. | 11/54<br>10/55 |
| Shiprock district, Apache County, Arizona: | | | | | | | | | | | |
| Carrizo Mountains | 24 | 3,032 | 126 | 0.03 | 100 | 0.25 | 1.50 | 500 | 3,000 | TEM-300<br>TEM-108 | 5/52<br>7/50 |
| Subtotals and averages: | 12,463 | 2,956,252 | 237 | 0.77 | 2,273,410 | 0.34 | 2.12 | 15,405,635 | 96,003,075 | | |
| Drilling for geologic information: | | | | | | | | | | | |
| Bull Canyon district, Montrose County, Colo: | | | | | | | | | | | |
| Monogram Mesa (Dry Creek Canyon) | 4 | 2,409 | 602 | ---- | -- | -- | -- | --- | --- | Mo. Sum. | 2/55 |
| Gateway district, Grand County, Utah, Mesa County, Colorado: | | | | | | | | | | | |
| Kirk's Basin-Pace Lake areas | 7 | 2,914 | 416 | ---- | -- | -- | -- | --- | --- | Mo. Sum. | 12/55 |
| Monument Valley district, Navajo County, Ariz.: | | | | | | | | | | | |
| Oljeto Wash | 41 | 5,741 | 140 | ---- | -- | -- | -- | --- | --- | Mo. Sum. | 8/55 |
| Slick Rock district, San Miguel County, Colo.: | | | | | | | | | | | |
| Disappointment Valley | 2 | 3,820 | 1,910 | ---- | -- | -- | -- | --- | --- | Mo. Sum. | 1/56 |
| White Canyon district, San Juan County, Utah: | | | | | | | | | | | |
| Clay Gulch | 9 | 1,932 | 214 | ---- | -- | -- | --- | --- | --- | (TEI-398) | |
| Subtotals and average depth | 63 | 16,816 | 267 | | | | | | | | |
| TOTAL DRILLING: | 12,526 | 2,973,068 | 237 | 0.76 | 2,273,410 | 0.34 | 2.12 | 15,405,635 | 96,003,075 | | |

*Calculated or estimated at cutoffs of 0.10% $U_3O_8$ or 1.0% $V_2O_5$ in layers 1 ft. or more thick.

## TABLE 16 COLORADO PLATEAU EXPLORATION PROGRAM, November 1947 - April 1956

Grade classification of indicated and inferred Class I* reserves containing $U_3O_8$ (short tons)

| Location | GRADE RANGE PERCENT $U_3O_8$ | | | | | | | | | | | | | | | | Total short tons |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | <0.10 | 0.10-0.14 | 0.15-0.19 | 0.20-0.24 | 0.25-0.29 | 0.30-0.34 | 0.35-0.39 | 0.40-0.44 | 0.45-0.49 | 0.50-0.54 | 0.55-0.59 | 0.60-0.64 | 0.65-0.69 | 0.70-0.74 | 0.75-0.99 | >1.00 | |
| Thompson district, Grand County, Utah: | | | | | | | | | | | | | | | | | |
| Yellow Cat area | 650 | 350 | 23,250 | 600 | 22,250 | 1,700 | 6,800 | 50 | 600 | — | 600 | — | — | — | — | — | 56,850 |
| Gateway district, Grand County, Utah, and Mesa County, Colorado: | | | | | | | | | | | | | | | | | |
| Beaver Mesa | 842 | 673 | 2,693 | — | 1,304 | 7,315 | 463 | — | — | 10,095 | 7,438 | 1,515 | 729 | — | — | 1,178 | 34,245 |
| Blue Mesa | 805 | 2,185 | 280 | 530 | — | 200 | 1,000 | — | — | — | — | — | — | — | — | — | 5,000 |
| Calamity Mesa | — | 3,150 | 5,150 | 13,450 | 300 | 6,850 | — | 3,800 | 7,350 | 3,350 | — | 3,200 | — | — | — | 500 | 47,100 |
| Maverick Mesa | 90 | — | 1,380 | 3,000 | — | — | — | 11,600 | — | 3,000 | 3,300 | — | — | — | — | — | 22,370 |
| Moon Mesa-Horse Mesa | 580 | — | 290 | — | — | — | — | — | — | | — | — | — | — | — | — | 870 |
| Outlaw Mesa | — | 30,100 | — | 3,780 | 7,650 | 76,950 | 103,160 | 1,720 | 1,270 | 43,545 | — | — | — | 125 | — | — | 268,300 |
| Paradox district, San Juan County, Utah, and Montrose County, Colorado: | | | | | | | | | | | | | | | | | |
| La Sal Creek | 1,141 | 3,253 | 16,618 | 23,420 | 36,120 | 15,527 | 13,675 | — | 5,486 | — | — | — | — | — | — | — | 115,240 |
| Uravan district, Montrose County, Colorado: | | | | | | | | | | | | | | | | | |
| Atkinson Mesa | 4,500 | 14,000 | 29,900 | 36,000 | 69,000 | 34,000 | — | 14,000 | — | 74,000 | 15,000 | — | 2,000 | — | 33,000 | 3,500 | 328,900 |
| Club Mesa | — | — | 700 | 16,250 | — | 104,050 | 1,000 | 35,500 | 15,500 | 24,000 | 1,000 | — | — | — | — | — | 198,000 |
| Dolores Bench | — | — | — | 4,150 | 45,700 | 4,400 | 1,100 | 34,750 | — | — | — | — | — | — | — | — | 90,100 |
| Long Park | 1,500 | 1,600 | 3,300 | 117,600 | 32,900 | 16,800 | 24,800 | 10,950 | 29,300 | 5,800 | 3,900 | — | — | | — | 2,350 | 250,800 |
| San Miguel Bench | — | 700 | — | — | — | 7,000 | 2,600 | — | 32,100 | — | — | — | — | 600 | — | — | 43,000 |
| Spring Creek Mesa | — | 7,500 | 19,500 | 8,500 | — | 1,200 | — | — | 800 | 12,900 | — | — | — | — | — | — | 50,400 |
| Bull Canyon district, Montrose and San Miguel Counties, Colorado: | | | | | | | | | | | | | | | | | |
| Jo Dandy | — | 20,596 | 3,516 | — | 108,574 | 126,909 | 120,782 | 147,040 | — | 10,903 | — | — | — | — | — | 9,980 | 548,300 |
| Monogram Mesa | — | 675 | — | 3,535 | 1,460 | — | 900 | 6,890 | — | — | — | 3,540 | — | — | — | — | 17,000 |
| Gypsum Valley district, Montrose and San Miguel Counties, Colorado: | | | | | | | | | | | | | | | | | |
| Gypsum Valley | 2,495 | 11,400 | 3,815 | 14,070 | 2,545 | 1,675 | 1,400 | — | — | — | — | — | — | — | — | — | 37,400 |
| Slick Rock district, San Miguel County, Colo: | | | | | | | | | | | | | | | | | |
| Charles T | 150 | 6,750 | 5,250 | 3,000 | 1,130 | 1,720 | — | — | — | — | — | — | — | — | — | — | 18,000 |
| Disappointment Valley | 210 | 576 | — | 210 | 4,357 | — | — | 449 | — | — | — | — | — | — | 898 | — | 6,700 |
| Ellison | — | — | — | — | 2,700 | — | — | — | — | — | — | — | — | — | — | — | 2,700 |
| Georgetown | — | — | — | 1,050 | 350 | 1,300 | 2,800 | 300 | 375 | 2,125 | — | — | — | — | — | — | 8,300 |
| Legin group | — | 440 | 6,480 | 9,190 | 10,280 | 14,070 | 5,240 | 2,260 | — | 7,670 | 1,040 | 630 | — | — | — | — | 57,300 |
| Lower group | — | 580 | — | 50 | 7,400 | 9,130 | 240 | — | — | — | — | — | — | — | — | — | 17,400 |
| Radium-Summit | 160 | 625 | — | 120 | — | — | — | 240 | 115 | 5,585 | 30 | 2,210 | 100 | 2,550 | — | — | 11,735 |
| Spud Patch | — | 950 | 1,360 | — | 3,220 | 14,970 | — | — | — | — | — | — | — | — | — | — | 20,500 |
| Upper group | — | — | 5,250 | 3,000 | 250 | — | — | — | — | — | — | — | — | — | — | — | 8,500 |
| White Canyon district, San Juan County, Utah: | | | | | | | | | | | | | | | | | |
| Deer Flat | — | 1,249 | 179 | 275 | — | — | 271 | — | — | 4,253 | — | — | — | — | — | 2,073 | 8,300 |
| Shiprock district, Apache County, Arizona: | | | | | | | | | | | | | | | | | |
| Carrizo Mountains | — | — | — | — | 100 | — | — | — | — | — | — | — | — | — | — | — | 100 |
| Totals (short tons): | 13,123 | 107,352 | 128,911 | 261,780 | 357,590 | 445,766 | 286,231 | 269,549 | 92,896 | 207,226 | 32,308 | 11,095 | 2,829 | 3,275 | 33,898 | 19,581 | 2,273,410 |
| Percent of total reserves: | 0.5 | 4.7 | 5.7 | 11.6 | 15.7 | 19.6 | 12.6 | 11.9 | 4.1 | 9.1 | 1.4 | 0.5 | 0.1 | 0.1 | 1.5 | 0.9 | 100.0 |

*Material 1 ft or more thick calculated or estimated to a cutoff of 0.10 percent $U_3O_8$ or 1.0 percent $V_2O_5$.

## TABLE 17 COLORADO PLATEAU EXPLORATION PROGRAM, November 1947 - April 1956

Grade classification of indicated and inferred Class I* reserves containing $V_2O_5$ (short tons)

| Location | GRADE RANGE PERCENT $V_2O_5$ | | | | | | | | | | | | | | | Total short tons |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | <1.00 | 1.00-1.24 | 1.25-1.49 | 1.50-1.74 | 1.75-1.99 | 2.00-2.24 | 2.25-2.49 | 2.50-2.74 | 2.75-2.99 | 3.00-3.24 | 3.25-3.49 | 3.50-3.74 | 3.75-3.99 | 4.00-4.24 | >4.25 | |
| Thompson district, Grand County, Utah: | | | | | | | | | | | | | | | | |
| Yellow Cat area | 3,500 | 14,200 | 16,100 | — | 15,850 | 6,600 | — | — | — | — | — | 600 | — | — | — | 56,850 |
| Gateway district, Grand County, Utah, and Mesa County, Colorado: | | | | | | | | | | | | | | | | |
| Beaver Mesa | 1,178 | 12,626 | 1,977 | 1,964 | 4,075 | 5,749 | — | 2,525 | — | 729 | — | — | — | — | 3,422 | 34,245 |
| Blue Mesa | 200 | 1,770 | — | 1,150 | 1,200 | 680 | — | — | — | — | — | — | — | — | — | 5,000 |
| Calamity Mesa | 4,450 | 13,250 | 4,150 | 7,650 | 14,850 | 1,950 | — | — | — | 600 | — | — | 200 | — | — | 47,100 |
| Maverick Mesa | — | 1,440 | — | 1,700 | 80 | 3,250 | — | — | 9,600 | — | — | 3,000 | — | — | 3,300 | 22,370 |
| Moon Mesa-Horse Mesa | 150 | 290 | 180 | 250 | — | — | — | — | — | — | — | — | — | — | — | 870 |
| Outlaw Mesa | — | 111,990 | 105,915 | 4,110 | 1,320 | 1,295 | 43,245 | 300 | 125 | — | — | — | — | — | — | 268,300 |
| Paradox district, San Juan County, Utah, and Montrose County, Colorado: | | | | | | | | | | | | | | | | |
| La Sal Creek | 16,967 | 18,059 | — | — | 10,050 | 34,000 | 4,520 | 17,240 | — | — | — | — | — | 5,569 | 8,835 | 115,240 |
| Uravan district, Montrose County, Colorado: | | | | | | | | | | | | | | | | |
| Atkinson Mesa | 21,900 | 22,500 | 23,000 | 10,000 | 2,000 | 73,000 | 32,000 | 14,000 | — | — | 15,500 | 79,000 | — | — | 36,000 | 328,900 |
| Club Mesa | — | 950 | 7,000 | 67,850 | 24,700 | 44,000 | 15,500 | 37,000 | 1,000 | — | — | — | — | — | — | 198,000 |
| Dolores Bench | — | 4,150 | 23,100 | 14,750 | 9,850 | 2,650 | 850 | — | 34,750 | — | — | — | — | — | — | 90,100 |
| Long Park | 29,300 | 3,400 | 21,000 | 71,100 | 8,250 | 37,650 | 8,400 | 4,900 | 5,800 | 49,800 | 8,700 | 700 | — | — | 1,800 | 250,800 |
| San Miguel Bench | 700 | 2,600 | 7,000 | 2,300 | — | 29,800 | — | — | 600 | — | — | — | — | — | — | 43,000 |
| Spring Creek Mesa | 7,100 | 20,400 | 22,900 | — | — | — | — | — | — | — | — | — | — | — | — | 50,400 |
| Bull Canyon district, Montrose and San Miguel Counties, Colorado: | | | | | | | | | | | | | | | | |
| Jo Dandy | — | — | — | 111,649 | 99,440 | 99,869 | 73,335 | 102,021 | 4,480 | — | 10,903 | — | 4,556 | — | 42,047 | 548,300 |
| Monogram Mesa | 5,665 | 1,575 | — | 675 | — | — | — | — | — | — | — | — | — | 5,545 | 3,540 | 17,000 |
| Gypsum Valley district, Montrose and San Miguel Counties, Colorado: | | | | | | | | | | | | | | | | |
| Gypsum Valley | 1,200 | 2,695 | 2,190 | 13,100 | 1,000 | 3,260 | — | 3,155 | 10,800 | — | — | — | — | — | — | 37,400 |
| Slick Rock district, San Miguel County, Colo: | | | | | | | | | | | | | | | | |
| Charles T | — | 1,600 | 950 | 3,550 | 4,630 | 7,000 | 10 | 260 | — | — | — | — | — | — | — | 18,000 |
| Disappointment Valley | 295 | 281 | — | — | 420 | 4,357 | — | 673 | — | 337 | 337 | — | — | — | — | 6,700 |
| Ellison | — | — | — | 2,700 | — | — | — | | — | — | — | — | — | — | — | 2,700 |
| Georgetown | — | 1,050 | 650 | 375 | — | — | 2,800 | 2,125 | 1,300 | — | — | — | — | — | — | 8,300 |
| Legin group | 740 | — | 8,720 | 4,010 | 15,750 | 2,730 | 9,080 | 4,100 | 3,820 | 8,300 | 50 | — | — | — | — | 57,300 |
| Lower group | — | — | 4,400 | — | 580 | 3,050 | 9,130 | — | — | — | — | — | 240 | — | — | 17,400 |
| Radium-Summit | 395 | — | — | 415 | 1,875 | — | 5,700 | 2,885 | 195 | 240 | — | 30 | — | — | — | 11,735 |
| Spud Patch | 220 | 570 | — | 320 | 6,820 | 6,280 | — | 6,290 | — | — | — | — | — | — | — | 20,500 |
| Upper group | — | — | — | 8,000 | — | 250 | 250 | — | — | — | — | — | — | — | — | 8,500 |
| White Canyon district, San Juan County, Utah: | | | | | | | | | | | | | | | | |
| Deer Flat | | | | Non-vanadiferous ore. Copper content estimated at 1.91 percent. Reserve of 8,300 tons in Deer Flat area shown on table of grade distribution for $U_3O_8$. | | | | | | | | | | | | |
| Shiprock district, Apache County, Arizona: | | | | | | | | | | | | | | | | |
| Carrizo Mountains | — | — | — | 100 | — | — | — | — | — | — | — | — | — | — | — | 100 |
| Totals (short tons): | 93,960 | 235,396 | 249,232 | 327,718 | 222,740 | 367,420 | 204,820 | 197,474 | 72,470 | 60,006 | 35,490 | 83,330 | 4,996 | 11,114 | 98,944 | 2,265,110 |
| Percent of total reserves: | 4.1 | 10.4 | 11.0 | 14.5 | 9.8 | 16.2 | 9.0 | 8.7 | 3.2 | 2.7 | 1.6 | 3.7 | 0.2 | 0.5 | 4.4 | 100.0 |

*Material 1 ft or more thick calculated or estimated to a cutoff of 0.10 percent $U_3O_8$ or 1.0 percent $V_2O_5$.

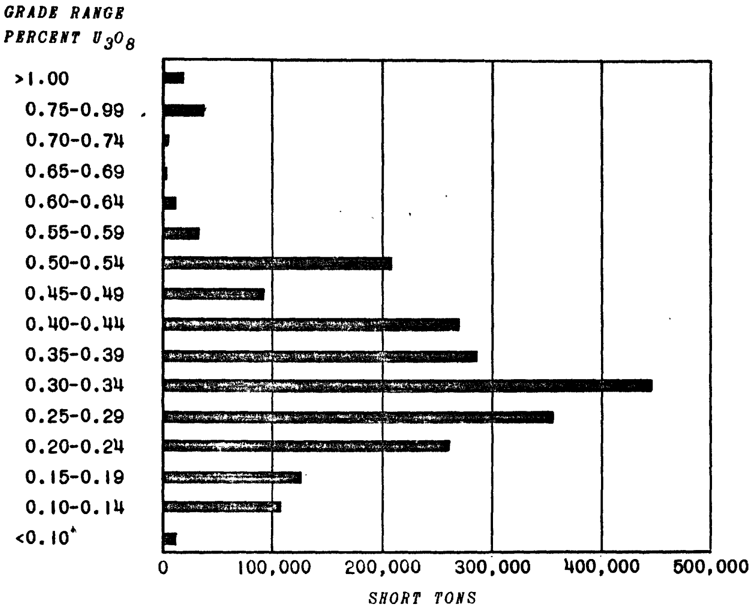


Figure 72--GRADE AND TONNAGE DISTRIBUTION OF CLASS I $U_3O_8$ ORE RESERVES.

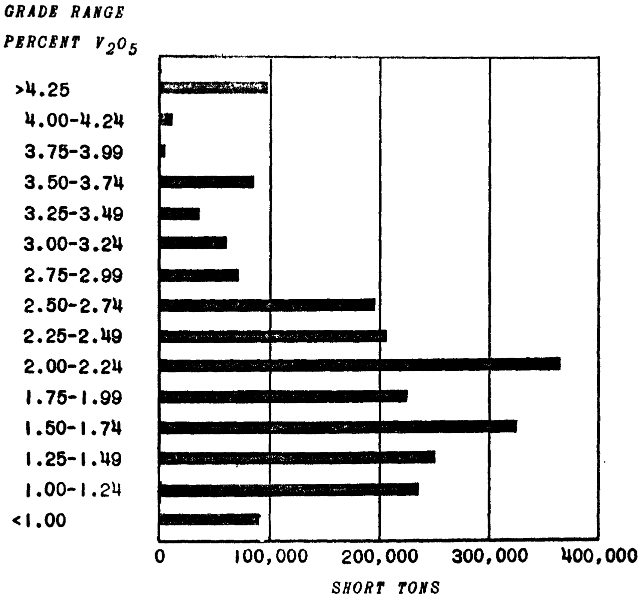
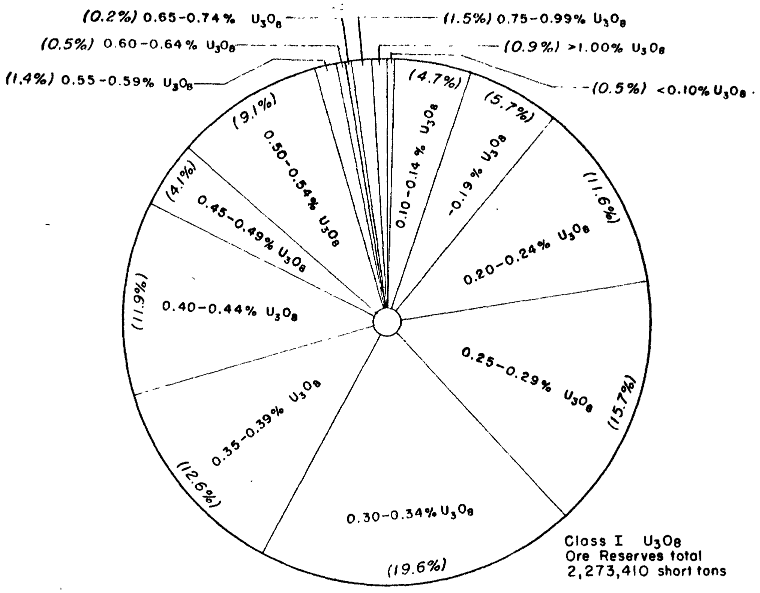
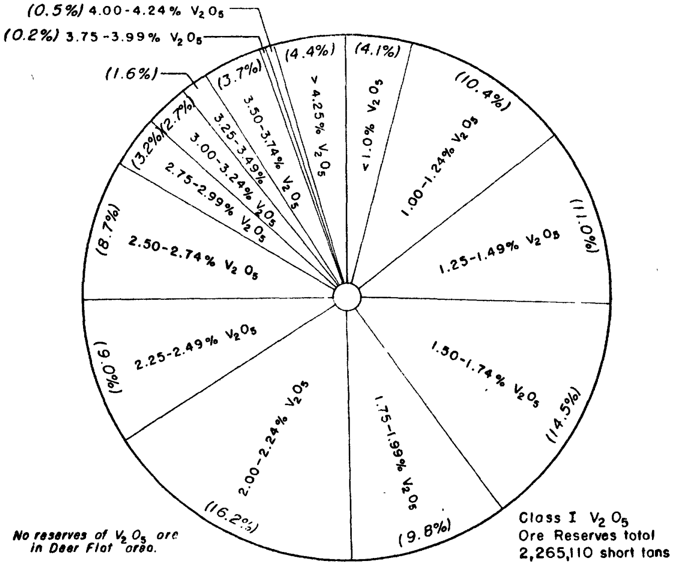


Figure 73--GRADE AND TONNAGE DISTRIBUTION OF CLASS I $V_2O_5$ ORE RESERVES.



Class I $U_3O_8$
Ore Reserves total
2,273,410 short tons

Fig. 74 -- PERCENTAGE DISTRIBUTION OF $U_3O_8$ ORE RESERVES BY GRADE CLASSES.



*No reserves of $V_2O_5$ ore in Deer Flat area.*

Class I $V_2O_5$
Ore Reserves total
2,265,110 short tons

Fig. 75 - PERCENTAGE DISTRIBUTION OF $V_2O_5$ ORE RESERVES BY GRADE CLASSES.

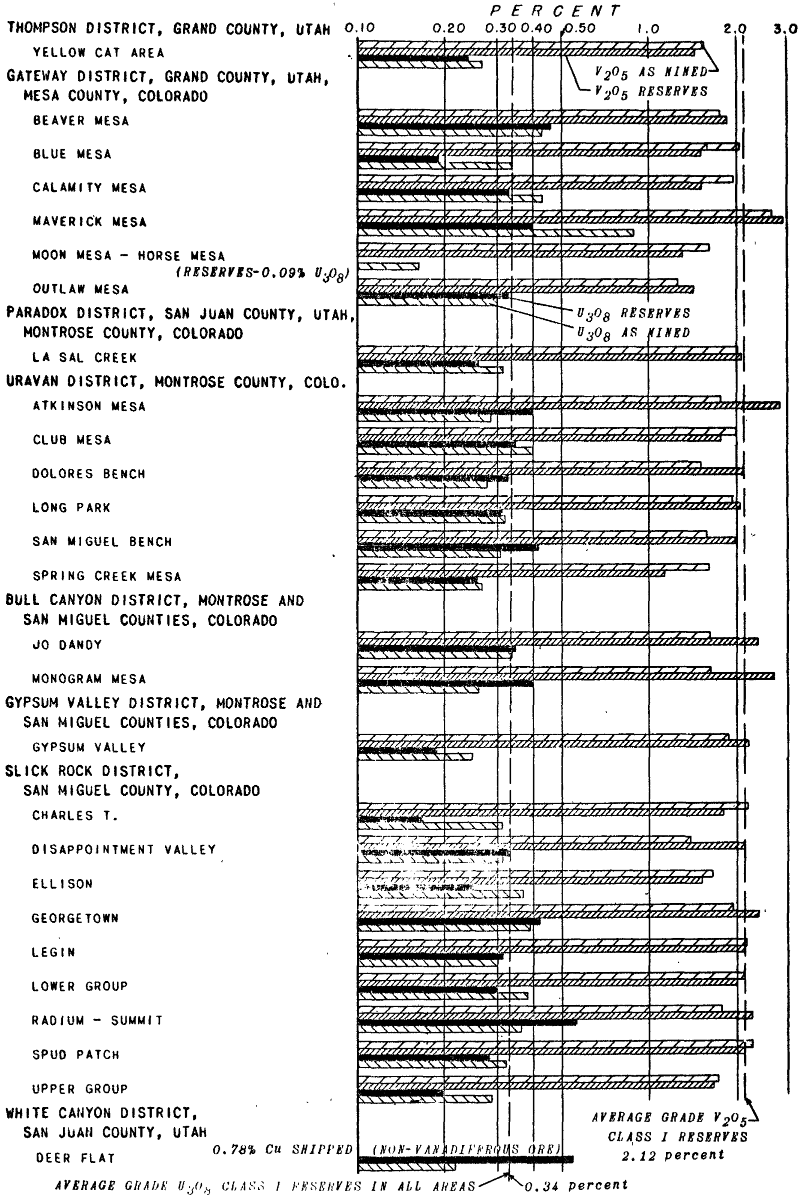


FIG [illegible].—GRAPH SHOWING AVERAGE GRADE OF $U_3O_8$ AND $V_2O_5$ IN CLASS I ORE RESERVES BY AREAS, AVERAGE GRADE OF $U_3O_8$ AND $V_2O_5$ RESERVES FOR ALL AREAS, AND GRADE OF ORE PRODUCED IN EACH AREA.

# GEOLOGIC TOPICAL STUDIES

## Colorado Plateau region

### General stratigraphic studies

by
L. C. Craig and Carl Koteff

The coincidence of uranium occurrences with certain stratigraphic features in the major uranium-bearing formations has been established by the work of many observers. Analysis of the distribution of these features in stratigraphic units not previously studied may permit delineation of new areas favorable for the occurrence of significant uranium deposits.

Study of the rocks of Cretaceous age of the Colorado Plateau was started late in 1956. Bibliographic and cross-reference files and index maps have been established. Preliminary stratigraphic reference sections for six areas of the Plateau were completed and much thickness data, particularly for the San Juan Basin area of northwestern New Mexico, have been plotted on maps showing the 12 stratigraphic units that constitute the Cretaceous column. Lithofacies data are sparse and lithofacies studies will have to be based largely on measured sections of surface exposures made by previous workers.

Preliminary compilations indicate that several formations of Cretaceous age in and around the San Juan Basin may duplicate or approximate the stratigraphic features of the major uranium-bearing formations of the Colorado Plateau; these formations may deserve detailed stratigraphic study. The transitional (marginal marine) or continental Menefee formation of the Mesaverde group and the more continental aspects of the Mesaverde group as a whole, along and to the southwest of the southwestern margin of the San Juan Basin, seem worthy of further stratigraphic study. These rocks show an intertonguing of marine and continental deposits which is similar to that of Black Mesa, northeastern Arizona, where the Mesaverde group is known to contain occurrences of uranium minerals. Transitional and continental facies are also found in the Kirtland and Fruitland formations of the northwestern part of the San Juan Basin; stratigraphic analysis of these units may demonstrate duplication of characteristics found in the major uranium host rocks of the Colorado Plateau.

The following report was published during the period:

Mullens, T. E., and Freeman, V. L., 1957, Lithofacies of the Salt Wash member of the Morrison formation, Colorado Plateau: Geol. Soc. America Bull., v. 68, no. 4, p. 505-526.

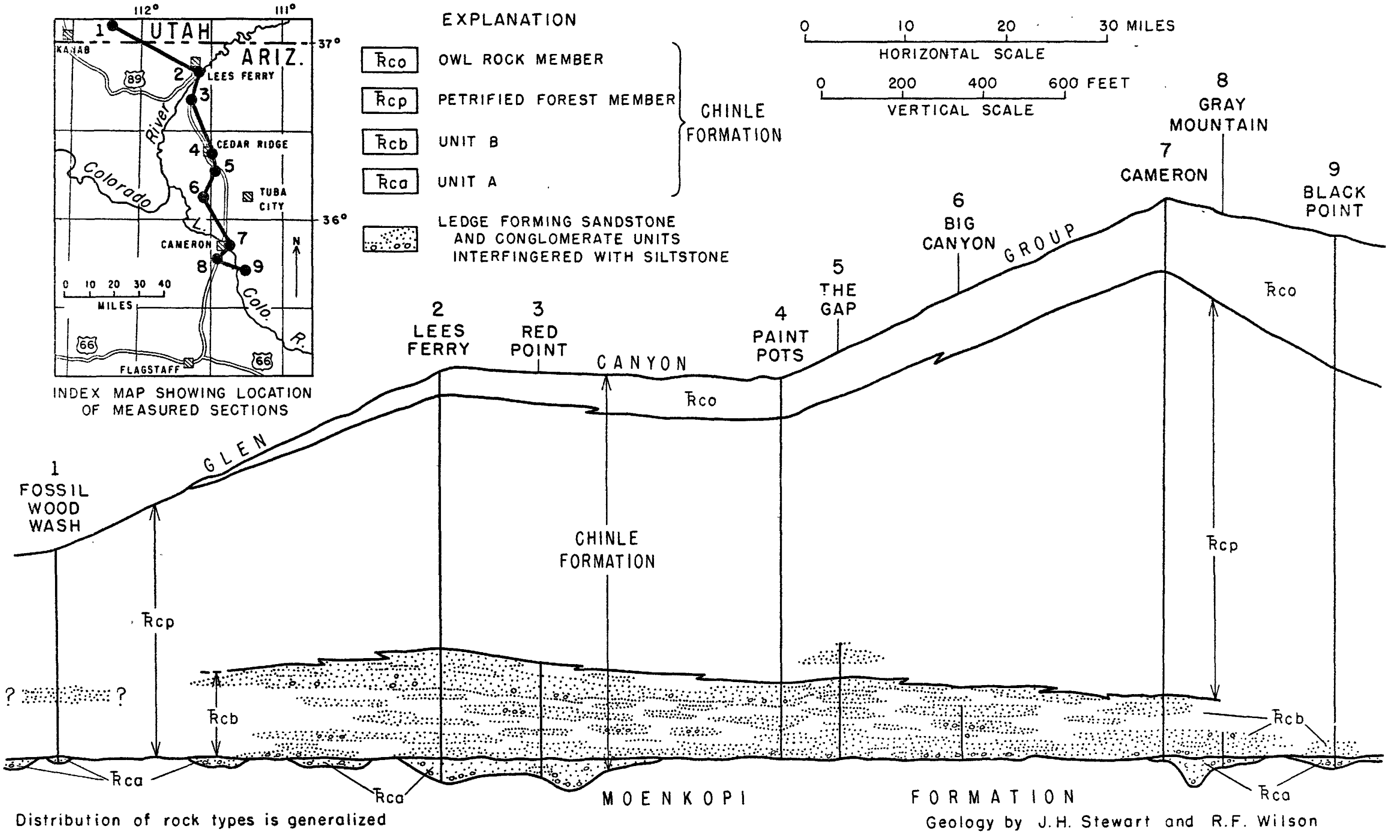
## Triassic studies

by

J. H. Stewart, F. G. Poole, and R. F. Wilson

### Chinle formation in north-central Arizona

Study during the report period has shown that the Chinle formation throughout most of north-central Arizona is divisible into four major units. The basal unit is a yellowish-gray sandstone and conglomeratic sandstone here referred to as unit A (fig. 77). The overlying unit, referred to as unit B, consists of yellowish-gray and grayish-red sandstone and conglomeratic sandstone interstratified with grayish-red and minor greenish-gray siltstone. The Petrified Forest member overlies unit B and consists of variegated bentonitic claystone and clayey sandstone. The Owl Rock member overlies the Petrified Forest member and consists of structureless red siltstone and interstratified thin beds of greenish-



Distribution of rock types is generalized

Geology by J.H. Stewart and R.F. Wilson

Fig. 77.--CORRELATIONS OF CHINLE FORMATION IN NORTH-CENTRAL ARIZONA AND SOUTH-CENTRAL UTAH.

gray and pale-red limestone.

Geologists previously working in north-central Arizona (Wanek and Stephens, 1953, and C. A. Repenning, M. E. Cooley, and J. P. Akers, written communication, 1956) did not recognize the units here referred to as units A and B, and, in most places, mapped both units collectively as the Shinarump conglomerate (now called the Shinarump member of the Chinle formation). Current mapping projects of the U. S. Geological Survey in East Vermilion Cliffs area have mapped units A and B separately.

Unit A correlates with the Shinarump member as defined in the type area near Kanab, Kane County, Utah. Unit B is laterally equivalent to strata overlying the Shinarump member in the type area and is probably best considered a separate unit or member of the Chinle formation, and not as part of the Shinarump member. Unit B has the same stratigraphic position as the Monitor Butte member of the Chinle formation in southeastern Utah, but the two units are lithologically dissimilar and are not considered to be lithologic correlatives.

Units A and B are separated on the basis of several textural and compositional differences. Unit B contains a large amount (commonly 20 percent) of interstitial silt or clay, whereas unit A contains little interstitial silt or clay. The sandstone and conglomeratic sandstone of unit B is interstratified with siltstone, whereas in unit A siltstone is rare. Unit B contains common or abundant grains of green and yellow chert (?), whereas this chert is rare in unit A. Unit B locally contains abundant grains of a white chalky material that is probably weathered or altered tuffaceous material. This material is absent in unit A. The sandstone and conglomeratic sandstone of unit B is dominantly yellowish-gray and grayish-red to grayish-red purple. The red and purple colors are commonly present as blotches or streaks in a dominant yellowish-gray rock. Unit A is dominantly yellowish-gray. Quartzite is the dominant pebble type in unit B, whereas quartz is the dominant type in unit A. Unit B contains pebbles of volcanic rocks, whereas such pebbles are rare or absent in unit A.

### Sedimentary facies of the Moenkopi formation

During the report period, sedimentary facies studies of the Moenkopi formation were completed. A preliminary facies map of the Moenkopi formation based upon ratios between different lithologic types at 67 measured sections in Nevada, Arizona, Utah, Colorado, and New Mexico is shown in figure 78.

Three principal lithologies, representing different processes of deposition, and based on those selected by McKee (1954), are differentiated in the Moenkopi formation. These lithologies are (1) cross-laminated to cusp-ripple-laminated sandstone and siltstone, (2) asymmetrical parallel- to cusp-ripple-laminated siltstone, and (3) horizontally laminated to very thick bedded siltstone, claystone, limestone, and gypsum. Cross-laminated sandstone and siltstone in the Moenkopi is believed to represent deposition from restricted currents, predominantly currents in stream channels. Parallel- to cusp-ripple-laminated siltstone probably represents deposition from unrestricted currents, such as "sheet-flow" currents on tidal flats or river flood plains. Horizontally laminated to very thick bedded siltstone, claystone, limestone, and gypsum probably represent quiet water deposition, such as in lakes and ponds on tidal flats and river flood plains, in marginal lagoons, and in marine waters. Restricted current

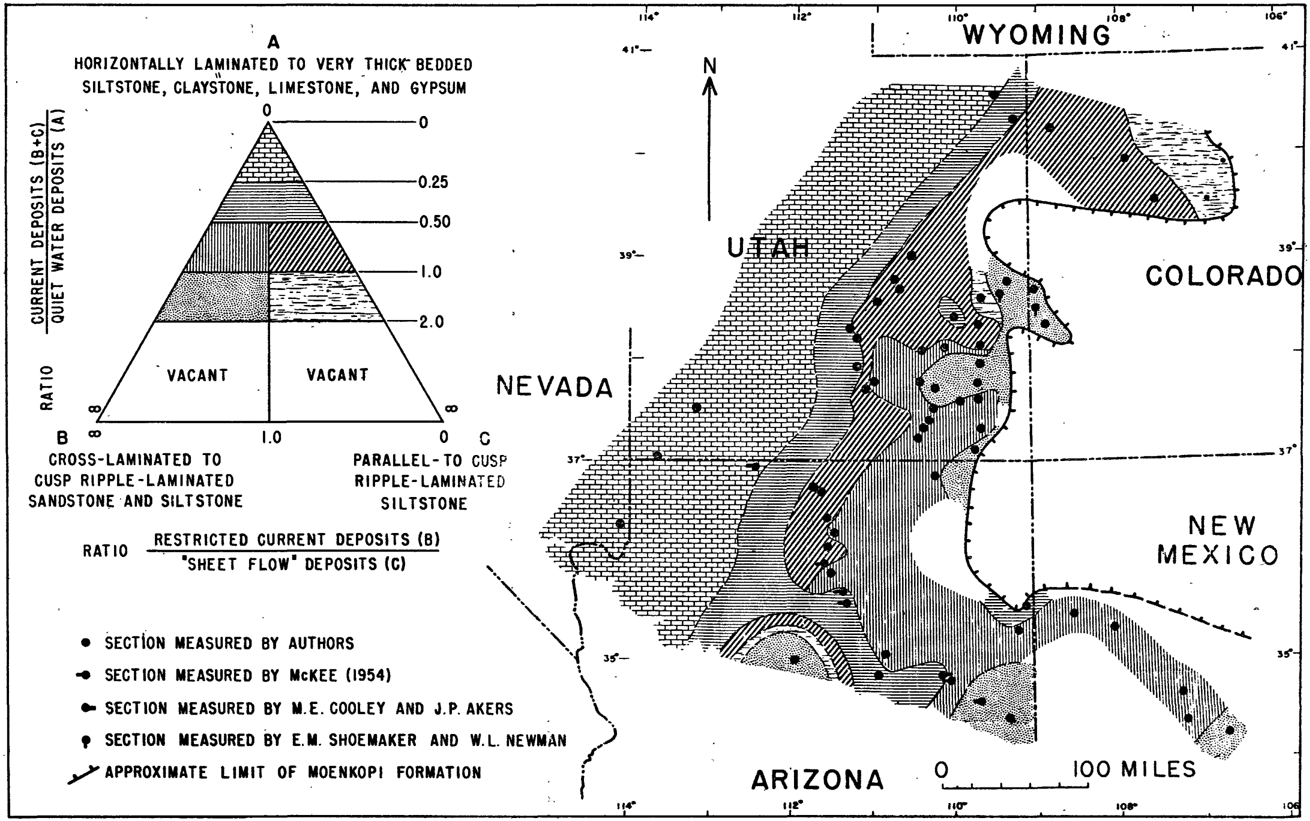


FIG. 78 .—SEDIMENTARY FACIES MAP OF THE MOENKOPI FORMATION.

deposits generally predominate closest to source areas, "sheet-flow" deposits are intermediate, and quiet water deposits predominate farthest away from source areas.

Inspection of the facies map of the Moenkopi formation reveals that multiple source areas supplied sediment to the basin in which the Moenkopi was deposited. A predominance of cross-stratified sandstone and siltstone in the Moenkopi in the salt anticline region of western Colorado and eastern Utah and in a deltaic or fan-like lobe in southeastern Utah indicate an important source east of the eastern limit of Moenkopi deposition in western and southwestern Colorado. Additional source areas in southern Arizona and New Mexico and in northern Colorado are also indicated by the facies trends. The general northwestward trend of facies from coarser stream channel deposits in the southeast to finer quiet water deposits to the northwest indicates a general northwestward trend of drainage into the Moenkopi depositional basin.

### Cross-strata studies

During the report period many cross-strata directional data were compiled and plotted on maps. Compilation of data for sandstone units of probable eolian origin ranging from Pennsylvanian through Jurassic in age has been completed. Figure 79 shows the resultant dip direction of cross-strata in sandstone units of Pennsylvanian and Permian age. Figure 80 shows the resultant dip directions of cross-strata in the Lukachukai member of the Wingate sandstone of Late Triassic age. Figure 81 shows the resultant dip directions of cross-strata in Navajo sandstone of Jurassic (?) and Jurassic age and the Aztec sandstone of Jurassic (?) age. Each arrow on the maps represents the resultant dip direction at a

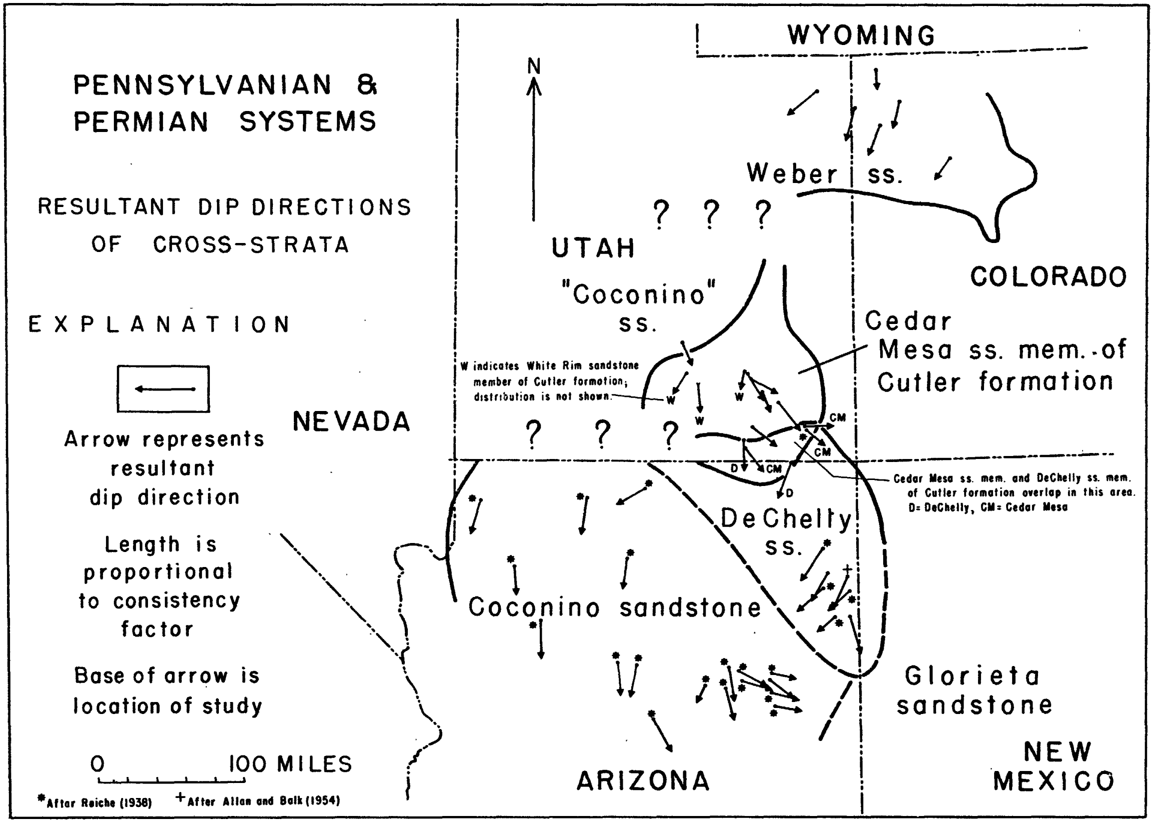


Fig. 79.--MAP OF RESULTANT DIP DIRECTIONS OF CROSS-STRATA IN SANDSTONE UNITS OF PENNSYLVANIAN AND PERMAIN AGE.

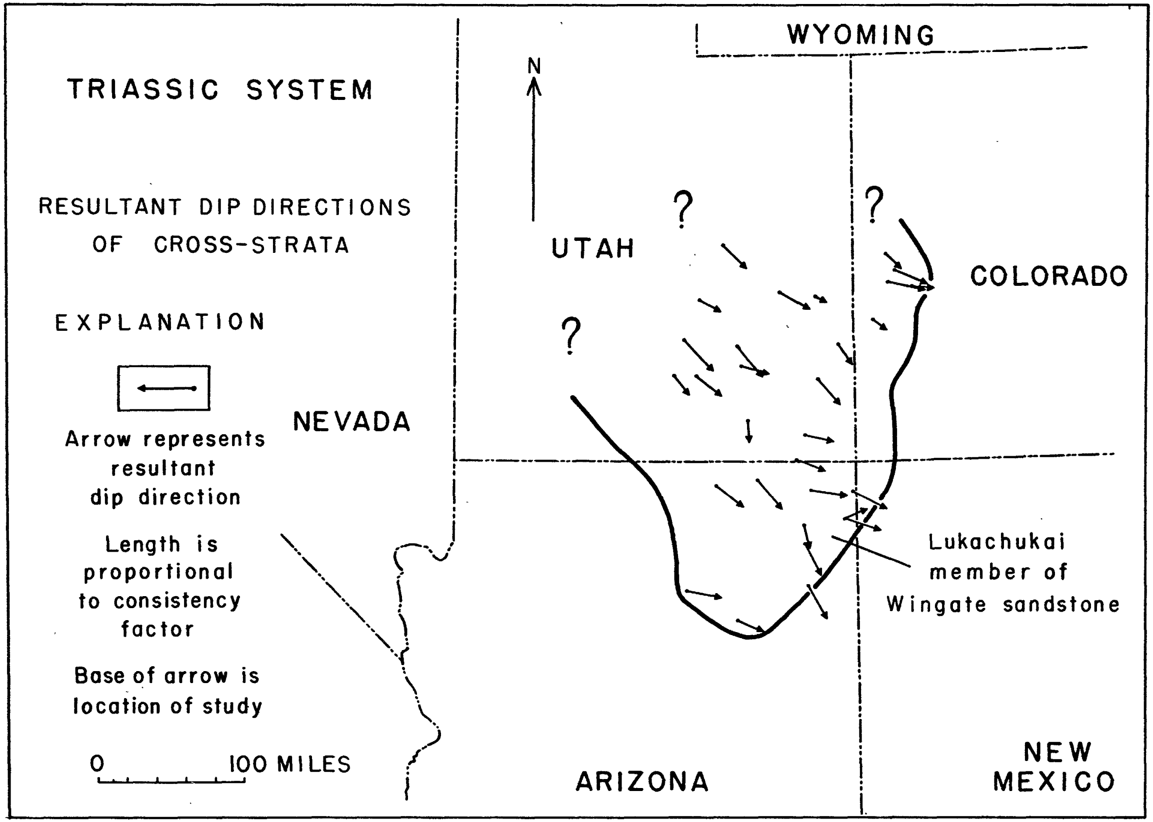


Fig. 80.--MAP OF RESULTANT DIP DIRECTIONS OF CROSS-STRATA IN LUKACHUKAI MEMBER OF WINGATE SANDSTONE OF LATE TRIASSIC AGE.

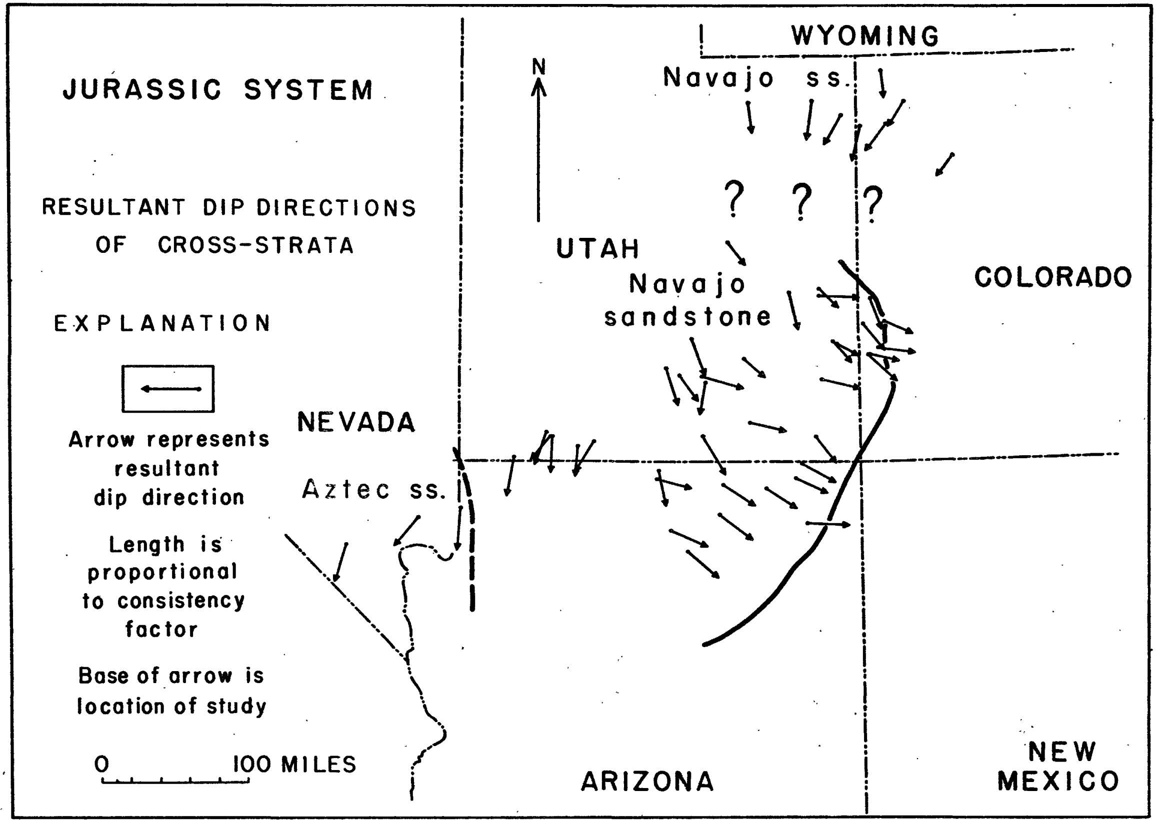


Fig. 81.--MAP OF RESULTANT DIP DIRECTIONS OF CROSS-STRATA IN NAVAJO SANDSTONE OF JURASSIC(?) AND JURASSIC AGE AND THE AZTEC SANDSTONE OF JURASSIC(?) AGE.

particular locality and is the resultant of 25 to 155 readings. The studies of Reiche (1938) shown in figure 79 represent 14 to 67 readings each. The length of the arrow is proportional to the consistency factor. The consistency factor is a measure of the spread of the readings. If all observations were identical, the consistency factor would be unity; if the vectors were disposed at random, the consistency factor would be zero. Solid lines in these illustrations are known limits of the sandstone units and the broken lines mark terminology changes for physically continuous units.

Resultant dip directions of these cross-strata are relatively constant in a southerly direction for all sandstone of probable eolian origin from Pennsylvanian through Jurassic in age. If the units are eolian, the wind directions were relatively constant throughout this entire span of time.

The following reports were published during the period:

Stewart, J. H., 1957, Proposed nomenclature of part of upper Triassic strata in southeastern Utah: Am. Assoc. Petroleum Geologists Bull., v. 41, p. 441-465.

Poole, F. G., 1957, Paleo-wind directions in late Paleozoic and early Mesozoic time on the Colorado Plateau as determined by cross-strata (abstract): Geol. Soc. America Rocky Mountain Section (10th Annual Meeting, Logan, Utah, May 1957).

## References

Allen, J. E., and Balk, Robert, 1954, Mineral Resources of Fort Defiance and Tohatchi Quadrangles, Arizona and New Mexico: State Bureau of Mines and Mineral Resources, New Mexico Institute of Mining and Technology, Bull. 36.

McKee, E. D., 1954, Stratigraphy and history of the Moenkopi formation of Triassic age: Geol. Soc. America, Mem. 61.

Reiche, Parry, 1938, An analysis of cross-laminations; the Coconino sandstone: Jour. Geol., v. 46, p. 905-932.

Wanek, A. A., and Stephens, J. G., 1953, Reconnaissance geologic map of the Kaibito and Moenkopi Plateaus and parts of the Painted Desert, Coconino County, Arizona: U. S. Geol. Survey Oil and Gas Inv. Map OM-145.

## Entrada (San Rafael) studies

by

J. C. Wright and D. D. Dickey

Studies completed in this report period have improved the understanding of the contact between the Glen Canyon and San Rafael groups in Utah and Colorado. These studies were incidental to the continuing general studies of the San Rafael group and have been aided by Geological Survey geologists mapping in the East Vermilion Cliffs, Elk Ridge, and Lisbon Valley areas, and by members of the Photogeology Section.

The sharp lithologic break between the Glen Canyon and San Rafael groups has long been recognized (Gregory and Moore, 1931, p. 61 and 71) and has been considered a possible unconformity. In central Colorado the strata equivalent to the San Rafael group truncate rocks ranging in age from Precambrian to Triassic. Near the Colorado-Utah border younger formations of the Glen Canyon group succeed each other in ascending order towards the west beneath this same surface; but because the Glen Canyon beds below and the San Rafael beds above are concordant (or nearly so) it has been impossible either to demonstrate or to disprove an unconformity or significant erosional break. In central Utah the concordance and the apparently complete stratigraphic succession from the Navajo sandstone of the Glen Canyon group to the Carmel formation of the San Rafael group has prevented the recognition of an unconformity, if one exists.

Recent geologic mapping in central Utah has shown that scattered white, gray, and pink angular clastic granules and pebbles of chert are widely disseminated on the top surface of the Navajo sandstone and also occur locally in the basal few feet of the Carmel formation where the Navajo sandstone has been reworked. The angularity of the pebbles and granules indicates that they were transported a few miles at most, although in most of central Utah no possible local source of the chert is known.

Near Seven Mile Canyon, northwest of Moab, Utah, abundant authigenic chert occurs in a widespread thin limestone bed in the upper part of the Navajo sandstone. Such limestone beds have been interpreted as fresh water deposits in ephemeral basins between sand dunes (Gilluly and Reeside, 1928, p. 72). The chert within this bed forms irregular, horizontally elongated red or pink masses a few inches thick and as much as a foot or more in length.

At one outcrop of this limestone bed the contact of the Navajo sandstone with beds of the San Rafael group is distinctly uneven. The highest point on the contact--more than 30 feet above the general level of the contact--is an ancient flat-topped hill, protected from deeper erosion by a layer of limestone 5 feet thick. As noted above, this limestone probably formed in a low basin between dunes; but by the end of an erosion cycle prior to the deposition of the San Rafael beds, its topographic position was inverted from basin to hilltop. This geomorphically anomalous feature has been preserved by burial beneath the younger San Rafael rocks and it is now re-exposed on a cliff face. The ancient inverted topography indicates pre-San Rafael erosion in this area of at least 30 feet and suggests even deeper erosion.

Abundant angular, pale-pink and white clastic chert is strewn down the sides of the ancient hill along the present upper surface of the Navajo sandstone. This chert quite obviously has been derived from erosion and weathering of authigenic chert from an eroded portion of the limestone bed. Sufficient time must have elapsed between the deposition and later erosion of the limestone to allow the accretion and hardening of the authigenic chert. During or after erosion of the limestone, but before burial by the San Rafael beds, enough time elapsed to allow for the weathering and bleaching of the red authigenic chert to the pale-white color which is predominant in the clastic chert.

No other source has been recognized for the widespread clastic chert that is present at this contact throughout eastern Utah. It therefore seems probable that most of the chert was derived from erosion of other similar limestone beds in the upper part of the Navajo sandstone. Because the presumed source beds are scarce in most of eastern Utah, it seems reasonable to assume a general depth of erosion somewhat greater than that observed at Seven Mile Canyon; an erosion depth of approximately 50 to 100 feet is considered reasonable.

Erosion at this unconformity has removed rock systems in central Colorado; has cut away formations of the Glen Canyon group along the Colorado-Utah border; and has removed a significant thickness of the Navajo sandstone in much of eastern Utah, where the chief evidence for it is a sharp contact and an accumulation of scattered residual weathered white chert. Towards central Utah its erosional significance continues to diminish, and in southwestern Utah an entirely conformable sequence is indicated by interbedding of the Navajo and Carmel formations.

## References

Gilluly, James, and Reeside, J. B., Jr., 1928, Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U. S. Geol. Survey Prof. Paper 150, p. 61-110.

Gregory, H. E., and Moore, R. C., 1931, The Kaiparowitz region, a geographic and geologic reconnaissance of parts of Utah and Arizona: U. S. Geol. Survey Prof. Paper 164, 161 p.

## Lithologic Studies
by
R. A. Cadigan

Studies to date suggest the existence of compositional differences between the upper part of the Cutler formation and the lower part of the overlying Dolores formation and between the upper and lower parts of the Dolores formation in southwestern Colorado.

A series of 13 samples taken at Stoner, Colorado, from the Dolores formation and the upper 460 feet of the Cutler formation were analyzed for texture and composition. The texture analysis was a statistical analysis of the phi (logarithmic) grain size distribution of the disaggregated rock. Particles were classed for size by means of sieve and pipette methods. Textural properties relating to size were computed from the first four statistical moments of the phi grain size distribution. Composition was estimated from 500 point-counts made on a thin section from each of the 13 samples. Potash feldspars were stained with sodium cobaltinitrite for ease of identification.

Table 18 lists summaries of the phi grain size distribution together with their respective calculated parameters. Table 19 lists the percentage composition of the respective thin sections with the mineral and rock fragment percentages grouped and combined into arbitrary sedimentary rock

Table 18. Summary of statistical properties of the phi grain size distribution of rock samples from Stoner, Colorado

| Sample No. | Parameters of the phi grain size distribution | | | | | | Grain size distribution by percentiles in phi units | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean (mm.) | Mode (mm.) | Median (mm.) | Standard deviation | Skewness | Kurtosis | $P_2$ | $P_5$ | $P_{16}$ | $P_{50}$ | $P_{84}$ | $P_{95}$ | $P_{98}$ |
| Dolores formation | | | | | | | | | | | | | |
| L2088 | 0.030 | 0.053 | 0.041 | 1.522 | 0.982 | 3.940 | 3.61 | 3.83 | 4.12 | 4.63 | 5.84 | 8.56 | 10.56 |
| 2087 | 0.029 | 0.038 | 0.039 | 1.579 | 1.031 | 3.922 | 3.43 | 3.73 | 4.17 | 4.70 | 5.88 | 9.12 | 11.80 |
| 2086 | 0.032 | 0.038 | 0.041 | 1.641 | 0.865 | 3.083 | 3.13 | 3.43 | 3.81 | 4.64 | 6.02 | 8.66 | 11.36 |
| 2085 | 0.033 | 0.038 | 0.046 | 1.599 | 1.103 | 4.655 | 3.42 | 3.72 | 3.96 | 4.45 | 5.57 | 9.28 | 11.68 |
| 2084 | 0.038 | 0.075 | 0.057 | 1.901 | 0.921 | 2.728 | 2.91 | 3.07 | 3.41 | 4.14 | 9.82 | 10.55 | 13.07 |
| 2083 | 0.046 | 0.075 | 0.068 | 1.847 | 0.896 | 2.824 | 2.59 | 2.82 | 3.13 | 3.89 | 5.67 | 9.09 | 10.77 |
| 2082 | 0.067 | 0.126 | 0.098 | 1.675 | 1.076 | 4.792 | 2.44 | 2.63 | 2.98 | 3.36 | 4.78 | 8.04 | 9.78 |
| 2081 | 0.056 | 0.063 | 0.072 | 1.769 | 0.937 | 3.585 | 2.44 | 2.66 | 2.98 | 3.82 | 5.27 | 8.52 | 10.69 |
| Cutler formation | | | | | | | | | | | | | |
| L2080 | 0.256 | 0.597 | 0.387 | 2.262 | 0.943 | 3.817 | -0.48 | -0.25 | -0.34 | 1.38 | 3.49 | 7.20 | 10.02 |
| 2079 | 0.031 | 0.038 | 0.041 | 1.503 | 1.107 | 4.939 | 3.64 | 3.81 | 4.14 | 4.62 | 5.69 | 9.02 | 10.75 |
| 2078 | 0.114 | 0.211 | 0.147 | 1.843 | 1.009 | 5.198 | 1.01 | 1.23 | 1.66 | 2.78 | 4.17 | 6.83 | 10.95 |
| 2077 | 0.057 | 0.126 | 0.076 | 1.925 | 0.781 | 2.533 | 1.86 | 2.10 | 2.57 | 3.74 | 5.54 | 8.54 | 11.13 |
| 2076 | 0.168 | 0.251 | 0.233 | 1.919 | 1.122 | 6.028 | 0.56 | 0.77 | 1.22 | 2.11 | 3.64 | 6.58 | 10.70 |

Table 19. Percentage mineral composition of 13 thin sections from the Cutler and Dolores formations (total rock), Stoner, Colorado

| | Sample numbers | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cutler formation | | | | | Dolores formation | | | | | | | |
| | 2076 | 2077 | 2078 | 2079 | 2080 | 2081 | 2082 | 2083 | 2088 | 2087 | 2086 | 2085 | 2084 |
| **Chemical components excluding silica** | | | | | | | | | | | | | |
| Calcite and dolomite plus minor amounts of barite, gypsum etc. | .2 | 18.2 | 12.0 | 32.0 | 24.0 | 41.6 | 10.8 | 22.0 | 21.8 | 18.6 | 37.0 | 24.8 | 39.6 |
| Red interstitial iron oxides | 2.2 | 15.6 | 6.4 | 1.6 | 1.0 | 5.6 | 2.2 | .2 | .4 | .4 | - | - | 10.8 |
| Totals | 2.4 | 33.8 | 18.4 | 33.6 | 25.0 | 47.2 | 13.0 | 22.2 | 22.2 | 19.0 | 37.0 | 24.8 | 50.4 |
| **Siliceous components** | | | | | | | | | | | | | |
| Quartz grains and overgrowths | 46.8 | 34.4 | 38.0 | 41.2 | 31.4 | 30.8 | 51.2 | 39.6 | 45.6 | 56.6 | 40.6 | 53.8 | 37.0 |
| Quartz fragments | .2 | - | .4 | - | .4 | .4 | .4 | .6 | - | - | - | - | - |
| Chert, detrital | .4 | .4 | .6 | .8 | .2 | .8 | 1.2 | 1.0 | .2 | .2 | - | .2 | .4 |
| Chert, chalcedony, interstitial | - | - | .8 | - | - | - | - | - | - | - | - | - | - |
| Totals | 47.4 | 34.8 | 39.8 | 42.0 | 32.0 | 32.0 | 52.8 | 41.2 | 45.8 | 56.8 | 40.6 | 54.0 | 37.4 |
| **Feldspar and feldspar-derived components** | | | | | | | | | | | | | |
| Potash feldspar | 20.2 | 12.2 | 15.6 | 4.2 | 19.6 | .2 | .6 | .6 | 13.6 | 7.6 | 6.6 | 2.4 | .4 |
| Plagioclase feldspar | 26.4 | 16.0 | 19.8 | 9.4 | 19.4 | 11.4 | 23.0 | 17.2 | 8.6 | 11.0 | 10.0 | 16.8 | 9.8 |
| Kaolinite and kaolinitic clays | .6 | .6 | 1.8 | - | 3.0 | - | .4 | .2 | - | - | - | - | - |
| Totals | 47.2 | 28,8 | 37.2 | 13.6 | 42.0 | 11.6 | 24.0 | 18.0 | 22.2 | 18.6 | 16.6 | 19.2 | 10.2 |

Table 19.—Continued

| | Sample numbers | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cutler formation | | | | | Dolores formation | | | | | | | |
| | 2076 | 2077 | 2078 | 2079 | 2080 | 2081 | 2082 | 2083 | 2088 | 2087 | 2086 | 2085 | 2084 |
| Dark mineral and rock fragments and related material | | | | | | | | | | | | | |
| Mica | 2.6 | 1.6 | 2.0 | 3.4 | .2 | 1.0 | 2.4 | 2.0 | .8 | 1.6 | .2 | - | .6 |
| Illite and micaceous clays | - | .2 | .6 | 4.6 | - | 1.2 | 4.6 | 13.0 | 7.8 | 3.2 | - | .6 | - |
| Micaceous and basaltic rock fragments | - | - | - | .4 | - | 2.8 | .2 | .2 | - | - | - | - | - |
| "Heavy minerals" | - | .4 | - | 1.0 | - | .4 | .2 | .2 | .2 | - | .6 | .6 | .6 |
| Miscellaneous | .2 | .2 | .2 | .6 | .4 | .6 | - | .8 | .4 | .2 | .6 | .2 | .4 |
| Totals | 2.8 | 2.4 | 2.8 | 10.0 | .6 | 6.0 | 7.4 | 16.2 | 9.2 | 5.0 | 1.4 | 1.4 | 1.6 |
| Volcanic components | | | | | | | | | | | | | |
| Altered tuff and felsitic rock fragments | .2 | .2 | 1.8 | - | .2 | 2.2 | 1.2 | 2.4 | .6 | .4 | .6 | .4 | .4 |
| Montmorillonite and montmorillonitic clays | - | - | - | .8 | .2 | 1.0 | 1.6 | - | - | .2 | 3.8 | .2 | - |
| Totals | .2 | .2 | 1.8 | .8 | .4 | 3.2 | 2.8 | 2.4 | .6 | .6 | 4.4 | .6 | .4 |

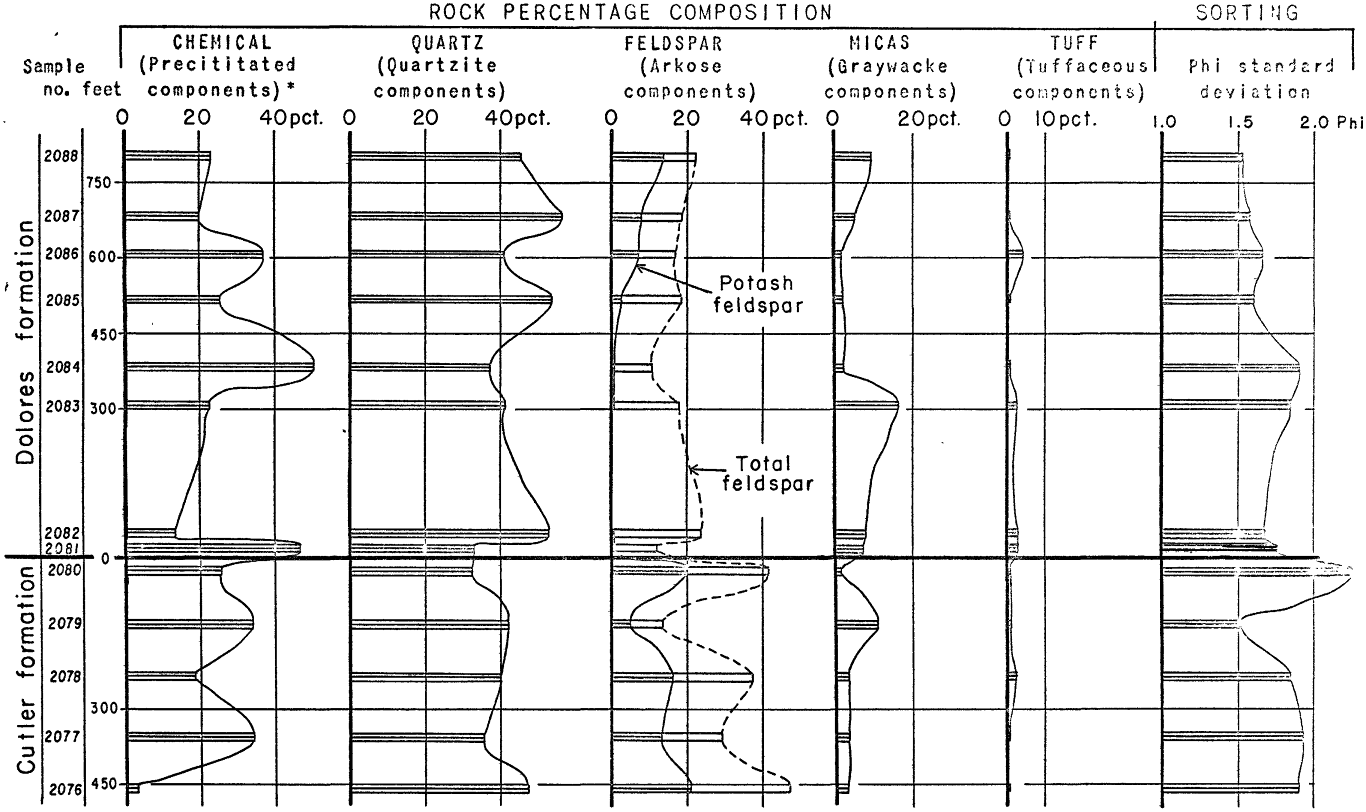
Table 20. Percentage detrital mineral composition of 13 thin sections from the Cutler and Dolores formations, Stoner, Colorado

| | Sample numbers | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cutler formation | | | | | Dolores formation | | | | | | | |
| | 2076 | 2077 | 2078 | 2079 | 2080 | 2081 | 2082 | 2083 | 2084 | 2085 | 2086 | 2087 | 2088 |
| **Siliceous components** | | | | | | | | | | | | | |
| Quartz grains and overgrowths | 48.0 | 52.0 | 46.5 | 62.0 | 41.9 | 58.3 | 58.9 | 50.9 | 74.6 | 71.5 | 64.4 | 69.9 | 58.6 |
| Quartz fragments | .2 | - | .5 | - | .5 | .8 | .5 | .8 | - | - | - | - | - |
| Chert, detrital | .4 | .6 | .7 | 1.2 | .3 | 1.5 | 1.4 | 1.3 | .8 | .3 | - | .2 | .3 |
| Chert, chalcedony, interstitial | - | - | 1.0 | - | - | - | - | - | - | - | - | - | - |
| Totals | 48.6 | 52.6 | 48.8 | 63.2 | 42.7 | 60.6 | 60.8 | 53.0 | 75.4 | 71.8 | 64.4 | 70.1 | 58.9 |
| **Feldspar and feldspar-derived components** | | | | | | | | | | | | | |
| Potash feldspar | 20.7 | 18.4 | 19.1 | 6.3 | 26.1 | .4 | .7 | .8 | .8 | 3.2 | 10.5 | 9.4 | 17.5 |
| Plagioclase feldspar | 27.0 | 24.2 | 24.3 | 14.2 | 25.9 | 21.6 | 26.4 | 22.1 | 19.8 | 22.3 | 15.9 | 13.6 | 11.1 |
| Kaolinite and kaolinitic clays | .6 | .9 | 2.2 | - | 4.0 | - | .5 | .3 | - | - | - | - | - |
| Totals | 48.3 | 43.5 | 45.6 | 20.5 | 56.0 | 22.0 | 27.6 | 23.2 | 20.6 | 25.5 | 26.4 | 23.0 | 28.6 |
| **Dark mineral and rock fragments and related material** | | | | | | | | | | | | | |
| Mica | 2.7 | 2.4 | 2.5 | 5.1 | .3 | 1.9 | 2.8 | 2.6 | 1.2 | - | .3 | 1.9 | 1.0 |
| Illite and mica clays | - | .3 | .7 | 6.9 | - | 2.3 | 5.3 | 16.7 | - | .8 | - | 4.0 | 10.0 |
| Micaceous and basaltic rock fragments | - | - | - | .6 | - | 5.3 | .2 | .3 | - | - | - | - | - |
| "Heavy minerals" | - | .6 | - | 1.5 | - | .8 | .2 | .3 | 1.2 | .8 | 1.0 | - | .3 |
| Miscellaneous | .2 | .3 | .2 | .9 | .5 | 1.1 | - | 1.0 | .8 | .3 | 1.0 | .2 | .5 |
| Totals | 2.9 | 3.6 | 3.4 | 15.0 | .8 | 11.4 | 8.5 | 20.9 | 3.2 | 1.9 | 2.3 | 6.1 | 11.8 |
| **Volcanic components** | | | | | | | | | | | | | |
| Altered volcanic material and felsitic rock fragments | .2 | .3 | 2.2 | - | .3 | 4.2 | 1.4 | 3.1 | .8 | .5 | 1.0 | .5 | .8 |
| Montmorillonite and montmorillonitic clays | - | - | - | 1.2 | .3 | 1.9 | 1.8 | - | - | .3 | 6.0 | .2 | - |
| Totals | .2 | .3 | 2.2 | 1.2 | .6 | 6.1 | 3.2 | 3.1 | .8 | .8 | 7.0 | .7 | .8 |

components. Table 20 is similar to table 19 except that mineral and rock fragment percentages are recomputed as percent of detrital components instead of percent of total rock, for purposes of rock classification.

Figure 82 is a graphic illustration of relative proportions of the different rock components: chemical (precipitated components excluding silica), quartz (siliceous components including precipitated silica), feldspar and kaolinitic clays, dark mineral and rock components, and volcanic components. Plotted with the rock composition is the phi standard deviation, the grain size parameter which measures the degree of sorting and thus reflects in some respects the conditions of deposition. Figure 83 is a refinement of figure 82 and shows graphically the relative proportions of the detrital components only, exclusive of the chemical components. Plotted with the detrital component percentages are two measures of the average grain size: the mean, which is the computed average grain size; and the mode, which approximates the visually observed average grain size.

The most conspicuous difference between the Cutler and Dolores formations is the change in potash feldspar content across the contact. It decreases from an average of 17.2 percent in the first three samples below the contact to 0.6 percent in the first three samples above the contact. The two closest Cutler and Dolores samples are separated by a distance of 30 feet, each being 15 feet from the contact. The evidence indicates that any reworking of the Cutler that may have occurred does not effect the sediments 15 feet above the contact. The average plagioclase feldspar content for the same samples is 21.4 percent for the Cutler and 23.3 percent for the Dolores, which is not a significant difference.



*excluding silica

Fig. 82 .--TOTAL ROCK (precipitated plus detrital components) PERCENTAGE COMPOSITION, AND SORTING MEASURED BY THE STANDARD DEVIATION OF THE PHI DISTRIBUTION OF THE GRAIN SIZE, IN THE UPPER PART OF THE CUTLER FORMATION OF PERMIAN AGE AND THE DOLORES FORMATION OF TRIASSIC AGE, STONER, MONTEZUMA COUNTY, COLO.

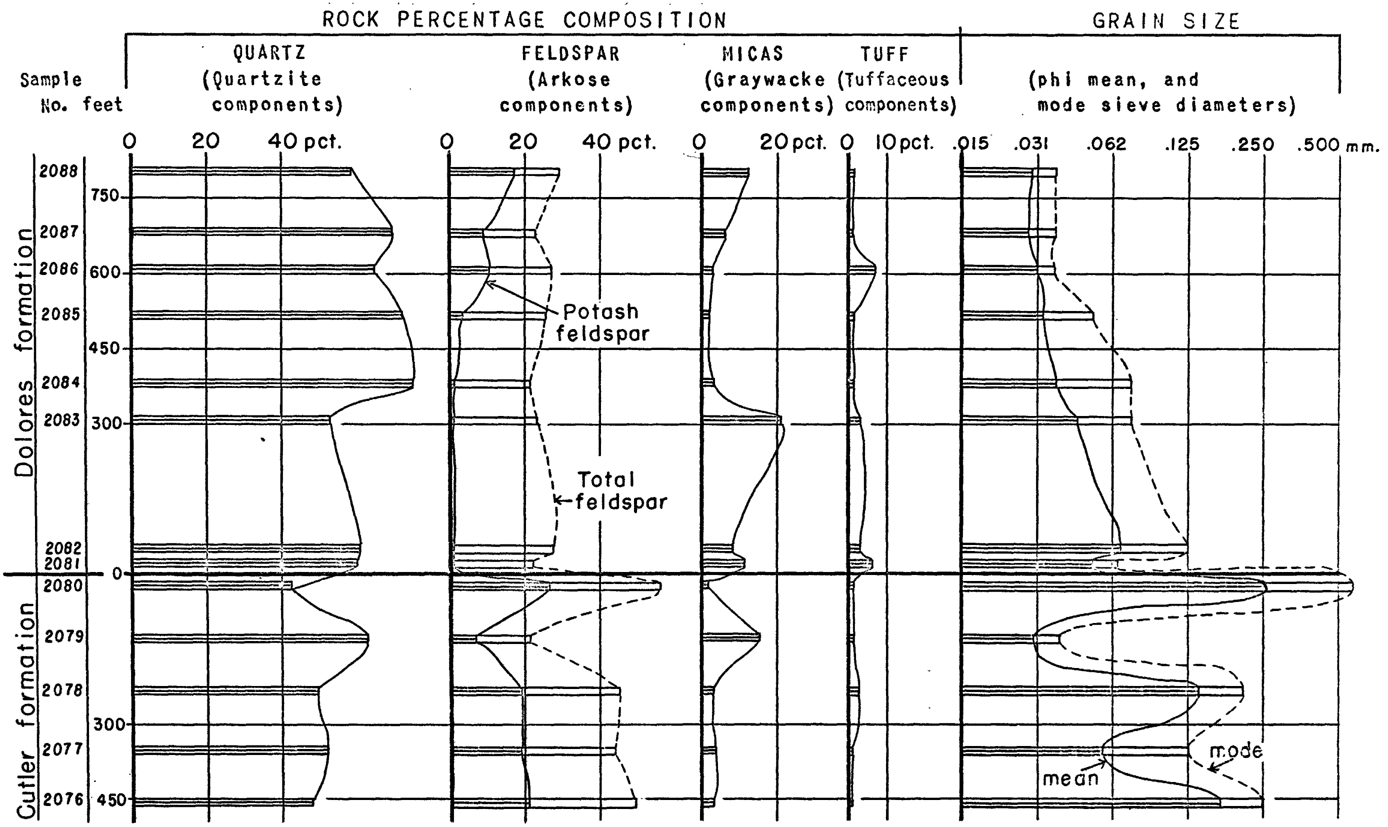


Fig. 83.--ROCK (detrital components) PERCENTAGE COMPOSITION AND GRAIN SIZE AS MEASURED BY MEAN AND MODE DIAMETERS OF THE PHI GRAIN SIZE DISTRIBUTION, IN THE CUTLER FORMATION OF PERMIAN AGE AND THE DOLORES FORMATION OF TRIASSIC AGE, STONER, MONTEZUMA COUNTY, COLO.

Two possibilities were considered as an explanation for the loss of potash feldspar; first, that a relationship existed between texture and potash feldspar content, and that a change in texture across the contact could be reflected in a change in feldspar content; second, that a change which would reflect a change in source areas occurred, i.e., that the lower sediments of the Dolores had a different source than the sediments of the upper Cutler in the Stoner, Colorado area.

A comparison of the sorting of the six samples closest to the contact gives an average standard deviation of 1.869 for the upper three samples in the Cutler compared with 1.763 for the samples from the lower Dolores formation, which is very little difference. However, the graph of sorting on figure 82 shows a wider range of variation in sorting in the uppermost Cutler than in the lower Dolores.

A comparison of the average grain size of the six samples closest to the contact gives an average of 0.136 and 0.281 mm. for the mean and mode diameters in the samples of the Cutler and an average of 0.056 and 0.088 for the mean and mode diameters in the samples of the Dolores, a relatively large difference. From a comparison of the grain size curves and feldspar curves at the top of the Cutler and at the bottom of the Dolores in figure 83, it appears that a good positive correlation exists. However, in the Cutler, the amount of potash feldspar bears a rough direct ratio (average 1:1.4) to the amount of plagioclase present and this relationship is not carried over into the Dolores.

It is concluded that the cause for the difference between the sediments of the upper Cutler and the lower Dolores, as measured by the difference in potash feldspar content, is a difference in areas of provenance.

Further examination of figures 82 and 83 reveals gradual but significant changes in the upper part of the Dolores formation. In the upper four samples, potash feldspar is present in significant quantities and upwards gradually constitutes a greater part of the total feldspar. Sorting gradually increases upwards (decreasing standard deviation), the grain size decreases, and the mica content increases.

The changes may be interpreted as signifying a change in source areas; a slowly decreasing rate of deposition, as indicated by the decrease in standard deviation; and a decreasing inflow of sediments, as indicated by the combined decrease in standard deviation and decreasing grain size.

Potash feldspars present are both orthoclase and microcline. Plagioclase consists of both twinned (albite twinning) and untwinned grains which vary in composition from albite-oligoclase to oligoclase-andesine. No changes in the plagioclase varieties were detected between the Cutler and the Dolores formations at Stoner.

The rocks studied in the Stoner section may be classified as follows:

| Dolores formation | | Cutler formation | |
|---|---|---|---|
| Sample No. | Classification | Sample No. | Classification |
| L2088 | arkose | L2080 | calcareous arkose |
| L2087 | feldspathic orthoquartzite | L2079 | calcareous feldspathic orothoquartzite |
| L2086 | calcareous arkose | L2078 | arkose |
| L2085 | calcareous arkose | L2077 | calcareous arkose |
| L2084 | feldspathic orthoquartzitic limestone | L2076 | arkose |
| L2083 | graywacke | | |
| L2082 | arkose | | |
| L2082 | calcareous feldspathic orthoquartzite | | |

Note: Term "calcareous" indicates about 25 percent to about 50 percent calcite and/or dolomite.

A brief investigation was made at Big Indian Wash in eastern Utah to determine the variety of plagioclase present in the top of the Cutler formation and the immediately overlying basal sandstone of the Chinle formation, which is the host rock for uranium deposits. Thin sections for the study were obtained from E. G. Gross, petrographer, U. S. Atomic Energy Commission. The sections were unstained and were taken from three samples of "bleached" basal Chinle ore-bearing sandstone, two samples of sandstone of the uppermost Cutler, and two samples of red siltstone or sandstone of the Chinle above the "bleached" ore zone.

Composition estimates listed in table 21 below are based on only 200 point-counts per thin section. No attempt was made to recognize different varieties of feldspar during the count.

Table 21. Estimated percentage composition of thin sections of the Chinle and Cutler formations, Big Indian Wash, Utah.

| Sample No. | Formation | Total Feldspar | Quartz | Carbonates | Montmorillonite-illite-chlorite clays | Other Minerals |
|---|---|---|---|---|---|---|
| In principal mining area | | | | | | |
| 43652 | Chinle ("bleached") | 19.5 | 52.5 | 15.0 | 11.5 | 1.5 |
| 43684 | Chinle (red) | 14.5 | 48.5 | 22.0 | 7.0 | 8.0 |
| 43653 | Chinle ("bleached") | 21.0 | 44.5 | 14.5 | 13.5 | 6.5 |
| 43654 | Cutler | 19.5 | 47.5 | 28.0 | 3.5 | 1.5 |
| South of principal mining area | | | | | | |
| 43694 | Chinle (red) | 8.0 | 51.5 | 25.5 | 12.0 | 3.0 |
| 43676 | Chinle ("bleached") | 17.5 | 71.6 | 4.5 | 4.0 | 3.0 |
| 43677 | Cutler | 20.5 | 67.5 | 0 | 9.5 | 2.5 |

Due to the wide variation within sections no significant difference in feldspar content among the thin sections was observed except for section 43694, which has significantly less feldspar than the others.

The thin sections of "bleached" rocks of the Chinle appear to reflect closely the total feldspar content of the underlying Cutler; the sections of rocks of the red Chinle are less similar. Thin sections of "bleached" rocks in the mining area contain more illite-montmorillonite-chlorite clays than the "bleached" rocks sampled away from the mining area.

The extinction angles of 10 albite-twinned plagioclase grains in each section except sample no. 43652 were measured according to the Michel-Levy method. All grains checked for optical sign were found to be negative. The maximum extinction angles in each section range from 12° to 21°. It was concluded that the composition of the basal sediments of the Chinle formation and underlying beds of the Cutler with regard to albite-twinned plagioclase was the same. The composition of the plagioclase is estimated to lie in the $Ab^{70}$ $An^{30}$ to $Ab^{60}$ $An^{40}$ range-oligoclase and andesine.

## Regional synthesis studies

Regional synthesis studies include the compilation and synthesization of all available geologic and economic data on known uranium deposits of the Colorado Plateau and their relations to stratigraphic units, lithologic character of host rocks, tectonic structures, and geochemical environment. Such syntheses make possible comprehensive appraisals of the uranium resources of the region, lead to the recognition of regional controls of ground favorable for ore deposits, and point to areas in which combinations of geolgic factors suggest the presence of concealed ore deposits.

Results of work in two large areas of the Plateau are reported below.

## Northwest New Mexico, by L. S. Hilpert and A. F. Corey.

During the report period special attention was focused on the stratigraphic and structural relations of the uranium deposits in the Morrison formation of Jurassic age in the Ambrosia Lake area, McKinley County, New Mexico (fig. 84). Although this area contains a large part of the uranium reserves of the Colorado Plateau, the geologic relations of the deposits are not well understood and have been the subject of considerable controversy among geologists.

The significant uranium deposits between Gallup and Laguna, including those at Ambrosia Lake, are in sedimentary rocks that dip generally northward at a low angle and form an almost continuous outcrop for about 80 miles, extending from Gallup to the west side of the Rio Grande Valley. Locally the rocks are broadly folded and broken by high-angle faults. North of U. S. Highway 66, between the towns of Grants and Laguna, the sedimentary rocks are largely buried by the lavas of the Mount Taylor volcanic field (fig. 85).

The sequence of sedimentary rocks containing the deposits is, from oldest to youngest, the Todilto limestone, the Summerville formation, a unit tentatively called the Bluff sandstone, and the Morrison formation, all of Jurassic age; and the Dakota sandstone of Cretaceous age. The Dakota sandstone unconformably overlies the older rocks and crops out along the margin of the area underlain by post-Jurassic rocks (fig. 85).

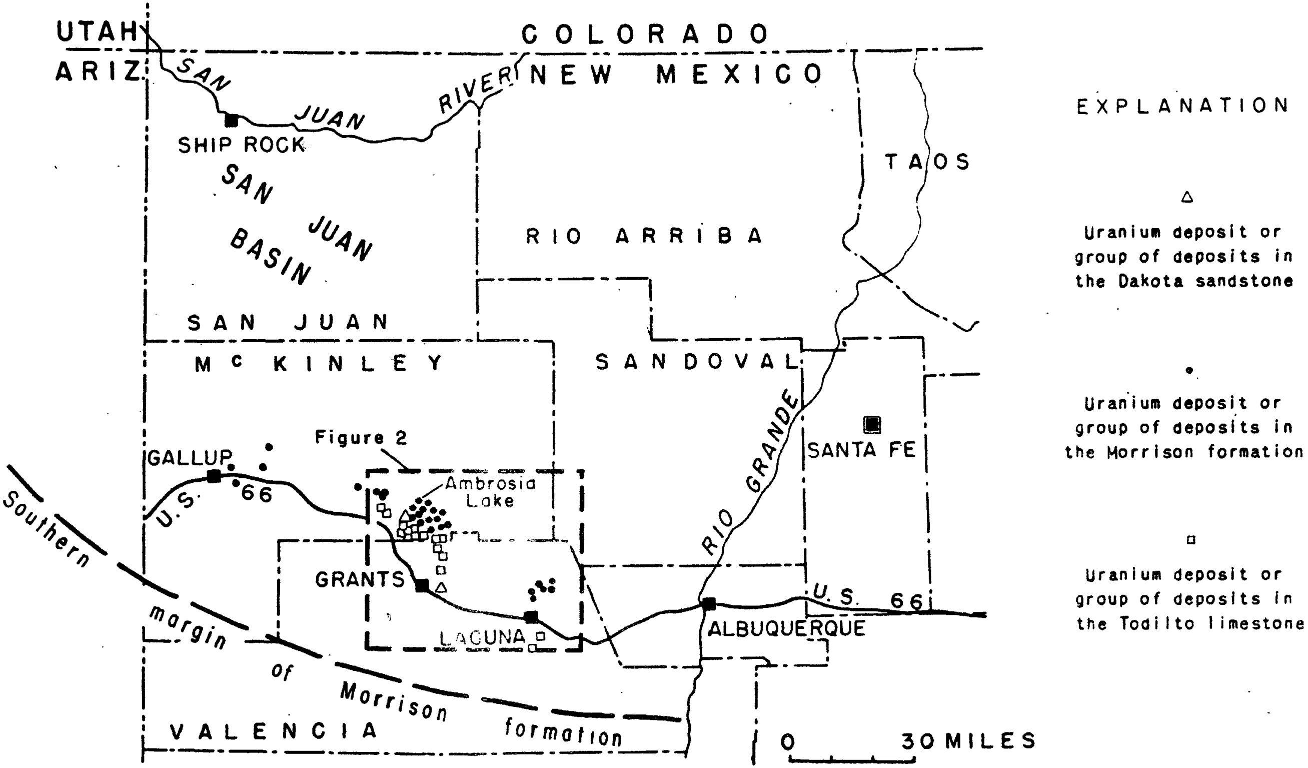


Fig. 84.--MAP OF NORTHWESTERN NEW MEXICO SHOWING URANIUM DEPOSITS BETWEEN GALLUP AND LAGUNA AND SOUTHERN MARGIN OF MORRISON FORMATION.

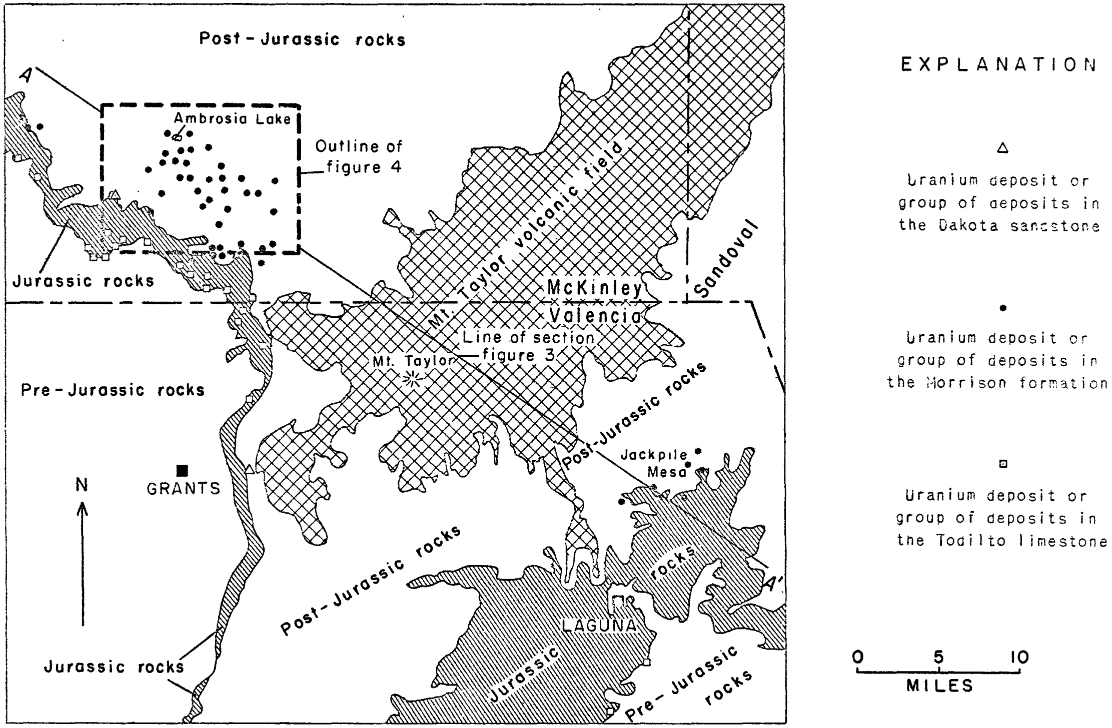


Fig 85 .--Geologic map showing uranium deposits and index of figures 86 and 87, Grants-Laguna area, New Mexico

The uranium deposits occur principally in the Todilto limestone, Dakota sandstone, and Morrison formation. The largest deposits are in the Morrison formation immediately north of Grants in the Ambrosia Lake area, and north of Laguna in the vicinity of Jackpile Mesa. The general stratigraphic relations of the units of the Morrison formation between these two areas are shown on the cross section, figure 86.

The Morrison formation consists, from base to top, of the Recapture, Westwater Canyon, and Brushy Basin members (fig. 86).

The Recapture member is a fine- to medium-grained friable sandstone that contains some beds of silty claystone. It ranges from about 20 to 170 feet in thickness and contains distinctive alternating light-gray and reddish-brown units 5 to 10 feet thick.

The Westwater Canyon member is a fine- to coarse-grained locally conglomeratic sandstone that contains discontinuous lenses of grayish-green claystone, and is characterized by trough-type crossbedding. The Westwater Canyon ranges from yellowish-gray to light grayish-red in color and in thickness from a knife edge to about 300 feet. It interfingers with the underlying Recapture and the overlying Brushy Basin members. In the eastern part of the area it is locally absent, and there the Brushy Basin rests directly on the Recapture member.

The Brushy Basin member consists of partly variegated but dominantly light greenish-gray claystone with thin hard green sandstone beds, and, locally, thick sandstone units lithologically similar to the sandstone units in the Westwater Canyon member. The Brushy Basin ranges in thickness from a knife edge near Gallup to about 375 feet north of Laguna. The range in thickness is partly the result of broad deformation and erosion

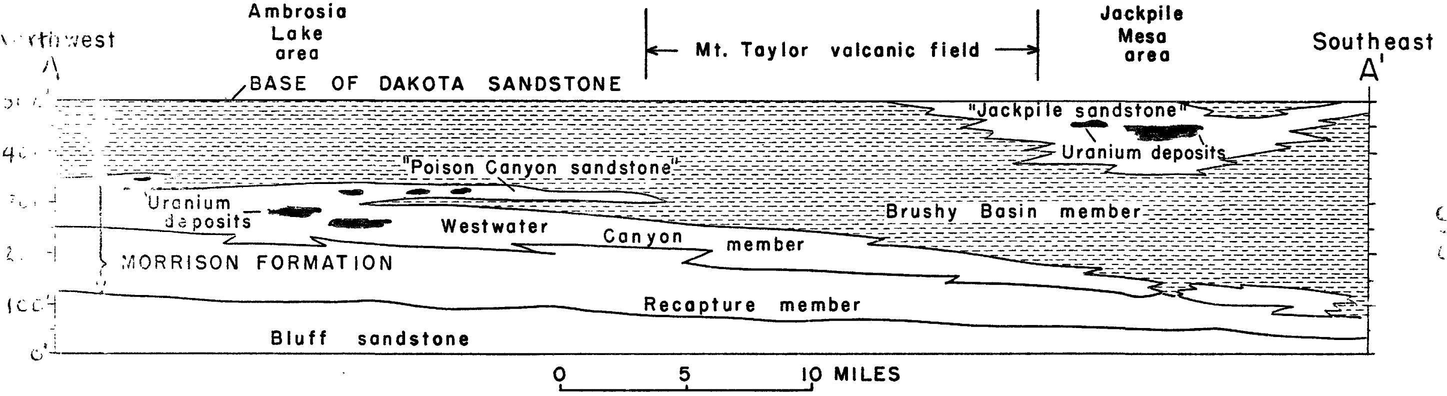


Fig 86 .--Generalized geologic section showing the uranium deposits and stratigraphic relations of the Morrison formation between Ambrosia Lake and Jackpile Mesa areas, New Mexico before the deposition of the Dakota sandstone.

Lithologically similar thick sandstone units in the Brushy Basin and Westwater Canyon members contain almost all of the uranium deposits in the area between Gallup and Laguna. In the Jackpile Mesa area the deposits are almost entirely in what is informally known as the "Jackpile sandstone," which is a relatively thick widespread sandstone lens near the top of the Brushy Basin member. In the Ambrosia Lake area the deposits are in the Westwater Canyon member and in sandstone units near the base of the Brushy Basin member. One of these is a tongue of the Westwater Canyon member that is referred to informally as the "Poison Canyon sandstone."

In sandstones of the Brushy Basin and Westwater Canyon members, the roughly tabular uranium ore bodies consist mostly of concentrations of coffinite or uranium in an organic complex. These bodies generally follow the bedding and range from a knife edge to several tens of feet in thickness, and from several feet to several thousand feet in width. They generally have an irregular outline, but some are elongate, having a length many times their width. They may consist of single tabular layers, or of multiple or compound layers. The amount of ore in individual bodies may range from a few tons to several million tons.

Figure 87 shows the Ambrosia Lake area in more detail, including the general outline and distribution of the uranium deposits in the Morrison formation. The structure contours are from Young and Ealy (1956), and the general geology, excepting the deposits, is modified from Young (1956).

A casual inspection of the map suggests a relationship of the westernmost deposits to the domal structure referred to here as the Ambrosia

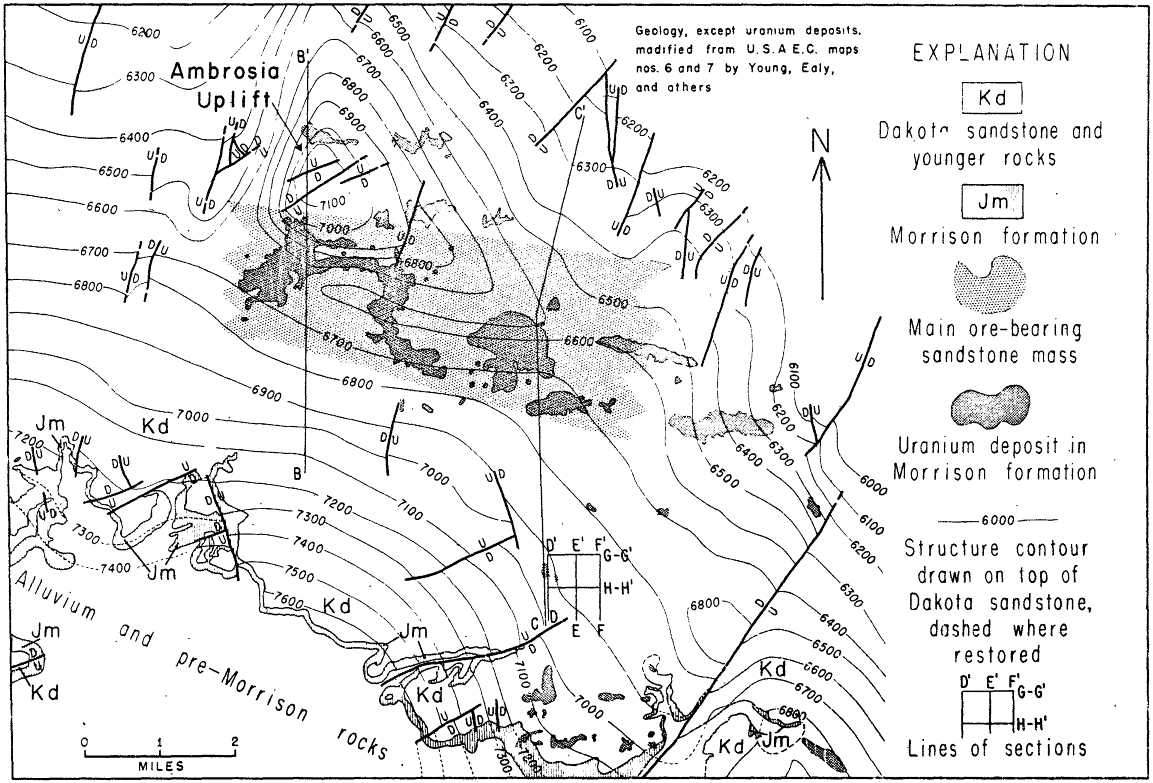


Fig 87.--GEOLOGIC AND STRUCTURAL MAP SHOWING URANIUM DEPOSITS AND INDEX OF FIGURES 88, 89, AND 90-GRANTS, NEW MEXICO.

Uplift. This possible relationship may be largely fortuitous, however, as the deposits are closest to the surface on the Uplift and the earliest drilling was concentrated there. A more probable explanation for the localization of the deposits is given below.

The deposits have an eastward elongation, which is apparent even though many of them have been incompletely outlined by drilling. This eastward elongation and the pattern of distribution of the deposits show a trend that appears to cross the southeastward nose of the Uplift and to extend eastward away from it. This trend seems to be related to stratigraphic features whose form and makeup were influenced by fold structures that developed before and during deposition of the Morrison formation.

In the southeastern part of the area shown on figure 87 an area of approximately one square mile was core drilled, providing excellent lithologic logs through the Morrison formation. The lines of sections constructed from these logs are shown on figure 87, and the sections are shown on figures 88 and 89. Figure 88 shows the sections drawn north-south. These show a relatively flat contact between the Dakota and Morrison formations, and broad folds in units of the Morrison, especially in sections E-E' and F-F'. Also, the discontinuity of the sandstone units in the Brushy Basin is noteworthy.

Figure 89 shows two cross sections drawn from west to east. These show better continuity of the sandstone units across the area and relatively little evidence of pre-Dakota folding. The relations shown on these two figures strongly suggest that the sandstone units are elongate eastward, confirming the work of Mathewson (1953) along the outcrop.

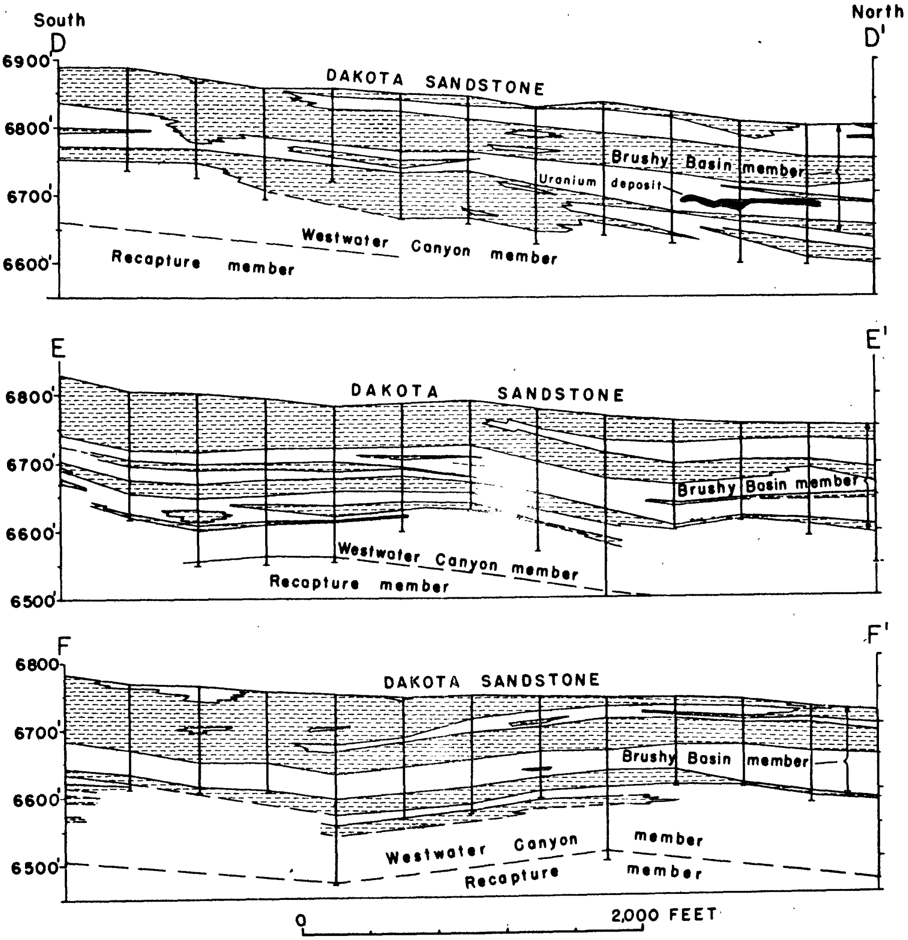


Fig. 88.--GEOLOGIC SECTIONS SHOWING LOCAL NORTH-SOUTH STRATIGRAPHIC AND STRUCTURAL RELATIONS OF THE MORRISON FORMATION NORTH OF GRANTS, NEW MEXICO.

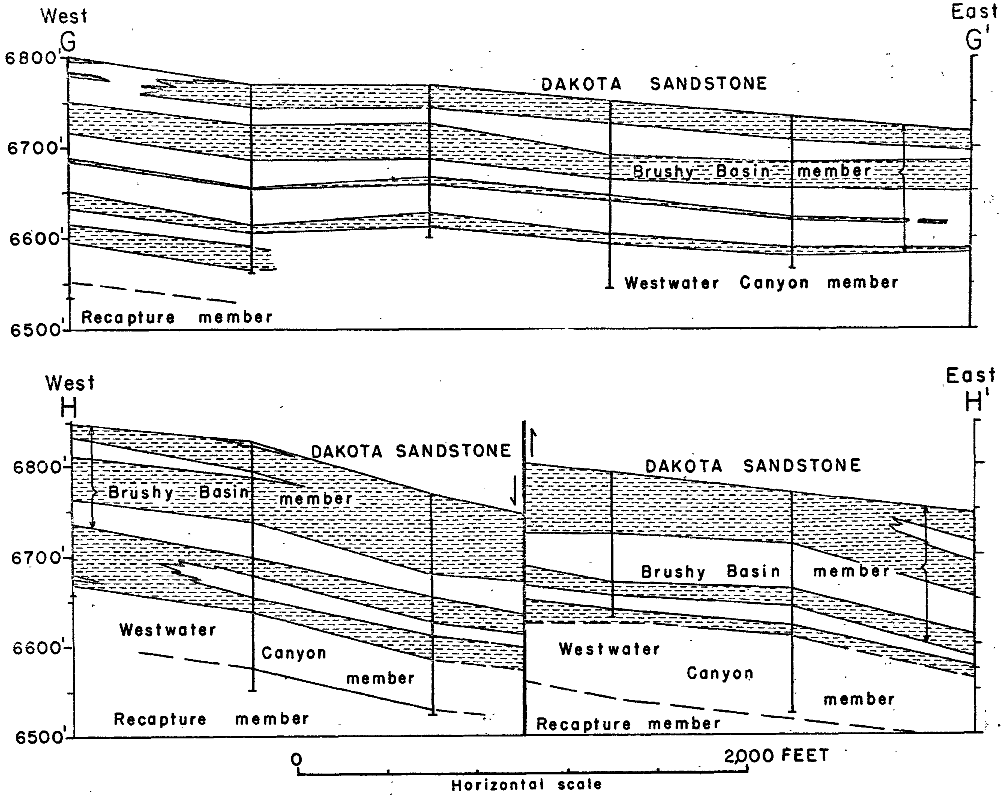


Fig. 89.--GEOLOGIC SECTIONS SHOWING LOCAL EAST-WEST STRATIGRAPHIC AND STRUCTURAL RELATIONS OF THE MORRISON FORMATION UNITS NORTH OF GRANTS, NEW MEXICO.

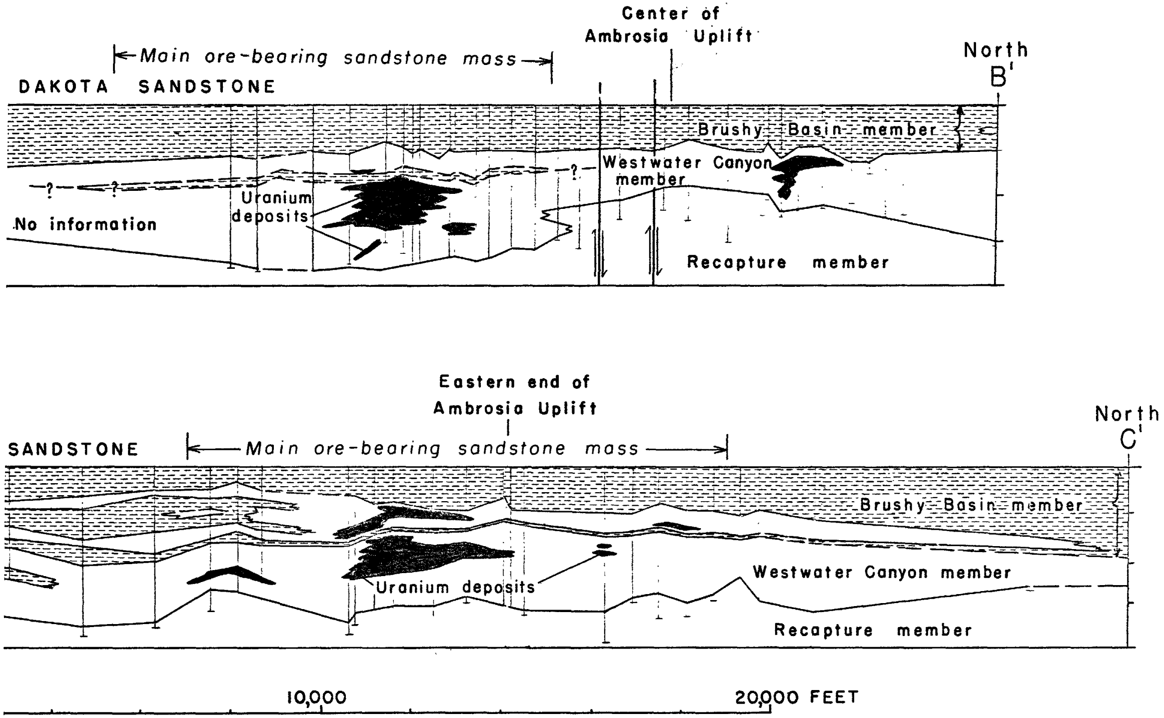
Section H-H' intersects a fault that is too small to be shown on figure 87.

More generalized cross sections drawn across the Ambrosia Lake area are shown on figure 90. The sections have been adjusted, using the base of the Dakota sandstone across the Ambrosia Uplift as datum, to exclude the effects of post Dakota folding.

Through the central parts of both sections the sandstone mass that contains the principal deposits appears to be thicker. Across the Ambrosia Uplift it is relatively thin, and apparently interfingers with finer materials.

Rough and rather arbitrary limits can be drawn on each of these sections to bound the main ore-bearing sandstone mass. Between these sections this mass has the general trend shown by the shaded area on figure 87. This trend conforms with the general trend of elongation of the individual deposits and with the general pattern of distribution of the principal deposits. It also conforms with the suggested easterly trend of the sandstone units that were shown in more detail on figures 88 and 89.

Although these data are preliminary they strongly suggest that the uranium deposits were emplaced along the trend of the rather thick continuous sandstone masses or units. As these masses occur where there is evidence of pre-Dakota folding, there may be a genetic relationship between the folding and the location of the sandstone masses. It is likely that the folds developed at least in part during deposition of the Morrison, creating shallow troughs or basins, which received the sediments that now constitute the sandstone masses. The thinning of the sandstone mass across the Ambrosia Uplift may be due to this area's



SHOWING THE STRATIGRAPHIC AND STRUCTURAL RELATIONS OF THE URANIUM DEPOSITS IN THE MORRISON FORMATION NORTH OF GRANTS, NEW MEXICO.

existing as a moderate "high" early during deposition of the Morrison. This ancient "high" probably had little resemblance in configuration or relief to the structure now called the Ambrosia Uplift, which was formed during the Tertiary period.

These relations, as determined in the Ambrosia Lake area, are strengthened by similar relations found in the Laguna area. There, as can be observed at the outcrop, broad folds in the Morrison are beveled at the base of the Dakota sandstone. Moench, Schlee, and Hensley conclude from this that the deposition of the sandstones of the Westwater Canyon and Jackpile type was controlled in part by the contemporaneous development of the pre-Dakota fold system (TEI-640, p. 77).

These conclusions permit some speculation about the distribution of uranium deposits in the Morrison formation away from the vicinity of Grants and Laguna. To understand this distribution it will be helpful to reconstruct the regional setting.

During deposition of the Morrison formation the sediments in New Mexico were contributed largely from a highland area that extended through southern New Mexico and Arizona. According to McKee and others (1956), the northern margin of this highland trended westerly through central New Mexico and northwesterly through Arizona, roughly parallel to the present southern limit of the Morrison, as shown on figure 84. Although the southern part of the Morrison was eroded in pre-Dakota time, the original southern limit may not have been very far south of the present limit. Thaden and Santos (TEI-640, p. 73) have observed, for example, that the Morrison pinches against the Bluff sandstone immediately south of Grants, a short distance north of where it is cut out by pre-Dakota erosion. During the time of deposition of the Morrison there was undoubtedly differential movement between the highland area and the basin of deposition. A large amount of differential movement very likely occurred near the southern edge of the basin of deposition, roughly in the area between Gallup and Laguna.

This area is considered most favorable for the discovery of significant uranium deposits in the Morrison formation; and the apparent west-northwesterly trend shown by the distribution of the known deposits may not be due to merely a fortuitous outcrop pattern. It does not seem likely, therefore, that the deposits were localized by structures such as the Ambrosia Uplift, which resulted from deformation in the Tertiary period, but rather were localized by sedimentary features resulting from deformation during deposition of the Morrison.

The uranium deposits between Gallup and Laguna include many in the Todilto limestone and some in the Dakota sandstone (fig. 84). Some comment regarding these other deposits may be pertinent. In the Laguna area Moench, Schlee, and Hensley (TEI-640, p. 77) have pointed out that minor folds and linear structures in the Todilto limestone conform to the major directions of the pre-Dakota folds, and ". . . appear to have formed by flowage of poorly consolidated lime down a surface of relief, probably as the larger pre-Dakota folds developed. As supporting evidence the Todilto limestone thins in the crests of the major folds and thickens in the troughs."

The minor folds referred to are structures in the Todilto limestone that contain the uranium deposits. Near Grants the deposits in the Todilto are also associated with folds in the limestone similar to those at Laguna. Not enough data are yet available to definitely assign the same age of formation for both the folds in the Todilto near Grants and the pre-Dakota folds, but it is likely they were formed at the same time and as a result of the same regional differential movements. If so, the Todilto deposits could be expected to have the same regional trend as the deposits in the Morrison formation.

Uranium deposits in the Dakota sandstone are relatively few and nearly all occur immediately east of Gallup (fig. 84). Pre-Dakota fold structures apparently have had little, if any, influence on the localization of the deposits. Most of them are in channel-filled scours at the base of the Dakota. Their distribution probably bears no relationship to the distribution of deposits in the Todilto and Morrison.

In summary, the significant uranium deposits in the Morrison formation and Todilto limestone near Grants and Laguna occur in sandstone masses and small folds whose formation was influenced by differential tectonic movements that developed after the Todilto was deposited, and in large part during deposition of the Morrison. The most intense differential movement likely occurred along the west-northwesterly trending zone between Gallup and Laguna now roughly marked by the trend of the known uranium deposits in the Morrison formation and Todilto limestone. It is in this zone that the potential is greatest for the discovery of significant deposits.

The following report was published during the report period:

Freeman, V. L., and Hilpert, L. S., 1956, Stratigraphy of the Morrison formation in part of northwestern New Mexico: U. S. Geol. Survey Bull. 1030-J.

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Young, R. G., 1956, Surface geologic map of the Ambrosia Lake area, McKinley County, New Mexico: U. S. Atomic Energy Comm. Map no. 7.

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## Utah and Arizona, by H. S. Johnson, Jr. and William Thordarson.

The regional synthesis study of Utah and Arizona evolved in fiscal year 1954 from the "Pre-Morrison studies" of the Resource Appraisal Project. Reconnaissance investigations were carried on in Utah and Arizona during fiscal years 1955-57 and the project will be recessed at the end of June 1957.

During the period of active study, uranium deposits and potentially uranium-bearing formations were investigated in the Cedar Mountain area and the San Rafael, Green River, Henry Mountains, Moab, Monticello, White Canyon, and Monument Valley districts of Utah and Arizona. Special emphasis was placed on the recognition of regional criteria for delineating ground favorable for significant uranium deposits and on the delineation of these favorable areas.

Uranium occurrences are known in all the sedimentary formations of the areas studied, but the Chinle and Morrison formations have been the only important sources of uranium ore and are the principal formations containing appreciable potential reserves. The ore deposits are tabular elongate bodies which are commonly oriented parallel to primary sedimentary trends in the host rock. The larger uranium ore deposits are as much as 10 to 20 feet thick, a few hundred feet wide, and several times as long as they are wide. Sedimentary features commonly control localization of the ore deposits and ground favorable for ore deposits. With a few exceptions direct control of ore deposits by tectonic structures cannot be recognized. The influence exerted by certain structures on sedimentation of the Chinle and Morrison formations has apparently resulted in stratigraphic features favorable for ore deposits. Work to date strongly indicates that most of the uranium ore tonnage is in deposits (or clusters of deposits joined by mineralized ground) over 10,000 tons in size; that these significant ore deposits are not distributed randomly throughout their host rocks, but occur in areas or belts of relatively favorable ground; and that the areas of relatively favorable ground can be recognized and delineated through detailed geologic studies.

Areas of relatively favorable ground in the Chinle formation are associated with (1) regional pinchouts of ore-bearing strata, (2) local pinchouts or facies changes on the flanks of salt anticlines, or (3) paleochannel systems in which the lithologic character and channeling characteristics of the ore-bearing strata make it a more favorable host for significant ore deposits than elsewhere. These favorable areas have been described in previous semiannual reports (TEI-590, p. 99-104; TEI-620, p. 110-113; and TEI-640, p. 188-195).

Areas or belts of relatively favorable ground in the Salt Wash member of the Morrison formation are coextensive with belts of thicker sandstone lenses representing major fluvial channel systems developed on the alluvial plain during deposition of the Salt Wash. These favorable areas are described in previous semiannual reports (TEI-590, p. 99-104; and TEI-640, p. 188-195).

A few miles southwest of Green River, Utah, uranium and minor amounts of molybdenum occur distributed evenly through a bed of carbonaceous siltstone 1 foot thick in the middle of the Brushy Basin member of the Morrison formation. The deposit crops out for a distance of about 3,000 feet and probably averages about 0.02 percent $U_3O_8$, although parts of the bed contain over 10 times that amount. Similar deposits in the Brushy Basin member in the southernmost part of the Monticello district, Utah, have been described in a previous semiannual report (TEI-640, p. 194-195). Uranium deposits of this type may be more common in the Brushy Basin member than has been realized and may contain appreciable potential reserves of low-grade uranium ore.

## Localization and origin of the vanadium-uranium deposits on the Colorado Plateau

by

R. P. Fischer

One unit of studies of the localization and origin of the uranium-vanadium deposits on the Colorado Plateau concerns the vanadium-uranium deposits in the Rifle Creek area, Garfield County, Colorado. A report on this area has been completed. This work began in 1944, as part of the strategic minerals program of the U. S. Geological Survey, and that year geologic maps of the area and the mines were made. The work was then recessed until 1954, when the geologic maps of the mines were brought up to date as part of the U. S. Geological Survey's work on behalf of the U. S. Atomic Energy Commission.

One of the largest vanadium-uranium deposits in the Colorado Plateau region is in the Navajo (?) and Entrada sandstones in the Rifle Creek area. This deposit is well exposed by mine development and offers a specially good opportunity to study and interpret structural features, ore habits, and geochemical relations. Several deposits are also present in the Morrison formation but as they are small and poorly developed they have not been studied in detail.

The Rifle Creek area is 10-15 miles northeast of Rifle, Colo. It is on the Grand Hogback monocline where this fold flanks the south side of the White River Plateau. The fold has a structural relief of 15,000 feet and exposes rocks ranging in age from Precambrian to Cenozoic, but only strata of late Paleozoic, Mesozoic, and Quaternary (?) ages are exposed in the area of detailed study.

The strata of late Paleozoic and early Mesozoic ages are about 4,000 feet thick and consist dominantly of red shale and sandstone. These beds were not studied for the purpose of correlating formational units. The top few hundred feet of this red bed sequence, however, resembles the Chinle formation of Triassic age, and has been correlated with the Chinle (Thomas, McCann, and Raman, 1945).

Above the Chinle is the sandstone that is tentatively correlated with the Navajo sandstone of Jurassic and Jurassic (?) age. The Navajo (?) is a clean fine-grained light-brown sandstone that is conspicuously layered with torrential crossbedding; it is hard and crops out as a rough vertical cliff. It is 30 to 75 feet thick in the area. The overlying Entrada sandstone is of Jurassic age, and also consists of clean fine-grained sandstone, but it is light gray in color, tangentially crossbedded, and soft enough to form rounded cliffs or steep slopes. It ranges from 75 to 125 feet in thickness. These two sandstones, which are quite similar in lithologic characteristics, contain the large vanadium-uranium deposit developed by the Rifle and Garfield mines.

The Morrison formation, also of Jurassic age, overlies the Entrada; it is divisible into two ill-defined parts. The lower unit is 150 feet thick and consists of lenses of pale-gray and greenish-gray sandstone interbedded with gray and red mudstone. Small deposits of vanadium-uranium ore occur in shaly sandstone beds in the middle and upper parts of this unit. The upper unit is about 350 feet thick and is composed mainly of gray, green, and maroon mudstone with thin beds of limestone, sandstone, and chert-pebble conglomerate.

The Dakota sandstone lies above the Morrison and is of Cretaceous age. It is about 80 feet thick and consists of brown and gray sandstone and shale. The Dakota is overlain by the Mancos shale, which is also of Cretaceous age and which consists of gray shale a few thousand feet thick.

Landslides of Quaternary(?) age have spread a thin cover of debris over parts of the Rifle Creek area.

The Rifle Creek area is bounded on the north and south by structural terraces of very gentle dip, but between these terraces the rocks mostly dip southward at angles ranging from 15° to 30°. Fractures are abundant and are grouped into three sets—two sets that dip at high angles and one of low-angle dip. One set of high-angle fractures trends generally eastward, approximately along the strike of the rocks; it is the stronger set and evidently the older one. The second set strikes northwestward. The low-angle fractures are bedding plane slips of small displacement. Joints of high-angle dip are especially abundant in hard sandstones like the Navajo(?).

The deformation that formed the Grand Hogback monocline probably began about the start of Tertiary time but most of the folding is generally considered to be of Late Eocene age.

The Rifle Creek area has yielded about 750,000 tons of ore, most of which has come from the deposit in the Navajo(?) and Entrada sandstones. This deposit has been mined for more than 7,000 feet along its trend in the Rifle mine and for several hundred feet in the Garfield mine. The ore contains 1 to 3 percent $V_2O_5$ and several hundredths percent $U_3O_8$; ore produced from the Morrison formation has about the same vanadium content but a little more uranium.

Primary vanadium minerals in the Navajo(?) and Entrada deposit consist dominantly of micaceous silicates with a little montroseite, and oxide. These minerals mainly occupy the sandstone pores, but to a small extent they also replace the sand grains. Secondary vanadium minerals are so sparse as to be negligible. Tyuyamunite or carnotite and bayleyite are the only uranium minerals recognized; they are secondary and the uranium in them probably comes from the oxidation of some finely disseminated mineral like uraninite.

The ore occurs in three tabular layers, called the no. 1, no. 2, and no. 3 "veins" in ascending order. Each layer lies nearly parallel to the major bedding but cuts across crossbedding in many places, and two of the layers even cross formational contacts in a few places. The no. 1 vein underlies the entire deposit; it is mostly in the Navajo(?) but in a few places along the south side of the Rifle mine it crosses into the top of the Chinle formation, and it is in the top of the Chinle beneath the Garfield mine. The no. 2 vein is mostly in the Entrada and forms several separate ore bodies, one of which connects with the no. 1 vein at the east end of the Rifle mine and another of which connects with the no. 3 vein at the west end of the Garfield mine. The no. 3 vein is known only in the Garfield mine, where it is wholly in the Entrada. If the separate ore bodies in the no. 2 vein are connected by some imagined link, the three layers have a vertical pattern of a broad "S" about 80 feet high and 10,000 feet long.

Each layer is bordered on one side by a thin layer of rock in which fine grains of a solid-solution mixture of galena and clausthalite are concentrated; the galena-clausthalite layer is generally only a fraction of an inch thick. This layer in turn is bordered by a 1- to 2-foot thick layer of greenish sandstone containing a micaceous chromium-bearing mineral. The galena-clausthalite and chromium-bearing layers lie above the no. 1 and no. 3 veins but below the no. 2 vein.

In the Rifle and Garfield mines the strata dip 15° to 30° southward. The eastern half of the deposit trends eastward almost parallel to the strike but the western half curves southwestward and rakes downdip. Fractures are abundant in the hard Navajo(?) sandstone, but less common in the softer Entrada. All faults displace and brecciate the ore. Some of the faults as well as joints stand open and contain small patches of coarsely crystalline calcite and marcasite with a little sphalerite, but except for the presence of secondary minerals such as tyuyamunite there is no recognized vanadium and uranium mineralization along fractures. Nevertheless, there is a coincidence in the local strike of the east-trending joints and the trend of the deposit in the Rifle mine.

Although this deposit is well exposed and its habits seem to be clearly revealed, the controls that localized the deposit are not yet recognized. Field relations, however, would seem to require the contemporaneous formation of all three ore layers under conditions that selectively mineralized a small part of a nearly homogeneous host and permitted the fractionation of the five elements--vanadium, uranium, lead, selenium, and chromium--that are enriched in the ore layers. Reactions at the interface of two solutions might satisfy these requirements. There is no recognized evidence to suggest the source of the mineralizing solution or the contained elements.

As most vanadium-uranium deposits on the Colorado Plateau are clustered in groups (Finch, 1955), it would seem likely that other deposits might be present in the vicinity of such a large one. Lacking ideas regarding the controls that localized the deposit, however, the only practical suggestion that can be offered to guide prospecting for another deposit relates to the apparent association of an altered zone at the top of the Chinle with the Rifle-Garfield vanadium-uranium deposit. This altered zone extends beyond the limits of the deposit and would offer a larger target than the ore itself.

Deposits in the Morrison formation occur in shaly sandstone beds containing carbonized plant fossils. Recognized ore minerals are micaceous and clayey vanadium minerals and tyuyamunite or carnotite. They form small tabular ore bodies 1 to 3 feet thick and a few yards across. These deposits show no physical continuity with the deposit in the Navajo(?) and Entrada formations.

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## Diatremes on the Navajo and Hopi Reservations, Arizona

by

E. M. Shoemaker, F. S. Hensley, Jr., and R. W. Hallagan

The Bidahochi formation (Pliocene) in part of the Navajo Reservation, Arizona, has been divided for purposes of mapping into six members, all of which are conformable. Four of the members predate diatreme activity, and one is contemporaneous with the main period of volcanism in the Hopi Buttes area.

The lower four members of the Bidahochi formation constitute a conformable sequence of claystone and siltstone or very fine-grained sandstone that corresponds approximately to the "Lower member" of Repenning and Irwin (1954). Over the area mapped these four members vary only slightly in thickness and lithologic character (fig. 91). Individual beds of siltstone or claystone, 1 to 3 or 4 feet in thickness, can be traced and correlated over many square miles. Twelve individual thin beds of white vitric tuff of rhyolitic composition (table 22) occur interbedded in the claystone and siltstone sequence, and many of these

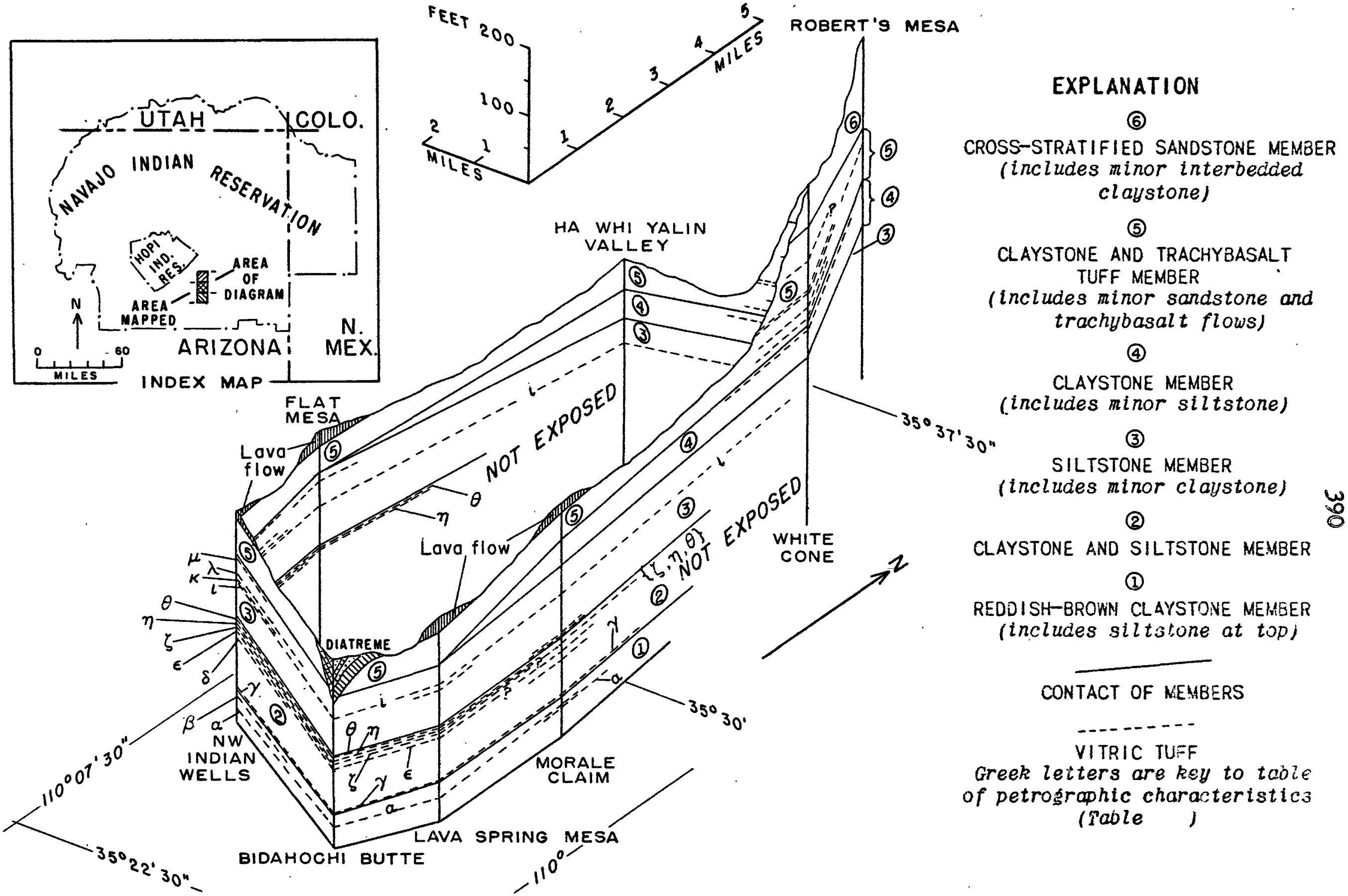


Fig. 92.--FENCE DIAGRAM OF BIDAHOCHI FORMATION IN PART OF HOPI BUTTES AREA, NAVAJO COUNTY, ARIZONA.

Table 22.--Petrographic characteristics of vitric tuffs in lower part of Bidahochi formation

| Bed | Percent glass | Glass index of refraction | Other distinguishing features |
|---|---|---|---|
| μ | Tr - 50 | 1.524 - 1.532 | |
| λ | Tr | 1.506 - 1.508 | |
| κ | 80 | 1.506 - 1.508 | |
| ι | 25-98 | 1.498 - 1.501 | |
| θ | 0 - Tr | [1] | Abundant accessory biotite |
| η | 0 - Tr | [1] | Abundant accessory biotite |
| ζ | Tr | ~1.98 (?) | Abundant accessory biotite |
| ε | 0 - 99 | 1.500 - 1.503 | |
| δ | Tr | ~1.49 (?) | |
| γ | 0 - Tr | [1] | |
| β | Tr | ~1.496 (?) | |
| α | 99 - 100 | 1.498 - 1.499 | |

[1] Shards too devitrified for determination of index of refraction.

vitric tuff beds extend throughout the greater part of a 7½-minute quadrangle despite the fact that some of them rarely exceed 0.1-foot in thickness. This regional uniformity of the stratigraphy, coupled with an almost complete absence of cross-stratification, support the interpretation suggested by Repenning and Irwin (1954, p. 1823) of a lacustrine origin for the lower part of the Bidahochi formation.

The fifth member of the Bidahochi formation consists mainly of interbedded trachybasalt tuff and claystone; for purposes of mapping, the base of the member is placed at the lowest occurrence of trachybasalt detritus. This member includes the major part of the section measured at White Cone by Gregory (1917, p. 82), which was designated the "White Cone series" by Reagan (1932, p. 255-256). It includes beds designated as the "Volcanic member" as well as beds included in the lower part of the "Upper member" of Repenning and Irwin (1954).

In general, the fifth member (which for convenience will be referred to in this report as the "White Cone" member--an informal field designation) has about 5 to 10 feet of claystone with sparse grains of trachybasalt at the base. Commonly this sparsely tuffaceous claystone is succeeded by coarse gray trachybasalt tuff or trachybasalt flows, which may be "apparent even at a distance of several miles" (Repenning and Irwin, 1954, p. 1822-1823); but the lowest occurrence of trachybasalt fragments can only be determined by careful inspection of the outcrops. Throughout the quadrangles mapped the basal tuffaceous claystone beds of the "White Cone" member lie conformably on the underlying claystones and siltstones. The contact is gradational, and is marked only by the occurrence (as the section is measured from base to top) of a few scattered grains of trachybasalt. There is no evidence of an unconformity at this contact, as indicated by Repenning and Irwin (1954, p. 1825), nor of any regional unconformity higher in the Bidahochi section in the Hopi Buttes area.

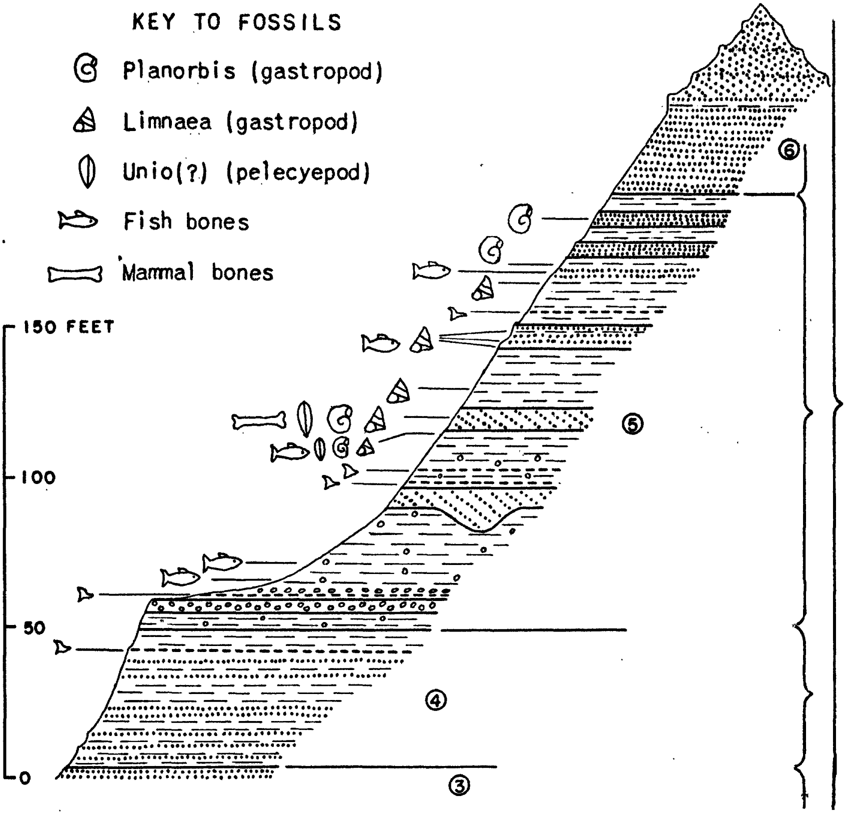
In contrast to the underlying members, the "White Cone" member exhibits abrupt local changes of facies which are related to the distribution of the diatremes, from which all the trachybasalt detritus has been derived. Away from the diatremes the "White Cone" member consists mainly of claystone, minor sandstone and vitric tuff, with only thin beds of trachybasalt tuff; near the diatremes the "White Cone" is made up predominantly of tuff with some interstratified lava flows. In areas of close-spaced diatremes west of the two quadrangles mapped, the tuff facies may reach a total thickness of 200 or 300 feet.

Where the "White Cone" member has been partly preserved from erosion many of the diatremes have been found to be immediately surrounded by a rim of stratified tuff ranging from a few tens of feet to as much as 100 feet in thickness. These tuff deposits thin gradually away from the diatremes, commonly to a thickness of only a few feet over distances ranging from a fraction of a mile to several miles. The landscape at the time of diatreme eruption thus included broad craters (the surface expression of the diatremes) surrounded by ridges of volcanic debris with gentle exterior slopes that merged with the surrounding plain. In general appearance the countryside must have presented many of the aspects of the maars of the Eifel region of Germany (Frechen, 1951), or the Xalapazcos and Valle de Santiago (Ordoñez, 1905 and 1906). The beds of the tuff rims in the Hopi Buttes probably originated in part by volcanic fallout, as in the case of modern maars (Shoemaker, 1957), and in part by fluvial reworking of the fallout deposits.

The claystone facies of the "White Cone" member at White Cone is abundantly fossiliferous. The fauna includes at least three species of fresh water invertebrates (Gregory, 1917; Reagan, 1932), fish, and water-loving and burrowing mammals (Stirton, 1936; Lance, 1954) (fig. 92). Some of the sandstone beds interbedded with the claystones are cross-stratified and locally fill small channels cut into underlying beds. Both the fossil fauna and the sedimentary structures support the interpretation, first advanced by Hack (1942, p. 344) for the entire Bidahochi formation, of a stream and swamp environment of deposition for the claystone facies of the "White Cone" member. A Hemphillian (middle Pliocene) age is indicated for the "White Cone" member by the mammalian remains (Stirton, 1936; Lance, 1954).

The sixth, and uppermost, member of the Bidahochi formation in the Hopi Buttes area is composed mainly of cross-stratified sandstone with minor interbedded claystone. This member is not preserved over most of the area around the Hopi Buttes diatremes, but forms the principal part of the Bidahochi formation north and east of the Hopi Buttes. Grains of trachybasalt and augite, which are disseminated fairly abundantly in the sandstones, probably were derived from ash showers produced by diatreme eruptions in the upwind Hopi Buttes area, either during or before the deposition of the uppermost member.

The diatremes that have been mapped are exposed at many different levels with respect to the base of the "White Cone" member and may be examined where they cut through pre-Bidahochi formations of Triassic



## EXPLANATION

▨ SANDSTONE AND SILTSTONE *(diagonal stipple indicates cross-stratification)*

▤ CLAYSTONE *(scattered circles indicate scattered trachybasalt fragments)*

○ TRACHYBASALT TUFF

▷----- VITRIC TUFF OR TUFFACEOUS CLAYSTONE

③ INDEX NUMBER *(refers to members of Bidahochi formation. Explanation on Fig. )*

Fig. 92.--GENERALIZED GRAPHIC SECTION OF BIDAHOCHI FORMATION SHOWING FAUNAL ASSEMBLAGES, WHITE CONE, NAVAJO COUNTY, ARIZONA.

age as well as through the lower part of the Bidahochi. In general, the walls of the diatremes dip steeply inward (45° to 90°) where they cut the Triassic rocks and more gently (0° to 45°) where they cut the rocks of the lower Bidahochi. During deposition of the "White Cone" member most of the larger diatremes at one time or another were expressed topographically as craters and were filled partly with fluvial and lacustrine sediments. Each crater was a local basin of deposition and each diatreme contains a unique sedimentary sequence. In addition to the sedimentary types that characterize the "White Cone" member, the rocks filling the diatremes commonly include thick masses of agglomerate, coarse breccias, a variety of limestones, and large and small intrusive as well as extrusive masses of trachybasalt.

The smaller diatremes, in general, tend to be filled mainly with agglomerate and intrusive trachybasalt. In two diatremes thick sills of trachybasalt have been found to contain dikes and pods of syenite, presumably derived by differentiation of the trachybasalt in place. The larger diatremes are filled mainly with either agglomerate and trachybasalt or with tuff and nonvolcanic sediments at the level in the vent at which they are now exposed. These sediments should not be confused with the "White Cone" member, with which they are contemporaneous but with which they never had any general physical continuity. Great thicknesses of sediments have accumulated in some diatremes as a result of repeated subsidence within the vent during deposition.

In some diatremes the structural and sedimentary evolution of the vent was climaxed by the extrusion of lava which formed either a broad dome capping the diatreme or flowed out onto the surrounding plain. Some of the flows tended to emerge from the diatremes as sills that cut across the diatreme wall into the surrounding pre-"White Cone" or "White Cone" strata and gradually rose through the stratigraphic section until they ultimately emerged at the pre-flow surface. Such flows tended to float large rafts of Bidahochi sediments that are now found embedded in the flows far displaced from their original position.

To date all major types of rocks within the diatremes except agglomerate and intrusive and extrusive trachybasalt have been found to contain uranium minerals. With one exception--at the Morale claim--the highest radioactivity has invariably been found in rocks rich in limonite, though not all rocks heavily impregnated with limonite are conspicuously radioactive. New mining developments at the Morale claim have revealed that some uraniferous limonite-bearing strata pass at relatively shallow depths into uraniferous dark-gray iron sulfide-bearing rocks. It is possible that much or all of the limonite associated with highly radioactive outcrops at various diatremes has been derived by oxidation of sulfides. The only uranium mineral recognized to date by the writers is schroeckingerite which was identified by T. Botinelly (oral communication, 1957), but the occurrence of sulfides in the ore at the Morale claim suggests that in the primary ore uranium may be present in low-valent mineral forms--possibly uraninite or coffinite.

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## Black Hills, South Dakota and Wyoming

### Petrography of some sandstone beds in the Inyan Kara group and associated rocks

by

R. E. Bergenback, W. A. Chisholm, and W. J. Mapel

Mechanical, thin-section, and heavy-mineral analyses have been made from about 350 samples of sandstone from the Fall River, Lakota-Fuson, Unkpapa, and Morrison formations to determine if stratigraphic and geographic variations in texture and mineralogic composition could be used in subdividing and correlating the formations. These analyses together with field studies now underway are intended to help provide a background against which the depositional history of the rocks and the localization of uranium deposits in the Inyan Kara group can be analyzed.

The samples are from 22 measured sections along the west side of the Black Hills from Aladdin, Wyoming, southward to Hot Springs, South Dakota, a distance of about 130 miles. (See fig. 93). A few additional samples were taken from the Sundance formation and from the Newcastle sandstone. Stratigraphic relations of the formations sampled are shown on figure 94.

## Grain size and sorting

Sandstone in all the formations examined is predominantly fine-grained. (See fig. 95). Sandstone in the Unkpapa and Morrison formations show the least range in grain size with about 95 percent of the grains in the fine and very fine grain size and the remainder in the silt and clay size. The Fall River formation contains nearly 15 percent medium-grained sand in the samples examined, but contains no grains coarser than medium-grained. The Lakota-Fuson formations undivided has the greatest range in grain size, all sizes from pebbles to clay being represented.

Nearly all sandstone from the Fall River and Unkpapa formations is well sorted, and on the average is appreciably better sorted than sandstone from either the Lakota-Fuson formations or the Morrison formation. (See fig. 95). The differences in sorting and grain size are not consistent enough in individual samples, however, to be useful in regional correlations.

## Thin-section analyses

Sandstones in the Inyan Kara group, and Morrison and Unkpapa formations are quartz-rich rocks containing 80 to 95 percent quartz in most samples as shown by table 23. Three varieties of individual quartz

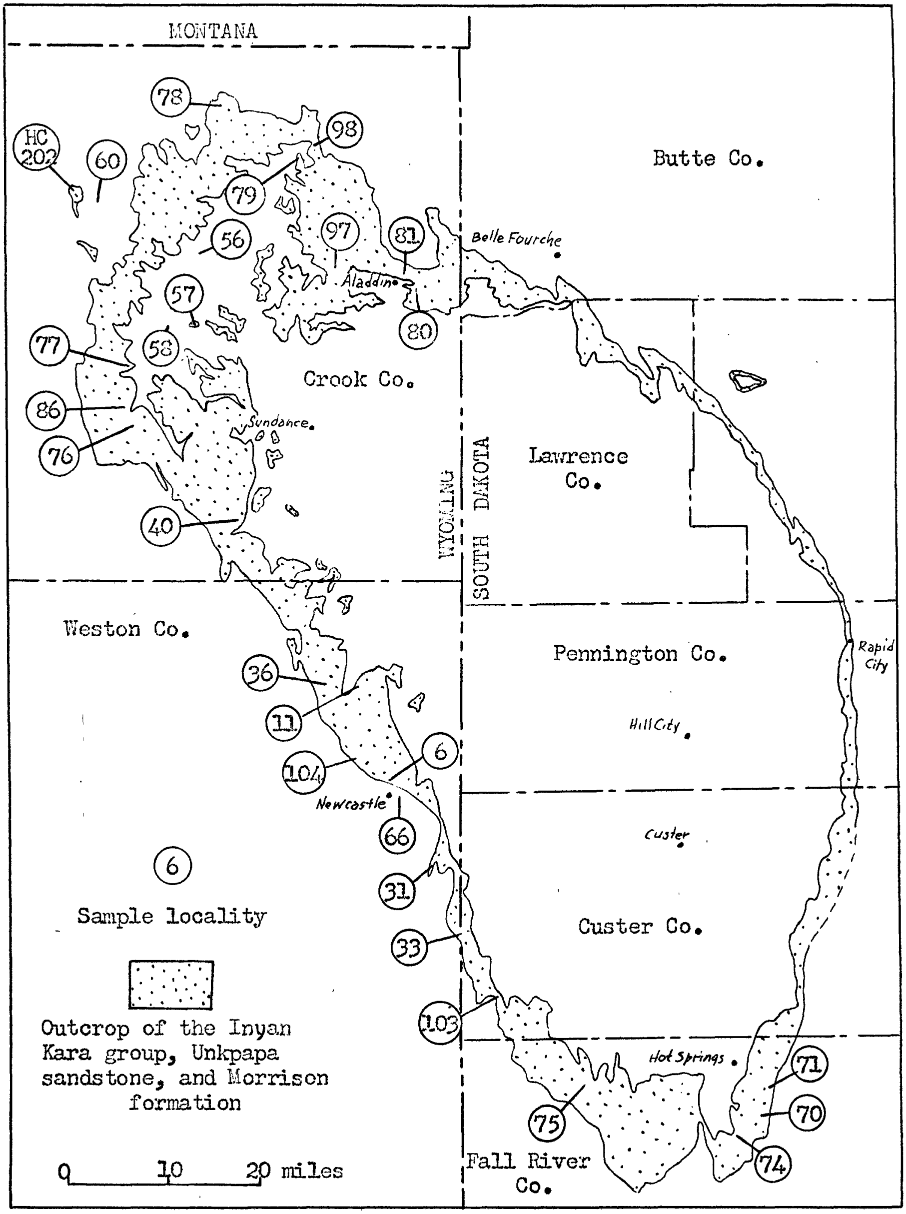


Figure 93.--Index map showing sample localities, Black Hills.

Figure 94.--Generalized stratigraphic section of Upper Jurassic and Lower Cretaceous rocks exposed along the western side of the Black Hills.

| Series | Group | Formation | Thickness (in feet) | Lithology |
|---|---|---|---|---|
| Lower Cretaceous | Colorado (lower part) | Mowry shale | 130-220 (thickens northward) | Mostly hard siliceous shale that weathers light gray and contains numerous thin beds of bentonite; commonly grades to soft black shale in the basal few feet; marine fossils. |
| | | Newcastle sandstone | 0-75 (commonly about 40 feet) | Discontinuous beds of sandstone, sandy shale, impure coal, bentonite, and (where thin) phosphatic nodules; marine and nonmarine fossils. |
| | | Skull Creek shale | 200-260 (thickens northward) | Black fissile shale with a few ferruginous concretions; thin silty seams in the lower part and a few lenses of sandstone locally; marine fossils. |
| | Inyan Kara | Fall River formation | 125-160 (thickens southward) | Interbedded and interlaminated brown-weathering sandstone, light- to dark-gray siltstone, and dark-gray shale; local seams of impure coal; sharp contact with the underlying formation; nonmarine pelecypods locally at the base. |
| | | Unconformity | | |
| | | Fuson, Minnewaste, and Lakota formations | 100-550 (mostly 100 to 250 feet in Wyoming, thickens southward) | Variable sequence of light-gray locally conglomeratic sandstone, and variegated claystone and sandy claystone; local seams of coal and carbonaceous shale at the base. A bed of light-gray limestone as much as 25 feet thick (Minnewaste limestone) crops out about 100 feet below the top in about 4 townships near Hot Springs, South Dakota, where it divides the sequence into an upper part (Fuson formation) and a lower part (Lakota formation). |
| Upper Jurassic | | Morrison formation<br>Unkpapa sandstone | 0-240 (commonly about 100 feet) | Morrison formation: lower 60 to 80 feet greenish-gray and dull-red calcareous claystone, light-gray limestone, and light-gray calcareous sandstone; remainder is greenish gray to dark-gray noncalcareous claystone; nonmarine fossils.<br>Unkpapa sandstone: massive sandstone commonly mottled shades of gray, red, and purple; present at the southern end of the Black Hills. |
| | | Sundance formation | 325-375 | Divided into 5 members as follows from youngest to oldest: Redwater shale member: greenish gray shale with some interbedded light-gray calcareous sandstone and light-gray limestone, glauconitic; a persistent bed of calcareous yellow-weathering sandstone at the top; 140 to 180 feet thick. Lak member: friable red and yellow sandstone and siltstone; 40 to 60 feet thick. Hulett sandstone member: cliff-forming grayish yellow sandstone; 50 to 75 feet thick. Stockade Beaver shale member: greenish gray shale with some interbedded sandstone; 60 to 80 feet thick. Canyon Springs sandstone member: light-gray to pale-red sandstone; 0 to 40 feet thick. Marine fossils in all but the Lak member which is iferous. |

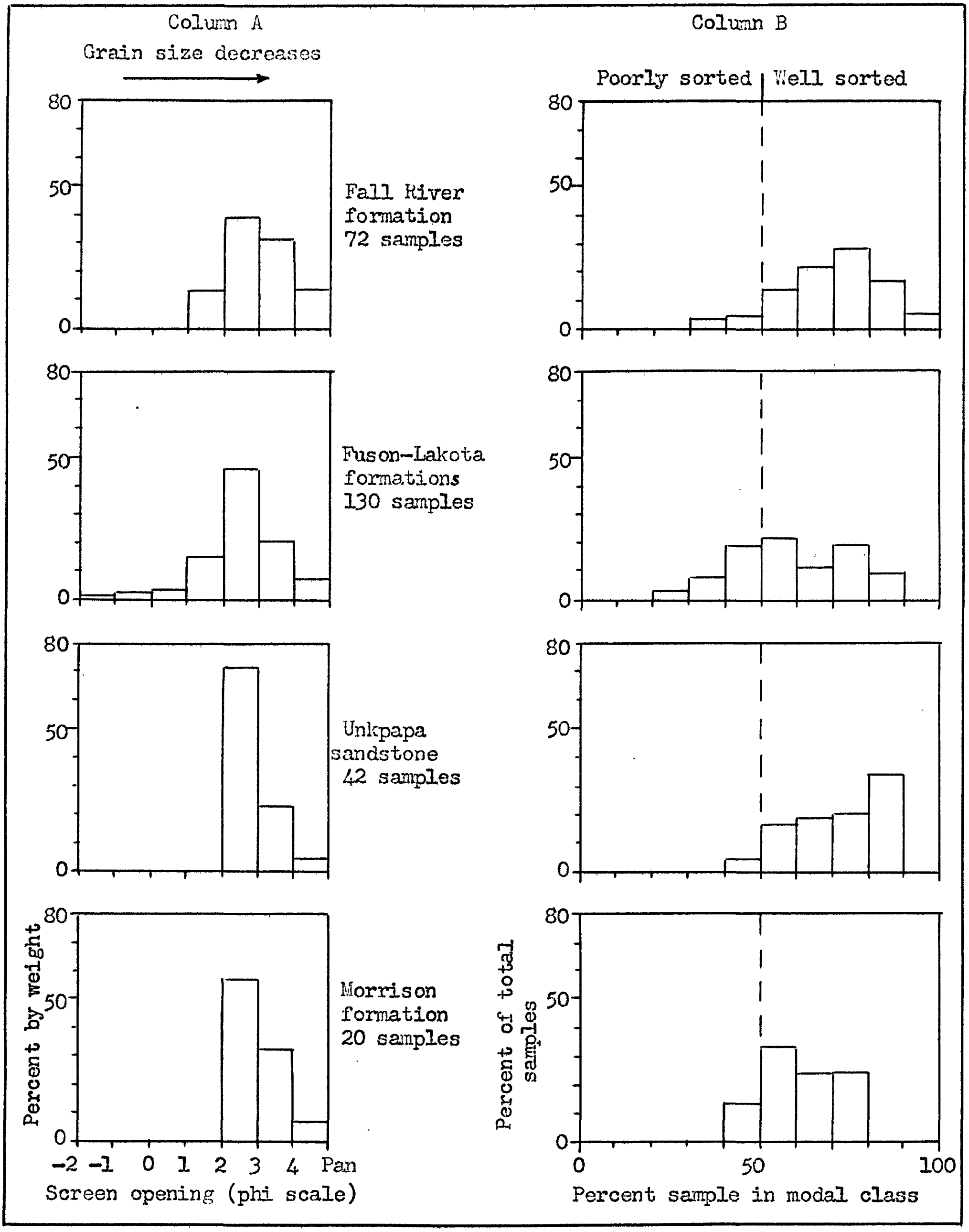


Figure 95.—Diagrams showing average grain size distribution (Column A) and sorting (Column B) in samples of sandstone from the Fall River, Fuson-Lakota, Morrison, and Unkpapa formations, Black Hills.

Table 23. Average percentages of mineral and rock fragments in thin sections of sandstone and siltstone (matrix excluded)

X, less than 1 percent; –, absent

| | | | Mineral fragments | | | | | | | Rock fragments | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Individual quartz grains | | | | | | | Composite quartz grains | | | | | | | | |
| | | Number of samples | Unstrained | Moderately strained | Strongly strained | Total | Feldspar | Muscovite | Glauconite | Parallel orientation, straight borders | Semi-parallel orientation, smooth borders | Random orientation, smooth borders | Random orientation, crenulated borders | Total | Chert | Schist | Claystone | Other 1/ |
| Fall River formation | | 56 | 33 | 28 | 20 | 81 | 1 | 3 | – | 1 | 1 | X | 8 | 11 | 1 | 3 | X | X |
| Fuson-Lakota formations | medium-grained and finer | 48 | 37 | 28 | 20 | 85 | 1 | X | – | 1 | X | X | 7 | 9 | 4 | X | X | X |
| | coarse-grained to conglomeratic | 11 | 18 | 13 | 9 | 40 | – | – | – | X | X | X | 5 | 6 | 49 | – | – | 5 |
| Unkpapa sandstone | | 8 | 52 | 18 | 8 | 78 | 4 | – | – | 11 | X | X | 7 | 18 | X | – | – | – |
| Morrison formation | upper part | 2 | 36 | 21 | 29 | 86 | 5 | – | – | X | – | – | 7 | 8 | X | X | – | X |
| | lower part | 3 | 34 | 26 | 16 | 76 | 7 | X | – | 1 | X | – | 8 | 10 | 2 | X | 3 | – |
| Sundance formation | | 1 | 32 | 17 | 23 | 72 | 3 | – | 22 | – | – | – | 2 | 2 | – | – | – | 1 |

1/ Mostly sandstone and chalcedony; 23 percent calcilutite in one sample of conglomeratic sandstone from the Fuson-Lakota formations.

grains were differentiated empirically by the extinction characteristics of the grains under crossed nicols, and four varieties of composite quartz grains were differentiated by the shape and optical orientation of the particles that make up the grains. Other constituents commonly found in small amounts include orthoclase, microcline, and plagioclase, fragments of cryptocrystalline granular chert, cryptocrystalline fibrous chalcedony, schist, claystone, calcilutite, sandstone, and siltstone.

Detrital chert is most abundant in the Lakota-Fuson formations, making up an average of 4 percent of the fragments in medium-grained and finer sandstone, and 49 percent of sandstone coarser than medium-grained. Muscovite flakes and schist fragments are slightly more abundant in the Fall River formation than in the other formations studied. Feldspar, in general, is most abundant in the lower part of the Morrison formation and decreases in abundance in the younger rocks. Chert, opal, and chalcedony are the common interstitial materials in the Lakota-Fuson formations and clay paste is the common interstitial material in the Fall River formation. Fine to coarsely crystalline calcite cements the sandstone in the lower part of the Morrison formation.

Highly polished pebbles as much as 6 inches long are found locally in thin, discontinuous layers in the Lakota-Fuson formations. Pebbles collected at localities 78 and 36 consist of about 60 percent pink, brown, and gray fine- to coarse-grained quartzite, and about 40 percent red, gray, or brown chert.

### Nonopaque heavy minerals

Heavy minerals were concentrated in bromoform from the very fine-grained sand size (0.062 to 0.125 mm.) of 310 samples from the Newcastle, Fall River, Lakota-Fuson, Morrison, Unkpapa, and Sundance formations. Table 24 shows the average percentages of minerals in each formation. Studies of grain roundness were made for the zircon and tourmaline grains which make up most of the nonopaque heavy-mineral concentrates in all of the formations examined. No study was made of the opaque heavy minerals which consist largely of hematite and limonite aggregates, authigenic pyrite, and leucoxene, and comprise as much as 50 percent of the concentrate of some samples. The total amount of heavy minerals concentrated by bromoform in the very fine-grained size ranges from 0.1 to 1 percent of the samples.

Three fairly consistent assemblages can be recognized depending on the proportions of nonopaque heavy minerals, the presence of a few distinctive minerals, and the shapes of the zircon and tourmaline grains. The principal differences between the three assemblages are tabulated on figure 96. The lowest of the heavy-mineral assemblages includes the lower calcareous part of the Morrison formation, the lower part of the Unkpapa sandstone, and the Sundance formation, and is characterized by a relatively high proportion of garnet. The middle assemblage includes, in general, the Lakota-Fuson formations, most of the Unkpapa sandstone, and the upper noncalcareous part of the Morrison formation. It has almost no garnet at most places, and has dominantly rounded zircon and tourmaline grains. The upper assemblage includes the Fall River formation and Newcastle sandstone. It contains little garnet, dominantly angular zircon and tourmaline grains, and, locally, fairly abundant chloritoid and hornblende.

Table 24.—Summary of the average percentages of nonopaque heavy minerals in the formations studied, Black Hills.
(0.062 to 0.125 mm. size fraction)

X, less than 1 percent, small amounts in most samples; R, rare; VR, very rare; -, absent.

| | | Zircon | | | | Tourmaline | | | | Zircon-tourmaline, combined. | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Euhedral crystals | Angular grains | Rounded grains | Total | Euhedral crystals | Angular grains | Rounded grains | Total | Crystals and angular grains | Rounded grains | Total | Garnet | Rutile | Staurolite | Apatite | Hornblende | Clinozoisite | Andalusite | Brookite | Anatase | Kyanite | Sphene | Sillimanite | Chlorite | Chloritoid | Spinel | Biotite | Epidote | Amphibole | Corundum | Blue mineral, uniaxial, positive | Monazite | Total number of samples |
| Newcastle sandstone | | 1 | 15 | 13 | 29 | 10 | 23 | 6 | 39 | 50 | 19 | 69 | 2 | 7 | 4 | - | - | - | - | R | R | - | - | - | - | 18 | - | R | - | - | - | - | - | 3 |
| Fall River formation | | 1 | 21 | 21 | 43 | 6 | 20 | 7 | 33 | 48 | 29 | 77 | 3 | 7 | 4 | X | X | R | R | X | X | VR | VR | VR | X | 6 | VR | VR | VR | VR | VR | VR | VR? | 96 |
| Fuson-Lakota formations | | 1 | 13 | 54 | 68 | 1 | 5 | 17 | 24 | 20 | 71 | 92 | 2 | 3 | 3 | VR | VR | VR | VR | VR | R | VR | - | VR | VR | VR | R | VR | VR | VR | VR | - | VR? | 160 |
| Unkpapa sandstone | | R | 2 | 86 | 88 | - | R | 9 | 9 | 2 | 95 | 97 | 2 | R | X | - | - | - | - | - | R | - | - | - | - | - | R | - | - | - | - | - | - | 13 |
| Morrison formation | upper part locality 11 | - | 4 | 64 | 68 | - | 1 | 24 | 25 | 5 | 87 | 92 | 5 | X | 2 | - | - | - | - | - | - | - | - | - | - | - | - | - | R | - | - | - | - | 7 |
| | lower part | X | 6 | 23 | 29 | 4 | 13 | 14 | 32 | 23 | 38 | 61 | 28 | 3 | 3 | 3 | - | - | R | R | R | - | - | - | R | - | VR | X | R | - | - | - | VR? | 21 |
| Sundance formation | Redwater shale member | R | 6 | 22 | 28 | 1 | 8 | 23 | 32 | 15 | 45 | 60 | 24 | 3 | 3 | 5 | - | - | R | - | R | - | R | - | - | R | R | 3 | - | - | - | - | - | 9 |
| | Hulett sandstone member | - | 5 | 54 | 59 | 1 | 1 | 5 | 8 | 7 | 59 | 67 | 24 | 5 | 3 | 2 | - | - | - | X | X | - | - | - | - | - | - | - | - | - | - | - | - | 2 |
| Precambrian rocks, central Black Hills 1/ | | - | - | - | - | 7 | 3 | - | 10 | 10 | - | 10 | 33 | R | X | 5 | 29 | 2 | X | - | R | - | - | R | R | - | - | 15 | X | 2 | - | - | - | 3 |

1/ 2 samples from deposits of streams draining Precambrian igneous and metamorphic rocks near Hill City and Custer, 1 sample from a low stream-terrace near Hill City.

Figure 96. Principal differences in nonopaque heavy-mineral assemblages (0.062 to 0.125 mm. size fraction)

| Heavy-mineral zone | Formations represented | Zircon-tourmaline | Garnet | Apatite | Other |
|---|---|---|---|---|---|
| Assemblage 1 | Newcastle sandstone, Fall River formation, upper 80 to 100 feet of the Lakota-Fuson formations at Mona Butte (loc. 79) and Aladdin (loc. 81) | Zircon and tourmaline about equal<br>Angular grains exceed rounded ones in the ratio of 5:3 | Present in small amounts | Fairly abundant locally | Chloritoid abundant locally, hornblende fairly abundant locally |
| Assemblage 2 | Lakota-Fuson formations, upper part of the Unkpapa sandstone, and upper noncalcareous part of the Morrison formation | Zircon exceeds tourmaline<br>Rounded grains exceed angular ones in the ratio of 2:1 for the Lakota formation, 18:1 for the upper part of the Morrison formation, and 45:1 for the Unkpapa sandstone | Rare but present locally | Very rare | |
| Assemblage 3 | Lower calcareous part of the Morrison formation, lower 20 feet of the Unkpapa sandstone at Sheps Canyon (loc. 74) and the Sundance formation | Zircon and tourmaline about equal<br>Rounded grains exceed angular ones in the ratio of 2:1 | Fairly abundant (averages 30 percent) | Fairly abundant locally (except in the Unkpapa sandstone) | Biotite fairly abundant locally (except in the Unkpapa sandstone) |

The difference in the proportion of rounded to angular grains in the Fall River and Lakota-Fuson formations is shown by figure 97. At most localities the change from predominantly rounded to predominantly angular grains is sharp at about the Fall River-Lakota-Fuson contact. At 2 localities (81 and 79, fig. 97) the change is sharp but within the Lakota-Fuson formations is 80 to 100 feet below the top. On the whole, differences in the proportion of rounded to angular grains appear consistent enough to be useful in correlations.

Chloritoid occurs somewhat erratically, but is locally abundant in samples from the Fall River and Newcastle formations. No chloritoid was found in the underlying Lakota-Fuson formations except for a single grain in a sample from the upper part at locality 81 (fig. 97).

Table 25 shows the varieties of tourmaline grains in the very fine-grained sand fraction classified according to color in the Fall River and Lakota-Fuson formations. Brown and green-brown tourmaline predominate in both formations. No appreciable difference was noted in the proportions of the various colors in rounded and angular grains.

Heavy minerals were separated from the fine-grained sand fraction of 13 samples from the Fall River and 27 samples from the Lakota-Fuson formations to check for differences in the mineral suite in the fine-grained and very fine-grained fractions. The results are summarized by table 26. In both formations tourmaline increases at the expense of zircon in the coarser size. Staurolite averages about the same for the two size fractions in samples from the Fall River formation, but increases markedly in the coarser size in samples from the Lakota-Fuson formations. The percentage of angular zircon and tourmaline grains increases and the

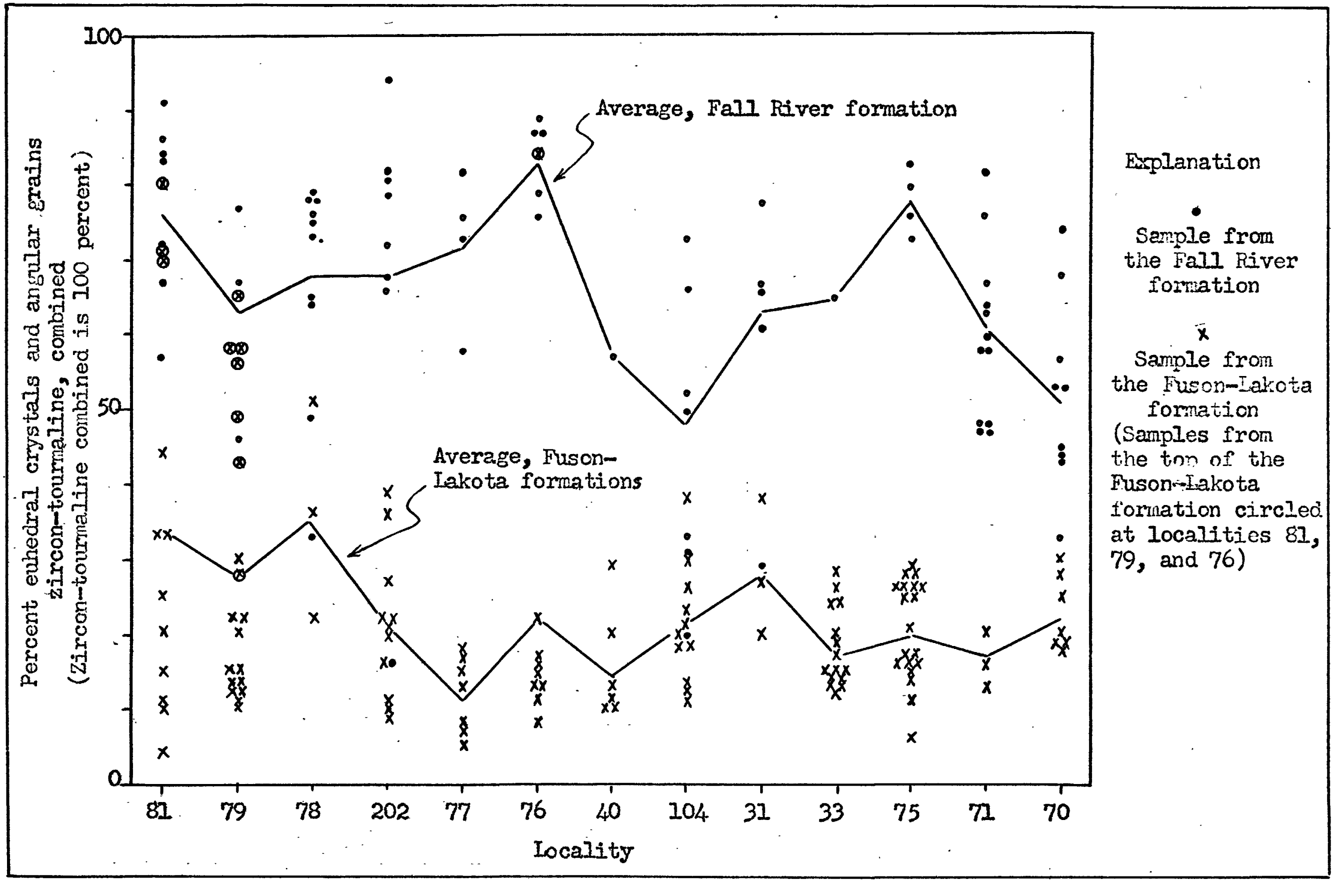


Figure 97.—Diagram showing angularity of zircon and tourmaline grains in samples from the Fall River and Fuson-Lakota formations (0.062 to 0.125 mm. size fraction).

Table 25. Tourmaline grains classified by color, Fall River and Fuson-Lakota formations, Black Hills
(In percent; 0.062 to 0.125 mm. size fraction)

X, less than 1 percent; -, absent

| | Locality number | Crystals and angular grains | | | | | | | | | | | Rounded grains | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Brown | Green-brown | Green | Blue and gray-blue | Gray | Pink to opaque | Orange and yellow | Red-brown | Colorless | Bicolor, brown and blue | Total number of grains counted | Brown | Green-brown | Green | Blue and gray-blue | Gray | Pink to opaque | Orange and yellow | Red-brown | Colorless | Bicolor, brown and blue | Total number of grains counted |
| Fall River formation | 81 | 59 | 23 | 1 | 3 | - | 7 | 5 | 1 | X | - | 300 | 62 | 22 | 3 | 5 | - | - | 6 | - | 2 | - | 64 |
| | 202 | 55 | 17 | 3 | 7 | X | 6 | 9 | 2 | - | X | 490 | 57 | 14 | 3 | 3 | X | 5 | 13 | 4 | - | - | 84 |
| | 76 | 55 | 9 | 10 | 5 | X | 2 | 18 | 1 | X | - | 349 | 57 | 7 | 2 | 4 | 4 | - | 24 | - | - | 2 | 49 |
| | 31 | 44 | 36 | 3 | 5 | - | 3 | 9 | - | - | - | 244 | 43 | 27 | 4 | 7 | - | 3 | 15 | - | - | - | 67 |
| | 70 | 51 | 32 | 2 | 5 | X | 4 | 5 | - | X | - | 237 | 46 | 38 | 3 | 7 | - | 1 | 4 | 1 | - | - | 76 |
| Weighted average | | 54 | 21 | 4 | 5 | X | 5 | 10 | X | X | X | 1620 | 53 | 22 | 3 | 5 | 1 | 2 | 12 | 1 | X | X | 340 |
| Fuson-Lakota formations | 80 | 49 | 25 | 4 | 6 | - | 7 | 8 | - | - | - | 80 | 54 | 27 | X | 6 | - | 1 | 11 | - | - | X | 324 |
| | 81 | 48 | 30 | 2 | 5 | - | 9 | 5 | X | - | X | 303 | 50 | 25 | 1 | 6 | - | 3 | 11 | 3 | X | - | 200 |
| | 202 | 41 | 15 | 3 | 10 | - | - | 28 | 3 | - | - | 39 | 50 | 24 | 3 | 6 | X | 2 | 15 | X | - | - | 240 |
| | 76 | 67 | 7 | 11 | 4 | 3 | X | 8 | X | - | - | 160 | 65 | 15 | 3 | 3 | - | X | 14 | - | - | - | 360 |
| | 33 | 50 | 21 | 7 | 8 | X | 2 | 8 | 4 | - | - | 131 | 53 | 27 | 1 | 5 | - | 3 | 9 | 2 | - | X | 555 |
| | 70 | 34 | 37 | - | 14 | - | 6 | 9 | - | - | - | 35 | 58 | 22 | 2 | 5 | - | 3 | 9 | 1 | - | - | 201 |
| Weighted average | | 51 | 22 | 5 | 6 | 2 | 5 | 7 | X | - | X | 748 | 55 | 24 | 2 | 5 | X | 2 | 11 | 1 | X | X | 1880 |

Table 26.—Average percentages nonopaque heavy minerals compared for the very fine (0.062–0.125 mm.) and fine (0.125–0.250 mm.) sand fractions, Fall River and Fuson-Lakota formations, Black Hills

X, less than 1 percent, small amounts in most samples; R, rare; VR, very rare: –, absent.

| | Size fraction (mm.) | Zircon | | | | Tourmaline | | | | Zircon-tourmaline, combined. | | | Garnet | Rutile | Staurolite | Apatite | Hornblende | Clinozoisite | Andalusite | Brookite | Anatase | Kyanite | Sillimanite | Chlorite | Chloritoid | Spinol | Biotite | Number of samples |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Euhedral crystals | Angular grains | Rounded grains | Total | Euhedral crystals | Angular grains | Rounded grains | Total | Crystals and angular grains | Rounded grains | Total | | | | | | | | | | | | | | | | |
| Fall River formation | 0.062 to 0.125 | X | 16 | 16 | 33 | 6 | 21 | 4 | 31 | 44 | 20 | 64 | 7 | 6 | 19 | R | R | R | X | X | – | R | R | X | 2 | – | R | 13 |
| | 0.125 to 0.250 | R | R | 2 | 4 | 5 | 52 | 8 | 66 | 58 | 12 | 70 | 3 | 3 | 20 | R | R | – | 1 | R | – | – | R | 2 | X | – | VR | |
| Fuson-Lakota formations | 0.062 to 0.125 | 1 | 13 | 58 | 72 | X | 4 | 15 | 20 | 19 | 73 | 92 | X | 2 | 5 | VR | VR | – | – | VR | VR | – | – | VR | – | VR | – | 27 |
| | 0.125 to 0.250 | X | 5 | 14 | 30 | 2 | 22 | 33 | 57 | 30 | 47 | 77 | 1 | 1 | 21 | – | – | VR | VR | – | VR | – | – | – | – | VR | – | |

percentage of rounded grains decreases in the coarser size in both the Fall River and Lakota-Fuson formations. Except for these differences, the mineral suites are similar.

Source

The impoverished nonopaque heavy mineral suite and the large proportion of quartz grains in the Morrison, Urkpapa, Lakota-Fuson and Fall River formations suggests that all of four formations were derived principally from pre-existing sedimentary rocks. Much of the clastic material has undergone several cycles of sedimentation as shown by the high proportion of rounded zircon and tourmaline grains in all four formations, and particularly in the Lakota-Fuson, Unkpapa, and upper part of the Morrison formations. Limestone was extensively exposed in the source area or areas during Lakota-Fuson time, judging by the large amount of chert fragments in the coarser fraction of sandstone and conglomerate from the Lakota-Fuson formations. During Fall River time streams in the source area may locally have cut through the sedimentary cover and exposed metamorphic rocks as shown by the rather consistent presence of schist fragments in small amounts in the Fall River formation, the increase in muscovite, and the local abundance of chloritoid and hornblende. The increase in angular tourmaline and zircon grains in the Fall River formation also suggest a partial shift to a crystalline-rock source. Except in the Aladdin and Mona Butte areas, the change upward from predominantly rounded to predominantly angular heavy mineral grains is fairly sharp at the Lakota-Fuson-Fall River contact. If this was essentially simultaneous for all of the Black Hills, then presumably the upper 80 to 100 feet of the Lakota-Fuson formations at Aladdin and Mona

Butte is younger than the upper part of the formation at most sections sampled elsewhere.

A local abundance of biotite and euhedral, needle-like apatite crystals suggest that small amounts of pyroclastic material may be present in the Redwater shale member of the Sundance formation, the lower part of the Morrison formation, and the Fall River formation.

Crowley (1951) has suggested, on the basis of spectrographic analyses of detrital gold from the Newcastle sandstone and the presence of cassiterite in heavy mineral assemblages from the Fall River formation and Newcastle sandstone, that Precambrian rocks in the Black Hills furnished some sediment to the Newcastle sandstone and the Inyan Kara group. Nonopaque heavy minerals from a stream deposit derived from Precambrian rocks in the Hill City-Custer area are shown on table 25. The suite from the Hill City-Custer area differs strikingly from the suites in the Newcastle sandstone and Inyan Kara groups in containing no zircon, relatively little tourmaline, and relatively large amounts of garnet, hornblende, and biotite. The analyses indicate that Precambrian rocks in the Hill City-Custer area are an unlikely source for sandstone in the Inyan Kara group. D. A. Brobst (TEI-640, p. 102-108) has outlined three major channel systems in the Inyan Kara group in the southern Black Hills. In all three the streams flowed from the southeast, suggesting a source in that direction for the Inyan Kara group.

<u>Reference</u>

Crowley, A. J., 1951, Possible Lower Cretaceous uplifting of Black Hills, Wyoming and South Dakota: Am. Assoc. Petroleum Geologists Bull., v. 35, p. 83-90.

## Central region exclusive of the Black Hills

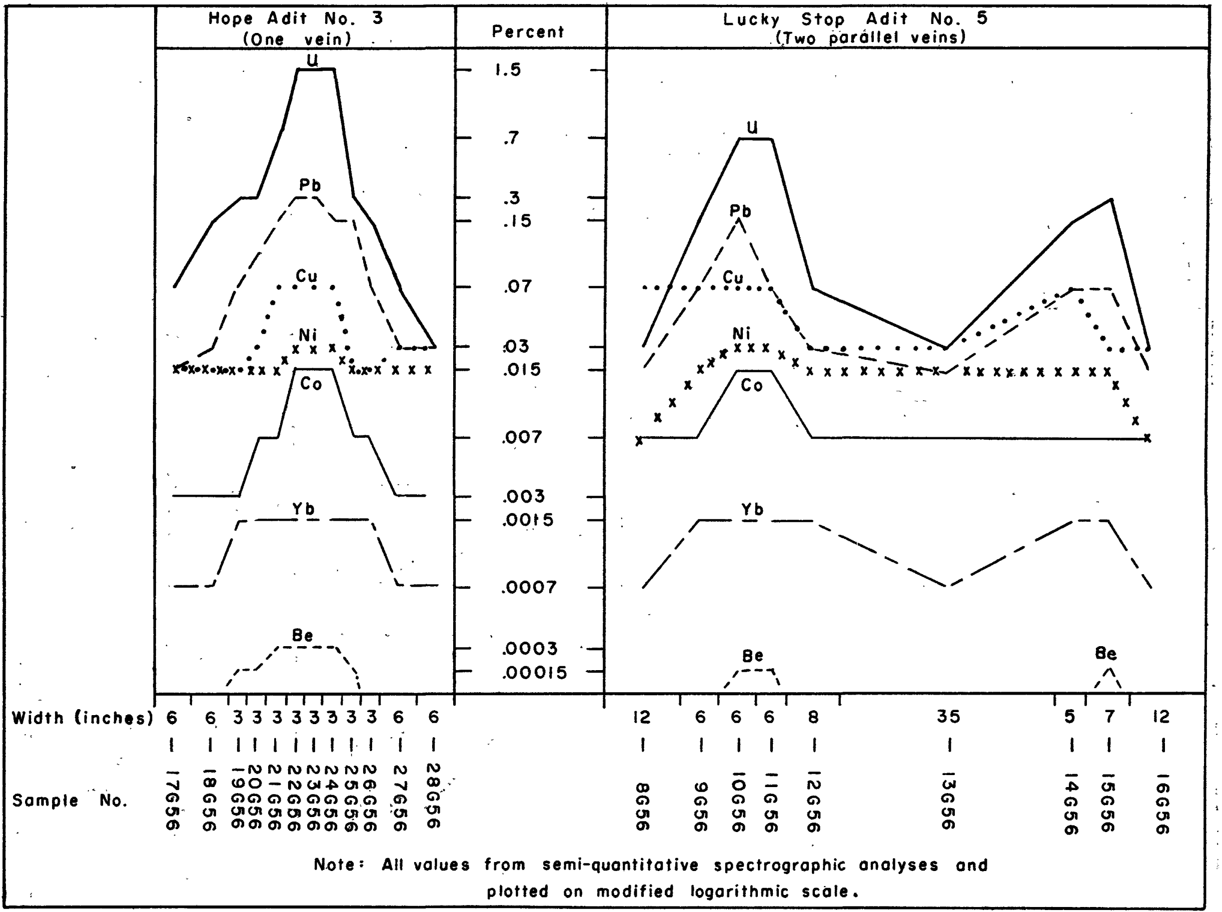
### Dripping Spring quartzite, Gila County, Arizona

by

H. C. Granger and R. B. Raup

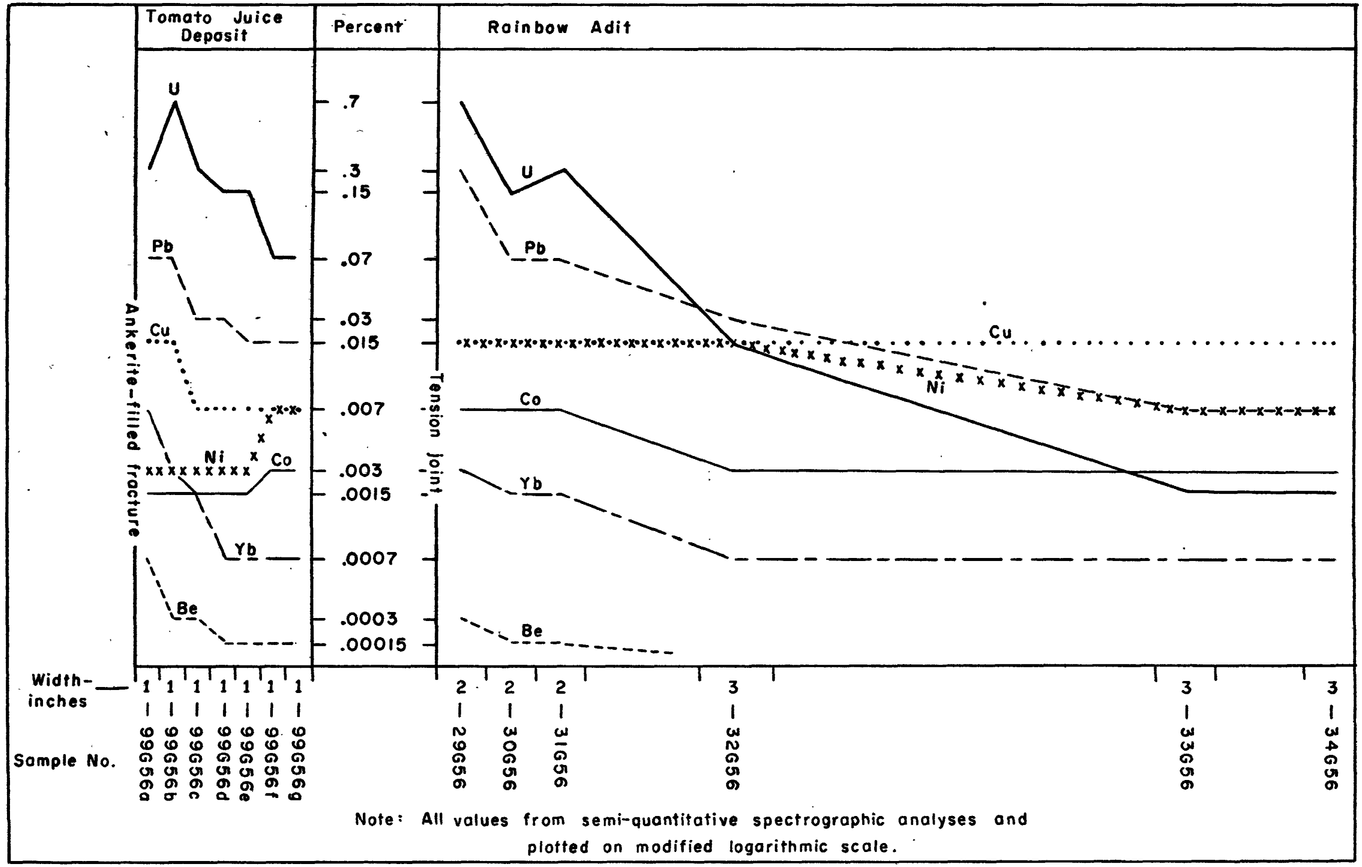
Investigations of the Dripping Spring quartzite, Gila County, Arizona, began in 1954 with the objective of studying the distribution of uranium in the Apache group and related igneous rocks, with particular attention to mineralizing processes. The stratigraphy of the area and other facets of the study were discussed in TEI-620, p. 204-209, which included a generalized strip map showing the outcrops of the Apache group and the Dripping Spring quartzite; and discussions of the mineralogy and of age determinations were included in TEI-640, p. 203-205. Other results of the study are discussed below.

The "veins" in the Dripping Spring quartzite are steeply dipping, tabular, disseminated bodies. The fracture from which the vein minerals were distributed is visible in some places, as at the Tomato Juice and Rainbow deposits but is commonly so obscure that it is unrecognizable. The position of a vein generally can be detected only by sampling or radiation dectection instruments. At the Tomato Juice deposit there is a 2 or 3-inch reddish bleached zone on either side of the ankerite-filled fracture but all the other samples within each group shown on figures 98 and 99 appear megascopically to be identical. It cannot be emphasized too strongly that although the unweathered parts of many deposits have a vein-like shape, they are very commonly not distinguishable visually from the surrounding barren host rock.



Note: All values from semi-quantitative spectrographic analyses and plotted on modified logarithmic scale.

FIGURE 98.—PLOT OF SELECTED ELEMENTS FROM ANALYSES OF CHANNEL SAMPLES ACROSS VEINS IN THE WORKMAN CREEK AREA.



Note: All values from semi-quantitative spectrographic analyses and plotted on modified logarithmic scale.

FIGURE 99.— PLOT OF SELECTED ELEMENTS FROM ANALYSES OF CHANNEL SAMPLES PROGRESSIVELY OUTWARD FROM VEIN CENTERS.

Analyses of samples spatially related to uranium-bearing veins in the Dripping Spring quartzite indicate that the mineralizing solution(s) deposited a diversified suite of elements in addition to uranium. Several veins were sampled by a series of short channel samples that extend either completely across (fig. 98) or outward from the centers (fig. 99) of the veins. The samples were analyzed by semiquantitative spectrographic methods and the results plotted graphically. Some of the values have been checked by more accurate (volumetric, fluorometric, colorimetric, and electrolytic) methods but these do not appreciably change the results.

On figures 98 and 99 it may be seen that there is a striking correlation among the elements U, Pb, Cu, Ni, Co, Yb, and Be. Other elements also show moderately good to excellent correlation but were not plotted. Yttrium is almost invariably 10 times as abundant as ytterbium. Some of the other rare earths such as Ce, Dy, Er, Nd, Pr, and La also show a correlation with U in some of the deposits. Ag, Ga, and Sc are erratic but generally show a positive correlation. Molybdenum behaves strangely, showing a positive correlation at the Tomato Juice and Rainbow but a negative correlation at the Hope adit and in one of the Lucky Stop veins. Calcium shows a positive correlation at the Tomato Juice, no doubt reflecting the carbonate fracture filling, but is negative or shows no correlation elsewhere.

No silicified material is present in the veins; this suggests either that the mineralizing solutions were deficient in silica or that the environment was not conducive to the precipitation of silica.

## Diabase differentiation

The differentiation of diabase and its possible relationship to uranium deposition were briefly described in a previous semiannual report (TEI-620, p. 206). At that time it seemed that the uranium was progressively concentrated in the more salic differentiates and that these might have constituted the source of the uranium in the deposits in the Dripping Spring. Recent studies suggest that a "last gasp" femic differentiate from the diabase may have been the vehicle by which the uranium was introduced into the deposits. This differentiate is represented largely by dark veinlets less than 0.1 inch wide that cut the diabase in many places. The veinlets are composed predominantly of green fibrous to granular hornblende with lesser quantities of biotite, chlorite, and zircon. The zircon is many times more abundant in these "deuteric" veinlets than in the normal diabase or the salic differentiates. Nearly all of the zircons are surrounded by a pleochroic halo either in the hornblende or biotite. The halos are about 0.02 mm. wide and probably result from uranium decay. No analyses are as yet available but it is likely that the "deuteric" veinlets will be found to be richer in uranium than any of the other differentiates. Presumably they are a residual lamprophyric differentiate, later than the albite aplites, and may have furnished the residual uranium a means of escape from the cooling diabase bodies.

### Age

Age determinations of uraninite by the unit cell method (TEI-620, p. 206, 208-209) have been temporarily halted by equipment failure. Preliminary results on one specimen from the Hope adit No. 1 suggest an age of 860 million years. This compares with a previous determination of 730 million years from a specimen from the Black Brush adit.

# Regional synthesis - eastern Montana and the Dakotas

by

J. R. Gill and N. M. Denson

During the report period compilation of geologic and structure contour maps at a scale of 1:20,000 showing areal distribution and grade of the near-surface uranium-bearing lignite occurrences in eastern Montana and the Dakotas were completed for areas 1 through 7 (fig. 100). Approximately three hundred gamma-ray and electric logs from oil and gas test wells throughout the region were studied to determine relationships of the uranium deposits to regional structure and to rock thickness between the uranium-bearing lignite deposits and the Precambrian basement.

Results of these studies indicate that there are four to eight appreciably radioactive zones in the Paleozoic and Mesozoic strata between the base of the lignite-bearing rocks and the top of the Precambrian. The zones are from 5 to 50 feet thick. They can be identified and correlated from well to well by means of gamma-ray logs and are known to extend over large areas within the region. The radioactive material in these zones appears to bear no relation to the major structural features (fig. 101) nor to the known occurrences of uranium-bearing lignite. The highest of these zones stratigraphically, the Sharon Springs member of the Pierre shale of Late Cretaceous age, is about 1,500 feet below the lignite-bearing sequence.

In the plains area of eastern Montana and the Dakotas the uraniferous lignite-bearing Late Cretaceous Hell Creek formation and the early Tertiary Fort Union formation have a maximum combined thickness of about 2,200 feet (table 27). These formations are of continental origin and contain

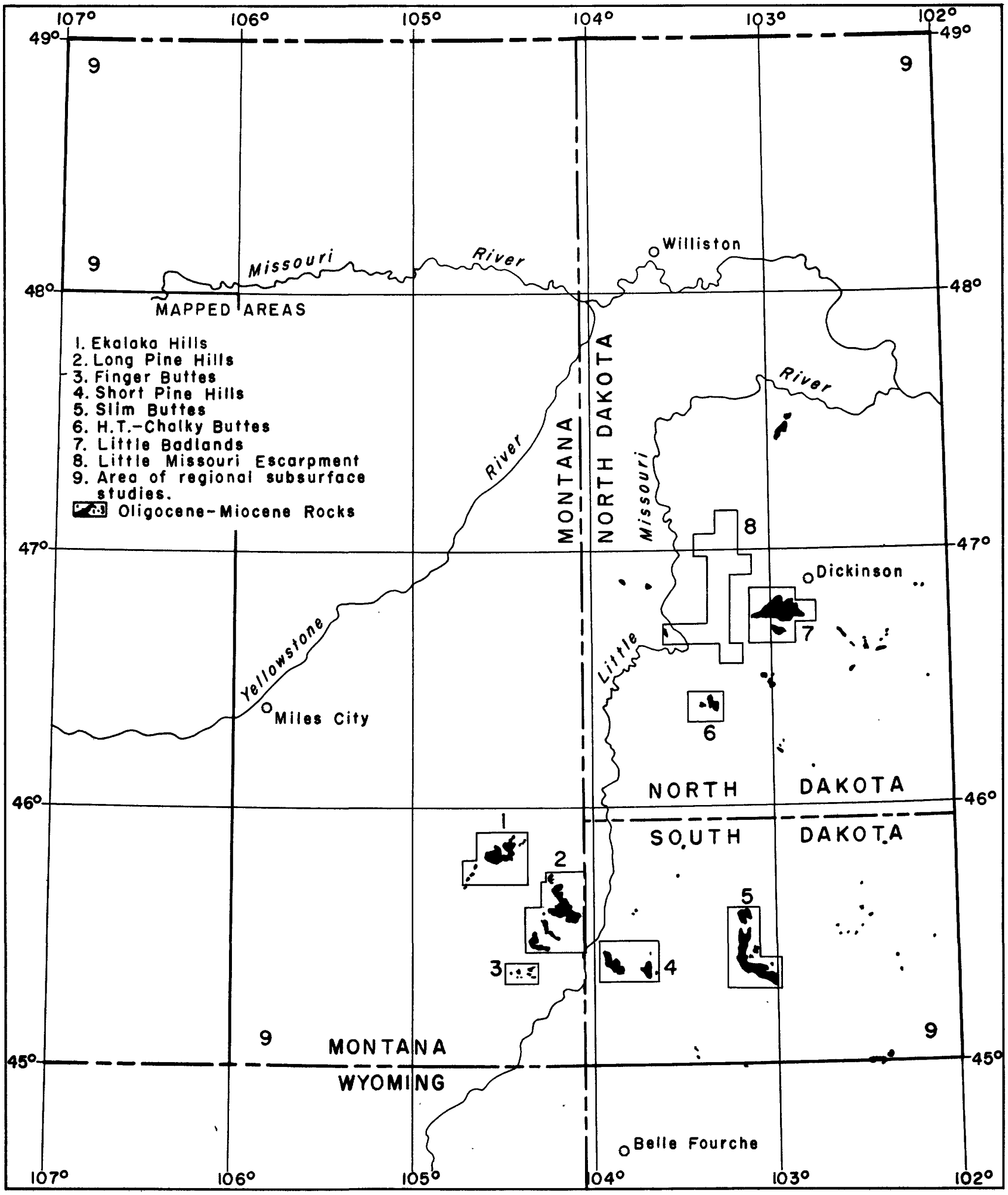


FIGURE 100—INDEX MAP SHOWING AREAS OF URANIUM-BEARING LIGNITE INVESTIGATIONS

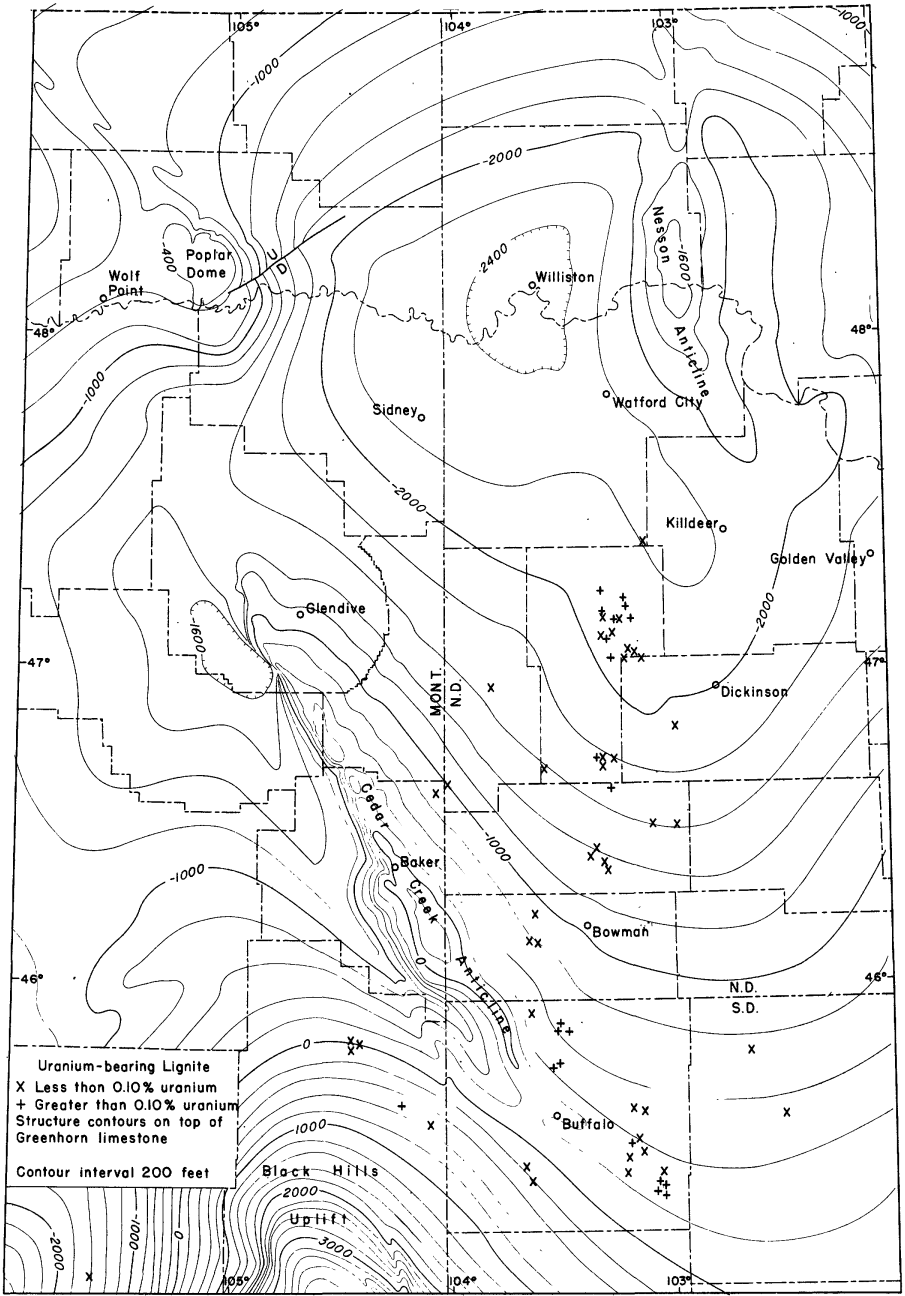


FIG. 101--PRELIMINARY MAP SHOWING RELATION OF REGIONAL STRUCTURE TO AREAL DISTRIBUTION OF URANIUM-BEARING LIGNITE IN EASTERN MONTANA AND THE DAKOTAS.

0 20 40 Miles

Table 27.--Stratigraphic distribution of uranium occurrences in southeastern Montana and adjacent parts of North and South Dakota

| System | Series | Group, formation, member | | Thickness in feet | Type of uranium occurrence |
|---|---|---|---|---|---|
| Quaternary | Recent and Pleistocene | --- | | 0 - 100 | |
| Tertiary | Miocene | Arikaree formation | | 260 | Local occurrences of carnotite in sandstone in the Slim Buttes and West Short Pine Hills. |
| | Unconformity | | | | |
| | Oligocene | White River group | Brule formation | 0 - 240 | Radioactive fossil bones and claystone in the Slim Buttes. |
| | | | Chadron formation | 0 - 160 | Local occurrences of carnotite in claystone in the Little Badlands, and in sandstone in the Slim Buttes. Metatyuyamunite in sandstone in the East Short Pine Hills. |
| | Unconformity | | | | |
| | Eocene | Golden Valley formation | | 0 - 175 | Radioactive lignite in the Little Badlands. |
| | Paleocene | Fort Union formation | Sentinel Butte shale | 760 | Ore-grade lignite and carbonaceous clay containing meta-autunite, metatorbernite, abernathyite 1/, and bassetite in the Little Missouri River escarpment area. |
| | | | Tongue River member | 650 | Sandstone containing uranophane 1/ near Bowman, N. Dak., and ore-grade lignite containing uraninite 1/, meta-autunite, metatorbernite, metazeunerite, saleeite in the Cave Hills area, Harding County, S. Dak. |
| | | | Ludlow member | 350 | Sandstone containing uranophane and ore-grade lignite and carbonaceous shale containing metatyuyamunite, metanovacekite, meta-autunite, and abernathyite 1/ in the Slim Buttes. |
| Cretaceous | Upper Cretaceous | Hell Creek formation | | 500 | Carbonaceous clay and sandstone containing becquerelite and carnotite in the Long Pine Hills; ore-grade lignite in the East Short Pine Hills. |

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1/ Identified by J. W. Gruner, Deane K. Smith, Jr., and James A. Knox, 1956, p. 16. All other uranium minerals identified in the laboratories of the U. S. Geological Survey by X-ray and optical methods.

many impure lignite beds and thick persistent permeable sandstone beds. A body of Upper Cretaceous impervious shale 2,700 to 3,000 feet in thicknexx directly underlies the lignite-bearing rocks of the region and is believed to have served as an effective barrier to either ascending or descending solutions.

Subsurface data from oil and gas test wells indicate that the axis of maximum subsidence of the pre-Tertiary basin, reflected by maximum thickness of sedimentary rocks between the top of the Pierre shale and the top of the Red River formation (Ordovician), trends northward through the more important uranium-bearing deposits in the region (fig. 102). The axis of maximum subsidence during deposition of the lignite-bearing rocks could not be determined by isopaching because at most places in the region much of the sequence has been removed by erosion. However, as the present structural axis of Williston Basin, based on contours on top of the Greenhorn limestone (fig. 101), coincides closely with axis of maximum subsidence during Late Ordovician to Late Cretaceous time (fig. 102), it is probable that subsidence continued along this axis into early Tertiary time. If so, it seems reasonable to conclude that the resulting regional synclinal structure in the coal-bearing rocks may have served to concentrate the flow of mineralizing solutions. The existence of this regional low would also have tended to preserve the deposits from late Tertiary erosion. Local shallow folds and troughs superimposed on the broad regional structure apparently partially controlled the distribution of ore-grade concentrations of uranium in lignite (TEI-620, p. 255). Changes in the permeability of the rocks over and underlying the lignite beds also influenced flow of uranium-bearing ground water and

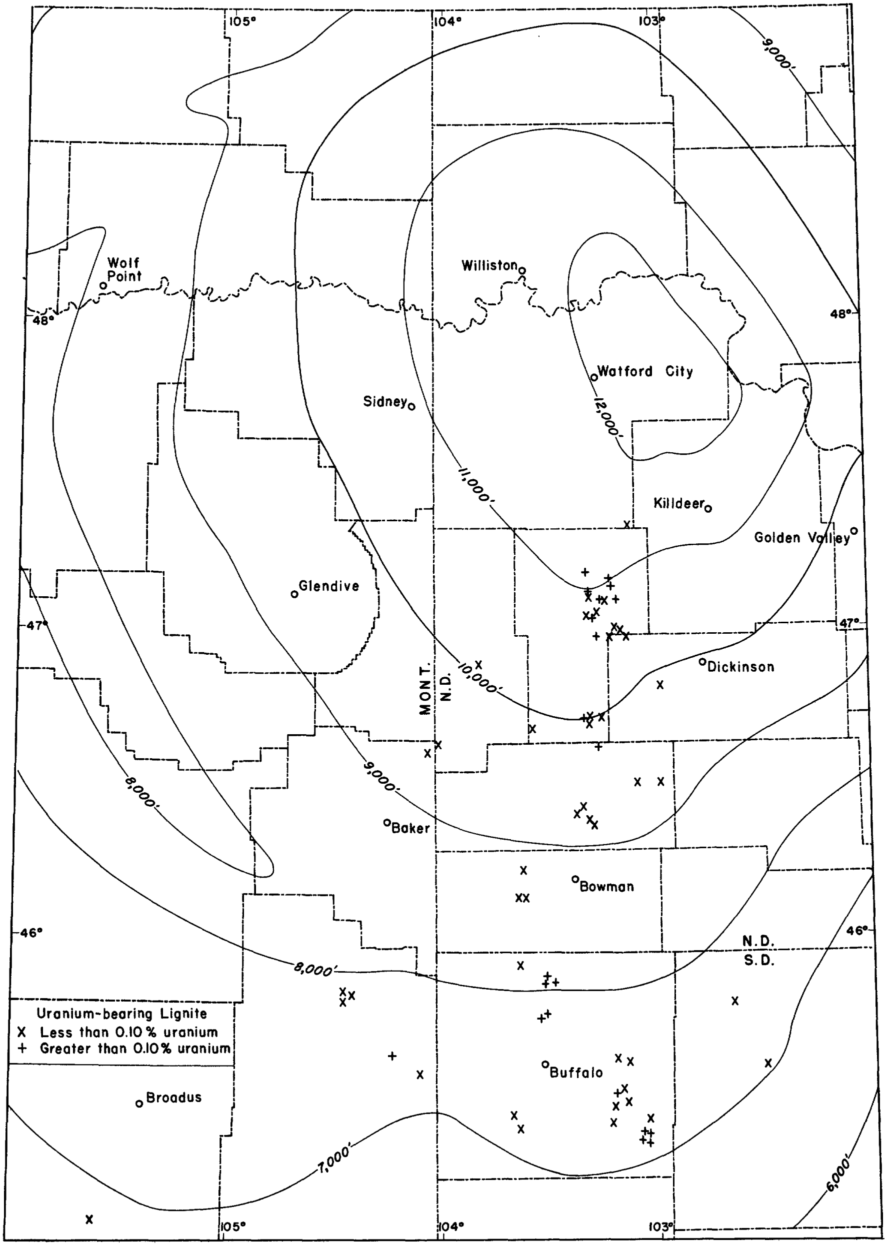


FIG. 102--PRELIMINARY MAP SHOWING AREAL DISTRIBUTION OF URANIFEROUS LIGNITE DEPOSITS IN THE WILLISTON BASIN AND THEIR RELATION TO THICKNESS OF ROCKS FROM TOP OF THE PIERRE SHALE TO THE TOP OF THE RED RIVER FORMATION.

the deposition of commercial grade uranium deposits.

Field evidence indicates that the uranium deposits are genetically related to a regional pre-Oligocene unconformity truncating more than 5,000 feet of rocks in the region. The uranium deposits are within 200 feet vertically of the restored position of this surface of unconformity, preserved now at only a few places mostly near the base of buttes capped with tuffaceous rocks of Oligocene and Miocene age (TEI-590, p. 234).

Reference

Gruner, J. W., Smith, J., Jr., and Knox, J. A., 1956, Annual report for April 1, 1955 to March 31, 1956, Part II: RME-3136 (Pt. II), U. S. Atomic Energy Comm., Tech. Inf. Service, Oak Ridge.

## Permian of north Texas and southern Oklahoma

by

Edward J. Mckay

A summary report of geologic studies started in the fall of 1955 integrated stratigraphic, lithologic, and structural data bearing on the distribution of uranium localities and radioactive anomalies in north Texas and southern Oklahoma (TEI-590, p. 257-262; TEI-620, p. 261-264).

Uranium has been found in two stratigraphic zones of Permian age — the upper half of the Wichita group in the Red River area, and the Rush Springs sandstone of the Whitehorse group in the Anadarko Basin. In the Red River area, the radioactive anomalies have a geographic distribution of about 6,000 square miles and a stratigraphic range of about 800 feet. Recognizable yellow uranium minerals are present at three of the 19 radioactive localities for which analyses are available. In the Anadarko Basin, a vein deposit containing carnotite and tyuyamunite occurs in or near fractures in the Rush Springs sandstone on the Cement anticline (TEI-640, p. 208-216).

The radioactive anomalies in the Red River area are associated with carbonaceous material in scattered red feldspathic sandstone lenses. The sandstone lenses are thin and in strata composed dominantly of shale, claystone, and mudstone. The Rush Springs sandstone in the Anadarko Basin is a thick, festoon-bedded red feldspathic well-sorted sandstone.

The distribution of radioactive localities in the Red River area has no apparent spatial relation either to regional structures (the Red River Uplift and Wichita Mountain Uplifts) or to subsidiary folds on those uplifts. The uranium deposit on the Cement anticline is genetically related to folding in the Anadarko Basin.

Integration of geologic data in the Red River area suggests that mobilization of uranium and its concentration by carbonaceous material in sandstones is favored by the "red bed" facies in the upper half of the Wichita group. In contrast the adjacent marine facies of limestone and drab shale farther south in the Permian Basin and thick channel sandstones and drab shales in the lower half of the Wichita group are barren. Apparently mobilization and movement in solution of uranium is favored in a sedimentary environment of high redox potential and inhibited by low potential. However, concentration of uranium as ore deposits in the upper half of the Wichita group appear to be limited by sandstone lenses which are discontinuous and relatively few in number, generally less than five feet thick, and less than 300 feet across.

The association of large concentrations of uranium with fractures on the Cement anticline, the presence of rocks suitable as hosts for large volumes of ore, and the presence of similar fractures on other anticlines in the Anadarko Basin should encourage exploration in that region.

## Pennsylvanian sediments of the Midcontinent Region

by

W. Danilchik and H. J. Hyden

Rocks of Pennsylvanian age in the Midcontinent Region include relatively uraniferous black shales. These black shales are parts of repetitive lithologic sequences, termed cyclothems, that include sediments of both marine and nonmarine origin and of several lithologic types deposited in contrasting geochemical environments. The distribution of uranium and other metals in black shales within the Des Moines series in Oklahoma, Kansas, and Missouri were studied, and the distribution of uranium and other metals in some coal and petroleum that occur in the Des Moines series was also investigated.

Two general types of black shale occur within this sedimentary sequence: one type is a hard black bituminous shale that contains phosphatic nodules and is relatively radioactive; the other type is a soft black carbonaceous shale that is typically devoid of nodules and is much less radioactive than the bituminous shale. Six carbonaceous shale units were sampled and the average uranium content of the shales at the sample localities ranges from 0.001 to 0.002 percent. Samples were collected from eight bituminous shale units and the average uranium content of the shales at the sample localities ranges from 0.002 to 0.005 percent. Channel samples of bituminous shale collected at closely-spaced horizontal intervals have uranium contents ranging from 0.004 to 0.009 percent and a relatively large range in uranium content was noted in vertical sequences of shale units. Phosphatic nodules collected from the bituminous shale units at various localities have average uranium contents ranging from 0.009 to 0.023 percent and average $P_2O_5$ contents ranging from 23.9 to 29.4 percent. Generally, lens-shaped nodules contain less uranium and phosphate than rounded nodules, and light-colored nodules contain less uranium and phosphate than dark-colored nodules. The quantities of the rare earth elements, dysprosium, erbium, and neodymium in the phosphatic nodules correlate positively with the $P_2O_5$ contents of the nodules. These phosphatic nodules contain greater amounts of the rare earth elements than are found in phosphatic rocks from other areas.

An unusually large uranium content, 0.085 percent, is present in the ash of coal from the uppermost few inches of a coal bed immediately underlying a bituminous shale unit. The lower part of this coal bed has an unusually large germanium content, 0.07 percent. Oil-impregnated sandstone from Vernon County, Missouri, contain relatively large amounts of uranium in comparison to similar materials from other areas.

Oil samples collected from Nowata field, Oklahoma, contained unusually large percentages of uranium in the ash, 0.016 to 0.045. A program of secondary recovery by water injection was in process at the field, and samples of injection water and produced water were collected in addition to the oil samples. In parts of the field, water samples collected at producing wells contain more uranium and more sulfate than do water samples collected at injection wells. Cores of the oil-producing section yielded coaly material, asphalt-like material, and oil; all of which were analyzed. Only the ash of the extracted oil contains appreciable amounts of uranium.

## Alaska

### Reconnaissance for uranium in Alaska
by
E. M. MacKevett, Jr.

During the report period work in Alaska consisted chiefly of laboratory investigations, map compilation and report writing on the Bokan Mountain uranium-thorium area on the southern part of Prince of Wales Island, and operating the radioactivity testing laboratory at College, Alaska.

The geologic setting of the uranium-thorium deposits in the Bokan Mountain area has been briefly described in TEI-640, p. 216-218. Most of these deposits are believed to be genetically related to the granite that forms a boss having an area of about 3 square miles near Bokan Mountain. This rock has been studied in detail. It is an uncommon type, a persilicic alkali granite, characterized by a high quartz content, albite, both microcline and sodian adularia, acmite, and a sodic amphibole. The accessory minerals, which typically form less than 1 percent of the granite, include zircon and less abundant pyrite, fluorite, xenotime, urano-thorite, uranoan thorianite, and possibly magnetite and monazite. Secondary minerals in the granite are hematite, limonite, nontronite and other clay minerals, and thomsonite.

Apparently the granite has had a complex history, as indicated by its range in texture and the two stages of formation of its constituent quartz and potassium feldspar. Locally it is porphyritic with coarse- or medium-grained phenocrysts, prevailingly quartz, in a fine- or medium-grained groundmass. Other textural variants include seriate porphyritic,

Table28.--Semiquantitative spectrographic analyses of seven granite samples from the Bokan Mountain uranium-thorium area 1/

| Sample No. | Percent >10 | 10 | 3 | 1 | .3 | .1 | .03 | .01 | .003 | .001 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1* | Si | Al | Fe<br>Na<br>K | | Zr | Ti<br>Ce | Ca,Mn,La | Ga,Nb,Sn | Mg,Ba,Cr, Cu,Ni,Y, Yb | Pb,Sc, Sr |
| 159* | Si | Al | Fe<br>Na<br>K | | Zr | Ti | Ca,Mn, Ba,Ce | Mg,La,Y, Nb | Cr,Ga,Ni, Sn,Yb | Be,Cu,Pb, Sc,Sr |
| 168* | Si | Al | Fe<br>Na<br>K | | | Ti | Ca,Mn, Ce,Zr | Mg,Ga,La, Nb,Y,Zn, Li | Ba,Cr,Sn | Cu,Ni,Sc, Sr,Yb |
| 219** | Si | Al | Fe<br>Na<br>K | | Ce | Ca<br>Ti<br>Zr | Mn,La,Nb, Nd,Y | Mg,Ba,Cu, Er,Pb,Zn Dy | Ni,Sn,Sr, U,Yb | Be,Cr,Ge |
| 225** | Si | | Al<br>Fe<br>Na | K | | Zr | Ca,Ti,Mn | | Nb,Ni,U,Y | Ba,Cr,Cu, Ga,Yb |
| 233** | Si | Al | Fe<br>Na<br>K | | Ca | Ti<br>Ce<br>Th<br>Y | Mn,La,Nb, Nd,Zr | Mg,Ba,Dy, Er,Sr,Zn | Pb,Sn,U | Be,Cr,Cu, Ga,Ni |
| 234** | Si | Al | Fe<br>Na<br>K | | | Ti<br>Ce<br>Zr | Mn,Y | Ba,La,U | Mg,Cu,Ni, Yb | Cr,Ga, Pb,Sr |

1/ Analyses by Geochemistry and Petrology Branch, U. S. Geological Survey. Elements reported in percent to the nearest number in the series 10, 3, 1, .3, .1, .03, .01, .003, .001.

* Chemical analyses for uranium pending.
** Uranium determined by chemical analysis.

Table 29.--Rapid-method chemical analyses of three samples of granite from the Bokan Mountain uranium-thorium area [1]

| Sample No. | 1 | 159 | 168 |
|---|---|---|---|
| | Percent | Percent | Percent |
| $SiO_2$ | 73.4 | 74.1 | 73.6 |
| $Al_2O_3$ | 11.0 | 12.3 | 11.6 |
| $Fe_2O_3$ | 3.6 | 1.5 | 2.1 |
| FeO | 1.8 | 2.0 | 2.5 |
| MgO | .05 | .05 | .05 |
| CaO | .05 | .05 | .05 |
| $Na_2O$ | 4.5 | 4.8 | 4.9 |
| $K_2O$ | 4.6 | 4.7 | 4.5 |
| $TiO_2$ | .20 | .15 | .14 |
| $P_2O_5$ | .00 | .00 | .00 |
| MnO | .05 | .08 | .10 |
| $H_2O$ | .35 | .38 | .37 |
| $CO_2$ | .26 | .29 | .26 |
| Sum | 100.00 | 100.00 | 100.00 |

[1] Samples analyzed by Geochemistry and Petrology Branch, U. S. Geological Survey, using methods similar to those described in U. S. Geological Survey Bulletin 1036-C.

hypautamorphic granular, and cataclastic. The granite contains abnormal quantities of certain minor elements, notably uranium, thorium, yttrium, lanthanum, niobium, and cerium and other rare earths. The results of semiquantitative spectrographic analyses of seven granite samples are shown in table 28.

Table 29 shows the results of rapid-method chemical analyses of three samples of granite from the Bokan Mountain uranium-thorium area.

The Ross-Adams deposit is the most important known uranium-thorium deposit in the area. It occurs within the alkali granite near its contact with older quartz monzonite and granodiorite. Laboratory studies of ore from the Ross-Adams deposit indicate two stages of ore formation--(1) the local concentration of uranium- and thorium-bearing accessory minerals, principally urano-thorite and uranoan thorianite, in the granite; and (2) the emplacement of numerous uranium- and thorium-bearing veinlets in the deposit. The veinlets consist of abundant calcite and hematite; lesser amounts of quartz, fluorite, pyrite, galena, limonite, a chlorite-like mineral, uranoan thorianite and urano-thorite, and probably other radioactive minerals.

### Reference

Shapiro, Leonard, and Bronnock, W. W., Rapid analysis of silicate rocks: in Contributions to Geochemistry, U. S. Geol. Survey Bull. 1036-C, 1956, p. 19-56.

## General studies

### Research and resource studies

The objective of research and resource studies is to analyze and correlate on a national scale all available data on the geology of radioactive materials. Results of some studies in progress are presented below.

## Uranium deposits in sedimentary rocks, by W. I. Finch and I. S. Parrish

Uranium deposits that are generally conformable to the bedding of sedimentary host rocks but cross-cut the bedding in detail are numerous in the United States; the host rocks include arenaceous, argillaceous, highly carbonaceous, and carbonate rocks deposited in continental environments or in marginal continental environments. These deposits are epigenetic in that they were formed later than the rocks in which they occur, but they are not vein deposits in that they do not conform to faults or shears.

The distribution of known uranium deposits of the type described above in the various geologic systems or series is tabulated in figures 103 and 104. The uranium deposits tabulated contain 0.01 or more percent $U_3O_8$.

In figure 103 showing the distribution of presently known uranium deposits in the various systems from Precambrian through the Quaternary, the curve outlining the distribution has two peaks, a major peak in the Jurassic and a minor peak in the Tertiary.

In figure 104 showing the distribution of uranium deposits by series within the systems from the Triassic through the Quaternary, the curve outlining the distribution shows marked peaks for the upper series in the Triassic, Jurassic, and Cretaceous systems; this distribution coincides in general with the extent of clastic sediments of continental origin in these systems.

The frequency distribution of uranium deposits reflects in part the extent of continental rocks in the various systems and series. In the

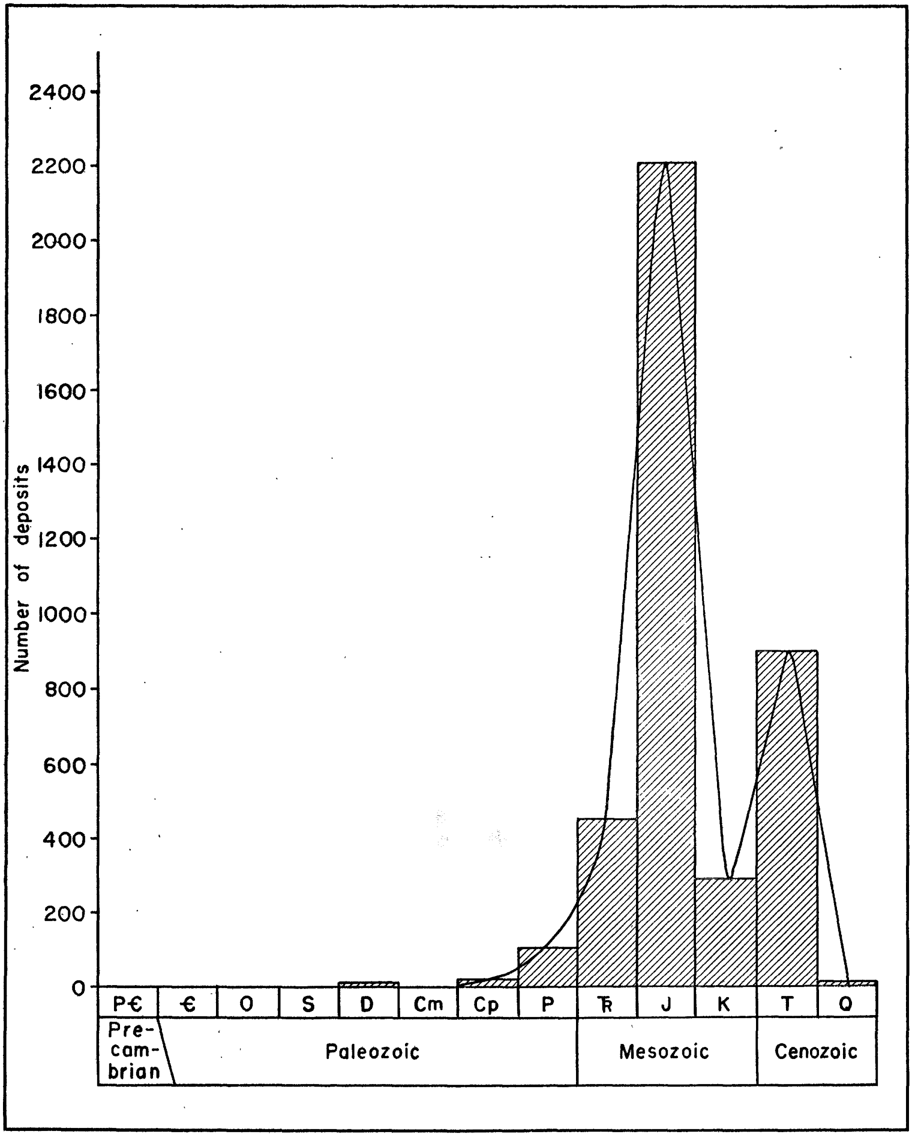


FIGURE 103-GRAPH SHOWING THE NUMBER OF KNOWN URANIUM DEPOSITS GENERALLY CONFORMABLE TO THE BEDDING OF SEDIMENTARY HOST ROCKS IN THE UNITED STATES WITH RESPECT TO THE GEOLOGIC SYSTEMS

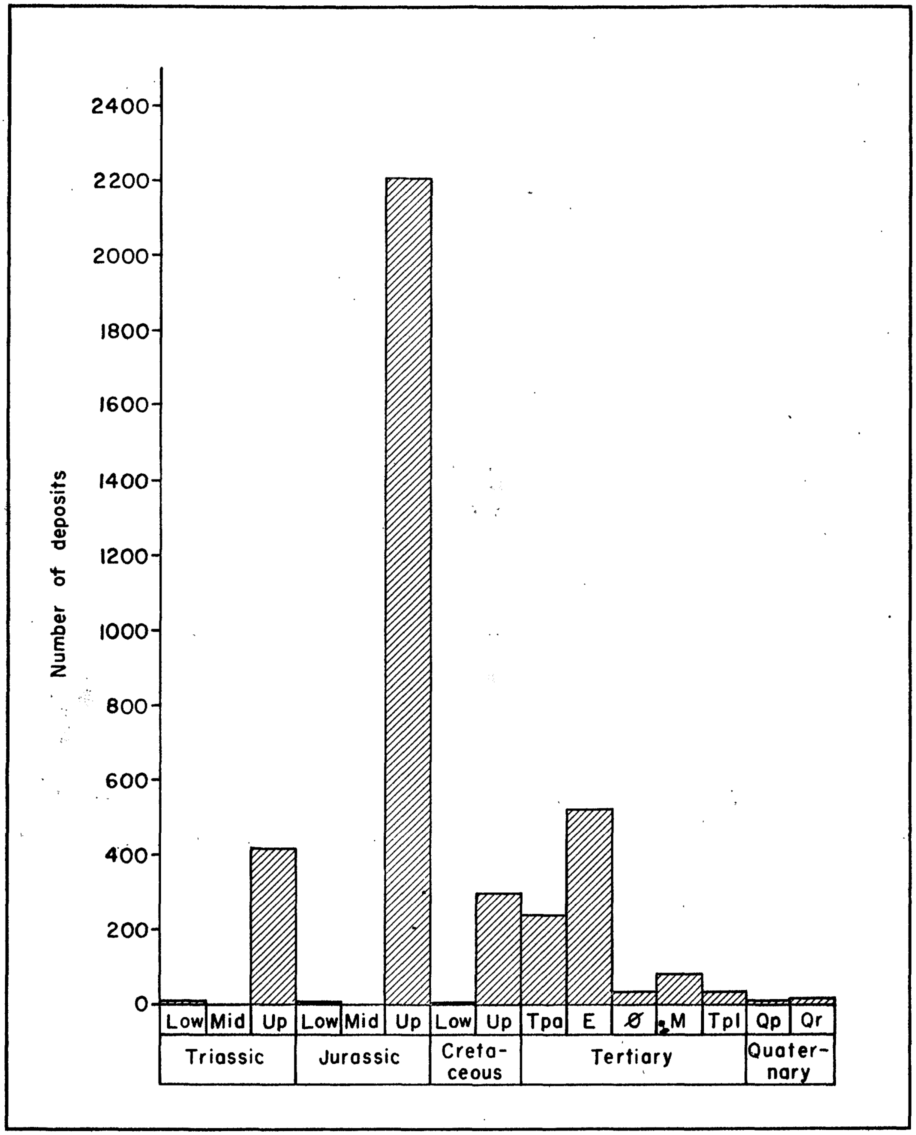


FIGURE104 -GRAPH SHOWING THE NUMBER OF KNOWN URANIUM DEPOSITS GENERALLY CONFORMABLE TO THE BEDDING OF SEDIMENTARY HOST ROCKS IN THE UNITED STATES WITH RESPECT TO THE SERIES OF THE TRIASSIC, JURASSIC, CRETACEOUS, TERTIARY, AND QUATERNARY SYSTEMS

Paleozoic, continental rocks are not widespread from the Cambrian through the Mississippian systems, and the number of deposits in these systems is correspondingly small; in the more widespread continental rocks of Late Pennsylvanian and Permian age, the deposits are correspondingly more numerous. In continental rocks of Mesozoic age, the upper series of the Jurassic system is the most widespread, and the deposits are correspondingly the most numerous. The frequency distribution of uranium deposits in continental host rocks of early Tertiary age again coincides with the extent of continental rocks.

The frequency distribution of uranium deposits in continental rocks ranging from Permian to Tertiary in age suggests that the source of the sediments and the metal were the same. A second interpretation is that the physical and chemical characteristics of the continental rocks in the various geologic periods were unique for the later introduction and deposition of uranium.

## Mineralogy of uranium-bearing veins, by J. W. Adams, and G. W. Walker

A study of the paragenesis of uranium-bearing vein deposits in the United States, based in part on published data and in part on examination of many polished sections, suggests that hypogene uraninite is almost invariably early or intermediate in the suite of metallic minerals with which it is associated in any particular vein stage. Further, no correlation can be demonstrated between the paragenetic position of uraninite and the geologic age of the deposit. This is in contrast to an earlier suggestion that in Precambrian deposits uraninite is early in the paragenetic sequence and in Paleozoic or younger deposits is either intermediate or late in the sequence (Everhart and Wright, 1953, p. 91).

Reference

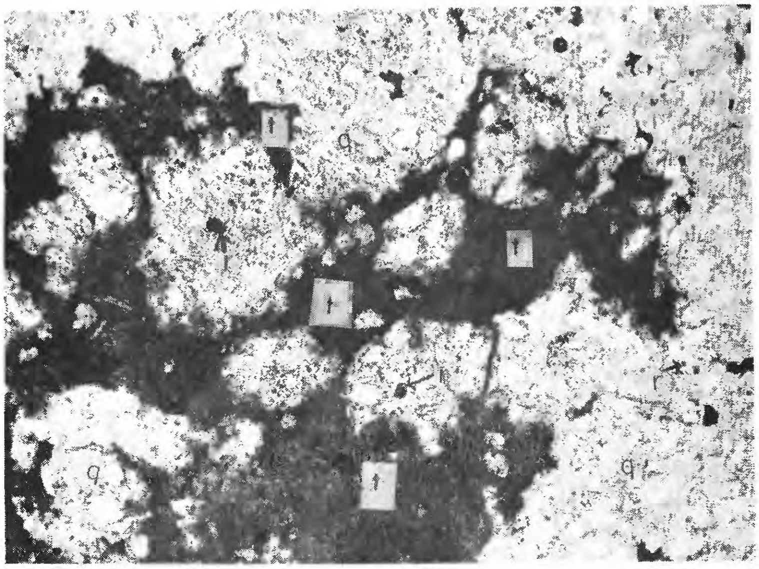
Everhart, D. L. and Wright, R. J., 1953, The geologic character of typical pitchblende veins: Econ. Geology, v. 48, p. 77-96.

Uranium minerals in a silicified log from Monument No. 2 mine, Apache County, Ariz., by T. L. Finnell

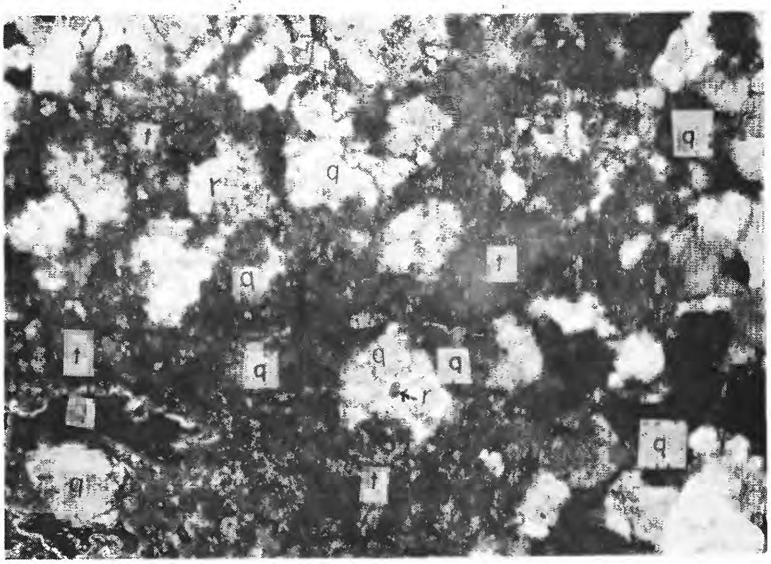
An occurrence of secondary uranium minerals along the rim of a 2-foot diameter silicified log from the north workings of the Monument No. 2 mine was sectioned and studied because it seemed to be an impregnation of fine- to medium-grained sandstone that penetrates the log as much as one inch along cracks. A thin section normal to the cell structure of the log (fig. 105, A) shows preservation of the wood cell structure even though the log is almost completely replaced by silica. Under cross nicols, the relict cell structure is partly obscured (fig. 105, B) because the anhedral to subhedral quartz grains replaced the log without apparent relation to the size and shape of the wood cells.

Secondary uranium minerals penetrate the edges of the log along the quartz crystal boundaries, and completely surround some quartz crystals. If the secondary uranium minerals had penetrated all of the silicified log in the same manner, the resultant effects could easily be misinterpreted as an impregnation of sandstone by the uranium minerals. Ore textures of uranium deposits in sandstone involving impregnation of quartz grains by uranium minerals should be examined with the thought that the quartz is not necessarily detrital and that it may represent silicified wood.

Secondary uranium minerals occupy two separate and distinct positions in the sections. Rauvite(?) (deep orange, high index of refraction) occupies



A. Wood cell structures outlined by minute inclusions in quartz (q). Rauvite(?) (r) occupies some cell pores and forms relicts in tyuyamunite (t) that penetrates the quartz. Plain light, X104.



B. Same as A. Polarized light. Crystals of quartz are not obviously related to the wood cell structure. Tyuyamunite and rauvite(?) penetrate the log along quartz crystal boundaries. X104.

FIG. 105 .--PHOTOMICROGRAPHS OF SILICIFIED LOG PARTLY REPLACED BY RAUVITE(?) AND TYUYAMUNITE.

discrete cell pores, (fig. 105, A) and tyuyamunite (yellowish green, n = 1.85 +, bladed, easily fusible, positive vanadium test) containing a few relicts of rauvite(?) penetrates the quartz along some of the grain boundaries (fig. 105, B). Where this penetration has proceeded very far into the log, single quartz crystals and aggregates of quartz crystals are completely surrounded by the secondary uranium minerals, giving the appearance in hand specimen of a quartz sand impregnated by uranium minerals. Relict wood-cell structure can still be seen in these grains, thus revealing that the uranium minerals have penetrated along the intergranular quartz boundaries in the silicified wood, either through replacement of quartz or through void filling following the solution of quartz.

It is not known whether the tyuyamunite and rauvite(?) formed by the oxidation in place of uraninite and a primary vanadium mineral, or whether the uranium and vanadium were released elsewhere by oxidation of primary minerals and were transported to their present location. Regardless of the history of the secondary minerals, the uranium-vanadium minerals were clearly emplaced along the periphery of the log after the silicification had occurred.

Unoxidized remnants of uraninite and montroseite occur elsewhere in the mine (Weeks and Thompson, 1954; Johnson, D. H., oral communication, 1953). The uraninite commonly preserves wood cell structure as an apparent replacement of the cell walls, although locally it also occupies the cell pores. Uraninite rarely fills the interstices between quartz grains and rarely fills fractures in the quartz (Resenzweig and others, 1954). Montroseite occurs only sparingly in the mine and where observed forms idiomorphic crystal growths arranged radially around detrital quartz grains.

The rauvite(?) that occupies the position of the cell pores may have formed from oxidation of uraninite and montroseite that entered the wood structure before silicification. However, oxidizing agents must have reached these seemingly isolated pores in order to effect the oxidation. The solutions that deposited the silica may have contained the oxidizing agents, but the preservation of cell structure in an undeformed log of this size suggests that the log was silicified shortly after burial in the sediments, some 160 million years ago, and lead-uranium ratios in the ore indicate that the ore minerals were deposited about 75 million years ago (Stieff and others, 1953). Although other minerals may have preserved the cell structure, it seems unlikely that their replacement by silica would have left intact the minute inclusions that outline the cell walls. Of course, if oxidizing solutions could penetrate the silica to attack primary minerals in seemingly isolated cells, then secondary solutions containing uranium and vanadium presumably could do the same thing and, if the metals were precipitated in the cells, the minerals thus formed would be younger than the silicification. It seems clear that some rauvite(?) and tyuyamunite is later than the silicification, and there is no compelling argument that the rauvite(?) which occupies the position of former wood cell pores is not also later than silicification of the log.

Caution should be exercised in the interpretation of uranium ore textures near fossil logs or in uranium deposits where fossil wood may have been present in the host rock - some of the ore textures that have been interpreted to be impregnations of sandstone by the ore minerals may actually be replacement of silicified wood along the boundaries between quartz crystals.

During this report period the following reports were published:

Finch, W. I., 1957, Application of punched cards to geologic data concerning uranium deposits in sandstone: Econ. Geology, v. 52, no. 2, p. 180-191.

Finnell, T. L., 1957, Structural control of uranium ore at the Monument No. 2 mine, Apache County, Arizona: Econ. Geology, v. 52, no. 1, p. 25-35.

Vine, J. D., 1956, Geology of uranium in the Tertiary basins of Wyoming and the northern great plains (abs.): Geol. Soc. America Bull. 67, no. 12, pt. 2, p. 1803.

## References

Rosenzweig, Abraham, Gruner, J. W., and Gardiner, Lynn, 1954, Widespread occurrence and character of uraninite in the Triassic and Jurassic sediments of the Colorado Plateau: Econ. Geology, v. 49, no. 4, p. 357.

Stieff, L. R., Stern, T. W., and Milkey, R. G., 1953, A preliminary determination of the age of some uraninite ores of the Colorado Plateaus by the lead-uranium method: U. S. Geol. Survey Circ. 271.

Weeks, A. D., and Thompson, M. E., 1954, Identification and occurrence of uranium and vanadium minerals on the Colorado Plateau: U. S. Geol. Survey Bull. 1009-B.

# GEOPHYSICAL INVESTIGATIONS

## Colorado Plateau region

### Regional Geophysical Studies

by
H. R. Joesting, P. E. Byerly, D. Plouff and J. E. Case

Compilation of aeromagnetic data covering about 22,000 square miles of the Colorado Plateau is nearing completion except for two 15-minute quadrangles near the Henry Mountains, where completion of the magnetic maps has been delayed pending availability of topographic maps. Compilation of aeromagnetic data covering several smaller areas involving special problems is under way: among these are the Abajo and La Sal laccolithic mountains in Utah, and the northern extension of the Uncompahgre uplift in Utah and Colorado.

Regional gravity data covering the La Sal Mountains area, the Orange Cliffs area and the Verdure area, all in Utah, have been compiled. Complete Bouguer anomaly maps have been prepared for the first two areas. Since mid-April gravity surveys have been made in the Thompson - Cisco and the Verdure areas in Utah, and along the San Juan River between the Four Corners and Mexican Hat, Utah.

Preliminary isopach maps have been prepared of the Devonian Elbert formation, and of the Mississippian and Pennsylvanian formations of the Colorado Plateau. Preliminary structure contour maps have also been prepared on the top of the Elbert and the top of the Mississippian formations. These maps are based largely on subsurface data furnished by oil companies and commercial stratigraphic services, and by publications of the U. S. Geological Survey and the Utah Geological and Mineralogical

Survey. The isopach and structure maps were prepared as part of a study of the larger stratigraphic and lithologic units of the Paleozoic rocks of the Colorado Plateau, to guide the interpretation of geophysical results.

Geothermal measurements have been made whenever suitable boreholes are available, as part of a study to determine temperature gradients, flow of heat from the earth's crust, and the effect, if any, of uranium deposits on temperature gradients and heat flow. Temperatures were measured during the past winter in a 1,100 ft. drill hole in the White Canyon area in Utah, and cores of part of the hole were obtained. Additional temperature measurements will be made until the hole has reached practical thermal equilibrium.

Analysis of magnetic and gravity data in the Lisbon Valley area yields additional evidence that a basement ridge or shelf bounds the major salt anticlines of the Paradox Basin on their southwest sides. According to this conception, the deepest part of the Paradox Salt Basin, and the thickest evaporite deposits, are bounded by the Uncompahgre Plateau on the northeast and a generally parallel basement ridge (or ridges) southwest of the Lisbon Valley salt anticline. No large salt structures are found beyond these limits. This postulated basement ridge may have been in existence before deposition of the Paradox Salt member of the Hermosa formation. It seems more likely, however, that it formed as a result of late Paleozoic structural activity when the Uncompahgre Plateau was also raised many thousands of feet.

The Lisbon Valley faulted anticline is marked by a prominent negative gravity anomaly, most of which is caused by upward thickening of salt through flowage. Part of the anomaly is also apparently caused by bottom thickening and greater depth of salt under the anticline. Bottom thickening would probably be contemporaneous with deposition of the salt, rather than with post-depositional flow. It could be caused either by structural activity or by lateral changes of facies of the Hermosa formation.

A marked correlation exists between gravity anomalies and surface structures in the Hatch Wash and Dry Valley areas, west and southwest of Lisbon Valley. The structures were formed, in part at least, by migration of salt during Mesozoic or post-Mesozoic times, as Jurassic and Cretaceous beds are involved in the folding. On the other hand, there is some discordance of gravity and structural trends northwest of Lisbon Valley, indicating migration of salt along somewhat different trends during Permian or early Triassic times. Local thinning of Permian and Triassic formations due to migration of salt is also indicated.

Analysis of a prominent negative gravity anomaly near Pine Ridge, north of Lisbon Valley, indicates that it is probably caused by a piercement salt plug, over which the upper Hermosa and Cutler formations are thin or absent. The Pine Ridge plug lies on the strike of the Gypsum Valley piercement salt anticline, as does the South Mountain group of igneous intrusions in the La Sal Mountains to the northwest. Correlation of these structures with magnetic anomalies and trends suggests basement control of the emplacement of both the salt and the igneous intrusions.

Preliminary analysis of the gravity map of the La Sal Mountain area shows that the shallow structures -- the salt anticlines and the diorite intrusions -- yield the most prominent gravity anomalies. These are superimposed on a northwest-striking regional gradient with lowest values along Sagers syncline, which borders the Uncompahgre uplift on the southwest.

At the margin of the Uncompahgre uplift the gravity values increase again, due to the influence of shallower basement rocks. A gravity nose which coincides with a domal structure in the sedimentary rocks is considered to indicate a buried igneous intrusion.

An augite-andesite porphyry dike, extending southeast for several miles, was found from aeromagnetic indications 15 miles east of Klondike Ridge, Colorado. The dike is apparently associated with Lone Cone. Magnetic indications of other shallow igneous intrusions exist in the same area.

Marked variations in average magnetic susceptibility and density are exhibited in specimens of igneous rocks from the various laccolithic mountains of the Colorado Plateau. In general, the variations in susceptibility and density are in agreement. Thus, specimens from the Abajo and Ute Mountains have the lowest average susceptibility and density, those from the La Sal Mountains are intermediate, and those from the Carrizo, La Plata and San Miguel Mountains are highest. No attempt has yet been made to relate the magnetic and mass properties of the rocks to their petrography. Magnetic susceptibilities are determined predominantly by magnetite content of the rocks, but it is doubtful if the variations in magnetite content are enough to account entirely for the variations in gravity.

## Central region

### Texas coastal plain geophysical and geologic studies
by
R. M. Moxham, D. H. Eargle, and J. A. McKallor

In the spring of 1956 an airborne radioactivity and magnetic survey was completed over an area of about 15,000 square miles in the Texas coastal plain (fig. 106). To date about 250 square miles, covering most of the Falls City 15-minute quadrangle in Karnes, Atacosa, and Wilson Counties, have been mapped geologically at a scale of 1:25,000, for the purpose of correlating the radioactivity and geophysical data with the general geology. In the area between Tordilla Hill and Deweesville in western Karnes County, where the largest known concentrations of uranium ore occur, geologic mapping of the mineralized areas at a scale of 1:4,800 is being done, and ground isoradioactivity surveys have been made in the same area. The detailed mapping is designed to determine the controlling factors in the distribution of radioactive materials, which will assist in evaluating the airborne and ground radioactivity surveys.

Airborne radioactivity and magnetic surveys.

The airborne radioactivity survey shows that the gross regional radiation features are a result of the lithologic character of the coastal plain sediments, modified both locally and areally by recent pedological and morphological processes, and of mineralization and other extrinsic qualities as yet unexplained. Figure 107 shows an airborne radiation profile extending from the Wilcox group of Eocene age to the Goliad sand of Pliocene age. The marked contrast in measured radiation intensities along the profile is the result of minute differences in the equivalent uranium content of the sediments. An outstanding example is the large contrast between the radioactivity of the upper part of the Wilcox and that of the Carrizo sand of middle Eocene age. According to an analysis of the radiation data by the Sakakura method (Sakakura, 1956), which is corroborated by ground radiation measurements and chemical analyses,

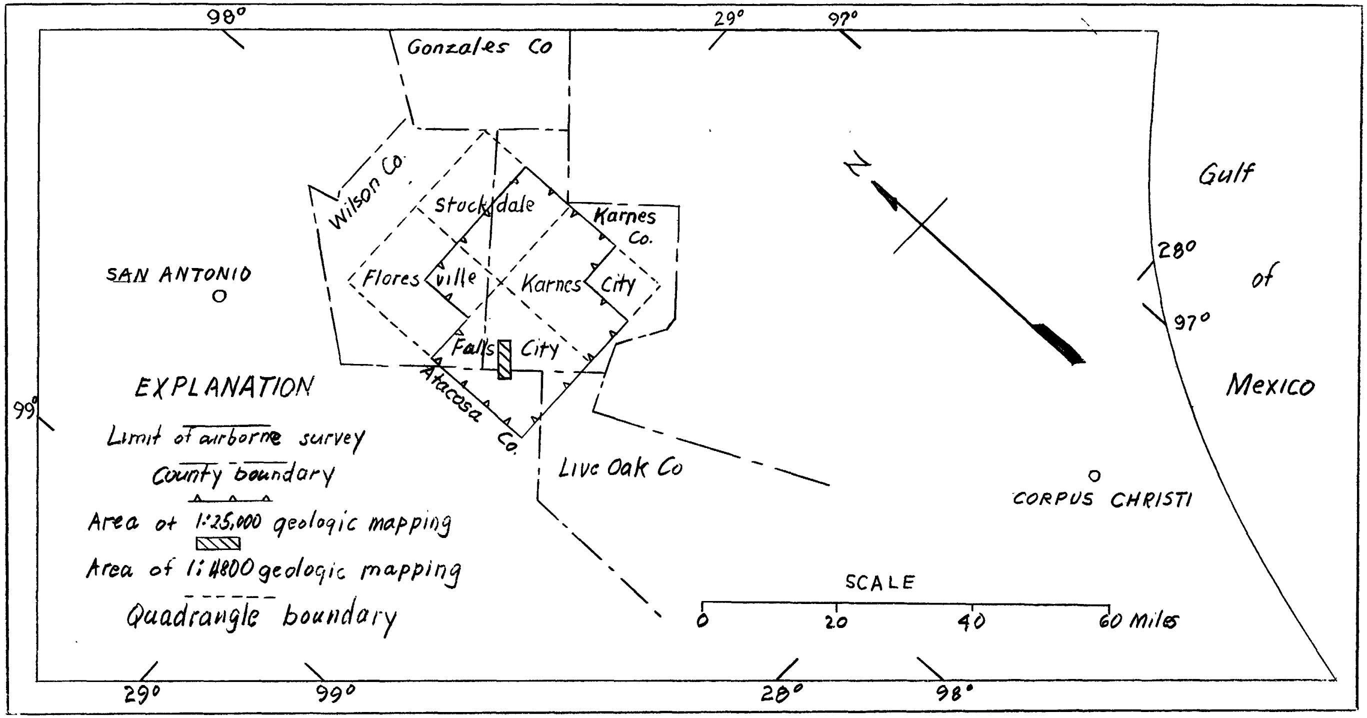


Fig. 106.—Index map of the Texas coastal plain project.

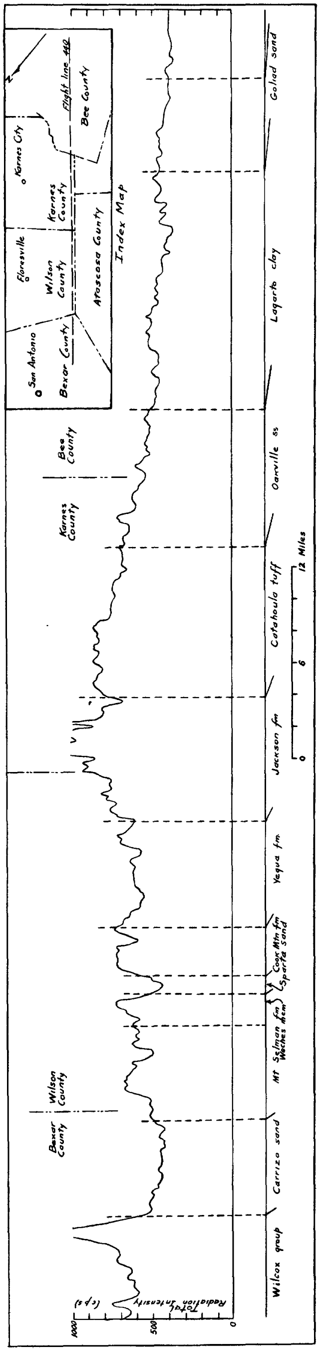


FIG. 107 GEOLOGIC SECTION AND AIRBORNE RADIOACTIVITY PROFILE ALONG FLIGHT LINE 440, TEXAS COASTAL PLAIN

the upper part of the Wilcox contains .0023 percent eU, the Carrizo sand .0008 percent eU. Regardless of the significance of the fourth place in the computed figures, it is apparent that regional and local radiation patterns can be recognized easily, even though they may be the result of differences in equivalent uranium content of only a few parts per million.

Radiation patterns in the "normal" intensity (a range of about 400 to 600 c.p.s.) resulting from lithologic and stratigraphic controls are in many instances persistent over distances of as much as several tens of miles; locally, however, they may be obliterated or modified by recent alluvial deposits, other consolidated deposits, and probably by soil creep. Perhaps the most striking of these regional features in the area being studied is the pattern from the Carrizo sand, a radiation "trench" that is strongly persistent across the entire width of the surveyed area.

At some localities the distribution of radioactivity is controlled largely by lithology and stratigraphy. Of more importance, however, are the abnormal radiation patterns found in districts containing deposits of uranium ore. The most important of these, which is in the central part of the region, includes the principal mineral deposits of Karnes and eastern Atacosa Counties. In this area an abnormal radiation pattern extends from Cibolo Creek to the Atacosa River along the strike, and from the base of the Jackson formation to the upper part of the Oakville sandstone across the strike. In this area, about 30 miles long and 12 miles wide, the basic stratigraphic and lithologic controls seem to be completely over-ridden by the mechanism that emplaced the extraneous radioactive material. This anomaly, though the largest known in the area, is not unique. Other abnormal areas occur to the northeast, in the Reklaw and

Queen City members of the Mt. Selman formation; near the center of the area, mostly in the Jackson formation; and to the southwest, in the Catahoula tuff.

Quadrangle mapping

In the 1:25,000 scale mapping particular attention is being paid to the depositional environments and to the relation of ore-bearing horizons to the regional pattern of structure, stratigraphy, and lithology. As some uranium deposits are associated spatially with silicified sandstone, and as some concretionary limestone is present, areas showing different degrees of silicification and calcification are being mapped.

In the area of quadrangle mapping (see fig. 106) three formations crop out; the Yegua and Jackson formations of Eocene age, and the Catahoula tuff of Miocene(?) age.

The Yegua formation consists principally of fine-grained sandstone but contains thin beds of tuffaceous siltstone and claystone. The formation weathers to yellow-orange and reddish-brown soils which can be readily distinguished from the gray-weathering Jackson formation which overlies the Yegua.

The lower part of the Jackson formation consists of a sequence about 300 feet thick in which massive tuffaceous siltstone and claystone are the dominant rock types. In places the sandstone beds are highly fossiliferous, and in the upper part of the argillaceous section a lenticular bed composed entirely of oyster shells crops out locally.

Overlying the basal Jackson is a sandstone unit which is referred tentatively to the Dilworth sand of Ellisor (1933). It is fine- to medium-grained, cross-bedded to massive, generally friable, but locally silicified. Its lower part contains abundant borings of Halymenites major;

its upper part contains a bed of carbonaceous shale, and is capped by a bluish-gray clayey very fine-grained sandstone several feet thick. Dilworth sand of Ellisor is about 25 feet thick at most places, but thickens appreciably near the Falls City fault. Overlying the so-called Dilworth sand is the Falls City shale of Ellisor, which in this area is about 65 to 70 feet thick. It is a chocolate to pale yellowish-brown bentonitic and carbonaceous claystone; about 15 feet below the top are fossiliferous beds of sandstone which make an excellent stratigraphic and structural marker.

The principal uranium-bearing beds in the area occupy a stratigraphic position equivalent to that of the Stone's Switch sand of Ellisor. These beds of the so-called Stone's Switch are fine- to medium-grained sandstones which contain <u>Halymenites</u> <u>major</u> borings and, near the top, plant root impressions and, locally, oyster shells. The upper beds are generally silicified but the lower 12 to 15 feet is soft and friable and, in places, grades into the underlying Falls City shale of Ellisor.

Overlying the Stone's Switch sand of Ellisor is a sequence of siltstone, clay, and sandstone which are the equivalent at least in part to the Dubose of Ellisor. This unit, which is about 65 feet thick, is overlain by a sandstone, the upper part of which caps Tordilla Hill. The upper 15 to 20 feet of this sand is normally silicified and hard, whereas the lower 10 to 12 feet is generally soft and friable. The unit is overlain by carbonaceous tuff, bentonitic clay, and siltstone which is in part the equivalent of the Fashing clays of Ellisor.

The Catahoula tuff of Miocene(?) age overlies the Jackson formation unconformably. It consists of several hundred feet of calcareous tuffs which locally are lignitic, and bentonitic clay. The Catahoula overlaps the Jackson progressively from southwest to northeast; in the southwestern part of the area it rests on the Fashing clays of Ellisor, in the northeastern part on the Stone's Switch sand of Ellisor.

All beds in the area dip gently to the southeast. The area is cut by two major faults; the Falls City fault, downthrown to the southeast, and the Fashing fault, downthrown to the northwest. A number of faults trending north or northwest cut the major fault zones. The throws of the faults are usually several tens of feet on the outcrops, but are reported to be much greater at depth because of movement along the fault planes contemporaneous with deposition of the beds.

Detailed mapping of mineralized areas

The Tordilla Hill-Deweesville area is about 4 miles long and 1 mile wide (see fig. 106) and includes the Climax and Boso claims. In this area the principal mineralization is in the Stone's Switch sand of Ellisor; that at the Boso claim in the lower Stone's Switch (unit E on the geologic section, fig. 108) and that at the Climax in unit F (fig. 108).

Moderate silicification is widespread in the area. It is confined to a zone within 10 to 12 feet of the present land surface and apparently is quite selective, certain beds being much more susceptible to silicification than others. Moderate silicification is widespread, but the more intense form which results in practically a quartzite is very localized. The contact between well-silicified and unconsolidated sands of the same stratigraphic unit is normally sharp and at places cuts across the bedding.

Carbonate concretions and occasional carbonate lenses occur in a zone near the top of the Falls City shale of Ellisor, but generally speaking

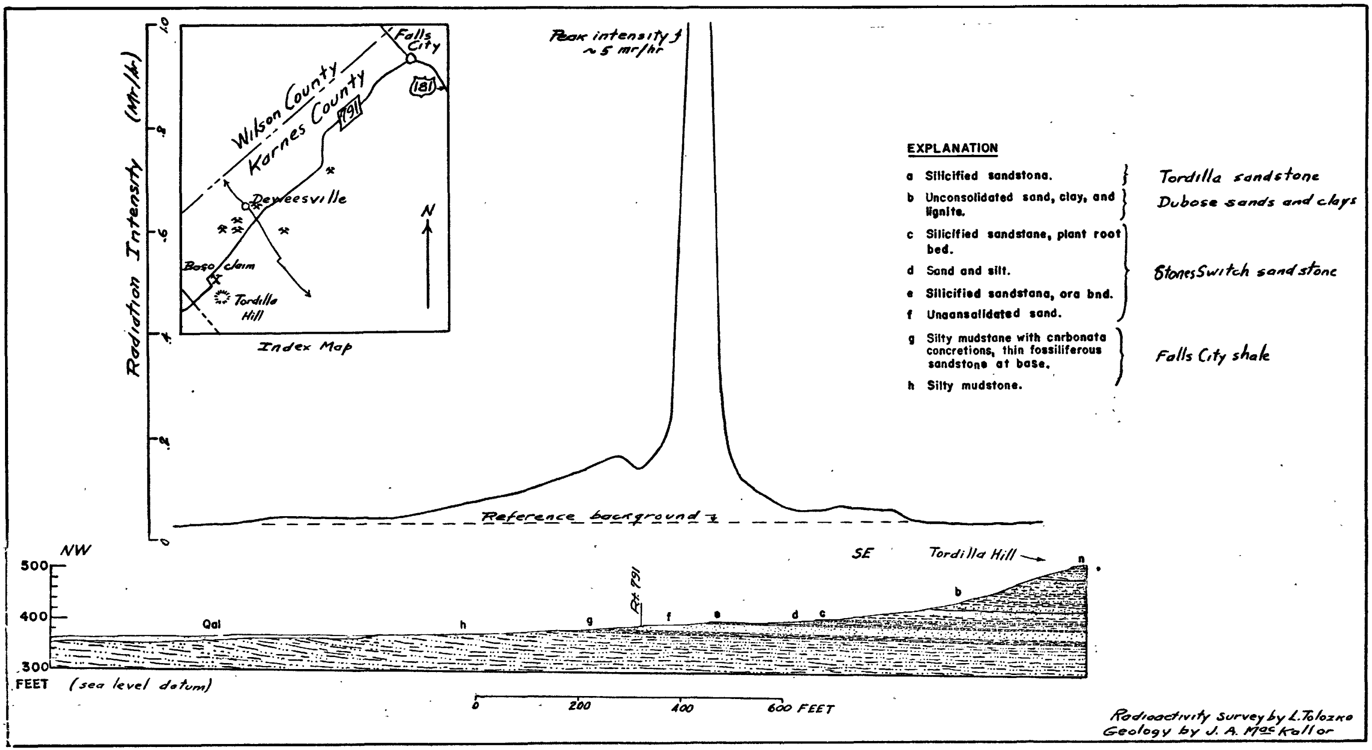


Fig. 108 Surface radioactivity profile and geologic section at the Boso claim, Karnes County, Texas

carbonate is rare in the immediate vicinity of the ore deposits. As a rule the uranium minerals are at the base of, or in friable sand beneath silicified strata, and stratigraphically above the horizon in which carbonate is found.

Over most of the mineralized area the beds strike about N. 35° E. and dip at a rate of about 60 feet a mile to the southeast. This dip is only about half the normal regional dip of the Jackson in the Texas coastal plain, and suggests either a structural terrace or tilting of a block between the Falls City and Fashing faults; either condition might have an important bearing on regional ore control.

Vertical joints are common in the silicified part of the Stone's Switch sand of Ellisor throughout the area mapped. Most belong to one of two prominent sets that strike N. 50°-60° E. and N. 35°-40°W. In plan view the Climax ore body shows protuberances of ore whose axes coincide almost exactly with the strike of a vertical joint, indicating that the joint system is at least a secondary control in the emplacement of ore.

## Isoradioactivity mapping

Isoradioactivity mapping in the Tordilla Hill-Deweesville area indicates that, if the reference background is assumed to be about .015 mr/hr, the zone of abnormal radiation includes not only the Stone's Switch sand of Ellisor, but extends downward in the section probably as far as the upper part of the Dilworth sand of Ellisor. Within the abnormal area are zones and "hot spots" of intense radioactivity. An apparent correlation exists between the highly abnormal zones and certain stratigraphic and lithologic horizons, such as the unconsolidated sand shown as unit F (fig. 108). Other controlling mechanisms, however, must be considered, as at some places the radioactivity contours cross lithologic and stratigraphic boundaries, and at others form radioactivity halos. This phenomenon is well illustrated at the Boso claim, near the foot of Tordilla Hill. Here unit E of the Stone's Switch sand of Ellisor (fig. 108) is the host rock for locally intense uranium mineralization. The thickness of unit E does not exceed a few feet and the width of its outcrop does not exceed a few tens of feet. However, abnormal radiation extends at least 1,000 feet up-dip to the northwest, and at least the same distance along the strike as shown in figures 108 and 109. Figure 108 shows a radioactivity profile through one of the pits where ore is exposed in unit E. Here the radiation is quite intense, reaching about 5 mr/hr but dropping precipitously in all directions. Toward the base, however, the radiation profile slopes off gently and does not drop to the reference background for many hundreds of feet from the locus of mineralization. It is quite apparent from the isoradioactivity contours (fig. 109) that this condition is due partly to topographic control; that is, the radioactive materials in unit E probably are being carried down the slope to the topographic lows. Surficial movement of this nature, however, apparently is confined to a comparatively thin veneer, as auger drilling shows that the bedrock is quite near the surface. Logs of the auger holes, which were drilled at 100-foot intervals, show that the radioactivity is not confined to surface material, but extends 10 to 15 feet below the ground surface. This is well shown by the log of hole 28, given in figure 110. Observations in the area and study of the drill-hole logs leads to the conclusion that the development of radioactivity halos probably results from a combination of chemical and mechanical factors.

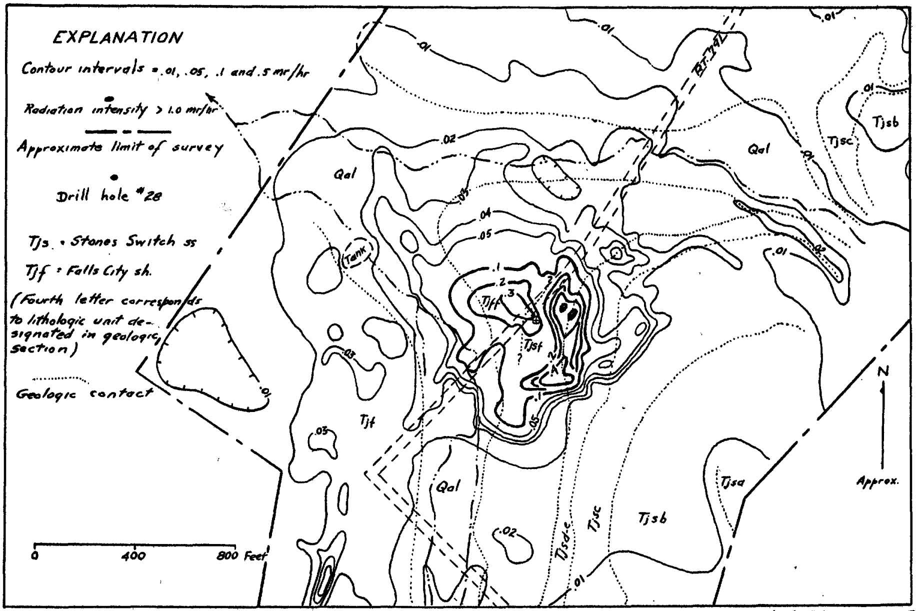


FIG. 109 GEOLOGY AND RADIOACTIVITY SURVEY BOSO CLAIM AND VICINITY, KARNES COUNTY, TEXAS

Radioactivity survey by L. Tolozko, 1956-7
Geology by J. A. MacKallor, 1956-7

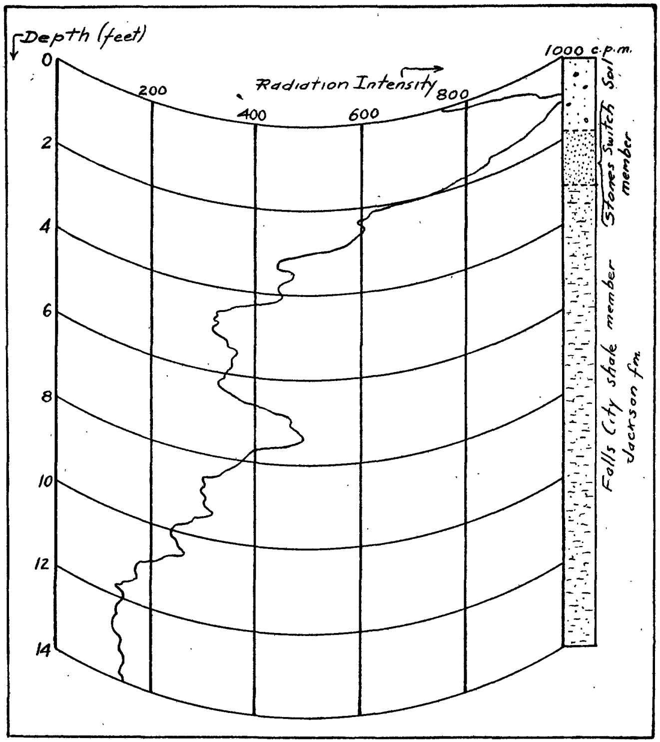


FIG. **110** GEOLOGIC SECTION AND GAMMA-RAY LOG, DRILL HOLE 28
KARNES COUNTY, TEXAS

## Geophysical field measurements, by R. A. Black

Geophysical field measurements were made in Karnes County in February and March, 1957, to obtain information on the fault patterns and to determine whether electrical anomalies are associated with the ore bodies. Test measurements made over known faults with the seismic refraction and D. C. electrical resistivity techniques were successful in delineating these faults. Approximately 5½ miles of seismic traverse were then shot to verify or disprove a number of faults postulated from lineations and drainage patterns on aerial photographs. The seismic data indicated that none of these postulated faults were actually present, or that, if present, they did not significantly offset detectable refracting horizons.

Resistivity horizontal profiles were run over a shallow uranium ore body to determine if resistivity anomalies were associated with the ore body. Several high resistivity anomalies, due apparently to silicified zones within the ore-bearing sandstone, were mapped, but these zones apparently bear no relation to the location of the uranium deposit. In the process of delineating these siliceous zones with resistivity horizontal profiles at electrode separations of 30 and 60 feet, a small fault was discovered in the vicinity of the ore body. Additional resistivity measurements were made to delineate the fault trend and, although the measurements were complicated by anomalies due to the siliceous zones, the fault was traced through the area in which the ore deposit is located.

Gamma-ray logging in the Texas coastal plain is discussed in the following section of this report.

## References

Ellisor, A. C., 1933, Jackson group of formations in Texas, with notes on the Frio and Vicksburg: Am. Assoc. Petroleum Geologists Bull., v. 17, no. 11, p. 1293-1350.

## General investigations

### Gamma-ray logging studies

by

Carl M. Bunker

The objectives of the gamma-ray logging program in Karnes Co., Texas, are to determine the relationships between surface and subsurface radioactivity anomalies, to determine lithology from the log interpretations, and to determine a third-dimensional picture of the shape of the radioactive deposits. Approximately 75 percent of the program was completed during this report period. An auger was used to drill 47 exploratory holes for probing. In addition, several privately-drilled holes and 5 holes drilled to obtain original state cores were logged, the total footage logged being 4,715 feet.

There is a general correlation between the grade of subsurface radioaction material and the surface radioactivity anomaly, although there are some exceptions. As the data and interpretations are still incomplete, the effect of depth of overburden has not been evaluated. The gamma-ray logs show the shape of the radioactive mineralization within and among the drill holes. In this area most lithologic contacts are poorly defined. This may be due to the highly lenticular characteristics of the formations and the less than ideal sampling from the auger cuttings.

Drill cores from the original state holes are being scanned with a 4-detector scintillation scanner to determine variations in radioactivity within the core and the results will ultimately be interpreted in percent equivalent $U_3O_8$. These data will be correlated with the gamma-ray logs to determine whether there is a variation between the quantity of radioisotopes in the drill core and in the formation adjacent to the drill holes.

Numerous equipment problems have impeded progress on both spectral work and gamma-gamma (density) logging. The slip-ring assembly in logging reels has been introducing spurious counts in the system which have a detrimental effect on spectral response and on quantitative determinations of radioisotopes being measured. Replacement of carbon brushes with bronze brushes eliminated this problem.

Initial spectral measurements were made using a short length of cable between the detector and the pulse height analyzer. Results are favorable and indicate that small quantities of isotopes may be analyzed in this manner. Increasing the cable length to the required 2,000 feet for inhole logging creates a major problem in transmitting undistorted pulses from the detector to the analyzing equipment. The present impedence matching circuit design is inadequate. Several transistor designs are being fabricated and tested at present.

Numerous data have been obtained to determine the effects of variables such as photomultiplier tube voltage, bias, clipping time, and count-rate on the spectral response of the pulse height analyzing unit. Barium, cesium, and cobalt radioisotope standards were used to make the analyses. These data will be used to develop logging procedures and to aid in the interpretation of spectral data.

# Physical and associated properties in ore-bearing and poorly mineralized uranium ground in Montrose County, Colorado and San Juan County, Utah

by [1]

G. E. Manger, G. L. Gates, and R. A. Cadigan

Original state core studies were started by the Geological Survey in 1952 as part of the geophysical program on the Colorado Plateau. The work has been coordinated with that of the Pacific Petroleum Experiment Station of the U. S. Bureau of Mines, San Francisco, California, which has assisted in the planning and execution of the coring program. The Bureau of Mines has also made extensive analyses of the physical properties of the cores obtained, and has assisted materially in the interpretation of the results. The following report discusses results of the original-state core program in three areas in the Colorado Plateau; Long Park and Bitter Creek, in Montrose County, Colorado and Lisbon Valley, in San Juan County, Utah.

Samples of drill core from uranium-bearing sandstone in the Colorado Plateau were studied to determine conditions that control the movement of uranium-bearing solutions and the deposition of uranium, and to discover geological and geophysical criteria for locating uranium ore. Physical, chemical and mineralogical properties of the sandstone were determined by laboratory investigations. Information on the physical properties of the corresponding sandstone in situ was ascertained from radioactivity and electric logging. In order to obtain rock samples as near as possible in the natural or original-state core drilling was done with essentially water-free oil-base mud or with air.

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A total of seven holes were core drilled. In each of three localities at least one hole was drilled in ore-bearing ground and one in poorly mineralized ground. These localities include the Jurassic carnotite terrane in Long Park, Montrose County, Colorado, where uranium ore is completely oxidized, the Jurassic corvusite terrane in Bitter Creek, Montrose County, Colorado, where the uranium ore is somewhat oxidized, and the Triassic uraninite terrane in Lisbon Valley, San Juan County, Utah, where the uranium ore shows no oxidation.

In Long Park extensive investigations have been made in the carnotite-bearing formations. Results show that the permeability of the sandstone surrounding the ore averages several hundred millidarcies and exceeds the permeability of other sandstones of the section drilled. Permeability within the ore (in this instance 0.93 feet of sandstone containing an average of 0.42 percent U) ranges from 3.3 to 45 millidarcies, but the maximum concentration of uranium and vanadium is not found in the interval of least permeability within the ore. Hence the decrease in permeability which accompanies the presence of ore probably is not a result of the emplacement of the ore. In zones where the average uranium content ranges from just above background to ore concentration the average clay content is always greater than in the vertically adjacent rock. The next most consistent relationships in all the uranium-bearing zones are a greater average pore water content, lesser average permeability, greater range in the size distribution of clastic particles, and a decrease in the average diameter of these particles. Exceptionally intervals of decreased permeability in the host sandstone are not accompanied by increased uranium content, but these intervals show large amounts of carbonate cement and only small amounts of clay. A causal relation between decreases of permeability and the deposition of uranium is suggested. In the ore the organic carbon content ranges from 0.2 to 7.0 percent and increases with increasing uranium content. Outside the ore, with uranium in the range from 0.0006 percent, which is the background amount, to 0.01 percent, the amount of organic carbon ranges from 0.10 to 0.30 percent, but shows no direct correlation with the amount of uranium nor inverse correlation with the permeability. A limited search shows that the amounts of mixed-layer hydrous mica and mica do not differ appreciably in uranium-bearing rock and barren rock. Chlorite was found only in the ore and 15 feet above. Vanadium spectrographic lines are strongest in the ore and decrease irregularly in strength upwards and perhaps downwards. Nearly all the poorly mineralized uranium-bearing zones lie above the ore; at only one place was it found below the ore.

In Long Park core drilling with essentially water-free oil-base mud or with air apparently has recovered formation water which is either unaltered or only slightly altered in amount and quality. The carnotite ore, which is about 1 foot thick, lies within a water zone, and the top of the ore is 3.7 feet below the top of this zone. The amount of formation water in this zone is considerably less than the amount needed to fill the pores of the sandstone but exceeds the capillary amount -- or the amount remaining after re-saturating core samples with a 3 percent sodium chloride solution and then desaturating through a semi-permeable membrane under a displacing air pressure of 100 pounds per square inch. In the ore zone there is a slight excess of formation water over capillary water and this excess increases irregularly with depth in the water zone.

Slow gravity drainage of ground or pore water therefore may occur in the water zone, but may be limited to the interval below the ore. The water zone without any effective permeability barrier passes abruptly upwards into a highly desaturated zone. As the amount of formation water in this desaturated zone is much less than the capillary amount, any movement of (liquid) water would necessarily be by capillarity. Electric logs of drill holes, together with analyzed core porosity, core water and clay content and water-leaching of the cores show: the resistivity is high in the host sandstone above the ore because the clay and pore or formation water content is low, even though the pore water is saturated with salts; the resistivity is low in the ore and in other uranium-bearing zones because the clay and pore water content is appreciable, even though the water probably is relatively fresh; the resistivity is high and reaches a maximum value in the host sandstone below the ore because the clay content is low and the pore water relatively fresh, even though the amount of pore water is appreciable. Variations in these three properties, the amount of clay, the amount of pore water and the salinity of the pore water-result in a characteristic electrical resistivity log.

A second hole in Long Park was core drilled with air, through poorer grade carnotite ore within 10 feet of the drill hole penetrating carnotite ore. Cores from the air drilled hole show appreciably greater water content than those of the other drill hole at comparable structural position and permeability. The variation of water content with depth, however, is similar in both drill holes, as are the variations in the character of the resistivity log in both drill holes. Although there is a difference in the magnitude of the resistivity peaks of the electric logs of the two drill holes, this difference is much less than is indicated by the difference in pore water content. The increase in the amount of pore water is approximately compensated electrically by a decrease in salinity. Hence the salinity of the pore water apparently is roughly inversely proportional to the fraction of the pore space occupied by water. Sandstone cores from above the carnotite which were subjected to water leaching yielded larger amounts of salt than the pore water could possibly hold in solution. Thus, the presence of salts precipitated on the walls of the pores in the natural state is indicated.

A third drill hole in Long Park penetrated poorly mineralized ground about 1,700 feet from the two drill holes penetrating carnotite ore. The ore zone and the next highest uranium zone carry through at constant stratigraphic levels to form the two identifiable radioactive zones at the poorly mineralized locality. These two radioactive zones are about one foot thick, are at the bottom of a very fine-grained silty sandstone of less than one millidarcy permeability, and are in contact with immediately underlying sandstone of several hundred millidarcies permeability. A genetic relation between permeability and mineralization at the poorly mineralized locality would imply some upward movement of the uranium-bearing solution from the more permeable into the less permeable sandstone. The chief differences at the location of the drill hole in poorly mineralized ground, as compared with the drill holes in ore-bearing ground, are the greater resistivity above the stratigraphic equivalent of the ore than below, a generally desaturated condition of the sandstone below as well as above the stratigraphic equivalent of the ore and the presence of several claystone beds in the host sandstone.

In the Bitter Creek corvusite locality and the Lisbon Valley uraninite locality cores were obtained by drilling with oil-base mud. Detailed investigation of the cores has not been completed, but the cores from these localities, like those from Long Park, show that the permeability of the sandstone enclosing the ore equals or exceeds the permeability of the other sandstones of the drill holes. In Long Park and Lisbon Valley this sandstone is appreciably permeable, but in Bitter Creek extensive silicification has greatly reduced the permeability of the entire section. As in Long Park, permeability within the ore in Bitter Creek and Lisbon Valley is variable, but the maximum concentration of uranium and vanadium, or maximum radioactivity is not found in the interval of least permeability within the ore. Hence the decrease in permeability which uniformly accompanies the presence of ore is probably not a result of the emplacement of the ore. Similar relations of permeability to the presence of uranium are found in poorly mineralized ground. The relation of lower permeability to the movement of uranium-bearing fluid may have been only that of decreasing the speed of fluid travel. If the rock of lower permeability is interposed as a widespread zone to upward movement of the uranium-bearing fluid, an increase in the negative presure gradient in this zone would result. As a consequence the release of gas that might be in solution would be facilitated and a means provided for the precipitation of minerals (Garrels and Richter, 1955). To the extent that analyses have been made, the estimates of thickness and grade of equivalent uranium oxide based on the radioactivity logs of the drill holes correspond reasonably well with the analyzed chemical uranium contents of the core samples. The uranium in the formation is therefore approximately in radioactive equilibrium with its decay products.

Cores from Long Park, Bitter Creek and Lisbon Valley show similar variation in the amount of pore water with respect to the position of the ore. In all three localities the ore is situated just below a desaturated zone and within the upper part of a water zone, the top of which is from 2.5 to 6.5 feet above the top of the ore. This relationship is remarkable because the carnotite drill hole is on the dip slope of a mesa, the corvusite drill hole on a valley rim and the uraninite drill hole in a valley floor. The resistivity logs of the drill holes in ore ground are similar in the carnotite, corvusite and uraninite localities, with the development of a resistivity minimum at the level of the ore, a resistivity peak above the ore and maximum resistivity below the ore. As shown by normal electrode spacings of 8, 16, or 24 inches, this maximum resistivity ranges from 1,100 to 2,500 ohm-meters in bore holes of 5-5/8 inches diameter, and with water (mud) resistivity ranging from 7 to 30 ohm-meters at 70° F. About two miles east of the Long Park experimental drill holes, or about midway between the experimental drill holes in carnotite and corvusite terraim, Ray Miller (USGS personal communication) found a similar development of resistivity logs in some 12 drill holes in ore ground. The resistivity logs of the drill holes in poorly mineralized ground in the carnotite, corvusite and uraninite localities are similar to the logs of the nearby drill holes cutting ore except that the resistivity peak below the ore zone is less than that above. It may be concluded that the correspondence of the resistivity logs and supporting analyses of cores in all three localities suggest similar variations in the clay content and the amount and salinity of pore water with reference to the position of the ore and poorly mineralized ground.

The preceding relations indicate in Long Park, Bitter Creek and Lisbon Valley the possible movement of pore or formation water either laterally or from below the ore and through the ore and upward into the overlying desaturated zone, where large amounts of water have been removed possibly by evaporation, while, as suggested by water leaches of the cores, large amounts of salts were deposited in the rock pores, and, as indicated both by the water leaches of the cores and the bore hole electric logs, the salinity of the pore water increased.

In Long Park the relations of permeability to the amount of formation water in the rock pores and to the observed capillary amount indicate that the base of the carnotite ore may be marked by the top of an interval of slow present-day gravity drainage of ground water with a lateral component of motion. In the Lisbon Valley uraninite locality the relation of permeability to the amount of formation water in the rock pores indicates that the ore is just at the edge and top of a zone of active ground water circulation. At the drill hole 50 feet distant in poorly mineralized ground this zone of active ground water circulation embraces the stratigraphic equivalent of the ore, but only traces of radioactivity are found there.

Although the general condition in the localities investigated of rock pores only partially filled with water is a most likely consequence of the present arid climate, the observed profile of water distribution where the drill holes penetrated ore and the assumed lateral or upward movement of pore water raise some difficult questions (Fuller, 1906). Such movement apparently cannot explain the oxidation of uranium to carnotite in Long Park, because no oxidation of the uraninite ore in Lisbon

Valley has taken place. The desaturated zone above the carnotite and corvusite ore in Long Park and Bitter Creek may be explained by the exposure of the rocks of this zone on a valley rim or canyon wall within a mile or so of the drill holes, but the desaturated zone above the uraninite ore in Lisbon Valley is below a valley floor and is within 50 feet laterally of a mine drift in the ore, and this mine has had to handle large quantities of water. Also in all three localities a zone of greater water content but of low permeability (perched water table?) overlies the desaturated zone. Chemical analyses of room temperature water leaches of cores from the carnotite drill hole, however, are fairly similar to analyses of samples from the nearby San Miguel River, in that the chloride is quite low and the sulfate and bicarbonate are high but variable.

The geological results of the original state core studies are summarized below.

A decrease in the permeability of the host sandstone invariably accompanies concentrations of uranium in amounts ranging from just above background to ore grade. This relation holds whether the host sandstone is poorly cemented with permeability averaging several hundred millidarcies, or is quartzitic with permeability averaging less than one millidarcy. The decrease in permeability in the host sandstone is not due to the deposition of materials from the mineralizing solution. A genetic relation between decreased permeability and deposition of uranium is suggested. This relation seems to be that of decreasing fluid pressure in the mineralizing fluid rising through a laterally extensive, less permeable zone. Decreasing fluid pressure may have permitted evolution and escape of gas with consequent chemical disequilibrium and deposition of minerals.

Regardless of degree of oxidation, of topographic or structural position, or of distance from the outcrop, the uranium ore is near the top of a water zone of low salinity. In that part of the water zone which is below the ore, present drainage of ground water apparently is taking place. Such drainage has removed or is removing uranium accumulations which are low structurally, as in Lisbon Valley. The zone of present-day draingage of ground water may indicate transmissivity effective for ingress of fluids at the time of mineralization and may denote ground favorable at the present time. Poorly mineralized ground generally is removed from present-day ground drainage and contains very small but salt-saturated amounts of pore water. Transmissivity may be too low to permit recharge to keep pace with desiccation, and may not have been sufficient to permit the influx of appreciable uranium-bearing fluid.

The geophysical results of this study show that conventional electric logging yielding self-potential and resistivity curves is useful for establishing stratigraphic correlations. Such logging is useful also for determining whether the maximum relative resistivity of the host sandstone is below the ore zone and consequently whether ore-grade accumulations of uranium may be present. The development of maximum resistivity below ore is a response to low salinity of a larger amount of pore water. Theoretically the salinity is calculable from the self-potential curve. The variability of the composition and composition of salts in the pore water over short vertical intervals, however, indicates that pore water salinity is derived preferably from values of the formation resistivity, as computed from special resistivity logging, combined with values of measured porosity and formation water content of the pores. Should drill hole indications of radioactivity be poor, but the resistivity reach a maximum value a few feet below the ore zone, further drilling for uranium would be indicated.

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## Geophysical studies in uranium geology

by

R. A. Black

The Geological Survey's geophysical studies in uranium geology conduct research in and development of geophysical methods of prospecting for uranium, and in the application of geophysical techniques to the solution of geologic problems related to uranium occurrences. During this report period geophysical field work in support of these objectives was carried out in the Texas coastal plain and in the Black Hills of South Dakota. The work in the Texas coastal plain is described under the report of that project (page 458, this volume). The work in the Black Hills is discussed below.

The regional gravity measurements made in the southern Black Hills in 1956 (TEI-640, p. 112) were compiled on a base map at a scale of 1:125,000 and contoured at a 10 gravity unit contour interval during this report period. Of the 1,127 gravity stations obtained in the Black Hills in 1956, it was necessary to make terrain corrections for 207 of these stations through Hammer's zone J. The largest terrain correction was found to be slightly more than 5 milligals. A terrain corrected gravity contour map has been prepared to a scale of 1:125,000, and aeromagnetic profiles flown over the Southern Black Hills area have been rectified and reduced to this same scale. Detailed comparison of the gravity contour map with the available geologic data has not been completed as yet, but it is apparent that the gravity data will be a valuable supplement to the known geology, and will provide a considerable amount of new information about the basement structures in this area.

Additional gravity field measurements were made in the southern Black Hills during April and May of 1957 to extend the present gravity coverage and to provide additional detail in parts of the area where the original coverage was insufficient to define the gravity anomalies. Approximately 500 additional gravity stations were occupied in the southern Black Hills during April and May of 1957.

In addition to the field work in the Texas coastal plain and in the Black Hills, a considerable amount of time was spent in the compilation and computation of geophysical data obtained during the 1956 field season and in the preparation of reports on the results of this work.

## Development and maintenance of radiation equipment

by

W. W. Vaughn

Two types of preamplifiers for use with geophones were designed and fabricated and will be field tested shortly. One amplifier using electron tubes has a gain of approximately 20 to 30 cycles while feeding a 700 ohm lode. This gain is down 3db at two cycles, but, this frequency response is better than the input transformer on the main amplifier at the central station. A second type amplifier uses a single transistor with grounded emitter. The transistor amplifier feeding a 700 ohm has a gain of approximately 15. Though both units work satisfactorily, however, use under field conditions will determine which has the least background noise and which is least affected by temperature and other factors.

The slip ring assembly for the Barnaby logging reels was redesigned - the carbon brushes were eliminated in favor of spring loaded wiping contacts. A much lower background noise resulted and fewer interference pulses were observed.

An acoustic logging system has been designed, built and laboratory tested. The system uses the "sing around" principle - that is, the interval between transmitted acoustic pulses is determined by the velocity of the signal through the material surrounding the bore hole. This system allows the use of a ratemeter to indicate the acoustic velocity because the interval between pulses, and therefore the pulse rate, is determined by the velocity constant.

Considerable modification was made on the original design of the circuit. One source of difficulty resulted from the internal delay of 2,000 microseconds between the reception of an acoustic pulse and the transmission of the next pulse. This 2,000 microsecond delay was included in the design to prevent false readings due to ringing in the bore hole. Another difficulty has been the problem of maintaining sufficient stability of indicated velocity. The 2,000 microsecond delay causes a multiplication of any error in the ratemeter circuit, and it has been necessary to go to extreme limits, including the use of a number of non-stock precision wire-wound resistors, to obtain a reasonable stability.

Some difficulty was also experienced in finding a suitable method of generating a usable acoustic pulse. However, a probe unit is now under construction which utilizes a cylindrical barium titanate element for the transmitting transducer and a similar element spaced three feet above the transmitting element for the receiving pickup. The pulse for the transmitting transducer is generated by discharging a capacitor through a thyratron into the primary of a pulse transformer which has its secondary connected across the transducer. The capacitor is charged between pulses from the power supply in the main unit, and the thyratron is triggered by pulses from the main unit. The receiving transducer is fed directly into the base of a transistor connected as an "emitter follower" (collector grounded) which in turn feeds the signal into a co-axial cable to the surface. The circuitry for both the receiving and transmitting transducers is located in the probe. A 5-conductor cable with a coaxial element transmits voltages and signals to and from the probe.

A detecting element using a 1P21 photomultiplier tube was designed and constructed for use with a model 520M photovolt densitometer. This equipment in conjunction with a RF induction furnace will help determine the ultimate design of a multi-stage direct recording thermoluminescence machine.

A driving mechanism involving synchronous motors and gear trains was constructed and mounted directly on the panel of the pulse analyser section of DIPARR to automatically sweep the energy spectrum with predetermined window adjustments.

A transistor impedance matching and driving circuit was designed and is presently being tested for use in the gamma-ray logging equipment. A PNP type transistor with the collector grounded to AC through a capacitor and the emitter connected to the center conductor of the RG59U coaxial cable is electrically in the anode circuit of the photomultiplier tube and matches the photube to the coaxial cable. An NPN type transistor at the surface with the base grounded to AC through a capacitor receives the signal from the cable on the emitter and provides a signal for the linear amplifier. Both transistors are operated approximately 1,000 volts DC above ground potential. These units were used to replace the transformer type impedance matching circuits. A decrease in pulse time from 20 to 5 microseconds has been observed; consequently, energy resolution should be improved.

## Correlation of airborne radioactivity data and areal geology

by
Robert Guillou

The investigation of the correlation of airborne radioactivity data and areal geology in the Lance Creek (East Pine Ridge Escarpment) area, Wyoming, has been completed. The study of the correlation in the Pine Mountain area, Wyoming, continues.

The studies of the relationship between areal geology and airborne radioactivity data in the Lance Creek and Pine Mountain areas, Wyoming, and in northern Michigan indicate two factors which limit the interpretation of airborne radioactivity data: (1) The rock units of an area to be surveyed must have radioactivity levels that can be differentiated; (2) The size of various radioactivity units in the area should approach the size of the cone of response of the scintillation equipment although narrower units with appreciably higher or lower levels of radioactivity can be recognized.

In the Lance Creek and Pine Mountain areas the predominant rock types are shales, claystones, and siltstones with lesser amounts of sandstone, and minor amounts of limestone. The shales, claystones, and siltstones comprise 70 to 80 percent of the outcrop area of the project and the radioactivity level of these fine-grained rocks is so nearly equal that in general they cannot be delimited on the radioactivity profiles unless separated by a formation or rock unit of distinctly different radioactivity level. It is impossible, for example, to locate the Pierre - White River contact except in those areas where the mineralized conglomeratic sandstone in the lower part of the White River formation is exposed.

The outcrop widths of many of the formations exposed on the flanks of the Old Woman anticline in the Lance Creek area are considerably narrower than the cone of response of the scintillation equipment. When two or more formations were within the cone at a given time it was impossible to determine the radioactivity level of an individual formation. In northern Michigan the geological units were large enough for discrimination but because of the almost ubiquitous swamps the cone of response seldom included only rock. This tends to preclude the picking of radioactivity levels.

Tests designed to show what combination of equipment settings (time constant, discriminator or energy level of radiation, and tape speed) and surveying altitude produces the most usable record were flown in May. Six flight lines, $\frac{1}{4}$ mile apart and about 14 miles long, were flown across the Triassic basin at Bealeton, south of Warrenton, Virginia and across an area of the crystalline Piedmont in Goochland County, Virginia. Flights were made in both areas using the following combinations:

| Altitude | Time Constant | Discriminator | Channel 1 Alt. Compensator in | Channel 2 A. C. out | Rect. A C. out |
|---|---|---|---|---|---|
| 500 feet | 1 second | 50 | 6 "/min | 6 "/min | 3 "/min |
| 500 | 1/2 | 50 | 6 | 6 | 3 |
| 300 | 1/2 | 50 | 6 | 6 | 3 |
| 500 | 2 | 50 | 6 | 6 | 3 |
| 500 | 1 | 100 | 6 | 6 | 3 |

The Bealeton area was also flown at 500 feet, time constant of 1 second, and discriminator at 50 with the rectilinear meter (3 inches per minute) in the compensated circuit.

These data will be studied to determine which combination gave us the most information about the geology in the areas. The results will guide us in further radioactivity surveys.

Another type of test was conducted in May. Data for the determination of airborne radioactivity lag at 500 feet using a time constant of 1/2, 1 and 2 seconds were obtained from traverses crossing a water-land interface 18 times for each time constant. Six interface crossings were made at 300 feet using a time constant of 1/2 second. From a study of these data we will be able to determine the average amount of lag for various time constants. In addition, it may be possible to get some idea of how the size of the cone of response enters in the lag problem.

# GEOCHEMICAL INVESTIGATIONS

## Colorado Plateau region

### Distribution of Elements

by
W. L. Newman

Study of the distribution of elements in rocks and ores of the Colorado Plateau, begun in July 1952, is divided into three phases: (1) distribution of elements in sedimentary rocks, (2) distribtution of elements in igneous rocks, and (3) distribution of elements in sandstone-type uranium deposits. Phase 1 has been completed and the results of that study are incorporated in this report.

Specific objectives of the study of sedimentary rocks are to determine (1) the average chemical composition and variation in composition, and geochemical coherence of elements in unmineralized host sandstones of the Colorado Plateau, with which the chemical composition and distribution of uranium ores can be compared; (2) the areal variations in concentrations of elements in the principal unmineralized host rocks and their relation to variations in concentrations of elements in the ore deposits; and (3) the average composition and variation in composition of mudstone and limestone of the Colorado Plateau, with particular emphasis on so-called red and green mudstone of the Salt Wash member and bentonitic and nonbentonitic mudstone of the Brushy Basin member of the Morrison formation.

Two of the principal uranium host rocks of the Colorado Plateau were selected for special study of the distribution of elements in sandstone: the Shinarump member of the Chinle formation of Late Triassic age (including the Moss Back member as presently defined, Stewart, 1957) and the Salt Wash member of the Morrison formation of Late Jurassic age. The estimated arithmetic mean compositions of sandstones from the two units are shown on table 30.

Sandstones of the Shinarump member are estimated to contain about twice as much titanium, zirconium, manganese, copper, chromium, and vanadium as sandstones of the Salt Wash member, about three times as much aluminum, iron, strontium, and boron, and about 10 times as much nickel and cobalt. The uranium contents of both units are similar, but sandstones of the Shinarump appear to contain more yttrium, ytterbium, arsenic, zinc, and lead. Part of the difference in the chemical compositions of these two rock units may be due to the somewhat tuffaceous and arkosic nature of sandstones of the Shinarump member, whereas sandstones of the Salt Wash member are well sorted or relatively clean quartzose sandstones commonly cemented by calcite.

Most of the uranium deposits of the Morrison formation occur in uppermost sandstone strata of the Salt Wash member; however, except for potassium and calcium no significant chemical differences between sandstones of the uppermost strata and intermediate and basal strata were detected in the samples studied. Sandstones of the uppermost strata contain on the average less potassium and calcium than sandstones lower in the section. Copper and vanadium occur in abnormally high amounts in unmineralized sandstone of the Salt Wash member in an area that coincides roughly with the Uravan mineral belt (TEI-490, p. 59-60). The distribution of elements commonly associated with igneous or crystalline rocks indicates three possible secondary source areas for detrital minerals in sandstone of the

Table 30. Estimated mean compositions of sandstone of the Shinarump member of the Chinle formation and sandstone of the Salt Wash member of the Morrison formation. (Composition shown in parts per million).

| Element | Sandstone of the Shinarump member1/ G.M.3/ | G.D.4/ | A.M.5/ | Sandstone of the Salt Wash member2/ G.M.3/ | G.D.4/ | A.M.5/ |
|---|---|---|---|---|---|---|
| Si | >100,000 | | | >100,000 | | |
| Al | 32,000 $\times\!\div$ 1.25 | 2.28 | 45,000 | 11,900 $\times\!\div$ 1.18 | 1.89 | 14,600 |
| Fe | 6,400 $\times\!\div$ 1.28 | 2.46 | 9,700 | 2,400 $\times\!\div$ 1.19 | 1.91 | 3,000 |
| Mg | 1,800 $\times\!\div$ 1.39 | 3.40 | 3,700 | 2,300 $\times\!\div$ 1.33 | 2.85 | 4,000 |
| Ca | 6,800 $\times\!\div$ 1.69 | 7.16 | 45,000 | 33,000 $\times\!\div$ 1.40 | 3.47 | 72,000 |
| Na | 790 $\times\!\div$ 1.46 | 4.04 | 2,100 | 890 $\times\!\div$ 1.42 | 3.73 | 2,100 |
| K | 3,200 $\times\!\div$ 1.39 | 3.44 | 6,900 | ~3,000 | | |
| Ti | 920 $\times\!\div$ 1.26 | 2.39 | 1,300 | 510 $\times\!\div$ 1.20 | 1.96 | 640 |
| Zr | 120 $\times\!\div$ 1.34 | 2.94 | 220 | 100 $\times\!\div$ 1.27 | 2.40 | 150 |
| Mn | 170 $\times\!\div$ 1.65 | 6.48 | 950 | 220 $\times\!\div$ 1.33 | 2.89 | 380 |
| Ba | 450 $\times\!\div$ 1.38 | 3.32 | 920 | 340 $\times\!\div$ 1.34 | 3.00 | 630 |
| Sr | 82 $\times\!\div$ 1.46 | 4.10 | 220 | 49 $\times\!\div$ 1.28 | 2.50 | 70 |
| Cu | 20 $\times\!\div$ 1.40 | 3.45 | 43 | 13 $\times\!\div$ 1.28 | 2.49 | 20 |
| Cr | 13 $\times\!\div$ 1.31 | 2.74 | 21 | 7 $\times\!\div$ 1.25 | 2.27 | 9 |
| V | 22 $\times\!\div$ 1.34 | 2.98 | 40 | 10 $\times\!\div$ 1.32 | 2.81 | 18 |
| Y | 5 $\times\!\div$ 1.22 | 2.06 | 7 | < 5 | | |
| As | 13 $\times\!\div$ 1.20 | 1.91 | 17 | <10 | | |
| Zn | <20 | | | <20 | | |
| Se | | | <0.5 to 15 | | | <0.5 to 8 |
| U | 2.4 $\times\!\div$ 1.21 | 2.00 | 3 | 1.8 $\times\!\div$ 1.21 | 1.99 | 2 |

1/ Estimate based on 97 samples.

2/ Estimate based on 96 samples.

3/ Geometric mean showing the 99 percent confidence interval for the population geometric mean: the limits of the confidence interval are determined from Student's t distribution (Fisher and Yates, 1953, p. 1 and 40) where t is the deviation in units of estimated standard error.

For a lognormal distribution: Confidence interval of geometric mean $\equiv \times\!\div \text{antilog} \left[ t \; \frac{\text{Log G.D.}}{\sqrt{n-1}} \right]$

4/ Geometric deviation or antilog of the log standard deviation.

5/ Arithmetic mean. The most efficient estimate of the arithmetic mean of a lognormal population may be obtained from the following equation if n is large:

$$\text{Log}_{10} \text{ estimated arithmetic mean} \equiv \text{Log}_{10} \text{ G.M.} - 1.1513 (\text{Log}_{10} \text{ G.D.})^2$$ (Sichel, 1952)

Salt Wash member: the Meeker-Craig area of Colorado; an area just south of the Four Corners in Arizona and New Mexico; and the San Rafael Swell area in east-central Utah.

The distribution of chromium, titanium, zirconium, boron, ytterbium, vanadium, uranium, and particularly copper in unmineralized sandstones of the Shinarump member shows two areas that contain abnormally high concentrations of these elements and may reflect possible source areas for material now comprising the Shinarump member. One area is located in east central Utah (fig. 111). The abnormal concentrations of these elements in sandstone of this area may be the result of accumulation of material derived directly from the exposed Precambrian core of igneous and metamorphic rocks of the Uncompahgre highland.

The second area is located in southeastern Utah (fig. 111) and is a poorly defined belt extending northwestward from the Four Corners area. The source of the minerals containing these elements may have been the Cutler formation that was exposed over a large area adjacent to the western edge of the Uncompahgre highland during Late Triassic time. High-copper uranium ores have been mined from deposits located within this belt.

Studies of the variations in chemical compositions of sandstone from many formations of the Colorado Plateau with regard to the occurrence of uranium deposits show that sandstones containing 0.5 percent or less potassium are more favorable than sandstones that contain an average of more than 0.5 percent potassium. Favorable host rocks, as judged by potassium content, include sandstones of the Dakota sandstone, the Cedar Mountain formation of Stokes, and the Burro Canyon formation, all of Cretaceous age; the Salt Wash, Westwater Canyon, and Brushy Basin members of

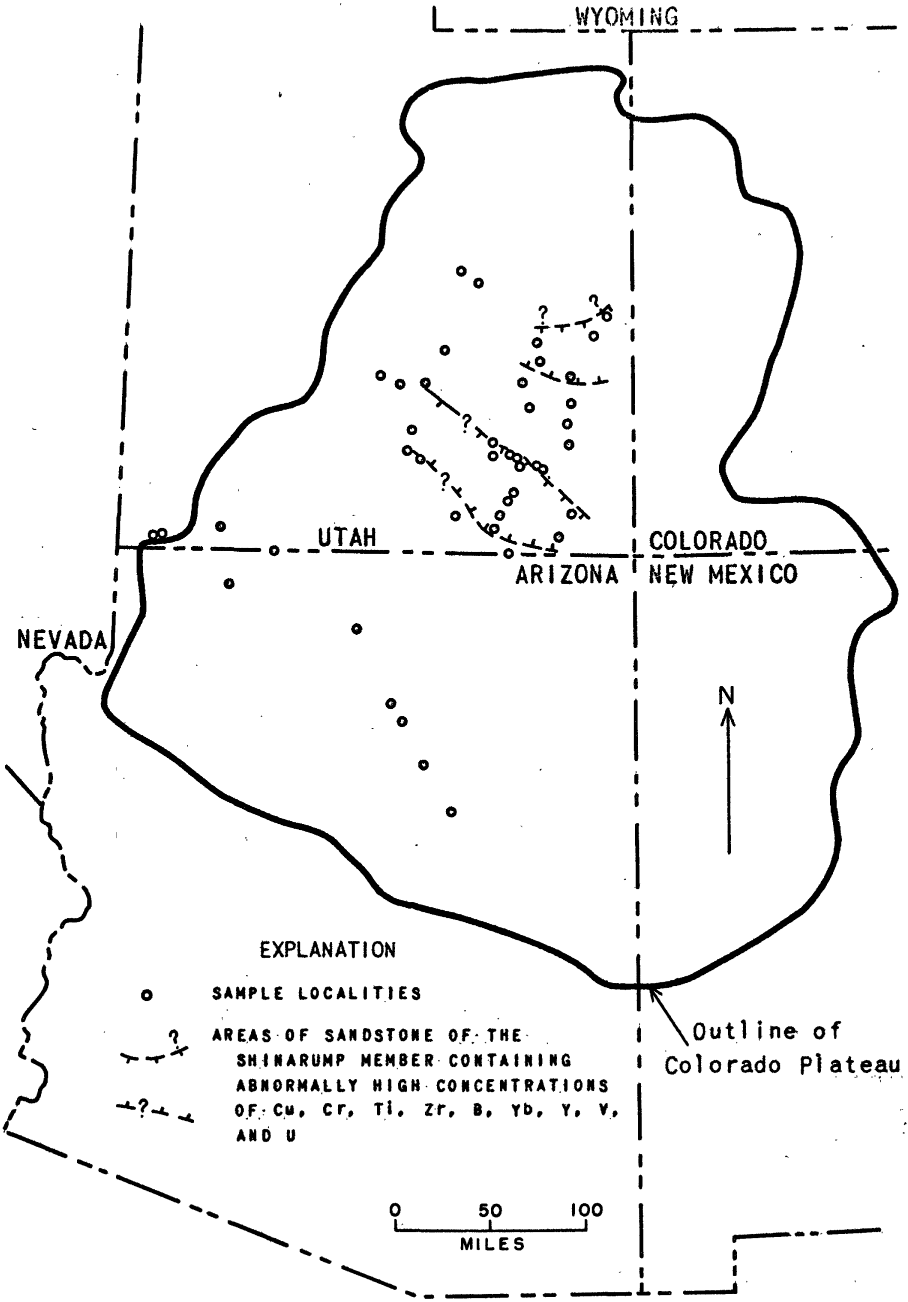

FIG. 111.—MAP OF THE COLORADO PLATEAU SHOWING AREAS OF SANDSTONE OF THE SHINARUMP MEMBER CONTAINING ABNORMALLY HIGH AMOUNTS OF

the Morrison formation of Jurassic age; the Shinarump and Moss Back members of the Chinle formation of Triassic age; and the Coconino sandstone of Permian age.

Average mudstone of the Shinarump and Moss Back members contains about twice as much uranium and vanadium as average mudstone of the Moenkopi formation or other units of the Chinle formation (table 31). "Bleached" mudstone (mudstone of varying shades of green, purple, and white) of the Moenkopi at or close to the contact of the Moenkopi and Chinle contains more uranium (up to 160 ppm) and more gallium, lanthanum, yttrium, ytterbium, scandium, niobium, and cerium than reddish-brown mudstone of either formation. The accumulation of some of these elements may indicate the presence of a fossil soil that developed during the Mid-Triassic depositional hiatus.

Detailed studies of the distribution of elements in the Salt Wash member of the Morrison formation in the Jo Dandy area, Paradox Valley, Montrose County, Colo., as determined from analyses of drill core, show that variations in concentrations of about 20 elements commonly detected by semiquantitative spectrographic analysis are of small magnitude for a specific rock type, and there appears to be no significant relation between chemical composition of sandstone or mudstone and distance from known uranium-vanadium deposits. However, sandstones of the Salt Wash member in the Jo Dandy area contain more potassium, magnesium, vanadium, and nickel than elsewhere in the Salt Wash.

The Jo Dandy area is also notable for the unusual occurrence of bismuth. Although present only in very low concentrations (about 0.005 percent or less) in some samples of rocks of the Salt Wash member of the

Table 31.--Estimated geometric mean composition[1] of mudstone from the Moenkopi and Chinle formations of Triassic age. (Composition shown in parts per million)

| Element | Mudstone of the Moenkopi formation (38 samples) | Mudstone of the Chinle formation[2] (41 samples) | Mudstone of the Shinarump member of the Chinle formation (18 samples) |
|---|---|---|---|
| Si | >100,000 | >100,000 | >100,000 |
| Al | 90,000 ×÷ 1.24 | 80,000 ×÷ 1.26 | 90,000 ×÷ 1.31 |
| Fe | 21,000 ×÷ 1.30 | 18,000 ×÷ 1.23 | 16,000 ×÷ 1.06 |
| Mg | 16,000 ×÷ 1.32 | 6,000 ×÷ 1.53 | 7,000 ×÷ 1.83 |
| Ca | 3,800 ×÷ 2.59 | 1,200 ×÷ 2.14 | 1,700 ×÷ 3.44 |
| Na | 6,000 ×÷ 1.38 | 4,600 ×÷ 1.88 | 5,000 ×÷ 2.19 |
| K | 5,000 ×÷ 1.19 | 2,400 ×÷ 1.48 | 3,000 ×÷ 1.71 |
| Ti | 2,600 ×÷ 1.21 | 2,900 ×÷ 1.12 | ~3,000 |
| Zr | 130 ×÷ 1.23 | 180 ×÷ 1.20 | 150 ×÷ 1.14 |
| Mn | 290 ×÷ 1.73 | 80 ×÷ 1.75 | 110 ×÷ 2.04 |
| Ba | 320 ×÷ 1.24 | 80 ×÷ 1.55 | 170 ×÷ 1.95 |
| Sr | 160 ×÷ 1.37 | 90 ×÷ 1.39 | 120 ×÷ 1.54 |
| Cu | 50 ×÷ 1.58 | 32 ×÷ 1.35 | 30 ×÷ 2.08 |
| Cr | 60 ×÷ 1.20 | 51 ×÷ 1.19 | 60 ×÷ 1.19 |
| V | 80 ×÷ 1.19 | 60 ×÷ 1.19 | 120 ×÷ 2.17 |
| Co | 10 ×÷ 1.47 | 7 ×÷ 1.49 | 9 ×÷ 1.58 |
| Ni | 25 ×÷ 1.51 | 15 ×÷ 1.32 | 19 ×÷ 1.44 |
| B | 47 ×÷ 1.23 | 48 ×÷ 1.20 | 50 ×÷ 1.52 |
| Be | 2 ×÷ 1.44 | ~1 | 2 ×÷ 1.32 |
| Yb | 3 ×÷ 1.37 | 3 ×÷ 1.21 | ~3 |
| Ga | 10 ×÷ 1.37 | 10 ×÷ 1.37 | 15 ×÷ 1.68 |
| Y | 28 ×÷ 1.43 | 24 ×÷ 1.24 | 30 ×÷ 1.28 |
| Sc | 20 ×÷ 1.25 | 17 ×÷ 1.23 | 16 ×÷ 1.37 |
| As | ~11 | ~9 | ~13 |
| Zn | ~70 | ~31 | ~50 |
| Se | < 0.5 | < 0.5 | < 0.5 |
| U | ~ 6 | ~4 | ~9 |
| Pb | 18 ×÷ 1.51 | 6 ×÷ 1.52 | 11 ×÷ 2.13 |

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[1] See footnote 3, table 30.

[2] Excluding mudstone of the Shinarump member.

Morrison formation and of the Paradox member of the Hermosa formation of Pennsylvanian age, these few samples are the only ones out of over 600 samples of sedimentary rocks collected from many of the formations of the Colorado Plateau that contain detectable amounts of bismuth.

At several places in Paradox Valley and within the Jo Dandy area the Salt Wash member rests upon the Paradox member of the Hermosa formation. The occurrence of bismuth in both the Salt Wash and Paradox members suggests that at least bismuth, and possibly some potassium and magnesium found in rocks of the Salt Wash, were derived either from solutions that ascended from the underlying Paradox member or were contained in material from the Paradox that was incorporated with detritus of the Salt Wash during deposition of that member.

The occurrence of green mudstone is used as a guide to uranium ore on the Colorado Plateau (Weir, 1952). Comparative studies of the chemical composition of red and green mudstone of the Salt Wash member in the Joe Dandy area (TEI-440, p. 44) indicate that the compositions of red and green mudstone are very similar except for calcium content. Red mudstone contains almost twice as much calcium as green mudstone. Likewise, studies of the clay minerals contained in mudstones of the ore-bearing formations of the Colorado Plateau show no difference in the gross clay mineralogy of red and green counterparts (W. D. Keller, written communication, 1956). The concensus of many writers on the subject of color of sedimentary rocks is that brown and yellow colors are due to coatings of iron in the form of ferric oxides in various states of hydration, whereas red colors are due to less hydrated or dehydrated ferric oxides (Hofer and Weller, 1947, p. 470; Dorsey, 1926, p. 138; MacCarthy, 1926, p. 21; Van Houten, 1948, p. 2090; Hager, 1928, p. 905). Thus the color of "red" mudstone is probably due to an iron pigment of the hematite type that is distributed as a pervasive paint. It should be pointed out that the red color is not due merely to the presence of ferric oxide as opposed to ferrous oxide as determined by laboratory analysis. Dorsey (1926, p. 143) states: "Many non-red rocks often contain more ferric oxide than do red rocks," and Ross and Hendricks (1945, p. 35, table 2) show analyses of 13 samples of nontronite clay, some described as having a green color, that contain from about 13 to as much as 30 percent ferric oxide but contain less than 1.5 percent ferrous oxide. The color of green mudstone, on the other hand, is probably not due to a "paint" of green iron oxide because such a mineral has not been recognized in spite of detailed studies by many workers. Instead, the color of green mudstone may be due to the intrinsic color of the clay minerals contained in the mudstone. Green mudstone commonly contains small crystals of pyrite and marcasite suggesting that iron which formerly coated the mudstone as hematite was converted to iron sulfides essentially in situ. However, some mudstone may never have been coated with hematite and may never have been red.

Comparisons of average amounts of chemical constituents in both bentonitic and nonbentonitic mudstones of the Brushy Basin member of the Morrison formation in the Thompson district, Utah, and Spring Creek Mesa, Uravan district, Colorado, show no chemical features that clearly distinguish the two types of mudstone. The estimated geometric mean compositions of bentonitic and nonbentonitic mudstones are shown on table 32.

Table 32. Estimated geometric mean composition of betonitic and nonbentonitic mudstones of the Brushy Basin member, Thompson district, Utah, and Spring Creek Mesa, Uravan district, Colorado. (Composition shown in parts per million)

| Element | Thompson district, Utah | | Spring Creek Mesa, Colorado | | | |
|---|---|---|---|---|---|---|
| | Bentonitic mudstone (4 samples) | Nonbentonitic mudstone (4 samples) | Bentonitic mudstone (10 samples) | | Nonbentonitic mudstone (10 samples) | |
| | G.M.1/ | G.M.1/ | G.M.2/ | G.D.3/ | G.M.2/ | G.D.3/ |
| Si | >100,000 | >100,000 | >100,000 | | >100,000 | |
| Al | >100,000 | >100,000 | 60,000 | 1.38 | 60,000 | 1.38 |
| Fe | 30,000 | 20,000 | ~14,000 | 1.28 | 20,000 | 1.38 |
| Mg | 30,000 | 20,000 | 12,000 | 1.68 | 12,000 | 1.68 |
| Ca | 5,000 | 4,000 | 4,000 | 3.18 | ~13,000 | 3.28 |
| Na | ~8,000 | 4,000 | 4,000 | 1.91 | 6,000 | 1.71 |
| K | 20,000 | 20,000 | 20,000 | 1.62 | 20,000 | 1.45 |
| Ti | 3,000 | 3,000 | 2,000 | 1.49 | 3,000 | 1.45 |
| Zr | 200 | 200 | 200 | 1.47 | 200 | 1.38 |
| Mn | 100 | 300 | 200 | 2.10 | 300 | 2.69 |
| Ba | 200 | 100 | 200 | 2.11 | 400 | 1.83 |
| Sr | 200 | 200 | 300 | 2.06 | 300 | 2.07 |
| Cu | 20 | 30 | 30 | 1.83 | 30 | 1.83 |
| Cr | 20 | 40 | 20 | 1.71 | 20 | 1.49 |
| V | ~ 50 | ~50 | 50 | 1.45 | 60 | 1.38 |
| Co | ~ 8 | ~ 8 | 2 | 1.71 | 5 | 1.45 |
| Ni | 20 | 10 | 7 | 1.76 | 11 | 1.71 |
| B | 40 | ~60 | 30 | 2.07 | 20 | 1.55 |
| Ga | 20 | 20 | ~14 | 1.76 | 10 | 1.50 |
| Y | ~ 70 | 20 | 30 | 1.45 | 30 | 1.38 |
| Sc | 20 | 10 | 9 | 1.45 | 9 | 1.71 |
| Pb | 10 | 10 | ~13 | 1.63 | 11 | 1.49 |

1/ Geometric mean. Confidence intervals and geometric deviations not calculated for so few samples.

2/ Geometric mean. Confidence intervals not calculated because of similarity of corresponding geometric deviations of elements in bentonitic and nonbentonitic mudstone at Spring Creek Mesa.

3/ Geometric deviation or antilog of the log standard deviation.

The average chemical composition of carbonate rocks was determined from samples collected in the Grand Canyon, Arizona, from the Bass limestone of Precambrian age, the Muav limestone of Cambrian age, the Temple Butte limestone of Devonian age, the Redwall limestone of Mississippian age, the Supai formation of Pennsylvanian age, the Toroweap formation and Kaibab limestone of Permian age, and from samples of the Rico formation of Pennsylvanian age in Moab Valley, Utah. The estimated arithmetic mean composition of Precambrian and Paleozoic carbonate rocks is shown on table 33.

Certain variations in chemical composition of Precambrian and Paleozoic carbonate rocks appear to show a systematic progression with respect to the age of the beds sampled. Silicon is more abundant in carbonate rocks of Precambrian and Cambrian ages and becomes progressively less abundant in carbonate rocks of Devonian and Mississippian ages. Carbonate rocks of Pennsylvanian and Permian ages contain about as much silicon as those of Precambrian and Cambrian ages.

The calcium content of carbonate rocks of Precambrian, Cambrian, and Devonian age range from about 1 to just over 10 percent, whereas the calcium content of carbonate rocks of Mississippian, Pennsylvanian, and Permian ages is greater than 10 percent. Magnesium, on the other hand, tends to be more abundant in older carbonate rocks and to become progressively less abundant in younger carbonate rocks. The greatest change in magnesium content occurs in the lower Redwall limestone where samples show that the magnesium content decreases upward from over 10 percent to about 0.07 percent. Daly (1909, p. 165) states: "The ratio (calcium-magnesium) abruptly rises in the Devonian and increases rapidly

Table 33.--Estimated mean composition of limestone of Precambrian and Paleozoic age of the Colorado Plateau (Composition based on 19 samples, shown in parts per million)

| Element | G.M. 1/ | G.D. 2/ | A.M. 3/ |
|---|---|---|---|
| Si | 23,000 $\overset{\times}{\div}$ 4.56 | 9.48 | ~220,000 |
| Al | 2,500 $\overset{\times}{\div}$ 3.47 | 6.33 | 12,000 |
| Fe | 4,000 $\overset{\times}{\div}$ 2.26 | 3.35 | 9,000 |
| Mn | 200 $\overset{\times}{\div}$ 2.99 | 5.08 | 700 |
| Mg | 30,000 $\overset{\times}{\div}$ 3.22 | 5.67 | 130,000 |
| Ca | >100,000 | | |
| K | <3,000 | | |
| Na | 450 $\overset{\times}{\div}$ 1.89 | 2.55 | 700 |
| Ba | 18 $\overset{\times}{\div}$ 4.81 | 10.30 | 200 |
| Sr | 60 $\overset{\times}{\div}$ 1.77 | 2.33 | 90 |
| Ti | 120 $\overset{\times}{\div}$ 4.14 | 8.23 | 900 |
| Zr | 16 $\overset{\times}{\div}$ 2.93 | 4.93 | 50 |
| Cr | 14 $\overset{\times}{\div}$ 1.81 | 2.42 | 20 |
| V | 18 $\overset{\times}{\div}$ 1.34 | 1.54 | 20 |
| Ni | 4 $\overset{\times}{\div}$ 1.92 | 2.63 | 6 |
| Cu | 6 $\overset{\times}{\div}$ 2.16 | 3.13 | 10 |
| Ga | <5 | | |
| Sc | <10 | | |
| Yb | <10 | | |
| Y | <5 | | |
| B | <10 | | |
| Co | <2 | | |
| Pb | <10 | | |

1/ See footnote 3, table 30.

2/ See footnote 4, table 30.

3/ See footnote 5, table 30.

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in the Carboniferous." The Redwall limestone of Mississippian age appears to be the turning point for changes in the chemical composition of carbonates. In addition to being somewhat more lean in silicon, aluminum, iron, and magnesium, the Redwall likewise contains little sodium, potassium, titanium, zirconium, barium, boron, scandium, cobalt, nickel, gallium, yttrium, and ytterbium.

Concentrations of manganese, vanadium, and chromium appear to be relatively constant in carbonate rocks of Precambrian and Paleozoic ages in northwestern Arizona.

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## General investigations

### Botanical research
by
Helen L. Cannon

Results of research in the Marshall Pass area, Saguache County, Colorado have been received during this reporting period. The geochemical study was carried out on the Lookout No. 22 claim on steep, heavily-forested slopes at an elevation of about 10,000 feet. The ore, composed of uraninite and gummite, has been found only as float in the colluvium. Presumably the uranium was originally introduced into brecciated zones of the granitic intrusions that occur in the schistose country rock of this area. (Ranspot and Spengler, 1957, DAO-3-TM-42). The purpose of the investigation was to test the chromatographic method of analysis for uranium in soils and plants and to learn whether soil and plant analysis are feasible methods of prospecting for pitchblende deposits in this type of terrain. Surface soil and Lodgepole pine samples were collected on a grid and soil profiles were sampled in detail. No anomaly was found in the uranium content of surface soils collected in the area; in profile, the first rise in uranium content was detected at a depth of two feet. Samples of Lodgepole pine needles, on the other hand, rise from <5 ppm over barren ground to an average of 40 ppm U in the ash of trees rooted in undisturbed mineralized ground. Trees rooted in oxidized ground near the small discovery pit contained 240 ppm. The area was free from dust contamination. Probably tree sampling is preferable to soil sampling as a means of prospecting in this district and offers an inexpensive method of prospecting for uraninite mineralization in a heavily forested terrain.

Further work on plant studies made in the Yellow Cat area, Grand County, Utah show that the distinct distribution patterns of the two most diagnostic selenium-indicator plants in the area, *Astragalus pattersoni* and *Astragalus preussi*, depend upon the availability of molybdenum and vanadium. Where molybdenum is more available than vanadium, *A. pattersoni* is the dominant species. Where vanadium is more available than molybdenum *A. preussi* is dominant. Thus *A. pattersoni* is commonly indicative of buried unaltered deposits and of secondary schroekingerite deposits where the amount of available vanadium is low; *A. preussi* is common along weathered exposures of highly vanadiferous ore. The distinction between the species is undoubtedly associated with the ability of certain legumes to substitute vanadium for the generally required molybdenum in the nitrogen-fixation process.

Reference

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## Uranium and other metals in crude oils

by

H. J. Hyden

One hundred and seventeen samples of crude oil and 16 samples of refinery residue were collected and analyzed for metal content from oil fields and refineries located in the western half of the United States. The oil and residue samples were reduced to ash; the uranium content of the ash was determined by fluorometric analysis, and the content of other metals by emission spectrograph. The uranium content of the ash samples ranged between .001 and .0002 percent, which is comparable to that of the crust of the earth. The calculated uranium content for most of the oil samples ranged between 1 and 10 parts per billion. The percentages of vanadium and nickel found in the crude-oil ash are greater than those of the earth's crust.

Bureau of Mines crude-oil analyses were available for most of the oil fields from which samples were collected. On the basis of these analyses crude-oil samples were categorized in 20 different classes and the metal contents of oil classes compared. The vanadium and nickel content of oils of the various crude-oil classes are significantly different, and gallium and molybdenum also show different content ranges in the different classes of oil. There is no significant difference in the uranium content of the oil samples of different crude-oil classes.

Rank correlations were determined for various metals as compared with nitrogen content and other crude-oil characteristics that are determined in the Bureau of Mines crude-oil analysis. Nickel, vanadium, gallium, and cobalt correlated best with the crude-oil characteristics, titanium, chromium, and molybdenum next best, and copper and uranium the least.

The vanadium to nickel ratios of the oil samples are restricted to a small range of values. These values increase with increasing age of reservoir rock and with increasing depth of burial of reservoir rock. Vanadium and nickel are thought to be present in crude oil mainly as porphyrins, which are organo-metallic complexes. Gallium, cobalt, and molybdenum are inferred, by comparison, also to be present as organo-metallic complexes.

From the comparisons of metal content with crude-oil classes and with crude-oil characteristics uranium does not appear to be present in crude oil as an organo-metallic complex. Empirical tests indicate that uranium can be leached from sandstones by crude oil and, hence, that uranium is oil soluble, although in some form other than an organo-metallic complex. Uranium content of crude oils, therefore, could indicate the presence of uranium deposits in the subsurface.

# MINERALOGICAL INVESTIGATIONS

## Colorado Plateau region

### Ore Mineralogy

by

Theodore Botinelly

A tentative paragenetic sequence for the ore and gangue minerals of the uranium deposits in the Lisbon Valley area, Utah, has been worked out and is given in a report currently being prepared by G. W. Weir and others on the geology of the Lisbon Valley area. The occurrences of molybdenum in these deposits mentioned in the previous semiannual report (TEI-640, p. 259) have been studied further: according to X-ray investigations the molybdenum mineral is jordisite, a black powdery colloidal form of what may be molybdenum sulfide (Palache, Berman, and Frondel, 1944, p. 331); in polished section part of the molybdenum seems to occur as very fine-grained molybdenite.

Copper deposits occur adjacent to the Lisbon Valley fault and in the La Sal Mountains; minor amounts of copper minerals occur in the uranium deposits of the Lisbon Valley area. The copper deposits in the La Sal Mountains are probably related to the Lisbon Valley copper deposits but no evidence other than the spatial association has been found.

Study of polished sections indicates that the copper in the uranium deposits in Lisbon Valley is probably later than the uranium. As yet the only evidence found to indicate that the uranium deposits in Lisbon Valley are related to the copper deposits in that area is the occurrence of uranium (in very minor amounts), copper, and vanadium at the Lucky Strike copper prospect on a branch of the Lisbon Valley fault; the occurrence of uranium in anomalous amounts (0.001 pct.) at the Woods prospect and the Big Indian Copper mine; and the occurence of copper in the various uranium and vanadium deposits. Most of the copper deposits and prospects in Lisbon Valley are barren of uranium.

The uranium and uranium-vanadium deposits contrast with the copper deposits in many ways. The copper deposits are oxidized and the uranium deposits are mostly unoxidized; the copper deposits occur for the most part adjacent to faults and the uranium deposits are bedded and not associated with the faults; temperatures of deposition of uranium deposits in the Colorado Plateau, as indicated by the Kullurud method, are low (below 138°C.) (Coleman, 1957, p. 2) and the only evidence of temperatures in the copper deposits is the presence of bornite-chalcopyrite exsolution textures which may indicate temperatures of 475°C. or more (Edwards, 1947, p. 82-84). These textures occur in copper deposits in igneous rocks in the La Sal Mountains and in sedimentary rocks close to igneous rocks. The textures are not wholly accepted as evidence of high temperatures.

Some of the differences between the deposits may be explained readily. The known copper deposits are near the surface and occur near fractures which would be excellent channelways for oxidizing solutions. The only copper ores that show evidence of high temperatures are in the La Sal Mountains where igneous intrusions may have caused locally high temperatures.

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## Studies of clays in Triassic rocks

by

L. G. Schultz

Studies of clays in the Triassic rocks of the Colorado Plateau began in July 1954, and are scheduled for completion by July 1957.

Clay minerals found in Triassic rocks of the Colorado Plateau include well and poorly crystallized varieties of kaolinite, illite, montmorillonite, chlorite, palygorskite, and several types of mixed-layer clay. Three groups in the illite-montmorillonite mixed-layer sequence were distinguished: (1) $X_1$ clay in which illite is dominant over montmorillonite, (2) $X_2$ clay in which illite is slightly dominant over, or equal to, montmorillonite, and (3) $X_3$ clay in which montmorillonite is dominant over illite. In addition, a mixed-layer montmorillonite-chlorite clay was found in many sandstone samples.

Distribution of the clay minerals in the Triassic rocks is summarized in figure 112. The inset on figure 112 shows the distribution of clays common over broad areas. In each box of the inset, the height of the pattern for each mineral is proportional to the abundance of the clay, and the width is indicative of its persistence in the unit. The units in the figure are generalized so that the mottled siltstone unit includes the Temple Mountain member of the Chinle formation in the San Rafael Swell; the Monitor Butte member includes the lower member of the Chinle formation and other unnamed units in Arizona; and the Church Rock member includes the Rock Point member of the Wingate sandstone in Arizona. Lateral variations in the clay assemblages of the upper Chinle and Moenkopi rocks are indicated on the inset by separating the Church Rock and Owl Rock members in the northern part of the Colorado Plateau from the equivalent but mineralogically different rocks further south, and by separating the Moenkopi clays into three assemblages common in different areas as shown on the fence diagram.

Generally speaking, the Moenkopi formation and the upper part of the Chinle formation are illitic, the Monitor Butte and Petrified Forest members of the Chinle formation are montmorillonitic, and the Shinarump and to a lesser extent the Moss Back members are kaolinitic. Superimposed on this distribution is a strong tendency for chlorite to be common in rocks of Triassic age in the eastern part of the Colorado Plateau, whereas kaolinite is common in the western part of the Plateau. Both chlorite and kaolinite are minor components of the rocks, however. Chlorite and well-crystallized kaolinite occur in larger grains than other clays, and because of this these two clays tend to be most abundant in the coarse-grained sediments.

Results of sedimentary facies and structure studies now being completed by personnel of the U. S. Geological Survey, together with the clay mineral distribution, indicate that two source areas--one to the east and another to the south of the Colorado Plateau--dominated sedimentation during deposition of the Moenkopi and Chinle formations. Components were probably derived concurrently from both sources so that sediments from both interfinger and are mixed. However, during certain periods of time one or the other of the two sources was dominant and

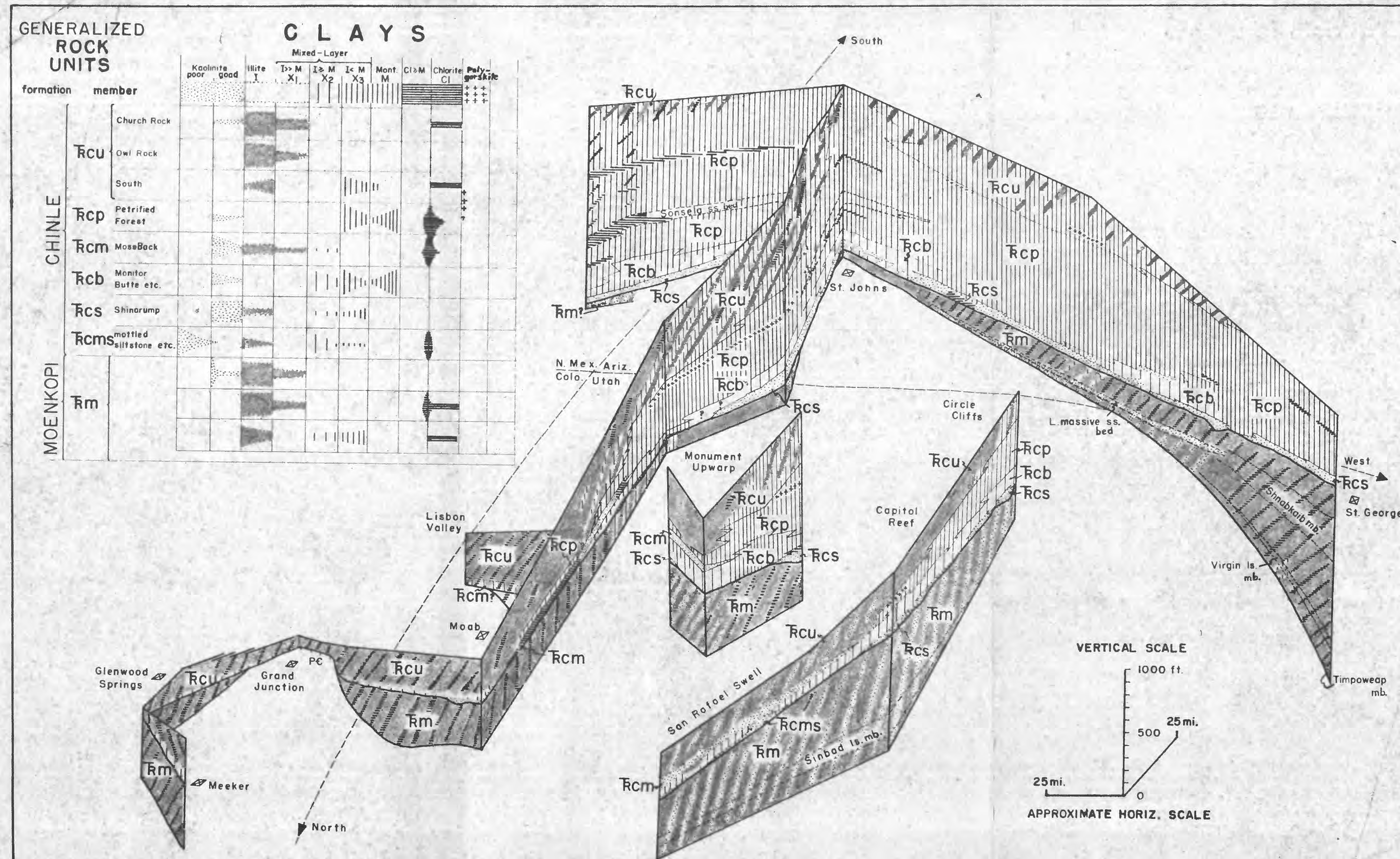

Fig. 112 CLAYS IN TRIASSIC ROCKS OF THE COLORADO PLATEAU

contributed the great bulk of sediments; at such times sediments from the other source were deposited as minor tongues along the fringes of the major depositional area.

The major part of the sediments of the Moenkopi formation and the upper part of the Chinle formation was derived from an eastern source, which contributed highly illitic sediments, and a smaller amount of chloritic sediments. During transportation westward, some of the less resistant components--such as chlorite and plagioclase feldspar--were destroyed and kaolinite was formed. However, not all of these less resistant components were destroyed before the transporting streams carried the sediments into the seas lying to the west.

Most of the sediments of the lower Chinle were probably derived from the southern source, where volcanic rocks were exposed. The most widespread evidence of volcanism is the occurrence of rounded tuff particles which are now altered to montmorillonite or mixed-layer clay. Composition of the sediments, including some volcanic pebbles from central and east central Arizona, indicates that the early volcanics were largely rhyolitic, whereas the later volcanics were latitic. The original volcanic rocks of the early phase had a high potash:soda ratio and sanidines in these rocks have an unusually high potash content ($Or_{85}Ab_{15}$). Rocks of this early phase altered mainly to $X_2$ clay. This early phase contributed material to parts, but not all, of the Monitor Butte member. The material of the latitic phase, in which plagioclase is the more abundant feldspar, has altered to $X_3$ clay or montmorillonite. Volcanic activity in the southern source evidently tapered off during deposition of the upper part of the Chinle formation, but even so, altered remnants of the volcanic material constitute a large part of the sediments of the upper Chinle in the southern part of the Colorado Plateau.

In the lowermost Chinle formation, the original character of the source materials of the sediments has been largely obscured, but they are interpreted to include material formed by weathering during the widespread hiatus between deposition of the Moenkopi formation of Early and Middle(?) Triassic age and the Chinle formation of Late Triassic age, which was incorporated in the basal sediments of the Chinle formation. That the source materials are in part of volcanic origin is indicated by the occurrence of pebbles of altered rhyolite in the Shinarump member and the occurrence of mixed-layer clays in the basal Chinle rocks. Mottled zones at the top of the Moenkopi, which are interpreted to be ancient soil zones and which apparently grade into sediments of the Chinle, indicate that weathered and reworked Moenkopi rocks were incorporated in the sediments of the lower Chinle. The clay assemblage in the soil profiles of probable Triassic age developed by weathering of Precambrian crystalline rocks of the Uncompahgre Upland suggests that some of the clays in the lowermost Chinle rocks may have been derived from similar soil zones developed on older rocks in the eastern and perhaps also the southern source areas.

Alteration of the materials derived by weathering probably occurred not only in the source areas, but also during the transportation cycle and after deposition. Alteration after deposition is indicated by the development in many basal Chinle rocks of a mottled coloration similar to that in the soil zones developed on the Moenkopi and Precambrian rocks. These highly weathered and altered materials comprise much of the Shinarump member, mottled siltstone units, and probably in some places the Monitor Butte member also.

Uranium mineralization apparently has affected the clay minerals of the Chinle host rocks very little. In areas where the host rocks are normally kaolinitic, as in White Canyon and the San Rafael Swell, the mineralized rock is also kaolinitic. In areas such as Lisbon Valley, where chlorite is a common component of the host rocks, chlorite also occurs in the mineralized rocks. The clays in "bleached" zones below the host sandstones also have not been appreciably altered. The only evidence for alteration by the mineralizing solutions is the presence of vanadiferous chlorites which may have been formed from normal chlorites by the solutions. Chlorite which is mixed-layered with lesser amounts of montmorillonite is common in barren sandstones of the Chinle in the eastern part of the Colorado Plateau. Chlorites in mineralized rock are less likely to be mixed-layered with an expandable component. The main structural difference between chlorite and montmorillonite is that in chlorite mica-like layers alternate with brucite ($Mg_3(OH)_6$) layers, and in montmorillonite the mica-like layers are separated by exchangable cations ($Ca^{++}$, $Na^+$, etc.), and water. X-ray, petrographic, and chemical evidence indicate that vanadium, which in its trivalent state has a radius nearly identical to that of the magnesium ion, is absorbed by the montmorillonite as an exchangable ion, then coordinates hydroxyl ions to form brucite-like $V_2(OH)_6$ layers, thereby converting the montmorillonite which was originally mixed-layered with chlorite to nonexpandable, 14A° layers.

The close relation between the occurrence of uranium deposits and sediments containing abundant volcanic material has been noted in many areas. Waters and Granger (1953) suggested that the uranium in the ore deposits in Triassic rocks could have been derived from volcanic debris in adjacent sediments. Present studies have found a close relation between the distribution of debris derived from the rhyolitic volcanic rocks and the large uranium deposits. Volcanic debris from the rhyolitic material only occurs in the rocks of the Chinle formation in the south end of the San Rafael Swell, Utah, near the Delta (Hidden Splendor), and Temple Mountain mines; and in the rocks overlying the mineralized sandstones of the Shinarump member of the Chinle in White Canyon and Elk Ridge, Utah. It also makes up part of the host rock of the uranium deposits in Lisbon Valley, Utah. The work of Denson and others (oral communication, 1956) indicates that, if present in a tuff, uranium will escape during the devitrification. Since at least some of the volcanic debris was altered after deposition, it could possibly be the source of the uranium in the deposits in Triassic rocks of the Colorado Plateau.

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## Studies of clays in Jurassic rocks

by

W. D. Keller

Clay mineral studies of the rocks of Jurassic age have been divided into two parts. One study had the objective of determining if the gross clay mineralogy of the green mudstones of the Morrison formation is different, or the same, as the gross clay mineralogy of the red mudstones.

The green mudstones are in places associated with uranium deposits and it was hoped that a characteristic clay mineralogy might be correlated with the occurrence of uranium ore. The study indicated that no difference in gross clay mineralogy of the red and green mudstones could be detected.

The other study of clay minerals in the Jurassic rocks was to determine the clay mineral assemblages in the mudstones and sandstones of the members of the Morrison formation, and to determine if a difference in clay mineralogy existed between the rocks of uranium-bearing and non-uranium-bearing regions. Results of this study indicate that: (1) the Brushy Basin member in the northern part of the Colorado Plateau is characterized by montmorillonite; (2) mudstone in the Salt Wash member contains primarily illite; (3) the clay mineralogy is more complex in the Jurassic mudstones in the southern part of the Colorado Plateau where mixed-layered clay minerals are predominant, as contrasted with the more nearly end-member types occurring in the Morrison of the northern part of the Colorado Plateau; (4) the interstitial clay mineral fraction in permeable sandstones, particularly in the Salt Wash, is different from the clay mineral assemblage in the relatively impermeable mudstones, and is likely to contain more kaolinite; and (5) chlorite is more abundant in rocks of the Morrison to the south than in those to the north.

The distribution of samples analyzed so far is such that no relation between occurrences of ore deposits in the Morrison and clay mineralogy has emerged. It is not yet possible to ascribe the regional and local differences in clay mineral assemblages to differences in sedimentary source areas or to post-depositional changes.

## General investigations

### Mineralogy of uranium deposits

by

Alice D. Weeks

A reconnaissance study of the mineralogy and oxidation of seven mines in the Elk Ridge district in San Juan County, Utah, were completed in cooperation with the field studies in that district.

All of the uranium ore in the Elk Ridge district is non-vanadiferous. The primary or unoxidized ore consists of uraninite and coffinite with pyrite and traces of sulfides or arsenides containing Pb, Zn, Mo, Ni, Co, or Ag. These minerals are stable in a reducing environment but when exposed to oxidizing conditions are easily altered. The commonly formed uranyl carbonates and sulfates are readily soluble and will wash away almost as soon as they form. Uranyl arsenates and phosphates are more stable than the sulfates and carbonates but insufficient arsenate and phosphate are available in this area to complex the oxidizing uranium. Vanadium which is most effective in complexing uranium and fixing it as carnotite in oxidized uranium deposits, is lacking in Elk Ridge. Therefore, in appraising the uranium potential of this district, one must consider not only the conditions favorable for deposition of ore but the conditions for preservation of the ore.

The close association of the unoxidized uranium minerals with carbonaceous material and sulfides indicates precipitation by reduction. Some coalified wood can be identified in every deposit. Whether the remainder of the carbonaceous material is a derivative of wood or of petroleum is a problem still under investigation. The oxidized uranium minerals identified from the Elk Ridge area include andersonite, zippeite, uranophane, cuprosklodowskite, meta-autunite, and metazeunerite. In addition to pyrite, traces of chalcopyrite, bornite, tennantite, domeykite, galena, siderite, ilsemannite, and malachite were found. Alteration of interstitial clay or of clay splits produced kaolinite, alunite, allophane, and jarosite.

A reconnaissance study of the mineralogy and oxidation of six mines in the La Sal Creek area in San Juan County, Utah, and Montrose County, Colorado, were completed in cooperation with field studies in that district. Five of the mines studied are in vanadiferous uranium ore in the Salt Wash sandstone member of the Morrison formation, and a few samples from the Cashin copper mine in the Wingate sandstone also were studied.

The vanadiferous uranium ores in this area have, on the average, about six times as much $V_2O_5$ as $U_3O_8$, and the predominance of vanadium over uranium is reflected in the mineralogy. The most abundant vanadium minerals are the vanadium-bearing silicates which impart a gray color to the ore sandstone and a dark brownish gray to clay pellets and stringers. The uranium is more irregularly distributed in the unoxidized ore than the vanadium. Uraninite and coffinite occur in black ore in the Firefly-Pigmy and the Grey Dawn mines. Pyrite and traces of galena, sphalerite, chalcopyrite and tennantite are associated with mineralized wood or disseminated in sandstone. Around the borders of the uraninite and coffinite in the Grey Dawn are various yellow secondary minerals including uranophane, beta-uranophane, phosphuranylite, metazeunerite, uranospathite, saleitenovacekite, boltwoodite, carnotite and tyuyamunite. Various vanadium minerals including a nolanite-like mineral, paramontroseite, melanovanadite, simplotite and hewettite are associated with the deposits according to the degree of oxidation. The vanadium silicates are relatively stable to changes in oxidation potential compared to the other vanadium minerals. The most oxidized deposits in the area are along the rim outcrop of the Salt Wash sandstone at the Yellow Bird group and near the portal of the Vanadium Queen mine.

## Mineralogy and geochemistry of uranium deposits in the Gas Hills district, Wyoming

by

R. G. Coleman

The Gas Hills uranium deposits (see "Gas Hills area, Wyoming," by H. D. Zeller, p. 272-276, this volume) contain a complex suite of uranium minerals, twenty of which were revealed in the present study. These deposits are distinctly different in mineralogy when compared to other uranium deposits in sedimentary rocks, particularly those from the Colorado Plateau. The chief differences are the lack of vanadium in both the oxidized and unoxidized ores, the high phosphate content, and the non-existence of Cu, Pb, and Zn sulfides in the unoxidized ores.

The oxidation and secondary enrichment of these ores produced an extremely heterogeneous suite of minerals; however, the various species seem to be representative of certain environments and can be placed in arbitrary brackets according to the associated minerals and zones of oxidation.

Group I - Minerals which generally have the low valent elements associated in an unoxidized environment and are considered to have formed under reducing conditions from solutions having a pH of 8 to 9.

Group II- Minerals characterized by high valent elements and associated with an oxidizing environment. These have formed in more acid or almost neutral conditions.

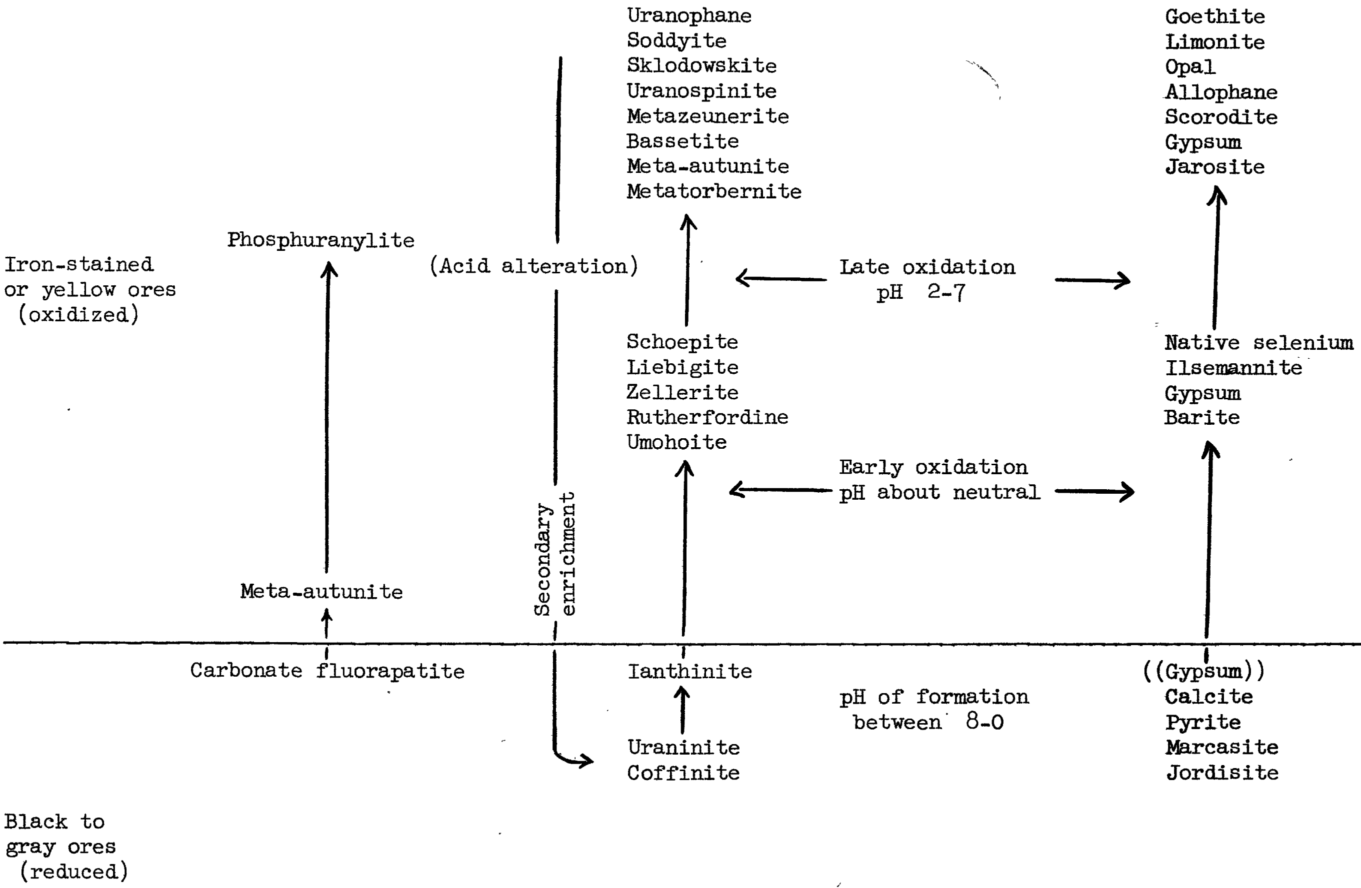
The black to gray ores contain a simple suite of introduced minerals (figure 113). In most cases the black ores are probably primary and give rise to the oxidized ores, but secondary enrichment common in the dark ores suggests that some of the uranium may have been originally precipitated in the hexavalent state. Later movements of ground water leached the primary oxidized minerals and solutions containing this uranium were brought into reducing environments to produce a secondary enrichment of low-valent uranium oxide.

The host rock for most of these deposits is a coarse arkose and its permeability seems to be the most important characteristic in localizing the ore deposits. Little or no alteration of the host rocks is evident in the unoxidized ores; however, the acid environment of the oxidized zone has produced strong alteration of the arkose.

A detailed study of the minor elements in the iron sulfides of the district shows interesting relationships. The nickel and cobalt content of the iron sulfides from the ore zones and barren rock remain consistent, i.e. Ni>Co. The consistency in this ratio suggests that these sulfides were formed by processes characteristic of sedimentary rocks. Since the Ni-Co ratio is the same in the containing rocks as that found in the iron sulfides it seems logical to imply that there was no introduction of these metals by the fluids that precipitated the iron sulfides in the ore zones. The iron sulfides from the ore zones show enrichment in Se, Mo, As, and Cu as compared to those from barren rock. The fluids giving rise to these deposits therefore must have been enriched in these elements.

A partial study of the minor elements in the deposits yielded information regarding which elements were enriched by the uranium-depositing

Figure 113.--Mineral sequence in the Gas Hills uranium deposits, Wyoming.



processes. The elemental composition of the ore zones was compared to the average crustal abundance for elements and also to the average found for these elements in normal clastic sediments. Those elements which show a concentration factor greater than 10 were considered to be geologically significant. Mo, U, Se, As, S, Zr, and P were found to be significantly enriched in the Gas Hills uranium deposits.

This suite of enriched elements was compared to element suites commonly enriched in other sandstone-type uranium deposits. It was found that there was a striking similarity between this suite of elements and that characteristic of the Colorado Plateau deposits.

A chemical study of several channel-type samples revealed that the black ore represents a reduced assemblage consisting of uraninite-coffinite and pyrite. These minerals alter as a result of oxidation and are partially dissolved and carried away or may be deposited as oxidation products above the ground water table. It is not yet certain whether the black ore is primary or whether it represents reworking and secondary enrichment of high-valent oxidized deposits.

The ores from this district exhibit strong disequilibrium on a local scale, but a comparison of all available radiometric and chemical uranium analyses shows general equilibrium. From this it might be concluded that the uranium was originally deposited in one period of mineralization and that post-depositional oxidation and leaching produced enrichment and deficiencies in both the uranium and its daughter products. The distribution of the daughter products illustrates the processes that might have been responsible for various types of disequilibrium. Oxidation and leaching of the dark ores must have taken place in a sulfuric acid environment, producing an excess of daughter products in this zone. The dark ores are almost in equilibrium and radiochemical methods indicate an age of about 150,000 years. Secondary enrichment has been important in the district and certainly must have been active in very recent times. A radiochemical age on secondary uranium-bearing allophane shows it to be about 16,000 years old. In fact, it is possible that migration and deposition of uranium is still going on in the district. Thus, recent changes in ground water conditions and erosional modifications of the terrain probably were important in the post-depositional history of these ores.

## Crystallography of uranium and associated minerals

by

Howard T. Evans, Jr.

The work of this period was concentrated on (1) crystal chemical studies of the uranium oxide hydrate minerals; (2) development of new computation facilities for crystal structure analysis; and (3) preparation of publications based on previously accomplished work.

Several uranium oxide hydrate minerals are being studied with the following goals: (1) definitive descriptions for each mineral, including morphological, optical and x-ray data, density determinations and chemical and x-ray fluorescence analysis; (2) crystal structure analysis; and (3) correlation of results with geological and geochemical studies. The minerals under investigation are becquerelite, billietite, fourmarierite, vandendriesscheite, mesuyite and schoepite. Descriptions are complete for the first four, all of which are distinct and valid mineral species. Vandendriesscheite has a large crystal unit cell and both optical and x-ray work give evidence for the coexistance of two phases. This finding is not surprising in view of the complicated situation that exists with respect to schoepite, which has a much smaller unit cell, and hence has been more intensively studied. Schoepite (amber) dehydrates slowly to a second phase (yellow), while retaining the original crystal form and orientation. The appearance of the x-ray patterns and optics depend on what stage the dehydration has reached. The x-ray studies indicate that under rapid dehydration, the orthorhombic $UO_3.H_2O$ may also be formed. Structure studies were carried out on billietite and they confirm the preliminary hypothesis of a $UO_2(OH)_2$ layer structure with interlayer water and cations (Ca, Ba, Pb), presumably basic to all the minerals of this group. Details of the structure are complex, and will require considerably more work for their elucidation.

The new USGS digital computer was placed in operation in January. This machine is intermediate in speed (500 additions per second), has magnetic drum (40,000 decimal digits) and magnetic tape (4 units, 4,000,000 digits each) storage, and is equipped with paper tape, typewriter, punch card and line printer input and output facilities. A large proportion of project time was spent in this period writing and checking out programs for 2-dimentional Fourier synthesis and 3-dimensional structure factor routines. Some time was lost because of unexpected problems associated with the installation of the computer, but these difficulties have been largely overcome and these two routines are now in constant production. Programs are also being developed for 3-dimensional Fourier synthesis, least squares analysis, Hauptman-Karle statistical phase determinations, and data preparation. It is believed that the new machine will completely remove the computing bottleneck that has seriously hampered all of our previous work.

A considerable backlog of work is still waiting for publication. Preparation of manuscript is in progress on thermodynamic equilibria of vanadium in aqueous systems, crystal chemistry of duttonite, crystal chemistry of doloresite, crystal chemistry of haggite, crystal structure of liebigite, crystal structure of carnotite, and several others.

# ANALYTICAL SERVICES AND RESEARCH ON TECHNIQUES

A total of 6,887 samples were submitted to the laboratories for analytical services during this report period. The high level of productivity continued with the laboratories spectrographically analyzing about 3,000 samples and chemically performing 3,179 uranium determinations and 8,700 other determinations. On May 1, the laboratories had completed the analytical work for projects to be concluded on July 1. This will allow the geologists to use the analytical data for the completion of their reports.

A summary of the analytical services and sample inventory for the six months period is given in table 34.

## Radioactivity

### Disequilibrium studies
by
F. E. Senftle

The study of radioactive disequilibrium as described in the previous report (TEI-640, p. 273-274) has continued. Emphasis was placed on the gamma-ray absorption method of analysis. By using a set of known standards (both in and out of equilibrium) an absorption method was devised which gives values of the uranium content that are very close to those chemically determined. By using two lead absorbers, one 10 mils and the other 20 mils thick, the percent uranium, the percent equivalent thorium (230) and percent equivalent radium (226) can be obtained. The method is reliable for samples containing greater than 0.3 percent uranium. Below this value the method is not reliable. Table 35 lists some typical results.

Table 34. Analytical services and sample inventory, December 1, 1956 - June 1, 1957

| | Analytical services completed | | | | | Sample inventory | | | |
|---|---|---|---|---|---|---|---|---|---|
| Project or source | Chem. Detns. | | Radio- activity | Spec. (samples) | X-ray (samples) | On Hand 12/1/56 | Rec'd. Dec.- June | Completed Dec.-June | On Hand 6/1/57 |
| | U | Others | | | | | | | |
| **Washington Laboratory** | | | | | | | | | |
| AEC | 170 | 126 | 89 | 24 | 14 | 107 | 127 | 213 | 21 |
| Colorado Plateau Sandstones | 40 | 199 | 133 | 102 | 8 | 459 | 149 | 145 | 463 |
| Sandstones-Other than Plateau | 208 | 35 | 201 | 97 | 31 | 172 | 204 | 362 | 14 |
| Veins | --- | 72 | --- | 10 | --- | 76 | 123 | 151 | 48 |
| Carbonaceous rocks | 82 | 164 | 11 | 161 | 2 | 172 | 276 | 363 | 85 |
| Southeast Phosphates | 215 | 535 | 272 | --- | 72 | 238 | 123 | 342 | 19 |
| Northwest Phosphates | 3 | 8 | 3 | 60 | --- | 123 | --- | 3 | 120 |
| Alaskan | 38 | 81 | 38 | 47 | 8 | 68 | 15 | 70 | 13 |
| Public Samples | 9 | 1 | 45 | 6 | 7 | 278 | 765 | 993 | 50 |
| Mineralogical Project | 48 | 282 | 16 | 416 | 185 | 505 | 599 | 786 | 318 |
| Geochemistry of Uranium | 499 | 1,408 | --- | 118 | 153 | 460 | 705 | 710 | 455 |
| Miscellaneous | 224 | 698 | 96 | 381 | 73 | 204 | 498 | 543 | 159 |
| Total (Washington) | 1,536 | 3,609 | 904 | 1,422 | 553 | 2,862 | 3,584 | 4,681 | 1,765 |
| **Denver laboratory** | | | | | | | | | |
| AEC | 448 | 114 | 295 | 83 | 74 | 424 | 470 | 742 | 152 |
| Plants and Soils | 29 | 14 | --- | --- | --- | 91 | 42 | 123 | 10 |
| Colorado Plateau Sandstones | 550 | 2,622 | 573 | 843 | 42 | 2,552 | 1,475 | 2,569 | 1,458 |
| Sandstones-Other than Plateau | 202 | 776 | 165 | 239 | 59 | 844 | 369 | 1,023 | 190 |
| Veins | 30 | 415 | 41 | 68 | 7 | 239 | 116 | 296 | 59 |
| Carbonaceous rocks | 21 | 131 | 62 | 114 | 21 | 189 | 186 | 371 | 4 |
| Phosphates | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Waters | 52 | 139 | --- | 19 | 1 | 62 | 23 | 84 | 1 |
| Public Samples | 4 | --- | 11 | 2 | --- | 27 | 31 | 57 | 1 |
| Geochemistry of Uranium | 39 | 24 | 39 | 70 | 16 | 95 | 63 | 132 | 26 |
| Miscellaneous | 268 | 834 | 239 | 181 | 56 | 878 | 528 | 932 | 474 |
| Total (Denver) | 1,643 | 5,069 | 1,425 | 1,619 | 276 | 5,401 | 3,303 | 6,329 | 2,375 |
| Grand Total | 3,179 | 8,678 | 2,329 | 3,041 | 829 | 8,263 | 6,887 | 11,010 | 4,140 |

Table 35. Analyses obtained by gamma-ray absorption method

| Sample No. | eU, percent | $eTh^{230}$, percent | eRa, percent | Chem. U, percent | U, This method, percent |
|---|---|---|---|---|---|
| 30063 | 0.22 | — | — | 0.28 | 0.28 |
| 253133 | 3.5 | 9.1 | 6.6 | 0.30 | 0.30 |
| 18734 | 0.22 | — | — | 0.32 | 0.37 |
| 30016 | 0.53 | — | — | 0.55 | 0.59 |
| 20031 | 0.43 | — | — | 0.68 | 0.61 |
| 229184 | 3.9 | 8.8 | 6.1 | 0.75 | 0.71 |
| 229176 | 9.2 | 15.0 | 15.0 | 3.0 | 3.0 |
| 248147 | 13.0 | 14.0 | 13.0 | 17.0 | 17.0 |

## Analysis and services
by
F. J. Flanagan and J. N. Rosholt

The project was initiated at Washington in March 1948 when it became evident that the number of samples expected for analysis would greatly exceed the capacity of the chemical laboratory to analyze them. It was believed that the radioactivity of geologic materials containing low amounts of uranium would furnish reasonable estimates of the uranium content in the absence of appreciable amounts of thorium. In 1949, a second laboratory for radioactivity determinations was established in Denver.

Both the conventional end-window Geiger tube and the thin-walled tube were used for the measurements. The thin-walled tube was used in the method developed by Battelle Memorial Institute with special holders of one quarter inch depth. When the holders were filled, the surface of the sample, when placed beneath and adjacent to a thin-walled Geiger tube in a horizontal lead chamber, affected approximately one third of the cathode area of the tube. In both methods standards of known uranium content and the unknown samples were counted for a predetermined time. Under the assumptions of equilibrium and the absence of thorium, the uranium content of the samples was estimated by direct proportion.

Samples where volumes were insufficient to fill the Battelle holders were counted by the conventional end-window tube technique. Sample holders of various materials and various heights were used normally to hold samples of small volumes. However, a convenient holder for most purposes is the ointment jar or the pill box (both approximately 5/8 inches high by 1-3/8 inches diameter) available from all scientific supply companies. Although the results obtained by counting pelleted samples have been shown to be less variable than those obtained after filling and leveling off a holder, the additional step of forming the pellet is too time-consuming where thousands of samples are involved and where the main purpose of the measurement is to furnish a reasonably correct estimate of the uranium content for the benefit of the chemical laboratory.

A large increase in the number of samples received occurred in 1949 and an unshielded coaxial method of counting samples was adopted as a rapid and relatively efficient method of making a large number of determinations in the time available. These coaxial holders were also used to increase the sample output of an automatic sample changer.

An estimated 3,700 determinations were reported in the last six months period including 343 radiochemical determinations of various nuclides in the three naturally-occurring radioactive series.

Contributions also were made as a result of research when sample loads were light. In anticipation of a large number of requests for the determination of thorium in monazite, members of the project developed in 1951 an indirect method for this determination. The method was based on the differences between the half-lives of $Ra^{226}$ in the uranium series and $Ra^{224}$ and $Ra^{228}$ in the thorium series. After solution of the sample the three radium isotopes are coprecipitated with 10 mg of $Ba^{++}$, the precipitate filtered and the $\beta$-activity of the precipitate measured between 24 and 26 hours after precipitation. These counts were corrected by subtracting the radium counting equivalent (under the assumption of equilibrium) of the uranium content of the filtrate. The plot of counts per minute against the percent thorium was linear from 1 percent to about 8.5 percent for maximum counting periods of ten minutes. The method was not tested below one percent thorium although this lower limit could be extended by increasing the counting time. It was estimated that six thorium determinations of this type could be made per man-day.

The variation with depth of the relation of the uranium content, radioactivity, and the blackness of the Chattanooga shale was investigated (Flanagan, 1953). The blackness of the shale had been assigned values in the field by geologists using a rock color chart but the laboratory investigation showed that a quantitative measure of the blackness can be made. The reflectance of a white light source from the surface of ground samples was measured at an angle of 45 degrees by a photomultiplier tube. The reciprocal of this reflectance (measured in microamperes) when plotted against the depth of the sample in the formation follows closely similar plots of the radioactivity and the uranium content. Hence if one of these four variables in this formation is known, it can be used to estimate the other three.

After the rate of receiving samples had stabilized in late 1953, more time was available for research activities. In addition to publications by members of the projects listed below, some of the more recent studies have concerned (1) a slotted cone splitter, (2) the uranium, thorium and potassium contents of the Conway granite at Redstone, Carroll County, N. H., and (3) the lead content of granite sample G-1, in which the best estimate of the lead content is shown to be 47.5 parts per million.

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# Spectrography

## Spectrographic methods
by
A. T. Myers and C. L. Waring

The Washington and Denver laboratories carried out spectrochemical analyses of 2,907 samples. Materials analyzed included igneous rocks of many types; vein materials; uranium and other ore pulps; sediments including coals, lignites, and shales, crude oil and plant ashes and water residues. Minerals analyzed included crysotile, garnet, uraninite, sphalerite, galena, pyrite, and pegmatite minerals. Several suspected new minerals were analyzed, a sulpharsenide of nickel (gersdorffite) with calcium or magnesium substitution, a sodium, calcium, strontium, barium-rare-earth carbonate (burbankite), a suspected new manganese phosphate mineral, and an unusual roscherite or childrenite with high beryllium.

The rare metal rhenium was found in 11 out of 30 sandstone type uranium ore samples from the Shinarump and Moenkopi formation of the Sun Valley mine near Tuba City, Arizona. The highest concentration, about 0.07 percent, was found in three samples.

Spectroscopic analysis is continuing to contribute to the study of pyrites from the Colorado Plateau (TEI-640, p. 275). This work is for the purpose of (1) establishing the minor and trace element partition in the sulfides as related to the uranium deposits (2) the period of sulfide deposition and (3) to determine which of these sulfides were introduced by the ore forming fluids.

Approximately 50 lithologic and mineralized specimens from the Jackson and Catahoula formations in the Texas Coastal Plain were analyzed. These results are being used in joint geophysical ore deposit and mineralogical and petrological studies concerning the geology and origin of the uranium of the Texas Coastal Plain. These studies will serve as an exploratory tool to show the general composition in the different formations and to guide the detailed mineralogic study. Of particular interest is the distribution of Mn, Cr, V, Co, Ni, Cu, Mo, Pb, Ag, and rare earths.

Spectrographic analyses of eleven suites of samples (46 total) taken across ore boundaries in nine mines in the Uravan mining district, Montrose County, Colorado, have been correlated with the mineralogy of the ore and the barren rock. The spectrographic data support the identification of dolomite, chlorite and vanadium minerals in the ore and indicate narrow bands of high concentration of lead, copper, zinc and other trace metals along the ore boundary. As a result of the spectrographic analyses mineralogic separations were made of some of these zones and descloizite was identified on ore boundaries of two mines.

Spectrographic analyses of samples representing many lithologic types in a barren drill core through Cretaceous and Jurassic formations in the Slick Rock district, Colorado are being correlated with pH and Eh studies of the ore samples in the Uravan and Slick Rock districts.

Work continued on the development of a combined chemical and spectrographic method for the determination of thorium in rock samples down to 1 gamma. The chemical problem of aluminum interfering with the precipitation of thorium was solved (TEI-640, p. 276). Chemical concentrates from 5-gram synthetic samples were arced and thorium at 1 gamma was detected. When the method was repeated with rock samples, it was found that zirconium was chemically concentrated with the thorium and interfered with the spectrographic detection of low amounts of thorium. A chemical method is now being developed to eliminate the zirconium.

Tests with a deep crater pedestal electrode showed increased sensitivity for As, Hg, and Te.

The following papers were published during the report period:

Deul, M., and Annell, C. S., 1956, The occurrence of minor elements in ash of low rank coal from Texas, Colorado, North Dakota, and South Dakota; U. S. Geol. Survey Bull. 1036-H, p. 155-172.

Gettens, R. J. and Waring, C. L., 1957, The composition of some ancient Persian and new eastern silver objects: Arsorientalis, v. 2, p. 83-90.

Gottfried, D., Sentfle, F. E., and Waring, C. L., 1956, Age determinations of zircons from Ceylon: American Min., v. 41, p. 157-161.

## Infrared spectroscopy
by
R. G. Milkey

During the report period, a variety of samples was analyzed. The presence of a derivative of phthallic acid was determined by means of infrared spectra of a number of isolates from a crude oil. The infrared absorptions of an alcohol prepared from the ester from the crude oil further characterize the hydrocarbon chain. A sample of oil extracted from a rock was shown to be composed almost entirely of long-chain, paraffinic hydrocarbons. Dopplerite (a substance related to humic acid), showed absorption spectra with strong aromatic bands and a general similarity to the spectra of extracts from lignite and subbituminous coals. The spectra of a minute quantity of oil extracted from an opalized rock indicated a complex structure containing both aliphatic material and multi-substituted aromatic rings. Absorption spectra of gilsonite, grahamite, albertite, and other asphaltic materials showed slight but definite variations in the infrared absorption spectra according to locality. This indicated that where such substances had been collected from different localities, they might actually contain differences in structure although considered to be identical.

Research in the field of infrared spectroscopy continued. Data were obtained and basic work substantially completed on techniques for analysis of insoluble compounds. As little as a few micrograms of some insoluble materials may be detected quantitatively, in the solid state, by means of their infrared absorptions. Work on the infrared spectra of the tectosilicates is substantially completed. In addition to serving as standard spectra, the absorption curves were compared for similarities in the silicate structures, and the frequencies of the absorption peaks correlated with the aluminum-silicon ratios of the minerals. Work is in progress on the infrared spectra of approximately 50 synthetic and naturally-occurring vanadates, including meta-, ortho-, and polyvanadates of such metals as potassium, calcium, sodium, zinc, and magnesium. Continuing the survey of the infrared spectra of the silicates, pure separates of 21 cyclosilicates were obtained, and their infrared spectra will be determined. Twenty-four sorosilicates have been obtained, and a survey will be made of their infrared absorptions.

New instrumental accessories acquired include a horizontal sampling stage, which facilitates the analysis of semi-viscous liquids.

# Chemistry

by

Irving May and L. F. Rader, Jr.

## Services

During the period, 8,974 chemical determinations were made on 5,132 samples which had been submitted on 425 requests for analysis. A summary of the determinations by type is presented in table 36.

## Research on analytical methods

An adaptation of a rapid colorimetric method for the determination of molybdenum and tungsten on the same aliquot of sample solution was investigated. The method is applicable to a range of 1 to 1,000 ppm in rocks. Molybdenum and tungsten are precipitated from an acid solution of the sample with alpha-benzoin oxime. After organic matter is destroyed the thiocyanate complex is extracted from tartaric acid medium to separate molybdenum from tungsten. The molybdenum is then determined spectrophotometrically. The acidity of the aqueous phase is then increased, tungsten is reduced with titanous sulfate, and the dithiol complex of tungsten is extracted into chloroform and determined spectrophotometrically.

A spectrophotometric procedure for selenium using 3,3'-diaminobenzidine which avoids the usual distillation step was tried on pyrite and limonite samples. In some cases, low results were obtained, while in others agreement with the classical procedures was excellent. The cause of this inconsistency is under investigation.

Table 36.—Completed Chemical Determinations
December 1, 1956 - May 31, 1957

| Determinations | No. completed Dec. 1956 - May 1957 |
|---|---|
| Aluminum | 94 |
| Arsenic | 337 |
| Ash | 158 |
| Calcium | 88 |
| Calcium carbonate | 256 |
| Carbon, organic | 217 |
| Carbon, mineral | 540 |
| Copper | 174 |
| Fluorine | 153 |
| Gold | 250 |
| Iron | 233 |
| Lead | 76 |
| Magnesium | 79 |
| Manganese | 109 |
| Molybdenum | 71 |
| Phosphorus | 660 |
| Potassium | 46 |
| Selenium | 519 |
| Silicon | 32 |
| Sodium | 51 |
| Sulfur | 231 |
| Thorium | 36 |
| Uranium | 2,750 |
| Vanadium | 518 |
| Water | 80 |
| Zinc | 376 |
| pH | 104 |
| Miscellaneous | 736 |
| Total* | 8,974 |

*Totals given in this table will not necessarily agree with those of table 34, Analytical service and sample inventory, because of time lag between laboratory completion and summary compilations in sample control audits.

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Limited studies were made on several established methods, including improving the precision of a quick carbon method, improving the instrumentation for the photometric versene titration of calcium and magnesium, and evaluating a spectrophotometric thiocyanate procedure for molybdenum in aqueous medium.

The construction of a thermogravimetric balance was begun. The weight recording part was completed and tested.

The following paper was published during the report period:

Grimaldi, F. S., Jenkins, L. B., and Fletcher, M. H., 1956, Selective precipitation of thorium iodate from tartaric acidhydrogen peroxide medium: Anal. Chem. v. 28, p. 848.

## Mineralogy

### Services and research on techniques
by
L. B. Riley and J. P. Owens

During the past six months the routine use of several techniques has permitted study of many varieties of materials. The untrasonic generator has been in use in the laboratories for more than a year; its use as a preliminary cleaning treatment before further studies or separations such as X-ray investigations of clay-size fractions, segregation by heavy liquids, magnetic classification, or hand sorting, is now routine. An alpha counter designed to measure the radioactivity of a few selected grains aids in identifying the mineral source in a heterogeneous radioactive sample. The alpha-track density in nuclear emulsions applied to thin sections or thinned polished sections allows not only recognition of areas of radioactivity but an approximation of the amount of radioactivity (TEI-640, p. 282).

Among the samples studied during the period was a suite from Marshall Pass, Colorado, submitted by the Atomic Energy Commission, in which at least one form of ianthinite was recognized. This purple mineral occurs in needle-like aggregates between uraninite and various yellow oxidation products and is of especial interest because like uraninite and coffinite it contains uranium in the 4-valent state. Only a small amount was found: apparently it is relatively unstable, formed by hydration that only slightly preceeds oxidation. Other minerals studied this period were metatyuyamunite from the uranium-vanadium ore body at Cement, Oklahoma, and jordisite from Lisbon Valley, Utah. The latter, a molybdenum sulphide, is not a well defined mineral due to its amorphous character.

A sample of native silver ore from the Cashin Mine, La Sal Creek, Montrose County, Colorado, is being investigated. The native silver contains native copper, with a texture suggesting exsolution. Associated with the native silver are small amounts of radioactive carbonaceous material which give a uraninite X-ray pattern. The uraninite is apparently very finely divided, essentially colloidal. Mercury and arsenic also were found in the sample.

Results of investigating some types of carbonaceous material by X-ray techniques have suggested that correlation exists between the patterns obtained, from the organic structure in the material, and the geologic nature of the sample; examples of asphalts, coals, natural resins and waxes were included in this study. In particular uranium-bearing asphaltites give a rather distinctive pattern. The patterns are not sharp, as with most minerals, but consist of broad bands.

Considerable attention during the period was devoted to development of a new low-temperature liquid-medium heating stage to aid in determining the temperature of formation of vein material submitted for analysis. An improved model of the prototype was completed and tested. The upper temperature limit, approximately 250°C, is controlled primarily by the liquid utilized in the stage. A series of organic compounds of known melting points were sealed in small glass tubes and immersed in the liquid of the heating stage at various temperatures. The accuracy of determining these melting points was ± 1 °C of the predicted value. It may be assumed that temperatures determined in this stage will have the same degree of accuracy.

## X-ray and electron diffraction services
by
George Ashby

During the last six months, 853 x-ray and electron diffraction determinations were made on 617 samples. In the same period, 291 references including new data on 107 minerals and compounds were incorporated into the powder data file.

The automatic controls and readout printer for the Fourier Synthesizer described in previous reports were tested for performance. Modifications were made in the printer circuit to increase the damping in the servo system and to eliminate an undesirable transient signal caused by the printer actuator.

A control console was assembled for the computer that permits its normal functions to be controlled from a remote location. The console consists of four sections; (1) the regulated power supply, (2) the printing voltmeter, (3) the X and Y sweep controls, and (4) the trouble-shooting panel. A source of power regulated to within ± 0.1 percent is supplied by an electronic type regulator of 3 KVA capacity installed in the base of the console. Directly above the regulator is a servo-operated printing device that periodically indicates the computer output on a 0 to 26 volt scale to within ± 0.26 volts. The X-Y sweep control has two servo-indicators that show the gear-train position and hence the values of X and Y at any instant. The operator by using a set of motor control switches and monitoring the servo-indicators can rotate the gear-train into any desired starting position to make an initial X and Y setting. After the initial setting has been made, several types of scanning of the unit cell can be selected with an automatic switching device. Calculations can be made over 1/10 by 1/10, $\frac{1}{4}$ by $\frac{1}{4}$, $\frac{1}{4}$ by $\frac{1}{2}$, $\frac{1}{2}$ by $\frac{1}{2}$, $\frac{1}{2}$ by 1, and 1 by 1 unit cells.

The trouble-shooting section consists of a signal selector, a voltmeter and an oscilloscope. Either the computer output, input or any of six other internal computer signals can be connected to the voltmeter of oscilloscope by the operator using the signal selector. The voltmeter has an 8" scale calibrated to read from 0 to 30 volts to within ± 0.3 volts. Signals from the selector switch are connected to the vertical sweep of the oscilloscope where the wave shape or phase shift with respect to the 420 cycle motor generator signal is displayed on the cathode ray tube face. The problems in trouble-shooting and computer control have been greatly simplified since the console has been assembled.

Work is in progress on the development of new electron diffraction methods for mineralogic studies. A study of the methods of interpretation of single crystal electron diffraction patterns were made resulting in several important improvements in the techniques. Partial symmetry determinations on about 15 fine-grained minerals that have previously defied X-ray diffraction analysis were made using election diffraction.

Four important modifications were made to the electron microscope optical system; (1) an adjustable compensator was added for correction of astigmatism, (2) an adjustable back focal plane aperture was added to improve the contrast and resolution, (3) a centering device was added to improve the alignment of the objective aperture, and (4) a beam oscillator was added to improve the focusing technique. These modifications are expected to improve considerably the quality of the electron micrographs supplied by this project.

# RESEARCH PROGRAMS

## Physical behavior of radon

by

Allan B. Tanner

Radon emanates from the mineral crystals in a rock by two mechanisms: by the passage of the recoil radon atoms from the disintegration of radium in the crystals into the void spaces in the rock, and by the diffusion of radon from the crystals into the void spaces. The ratio of radon emanated to total radon produced is known as the emanating power of the rock, and sometimes is referred to as radon leakage. Emanating power is a parameter of interest in some methods of geologic age determination and in calculation of the transport of radon by fluids in permeable media.

A survey of the literature pertinent to the emanating power of rock is being conducted. The more important conclusions drawn so far may be summarized as follows:

(1) That portion of the emanating power of a granular aggregate due to the recoil of radon atoms into void spaces during the disintegration of radium has been shown theoretically to be not more than about 1 percent, regardless of grain size. Grain size is critical in the determination of the recoil portion of the emanating power when the grain radius is of the order of $10^{-3}$ to $10^{-5}$ cm.

(2) The remainder of the emanating power of the aggregate, which may be as high as 80 percent, is due to diffusion of radon atoms of thermal energy through the crystal structure and into the void spaces. It follows that changes in crystal structure or in the thermal energy of the radon atoms will influence the diffusion of the atoms and hence, the emanating power.

(3) It has been demonstrated theoretically (for isotropic, homogeneous grains) and experimentally (with crystals) that the emanating power varies with temperature if a significant portion of it is due to diffusion. Since many minerals have emanating powers exceeding 1 percent and therefore have significant parts of their emanating powers due to diffusion, it is to be expected that the emanating power of a rock should vary with temperature. When the emanating power of a rock is being considered in a geologic problem it is necessary to have a good idea of the emanating power of the rock for the temperature range prevailing in the geologic situation.

A core holder has been designed for studies of the emanating power of rock at steady-state high temperatures and moderate pressures. The holder uses hydrostatic pressure acting on a flexible jacket to hold the core in place and to prevent side leakage of the gas used to flush the emanated radon from the core.

Calculations are being made to determine the extent to which diffusion plays a part in the migration of radon into drill holes. The results so far indicate that radon migrates into drill holes because of movement of the interstitial fluid in the rock, rather than by diffusion of the radon through the fluid.

## Absorption and scattering of gamma-radiation

by

A. Y. Sakakura

Based on published point source solutions of the Boltzmann Equation, numerical values for the integral gamma flux at the center of an infinite cylinder, as function of its radius, were calculated. The sources considered were the infinite plane source and the infinite homogeneous source of radium. The effects of fluid within the cylinder and concentric absorbers were taken into account through the use of effective electronic density and penetration depths.

The dependence of flux gamma on the effective electronic density, atomic number of surrounding medium, and radius of the cylinder is now being studied. For the case of the infinite plane, the counting rate for any given surrounding material and composition of surrounding absorber, and radius of bore seem to be function only of the atomic number of the surrounding material within approximately 15 percent. Thus, it may be possible to obtain absolute calibration, via a standard medium (water), and determining the various (multiplicative) factors for other media. For pulse height acceptance level of 0.4 mev., $H_2O$, Al and Fe show identical dependence on radius (expressed in mean free paths) except for a density factor. The effect of radius, at 0.5 mev., is strongly dependent on effective electronic density.

Analysis of the gamma-ray spectra at considerable distance from source continues. Integral spectra have been calculated for Ra, Th, and $K^{40}$. All exhibit approximately exponential behavior beyond 300 feet above infinite thick sources.

The build-up factors determined experimentally for both the 2" and 4" pipes show that the boundary effect of the cavity is significant, i.e., the factors are not solely a function of total penetration distance. Due to electronic difficulty, the results have not been reproduced. This difficulty is now in the process of being corrected.

## Radon and helium studies

by

J. W. Mytton

Studies of uranium-bearing asphaltite will terminate in July 1957. These studies were originally undertaken in the West Panhandle field, Texas, as a result of the discovery of uranium-bearing asphaltite in drill cuttings, during the investigation of radon and helium in the natural gases.

At the beginning of this investigation, it was believed that the presence of trace amounts of asphaltite, where present in the reservoir rocks, might possibly account for at least part of the radon and helium in the area. It soon became evident that before the relationship of the asphaltite to the anomalous concentrations of radon and helium in the field could be fully understood, a comprehensive study of the nature of the material and its distribution in the area of investigation would have to be made.

This involved detailed analytical work, including petrographic studies, X-ray and spectrographic determinations, and chemical and radiochemical analyses of asphaltite and associated reservoir materials and fluids, such as acidized reservoir rock, cements, crude oil and bottom hole brines, as well as an evaluation of its physical and chemical relationship to these materials and fluids and its spatial relationship with regard to the radon and helium anomalies within the geologic framework of the area.

The investigation of uranium-bearing asphaltite has taken on a much greater scope and gone beyond the confines of the West Panhandle field to include other areas in the United States, notably the Amarillo-Wichita uplift, southern Missouri, southeastern New Mexico, the Colorado Plateau, and localities in Colorado, Wyoming, Arkansas, and California; and other areas in the world such as Parry Sound and the Blind River District in Canada, the Witwatersrand in South Africa, and Rum Jungle in Australia.

The principal conclusions reached by these studies are: (1) that the asphaltite is a petroleum derivative, which, through polymerization with resultant dehydrogenation and carbonization produced by the radioactive decay of included uranium, has changed to a dark, hard, brittle, highly lustrous insoluble radiogenetically metamorphosed metallo-organic compound that forms nodules, exhibiting a characteristic botryoidal surface; (2) that the uranium and other trace metals in the asphaltite in most cases have probably been introduced by solutions of relatively high salinity which have picked up these metals in the beds in which the solutions originated or in rocks through which they migrated and deposited them in an acid reducing environment in which petroliferous material was present; and (3) that the uranium-bearing asphaltite in the West Panhandle field, Texas, accounts for the abnormal radon contents of the natural gases, and may be of sufficiently widespread occurrence to contribute importantly to the helium content of the gases which have migrated into the major gas reservoirs from the basins adjacent to the Amarillo uplift.

## Uranium in natural waters

### Hydrogeochemical prospecting

by
Philip F. Fix

Studies of uranium in natural waters began in 1952, and will be complated in the summer of 1957. Emphasis has been placed on the use of anomalous amounts of uranium in natural waters as indicators of uranium concentrations in rocks. Particular attention was paid to standardization of techniques for collecting water samples, and to working out the correlations of geochemical, hydrologic, geologic, climatic, and botanical factors that control the concentration of uranium in natural waters.

The "background" concentration of uranium in waters of the "cold" portions of the United States and Alaska has been established as about 0.1 ppb (Fix, 1956, p. 669-670). In highly uraniferous areas the uranium content of natural surface waters normally is greater than the background by 1 to 3 orders of magnitude, that of ground waters by 2 to 4 orders, and that of beneficiated waters (i.e., waters artificially contaminated by such activities as test drilling, recent disturbance of the ground by mining, or the addition of uraniferous industrial wastes) by 4 to at least 7 orders of magnitude. This, however, is only part of the story. Studies have shown that hydrogeological interpretations, instead of being applied indiscriminately to all waters present, are best divided into the following three types for field application, distinction being made between the uranium content of natural and beneficiated waters in each category: (1) surface water type, which is vastly superior for rapid exploration of large areas; (2) ground-water type, for special conditions; and (3) combined surface- and ground-water type for intensive exploration of the more promising areas.

It has been shown that waters containing different minerals affect the behavior of uranium in both weathering and hydrodispersion trains. For example, other things being equal, water high in sodium bicarbonate will dissolve uranium from a given sediment much more effectively than water high in calcium-magnesium-bicarbonate. Further, water strongly acid from oxidizing sulfates leaches uranium very effectively. The nature and amount of floral population must also be considered, as algae and similar plants may reduce the true uranium content of water by as much as 90 percent. Also, hydrogeochemical methods must be applied differently in dealing with primary as opposed to secondary uranium mineralization, because of the different responses made by quadrivalent and hexavalent uranium to weathering processes and hydrogeochemical dispersion.

The methods used by the uranium in natural waters project are best suited to semi-arid to humid climates where water supply is neither so excessive as to dilute hydrodispersion trains of uranium beyond recognition, nor so scanty as to preclude a sampling pattern of sufficient density distribution around the geologic targets. Even in deserts, however, data from scattered wells and springs can yield much information useful in interpreting the geology. In fact, the application of hydrogeochemical data to geologic interpretation, entirely apart from its usefulness in uranium exploration, indicates a wide usefulness for hydrogeochemical methods as a new tool for the geologist.

## References

Fix, Philip F., 1956, Hydrochemical prospecting for uranium, in Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U. S. Geol. Survey Prof. Paper 300, p. 667-672.

# Uranium content of ground and surface waters in western Kansas, eastern Colorado, northeastern New Mexico, and the Oklahoma Panhandle

by

E. R. Landis

During 1954, 1955, and 1956, water samples were collected in western Kansas, eastern Colorado, the Oklahoma Panhandle, and northeastern New Mexico, to determine the uranium content of water from the various rock units in the region, and to indicate areas in which large amounts of uranium in the water might reflect the presence of nearby uranium accumulations.

Three geologic terranes are present in the report area; the Tertiary-Quaternary tuffaceous terrane, the Upper Cretaceous shale terrane, and the upper Permian through Lower Cretaceous sandstone terrane. The average uranium content of 179 water samples from the tuffaceous terrane, which is composed primarily of tuffaceous, fluviatile rocks ranging in age from Pliocene to Pleistocene, is 6.7 parts per billion. A total of 48 samples from the Upper Cretaceous shale terrane, which is composed almost entirely of shale and limestone of marine origin, contain an average of 20.4 parts per billion uranium. Sandstone, siltstone, and claystone of terrestrial and near-shore marine origin are the predominant constituents of the upper Permian through Lower Cretaceous sandstone terrane, and the 83 water samples collected from, or related to, rock units of this terrane contain an average of 10.2 parts per billion uranium. The average uranium content figure derived for the Upper Cretaceous shale terrane may not be representative of the uranium content of waters from this terrane throughout the report area because more than half of the samples obtained from the terrane were collected in a small area that may contain more uranium in water than is normal for the shale terrane as a whole. Compared to the shale terrane, the tuffaceous terrane and the sandstone terrane are both represented by a greater number of samples collected over a much larger area and the average uranium content figures derived for them are believed to be representative of the uranium content of waters from, or related to, rock units of the two terranes in the report area.

The average uranium content figures derived for each of the different rock units, or groups of rock units, subdivided by the source type from which the samples were collected (well, spring, stream, municipal water system, reservoir, or lake), are believed to be of more potential use in any future hydrogeochemical exploration in the area than are the average uranium content figures derived for the three geologic terranes (see table 37). The average uranium content of water samples from 10 individual rock units or groups of rock units ranges from 3.1 to 38 parts per billion. Several rock units were sampled over large enough areas to indicate that waters from the same rock unit in different parts of the report area may range widely in average uranium content.

Water samples from some of the rock units in the area, particularly those of Triassic and Permian age, contain large amounts of uranium, and in some parts of the report area, such as the Cimarron River area of westernmost Oklahoma and northeastern New Mexico, and the Rule Creek area in Bent and Las Animas Counties, Colo., most, or all, of the water samples collected contain relatively large amounts of uranium.

General conclusions from the water-sample data gathered for this report are: (1) water samples collected from the geologic terranes and

Table 37--Average uranium content in parts per billion of water samples by source type and stratigraphic unit in western Kansas, eastern Colorado, and the Oklahoma Panhandle.

| Stratigraphic units | WELLS | | SPRINGS | | STREAMS | | MUNICIPAL WATER SYSTEMS | | RESERVOIRS | | LAKES | | TOTAL | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of samples | Average U content | No. of samples | Average U content | No. of samples | Average U content | No. of samples | Average U content | No. of samples | Average U content | No. of samples | Average U content | No. of samples | Average U content |
| Recent: | | | | | | | | | | | | | | |
| alluvium related to tuffaceous terrane | 21 | 3.4 | 1 | <1 | 24 | 4.2 | 2 | 4.0 | 4 | 7.8 | 1 | 5.0 | 53 | 4.1 |
| alluvium related to shale terrane | 11 | 31.0 | 2 | 1.0 | 9 | 8.1 | 3 | 14.0 | 14 | 31.9 | 1 | 7.0 | 40 | 22.8 |
| alluvium related to sandstone terrane | 9 | 9.7 | - | - | 35 | 9.8 | - | - | - | - | - | - | 44 | 9.8 |
| alluvium combined | 41 | 12.2 | 3 | <1 | 68 | 7.6 | 5 | 10.0 | 18 | 26.6 | 2 | 6.0 | 137 | 11.4 |
| Pleistocene: | | | | | | | | | | | | | | |
| fluviatile and aeolian sediments | 12 | 3.4 | 1 | 15.0 | 4 | <1 | - | - | 2 | 1.0 | - | - | 19 | 3.1 |
| Miocene-Pliocene; Pliocene; and Pliocene-Pleistocene: largely fluviatile | 61 | 10.6 | 8 | 9.5 | - | - | 21 | 6.5 | 2 | <1 | 2 | 14.5 | 94 | 9.4 |
| Upper Cretaceous: | | | | | | | | | | | | | | |
| predominantly shale | 4 | 2.3 | 4 | 14.8 | - | - | - | - | - | - | - | - | 8 | 8.5 |
| Lower Cretaceous: | | | | | | | | | | | | | | |
| predominantly sandstone, Dakota sandstone and Purgatoire formation | 21 | 7.0 | 2 | 25.5 | - | - | 6 | 8.5 | - | - | - | - | 29 | 8.6 |
| Jurassic: | | | | | | | | | | | | | | |
| Entrada sandstone | 1 | 4.0 | - | - | - | - | - | - | - | - | - | - | 1 | 4.0 |
| Triassic: | | | | | | | | | | | | | | |
| sandstone and red beds, Dockum group ? | 2 | 38.0 | - | - | - | - | - | - | - | - | - | - | 2 | 38.0 |
| Permian: | | | | | | | | | | | | | | |
| sandstone and red beds, Taloga and Cloud Chief formations | 5 | 16.0 | - | - | - | - | 1 | 8.0 | - | - | - | - | 6 | 14.7 |
| Undetermined and mixed aquifers | 20 | 6.5 | - | - | 1 | 7.0 | 4 | 3.8 | 1 | <1 | 1 | 3 | 27 | 5.7 |
| Totals and averages | 167 | 9.5 | 18 | 11.3 | 73 | 7.2 | 37 | 7.1 | 23 | 20.9 | 5 | 8.8 | 323 | 9.7 |

stratigraphic units in the report area contain an average of from about 3 to about 38 parts per billion uranium though individual samples may range in uranium content from less than 1 to about 400 parts per billion; (2) water samples from the upper Permian through Lower Cretaceous sandstone terrane contain on the average as much or more uranium than samples from the tuffaceous terrane in the report area; though this conclusion may be revised as some of the rock units of the sandstone terrane are sampled more extensively; (3) the difference in the uranium content of water samples from specific rock units in different parts of the report area indicates that samples collected for hydrogeochemical exploration purposes should be compared not only to the averages derived for the terrane or rock unit in the report area as a whole but should also be compared to samples and sample averages from the same terrane or rock unit in a relatively local area around the sample point; (4) further exploration and evaluation may be worthwhile to determine the source of the uranium in (a) waters from those parts of the report area in which most, or all, water samples contain relatively large amounts of uranium, and (b) waters from several rock units, particularly those of late Permian and Triassic age, that have a large average uranium content in samples collected from them.

## Organic geochemistry of uranium

by

Irving A. Breger

Eighteen coalified logs collected in various parts of the Colorado Plateau region during the past field season were analyzed in detail. Data so obtained confirm previous conclusions (TEI-620, p. 334) regarding the relationships of uranium to the fossil logs, and the effects of radiation from the uranium and its daughter products on the coalified material. Twenty additional specimens were separated from adhering mineral matter by large scale sink-float procedures and the isolates of coalified wood so obtained also are being analyzed in detail.

Studies are in progress to determine the origin and nature of interstitial carbonaceous material associated with the Harding sandstone (Saguache County, Colo.) and with a granitic wash from the Copper Mountain area (Sec. 29, T. 40 N., R. 92 W.), Wyoming. Initial data for the separates are shown in table 38. Similar information is being accumulated for impregnations from other areas where such occurrences have been reported in order to round out and complete a chemical study of the association of uranium with the carbonaceous material called "asphaltite" on the Colorado Plateau.

Analyses were completed for coals subjected to pile radiation at the Brookhaven National Laboratory. In all cases carbon content, volatile content, and BTU values dropped for exposures to integrated neutron fluxes up to $2 \times 10^{19}$ n/cm$^2$. For the same exposure, however, the carbon content of humic acid isolated from peat increased by over 6 percent indicating a different radiochemical mechanism to be effective for this substance. New experiments were designed and possible mechanisms responsible for the changes are being studied.

Continuing investigation of an isolate from a paraffinic crude oil from the Unitah Basin, Utah has indicated the material to be dioctylphthalate. Although identification is not yet complete, this represents the first reported isolation of an ester from a crude oil.

Table 38.--Data for carbonaceous separates from Wyoming and Colorado

| Source | Sample lbs. | Organic isolate* mgs. | Analysis of dry isolate Ash percent | C** percent | H** percent |
|---|---|---|---|---|---|
| Harding ss., Colo. | 14 | 2,060 | 18.5 | 74.0 | 2.0 |
| Copper Mt. area, Wyo. | 47 | 100 | 18.3 | 69.3 | 3.3 |

* Represents partial separation estimated to account for about 50 percent of total organic matter present.

** Moisture - and ash-free basis.

## Distribution of uranium in igneous complexes

by

E. S. Larsen, Jr., and David Gottfried

During this report period nearly all work was directed to preparation and revision of manuscripts. Analytical investigation involved additional studies on the leachable uranium from the rocks of the batholith of northern California and separation of minerals from rocks of the Precambrian granites of Colorado.

### Leachable uranium

Acid leaching experiments were conducted on six rocks ranging from norite to quartz monzonite from the batholith of southern California. The rock powders were treated with 100 cc of HCl (1 part concentrated HCl + 4 parts water) on a steam bath for 24 hours. The data are given in table 39. The results indicate that both the amount and percent of uranium leached increases with the uranium content of the rocks. A similar pattern was reported for a suite of igneous rocks from the Boulder

Creek batholith of Colorado (TEI-640, p. 292).

Table 39.--Leachable uranium from rocks of the Southern California batholith

| No. | Rock Type | U(ppm) before leaching | U(ppm) after leaching | U leached percent |
|---|---|---|---|---|
| EL 38-265 | Quartz Monzonite | 7.1 | 1.2 | 83 |
| EL 38-167 | Quartz Monzonite | 3.4 | 0.90 | 73 |
| Re-135 | Granodiorite | 1.5 | 0.72 | 52 |
| SLR-1016 | Tonalite | 0.74 | 0.34 | 54 |
| SLR-229 | Norite | 0.67 | 0.38 | 50 |
| EL-303 | Gabbro | 0.43 | 0.26 | 40 |

## Age

Lead alpha age determinations have been completed on 83 rocks from the major batholiths of western North America extending from Alaska to Mexico. These include the batholiths in Mexico, Southern California, Sierra Nevada, Idaho, Washington, British Columbia and Alaska. The average age for each of the batholiths is very nearly the same. A summary of the data is given in Table 40.

Table 40.--Summary of lead-alpha age determinations on accessory minerals from batholiths of western North America

| Batholith | No. of rocks | Average age (MY) |
|---|---|---|
| Mexico and Southern California | 35 | 107 ± 11 |
| Sierra Nevada | 15 | 102 ± 11 |
| Idaho | 17 | 108 ± 12 |
| Coast Range | 16 | 105 ± 13 |
| Average of 83 rocks | | 107 ± 12 |

The following reports were published during the period:

Gottfried, David (1956) Dating by the lead-alpha method (Abstract) Geol. Soc., America Bull. 67, p. 1814.

Jaffe, H., Gottfried, David, Waring, C. L., (1957) Age determinations on zircon, a possible aid in provenance studies (abstract) Am. Assoc. Petroleum Geologists, Annual meeting St. Louis.

## White Mountain plutonic series, New Hampshire

by

A. P. Butler, Jr.

During this reporting period additional samples of the Conway and Mount Osceola phases of granite in the central batholic mass of the White Mountain plutonic series in central New Hampshire were studied in thin section. An interpretation also was made of chemical and semiquantitative spectrographic analyses of these rocks.

The proportions of the different minerals in the several phases of the granite as determined in thin sections support the general pattern already distinguished, namely that biotite granite in general contains more uranium than amphibole granite (see TEI-620, p. 217-318 and TEI-640, p. 298-299). So far, however, this study reveals no other distinctive systematic differences in the kind and proportions of the major, minor, and accessory minerals that can be related to differences in uranium content either within or between different phases of the granite.

On the other hand, a comparison of uranium content with other chemical components of the rocks indicates relationships, not clearly reflected in the mineralogic composition, between uranium and $SiO_2$, $TiO_2$, and Fe (recalculated as the element). In 16 samples of granite for which complete rapid chemical analyses were made, uranium increases with increase in $SiO_2$, decreases with increase in $TiO_2$, and decreases with increase in

Fe (fig. 114). These relationships are especially clearcut in biotite granite (Conway type) where all the correlation coefficients are significant at the 5 percent-95 percent level indicating that the chances of the relationship being accidental are less than 1 in 20. The same relationships also prevail among all the samples of granite taken as a group, but are not well marked in the biotite-amphibole and amphibole-biotite phases (Mt. Osceola type).

The uranium content tends to vary inversely as the contents of $Na_2O$, MgO, and CaO, but this relation is not as definite as the relation between uranium and iron. The relation between uranium and $K_2O$ is random.

The relations outlined above indicate that uranium tends to increase with increasingly felsic character within the granite masses themselves as well as from the more mafic to the less mafic members of the White Mountain and other plutonic series as reported by Larsen and others (1956).

Thirteen of the 16 samples chemically analyzed were also analyzed by semiquantitative spectrographic methods. In addition, one sample of riebeckite granite was analyzed spectrographically. Twenty elements in addition to those determined chemically were found by spectrographic analyses in some or all of those samples. The data are summarized in table 41.

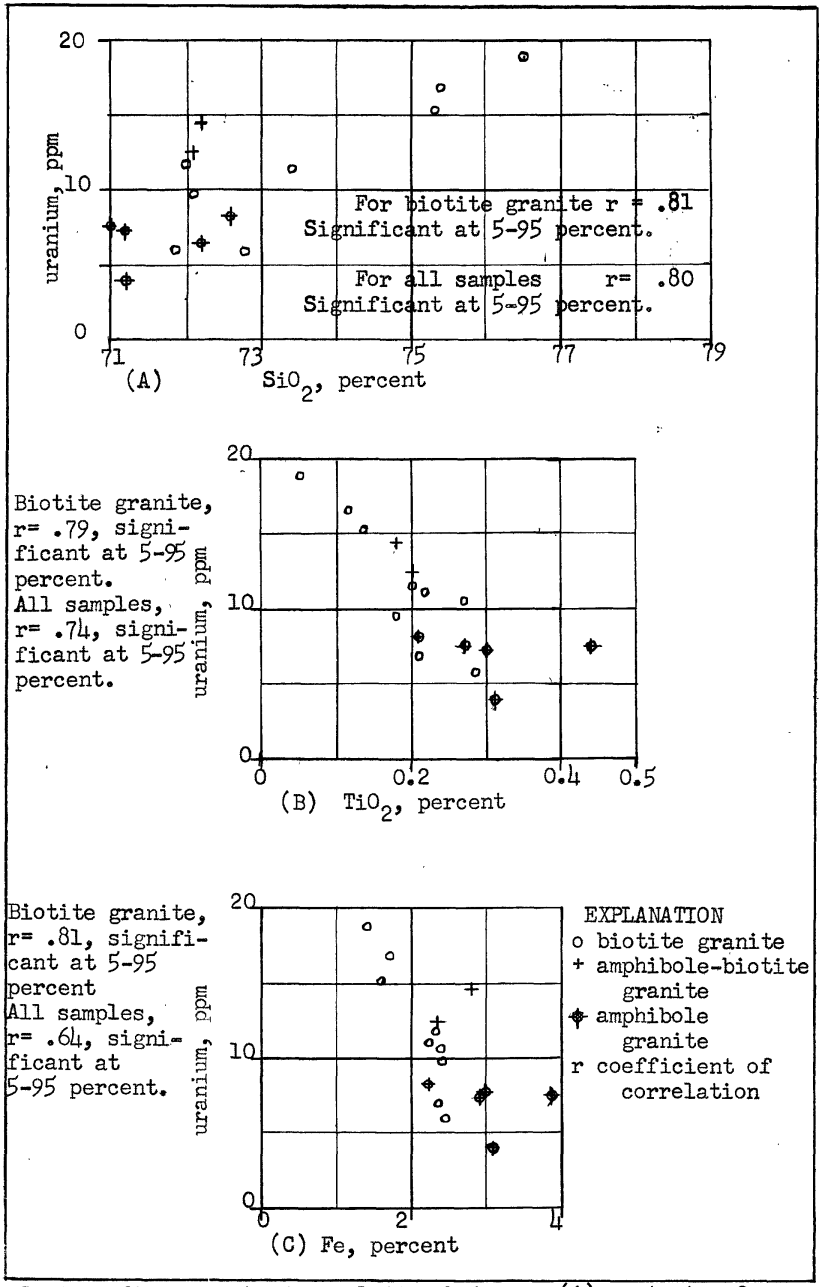

Fig. 114.--Scatter diagrams showing relation between: (A) contents of uranium and $SiO_2$; (B) uranium and $TiO_2$; and (C) uranium and Fe in granites of the White Mountain plutonic series, N. H. (All analyses made in the laboratories of the Geological Survey.)

Table 41.--Summary of semiquantitative spectrographic analyses of 14 samples of granite in the main batholith, White Mountain plutonic series, N. H.

| Element | Range (ppm)1/ | Modal Amount (ppm) | Not Found No. of Samples | Element | Range (ppm) | Modal Amount (ppm) | Not Found No. of Samples |
|---|---|---|---|---|---|---|---|
| Be | 1-10 | 1-5 | 0 | Zr | 50-500 | 100-500 | 0 |
| B | < 50-100 | < 50 | 10 | Nb | 10-500 | 50-100 | 0 |
| Sc | < 5-50 | 2/5 | 7 | Mo | < 5-50 | < 5 | 12 |
| V | 10-50 | 10-50 | 0 | Sn | < 10-50 | < 10 | 8 |
| Cr | 5-50 | 10-50 | 0 | Ba | 10-5000 | 100-500 | 0 |
| Ni | 50-100 | <50 | 13 | La | 10-500 | 100-500 | 0 |
| Cu | 1-500 | 1-5 | 4 | Ce | 100-1000 | 500-1000 | 0 |
| Ga | 10-100 | 10-50 | 0 | Nd | < 10-500 | 100-500 | 2 |
| Sr | 10-1000 | 100-500 | 0 | Yb | 1-50 | 2/ 5-10 | 0 |
| Y | 10-500 | 50-100 | 0 | Pb | 10-50 | 10-50 | 0 |

1/ parts per million.

2/ modal point falls at dividing line of adjoining lesser interval.

The semiquantitative analyses summarized here are reported in intervals with a range of half an order of magnitude. Among these twenty elements, only Cu, Sr, Y, Nb, Ba, Yb, and possibly Sc have enough reported values distributed through three or more range intervals to permit even tentative inferences with respect to the differences in their amounts in different phases of the granite or with respect to their relations with each other and with uranium.

The amphibole granite phase of the Mt. Osceola is richer in barium than the biotite granite (Conway) and the amphibole-biotite phase of the

Mt. Osceola. As a consequence, barium tends to have an inverse relation to uranium. None of the other elements shows any very clearcut relation to uranium.

Biotite granite contains more Nb and Cu than does amphibole granite.

Niobium varies directly as Y and Yb vary; the relations between these three elements and the other four and among the other four show no distinct trends.

## Reference

Larsen, E. S., Jr., Phair, G., Gottfried, D., and Smith, W. L., 1956, Uranium in magmatic differentiation: in U. S. Geol. Survey Prof. Paper 300, p. 67, 72.

## Synthesis and solution chemistry of uranium-bearing minerals

### The system $U-H_2O-CO_2$

by
R. M. Garrels, P. Hostetler, and C. L. Christ

A portion of the pH-Eh-$P_{CO_2}$ diagram of the $U-H_2O-CO_2$ system was constructed from thermodynamic data and is shown in Figure 115. The information contained herein confirms indications previously reported (TEI-620, p. 319) that uranium minerals may have been deposited from uranyl carbonate complexes by reduction with carbonaceous material.

### Studies on vanadate systems

by
R. F. Marvin and G. B. Magin, Jr.

Diagrams were constructed showing the stability of potassium and calcium vanadates in the pH-temperature field (figs. 116 and 117).

In connection with these studies, the following new compounds were prepared:

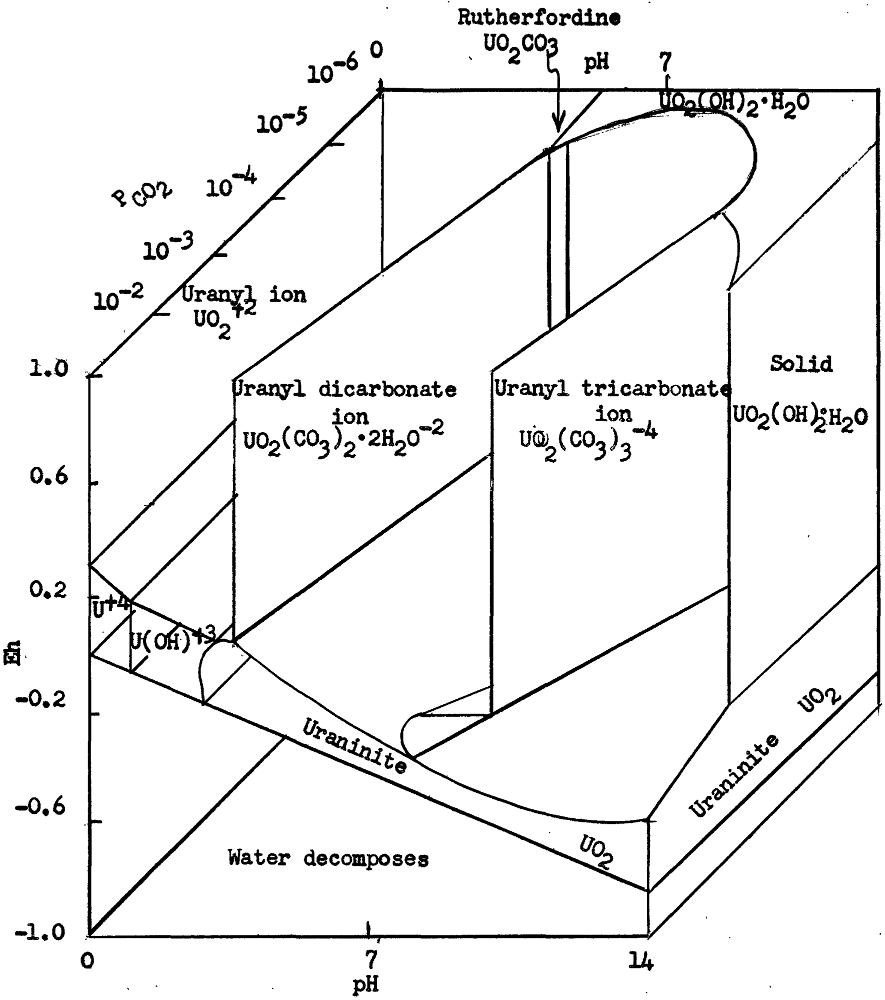

Fig. 115.—A portion of the system $U$-$H_2O$-$CO_2$ at 25° C.

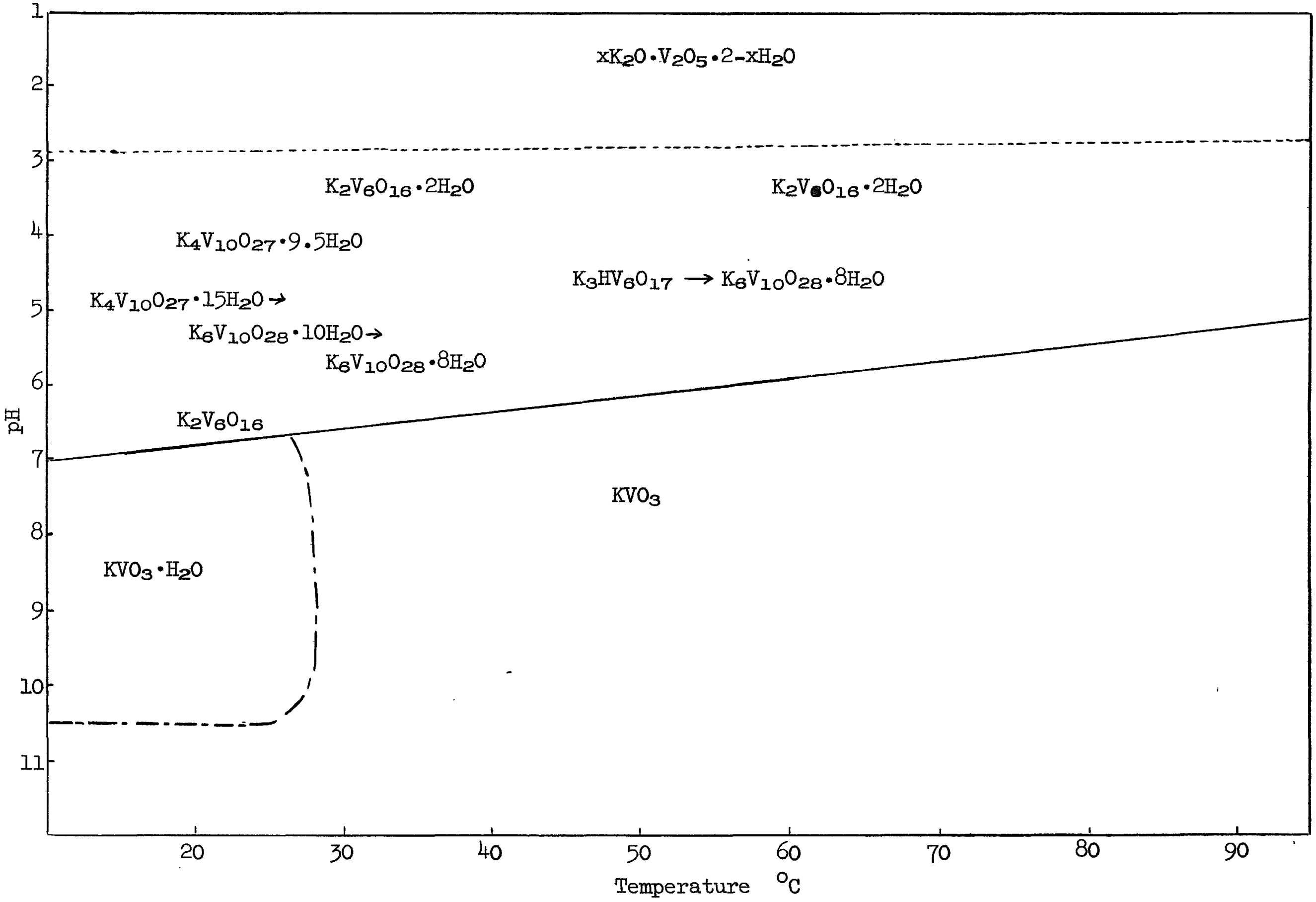

Figure 116.--Diagram showing pH and temperature relationship of potassium vanadate phases crystallizing from solutions with a 0.4 $V_2O_5/K_2O$ mol ratio.

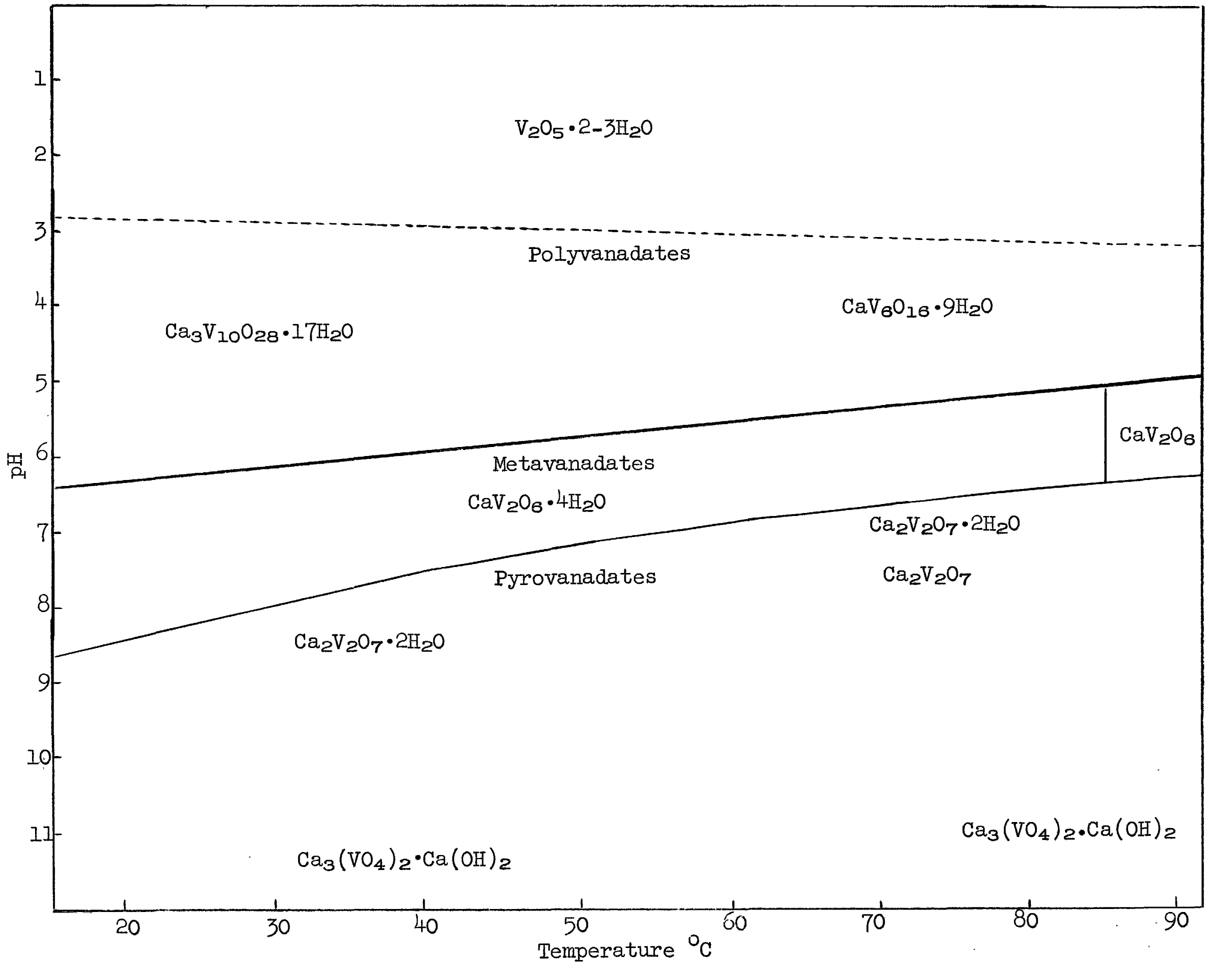

Figure 117.--Diagram showing the relationship of calcium vanadates to pH and temperature.

| Compound | $K_2O$ | CaO | $VaO_5$ | $H_2O$ | Total | Description |
|---|---|---|---|---|---|---|
| $K_3HV_6O_{17}$ | 22.03 | - | 77.20 | 1.00 | 100.23 found | Dark red, transparent, |
|  | 20.31 | - | 78.40 | 1.29 | 100.00 calc. | hexagonal crystals with good cleavage normal to 0001 |
| $CaV_2O_7$ | -- | 36.8 | 61.2 | 2.5 | 100.5 found | Colorless, transparent, platy |
|  | -- | 38.14 | 61.86 | - | 100.00 calc. | crystals with rectangular shape. |

## Synthesis and the environment of deposition of uranium and vanadium minerals

by

A. M. Pommer and J. C. Chandler

An inspection of the Eh and pH values of solutions from which solid phases are formed indicates the hydrogen pressure of a solution in several cases may be an important factor in determining which phase is formed. The reason is as yet obscure.

Copper can be carried in the 0.X g/l range in carbonate-polysulfide complexes at a pH of about 9.4. This solution mixes with uranyl carbonate solutions without precipitation, but will not carry iron and is not yet satisfactory in its present form as a possible source of chalcopyrite-uraninite ore of the type found, for example, in the Happy Jack mine.

## Volcanic glasses as a possible source of uranium

by

R. M. Garrels

Theoretical and practical considerations indicate that volcanic glasses upon devitrification give very alkaline solutions on exposure to ground water. This lowers the partial pressure of $CO_2$ in such solutions and creates, in effect, a carbon dioxide sink; this in turn may deplete the waters of adjacent rocks of $CO_2$, and cause formation of carbonate-rich waters. These waters may well leach uranium from uraniferous rocks and constitute an important source of uranium-bearing mineralizing solutions.

## Experiments on leaching of rocks

by

A. M. Pommer, J. C. Chandler, and R. F. Marvin

Studies on an obsidian from the New Mexico area showed that ground-up volcanic material may, upon contact with water, yield solutions with a pH of about 9. The maximum pH of 8.8 for adularia feldspar under similar conditions could not be increased by ultrasonic vibration; this indicates that the developed alkalinity is not limited by the formation of a surficial layer upon the rock powder.

## Analysis of a synthetic duttonite

by

G. B. Magin, Jr.

The composition of a synthetic solid having an X-ray pattern identical with duttonite was: $V_2O_4$, 60.08 percent; $V_2O_5$, 24.35 percent; $H_2O$, 15.10 percent; total 99.53 percent. This indicates that duttonite retains its crystal structure for some time after it starts to undergo oxidation.

The following paper was published during this period:

Garrels, R. M., Geochemistry of "Sandstone Type" Uranium Deposits. Technical Paper No. 57-NESC-121, Second Nuclear Engineering and Science Conference (Obtainable until January 15, 1958 from ASME Order Dept., 29 W. 39th St., New York, 18, N. Y.).

## Stable isotopes

by

Irving Friedman

The analysis of water in glassy rhyolites was continued during the last six months.

A group of tektites from various localities was analyzed for total gas content, water, and deuterium. Samples of tektites from Bohemia (modlavites) contain less than 3 ppm of water plus other volatiles. This is the most anhydrous glass analyzed to date; the figure compares with 20-100 ppm for other tektites, and 800-3000 ppm for volcanic glasses. Samples of tektite containing 20 ppm of water vesiculate on heating to almost the same extent as does obsidian. Samples with approximately 3 ppm of water show very slight vesiculation. Vesiculation in volcanic glasses therefore is a poor indicator of the amount of water in the original magma.

Samples of Greenland ice show a seasonal variation of deuterium content. It is hoped to apply this effect to the study of climatic changes accompanying glaciation by studying deep ice cores from Greenland.

Samples of sea water from Aransas Pass, Texas, and of salt brines from a salt works near San Francisco, California, were analyzed for deuterium. These two series give a measure of the change of deuterium concentration in saline water during natural evaporation. This change is more complex than previously had been considered likely. In the case of the salt brines there is no significant change in deuterium content during evaporation. The Aransas Pass samples show an appreciable concentration of deuterium as evaporation proceeds.

# Nuclear geology
by
Frank E. Senftle

The first phase of the study on variation of $Cu^{63}/Cu^{65}$ ratios in nature is in its final stages. A sample variation from the National Bureau of Standards CuO standard No. 29 of -8 to + 5 ppm was found. While the variations are not large, they are significantly larger than the experimental error, which is estimated to be 0.1 percent of the ratio. However, the precision of the mass spectrometer determinations is somewhat better. Additional work is in progress to extend this order of precision from 50 mg samples to less than 2 mg samples. Instead of a general survey it is planned to concentrate effort on a few selected localities of geologic interest.

During the period the mass spectrometer was moved to a new laboratory where improvements were made when the instrument was reassembled. A new tube frame and magnet adjustment assembly were made which greatly relieved alignment problems. The instrument performs better than ever, which can be attributed to these improvements as well as to reduction of vibration in the new location.

The neutron activation technique of $Cu^{63}/Cu^{65}$ analysis was dropped until further work can be done to improve the electronic counting techniques. The electronic units do not have the required stability to make the method feasible.

The magnetic susceptibility balance was dismantled, set up in a new laboratory, and calibrated. Several analyses have been made and with increased experience, it is expected that within the next few months, the work will proceed faster and considerable data accumulated.

## Geochronology
by
Lorin R. Stieff

In December the 12-inch radius mass spectrometer was moved from the Naval Gun Factory Laboratory, reassembled, and placed in operation in new laboratory space at the National Bureau of Standards. Project personnel and remaining equipment were moved into the new space following alignment and testing of the 12-inch spectrometer. All parts for the construction of the second 12-inch radius mass spectrometer have been assembled.

Twenty samples of uranium, thorium and lead ores were prepared for chemical and isotopic analysis. Fifty-three samples were analyzed isotopically and analytical chemical work was completed on 28 samples. A major effort of the project was spent in preparation of reports.

The following paper was published during the report period:

Senftle, F. E., Stieff, L. R., Cuttitta, F., and Kuroda, P. K., 1957, Comparison of the isotopic abundance of $U^{235}$ and $U^{238}$ and the radium activity ratios in Colorado Plateau uranium ores: Geochimica et Cosmochimica Acta, v. 11, pp. 189-193.

Two papers were presented during the report period:

(1) Stieff, L. R., The problem of old radiogenic lead in Pb-U dating, AAAS Symposium on recent advances in geochronometry, Dec. 27, 1957.

(2) Stieff, L. R., Stern, T. W., Jaffe, H. W., and Cialella, C., Isotopic age studies at key points in the geologic column, AAPG, April 4, 1957.

## Isotope geology of lead
by
R. S. Cannon, Jr.

Selected sample materials were collected in the field last period to test the hypothesis that the Precambrian of southwest Wyoming may include some exceptionally old rocks. This hypothesis was first suggested by lead-isotope analysis of a galena (GS-229) from the Mary Ellen mine, Atlantic City district, Wyoming, exceptionally primitive in isotopic composition. When reported in 1953 (TEI-390, p. 252), this was the most primitive sample of earth-lead then known outside the African Shield. Isotope analyses of this sample are tabulated below together with recent results on other galenas from the Precambrian of the Wind River and Park Ranges in Wyoming and Colorado. The recent results confirm the original analysis and prove that traces of exceptionally primitive lead were deposited during the gold-quartz mineralization of the Atlantic City district in Precambrian time. The analyses correspond to so-called "model ages" (Houtermans 1953) ranging from 2,740 to 2,900 million years, but they do not prove that the veins originated at that time. The galenas from the Park Range are less primitive than those from the Wind River Range, and variations in their isotopic composition are compatible with field evidence as to relative age of the veins sampled.

| Lab. No. | Sample | 204 | 206 | 207 | 208 | "Model Age" |
|---|---|---|---|---|---|---|
| GS/229 | Galena from gold-quartz vein of Precambrian age, Mary Ellen mine, Atlantic City district, Wind River Range, Fremont Co., Wyo. | 1.00 | 13.73 | 14.78 | 33.38 | "2890 M.Y." |
| GS/385 | Replicate analysis of GS/229 | 1.00 | 13.63 | 14.74 | 32.88 | "2900" |
| GS/424 | Galena from gold-quartz vein of Precambrian age, Zenith claim, same district as above | 1.00 | 13.91 | 14.93 | 33.74 | "2800" |
| GS/525 | Second sample from same vein as GS/524 | 1.00 | 14.17 | 15.11 | 34.13 | "2740" |

| | | | | | |
|---|---|---|---|---|---|
| Average for 2 galenas from cotectonic lead-zinc veins of Precambrian age, Park Range, Colo. | 1.00 | 15.68 | 15.30 | 35.25 | "1775" |
| Average for 2 galenas from post-tectonic lead-zinc fissure veins of Precambrian? age, Park Range, Colo. and Wyo. | 1.00 | 16.28 | 15.35 | 35.36 | "1650" |

The implicit possibility that exceptionally old rocks may be present in the Atlantic City district is being tested in several ways. Recently H. W. Jaffe of the Geological Survey has completed lead-alpha age determinations on radioactive accessory minerals from several rocks from the Wind River and Park Ranges, as listed below. These lead-alpha ages show some variations that seem to parallel the lead data, and in addition suggest the possibility that batholithic massifs may have been emplaced simultaneously in the two ranges, some 1,400 million years ago. Of particular interest is the lead-alpha age of 1,880 million years for zircon from graywacke in the Atlantic City district, for this is the oldest apparent age so far reported for zircon from any locality, by either lead-alpha or isotopic methods. This zircon is an accessory mineral in a graywacke or crystal tuff bed in the metasedimentary formation that is cut by the Atlantic City gold-quartz veins. If this apparent age is a minimal figure, then the host rocks of the primitive galenas may well be more than two billion years old. Further studies will be made to test this possibility by other techniques.

| Field No. | Sample | /mg/hr | Pb(ppm) | Age (M.Y.) |
|---|---|---|---|---|
| G-R-S1 | *Zircon* from post-tectonic pink granite porphyry judged to be the youngest rock in the Precambrian terrane, Park Range, Colo. | 164 | 52 | 720 |
| Co-R-G00 | *Monazite* from granite pegmatite judged to be cotectonic and penecontemporaneous with base-metal-sulfide mineralization, Park Range, Colo. | 1700 | 1260 | 1412 |
|  | *Xenotime* from same sample. | 2390 | 1555 | 1410 |
| Wy-F-GMg | *Zircon* from quartz diorite younger than Atlantic City metasediments, Grannier Meadow, Wind River Range, Wyo. | 174 | 116 | 1400 |
| Wy-F-MDgw | *Zircon* from graywacke bed in metasedimentary formation of Atlantic City district, Wyo. | 140 | 133 | 1880 |

## Natural radioactivity of the atmosphere

by

H. B. Evans

The equipment and procedure now used for determining the influence of temperature, pressure, and water saturation on the movement of radon through various types of rock core was discussed in TEI-640, p. 313-316. However, extensive replacement of components and modification of ionization chambers has been necessary to eliminate leakage and high background in the chambers. The modified chambers are fitted with two external tubes so that both chambers can be evacuated and filled while a core is connected between them. Such an arrangement also provides a closer coupling between the core and the chamber.

The modified chambers have been in operation for such a short time that calibration of the chambers using six standard radium solutions is still being carried out. Since the chambers must operate at various pressures, it is also necessary to determine the background for each chamber over a wide range of chamber pressures.

A phosphor-phototube detection unit was tested as a possible replacement for the ionization chambers, but the arrangement proved to be unsatisfactory in radon flow studies.

A jacket was designed and constructed to provide a control of the core temperature. The jacket consists of a hollow plastic cylinder five inches in diameter, closed at one end. A movable plastic disc slides inside the cylinder to adjust for cores of different lengths, and the plastic connecting tubes at the ends of the core protrude through holes in the ends of the cylinder. A flexible heating tape is wrapped around the core and connected to a variable voltage transformer which provides the heating current. A thermocouple in contact with the core face provides the core temperature for any applied heating voltage.

Due to instrumentation difficulties and necessary modifications, few reliable flow rate determinations are available. However, to determine the importance of diffusion in radon movement, an ionization chamber was filled to atmospheric pressure with a known amount of radon and connected through a sandstone core to a second chamber that was filled to atmospheric pressure with argon. The radon diffused through the core (diameter 32 mm, length 51 mm), and the system reached equilibrium in approximately fourteen days. Although a relatively long period of time was required for the system to reach equilibrium, the ion current in the chamber containing argon was noticably above background current within 30 minutes after the two chambers had been connected.

The continuous air monitor unit has been tested and mounted in a field vehicle. Surface radon measurements and near surface radioactive gradient determinations will begin early in the next fiscal year.

## Thermoluminescence of radioactive minerals

by

C. L. Christ and George Ashby

Construction of the multiple use thermoluminescence apparatus ("Mutla"), described in a previous report (TEI-640, p. 317) was completed. Using this equipment, one hundred glow curves, four saturation curves and one decay curve have been recorded at temperatures ranging from -100° to + 400° C on a variety of samples.

A study of the effect of radiation on the thermoluminescence properties of minerals was made. Two minerals, zircon and sphene, that are known to exhibit coloration effects from radiation damage ($\alpha$ -particle bombardment) have been shown to be thermoluminescent. Brown zircon has a strong natural thermoluminescence over the temperature range 180° to 400° C. This thermoluminescence can be reactivated by bombardment with long wave length (1.5A) X-rays. Since no bleaching of the color or annealing of radiation damage to the crystal structure can be detected after a glow curve experiment, it is concluded that the emission is not directly related to the destruction of a "brown color center" or to a recrystallization phenomena such as is observed during the annealing of some metamict minerals. Brown sphene does not exhibit natural thermoluminescence but does exhibit some thermoluminescence after bombardment with X-rays. The relationships, if any, between the thermoluminescence yield from these minerals and alpha particle dosage are now being explored.

An experimental technique that avoids one of the major problems associated with heterogenous samples has been developed. By this technique, the number of trapped electrons and the number of traps can be determined on exactly the same part of a given sample. The sample is first carefully oriented on the sample stage with the apparatus mounted on a camera track adjacent to an X-ray tube housing and a natural glow curve is recorded, to indicate the number of trapped electrons. Then the X-ray tube is energized to irradiate the sample. Progress in the refilling of the traps can be monitored by observing the intensity of luminescence induced by the X-rays. When the luminescence reaches a constant value the electron traps are filled and irradiation can be terminated. An artificial glow curve is then obtained that indicates the number of traps that can be filled. No movement of the sample is required during any portion of this sequence and the same sample is examined in each case.

## Geology and geochemistry of thorium

### Spectrophotometric method for determination of thorium

by

Esper S. Larsen, 3rd.

A fairly rapid and reliable procedure for the determination of $ThO_2$ in rocks in the concentration range 0.2 to 10 ppm, which is a further development of the spectrophotometric method of Grimaldi and Fletcher (TEI-620, p. 305) has been developed. Under this procedure, a 5-gram sample of rock is taken completely into solution as described in TEI-640, p. 320. The method involves concentrating thorium by mesityl oxide extraction; then purification by iodate precipitation from nitric acid medium containing tartaric acid and hydrogen peroxide, and finally determining the thorium spectrophotometrically with thoron from mesotartaric acid medium.

Experiments on a 5 gm. sample of San Marcos gabbro from the Southern California batholith, spiked with known amounts of thorium and carried through the complete procedure, gave excellent recoveries of the thorium added (see table 42). The procedure also gave reproducible results on standard diabase (W-1) and standard granite (G-1) (see table 43). P. M. Hurley determined thorium in these rocks by the gamma ray spectrometer and reports (personal communication) G-1 = 60.6 ppm $ThO_2$, and W-1 = 3.6 ppm $ThO_2$.

In the parts-per-million range and above, the method should give results ordinarily within 10 percent of the amount present although it is expected this usually will be within 5 percent. The identity of the results on the standard diabase and standard granite is clearly fortuitous. Replicate analyses on the San Marcos gabbro, which is near the limit of sensitivity of the method, gave 0.2, 0.3, and 0.4 ppm.

Table 42.

Recoveries of Thorium added to Gabbro

| Thorium added to 5 gm. sample $\gamma$ $ThO_2$ | Added thorium in ppm $ThO_2$ | Thorium found for added thorium * in ppm $ThO_2$ |
|---|---|---|
| 2 | 0.4 | 0.4, 0.4 |
| 3 | 0.6 | 0.6 |
| 5 | 1.0 | 1.0 |
| 10 | 2.0 | 2.0, 2.0 |
| 25 | 5.0 | 4.5 |
| 30 | 6.0 | 5.8 |
| 50 | 10.0 | 9.8 |

* Thorium content of gabbro blank analyzed with the above series was 0.3 ppm $ThO_2$. This value has been subtracted from the reported values.

Table 43.

Reproducibility of results on Standard Granite G-1 and Diabase W-1

| Diabase (W-1) ppm $ThO_2$ | Granite (G-1) ppm $ThO_2$ | |
|---|---|---|
| 2.1 | 52 ) | Analyzed simultaneously on separate samples |
| 2.1 | 52 ) | |
| 2.1 | 52 ) | |
| 2.1 | 52 ) | |
| 2.2 | 51 ) | Separate samples analyzed at a later date |
| 2.3 | 51 ) | |

A further test for precision of the basic spectrophotometric method for thorium is shown in table 44. The rocks analyzed are Laramide intrusives from the Front Range, Colorado, and in part were reported previously (TEI-640, p. 322). The earlier and later results were obtained by different chemists. The agreement is generally satisfactory.

Table 44.
Replicate analyses for $ThO_2$ on Laramide intrusives from the Front Range, Colo.

| Sample No. | Earlier results $ThO_2$ in ppm | Later results $ThO_2$ in ppm |
|---|---|---|
| P118L | 100, 107 | 105 |
| P370L | 33, 36 | 33 |
| P581L | 213, 218 | 240 |
| P633L | 75, 84 | 74 |
| P914L | 39, 37 | 27 |
| P640L | 17, 17 | 17 |

## Investigations of thorium in igneous rocks

by

Esper S. Larsen, 3rd.

Work was started on determining the thorium content of selected igneous rocks from the Southern California and Idaho batholiths. In addition, selected rocks are being separated into their component minerals for thorium analysis to determine how thorium crystallizes from magma.

Common problems of mineral separation are being met. One, the separation of barite from zircon, has been solved with flotation media in the Mayeda cell. A Mayeda cell was filled to about half capacity with tap water and 15 drops of a 10 percent suspension of a reagent was added and mixed thoroughly. To this was added 6 drops of a sodium silicate suspension and 12 grams of sized mineral powder. The paddle in the cell was run at fairly high speed to develop a heavy froth. The separation was continued by adding water until frothing ceased. This yielded a sample of zircon about 95 percent pure. Repeated flotations yielded fractions of both barite and zircon better than 99 percent pure.

Attempts to separate quartz from oligoclase feldspar by flotation methods have been unsuccessful.

## Investigations of uranium in veins, Gunnison County, Colorado

by

J. C. Olson and D. C. Hedlund

Geologic mapping in the Powderhorn district, Gunnison County, Colorado, was begun in July 1956, and the northwest quarter of the Gateview 7½-minute quadrangle--an area of about 20 square miles--was mapped to determine the geologic setting of the thorium-bearing veins. During the report period, work consisted chiefly of petrographic and mineralogic studies of veins and igneous and metamorphic rocks, and compilation of data from the literature on the geologic occurrence of thorium and rare earths.

Approximately 150 veins, prospect pits, and mines have been tested by scintillation counter for radioactivity in 1956. Of the 150 localities, 21 have radioactivity of 0.1-0.4 mr/hr, or 5 to 20 times background, and the remainder showed less than 0.1 mr/hr. The more radioactive veins generally strike N. 10°-55° W. and dip steeply or are vertical, whereas the non-radioactive veins strike northeast as well as northwest. The chief minerals that make up the radioactive veins are massive white to clear quartz, chalcedony, steely gray hematite, earthy limonite, barite, calcite, and smaller quantities of fluorite, sphalerite, pyrite, chalcopyrite, and galena.

The radioactive mineral in which the thorium occurs is probably thorite or thorogummite in some of the deposits but in most of the veins it has not been identified. A study was made of four representative samples from different veins, containing 0.02, 0.04, 0.21, and 0.33 percent thoria and less than 0.002 percent uranium. Splits of the samples were ground to 65-, 100-, and 150-mesh sizes, and these were further separated magnetically in the Frantz separator. No thorium-bearing minerals were isolated, and none could be found by optical methods. The sized samples were checked for radioactivity with an alpha counter, which showed that the finer-grained fractions with abundant hematite were as much as 24 times more radioactive than the coarser fractions with lesser quantities of opaque minerals. One X-ray powder photograph of the more radioactive sample fraction has given only strong diffraction lines for hematite.

## Geologic thermometry of radioactive minerals

by

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Sphalerite-pyrite assemblages in three samples from uraniferous deposits of the Colorado Plateau yielded minimum temperatures of deposition of somewhat less than 140°C. These results are similar to those reported earlier by Coleman (1957). The localities and other pertinent data are listed in table 45. The temperature of ore deposition on the basis of this evidence at least exceeded 85° C ± 30° C. However, since pyrrhotite was not found with the pyrite-sphalerite assemblages, saturation of the sphalerite with FeS cannot be established and therefore, the absolute temperature of deposition remains unknown.

The mineralogy of the Daybreak Mine, Spokane, Washington, has been studied in detail. The deposit consists of mineralized shear zones in granite and quartz monzonite. Hydrothermal alteration is limited to sericitization away from the shear zones, but is intense in the gouge.

Montmorillonite, kaolinite and possibly halloysite are developed in the gouge. Several varieties of autunite were found and purified for chemical analysis. Meta-autunite I was observed in many samples. Textural evidence and the absence of any unoxidized uranium minerals indicates that autunite was a primary hydrothermal mineral in this deposit. This conclusion together with the widespread geologic occurrence of autunite resulted in the start of an experimental study of the synthesis and stability limits of the autunite minerals.

Table 45
Geologic thermometry data on sphalerites from the Colorado Plateau

| Sample No. | Density | Unit Cell Å* | Mol % FeS in ZnS | Minimum Temperature of Deposition |
|---|---|---|---|---|
| 451-RGC-56 | 4.07 ± 0.01 | 5.4112 ± 0.0005 | 0.16 | <138°C |
| SP-2 | | (5.4091 ± 0.0008 dark)<br>(5.4069 ± 0.0005 light) | 0.16 | <138°C |
| WN-1 | 4.07 ± 0.01 | 5.4097 ± 0.0009 | 0.11 | <138°C |

| | |
|---|---|
| 451-RGG-56 | Good Hope Mine, Lytner Creek, Colorado. Yellow sphalerite associated with pyrite in late fractures in roscoelite-bearing Entrada sandstone. |
| SP-2 | AEC No. 8 Mine, Temple Mountain, Utah. Colorless to brown sphalerite with pyrite in mineralized coalified log. |
| WN-1 | W. N. Mine, Deer Flats, Utah. Dark sphalerite in uranium ore associated with pyrite. |

* Determined by Daphne Ross of the Geological Survey. Broad peaks observed on X-ray photos may be caused by variations in FeS content in the sample.

Approximately fifty purified samples of sulfide minerals from uranium deposits on the Colorado Plateau and Wyoming have been supplied to Prof. M. L. Jensen of Yale University for study of their sulfur isotopes.

Laboratory facilities for rapid and precise separation of minerals, especially sulfides, were established at Menlo Park, California.

Equipment to synthesize minerals and determine their stability relations at pressures up to 100,000 p.s.i. and temperatures to 1000° C is being assembled in Washington.

The following paper was published during the period:

Coleman, R. G., 1957, Mineralogical Evidence on the Temperature of Formation of the Colorado Plateau Uranium Deposits, Economic Geology, v. 52, p. 1-4.