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JAMES GHEEULY

GEOLOGY AND MINERALOGY

**U. S. DEPARTMENT OF THE INTERIOR**

**GEOLOGIC INVESTIGATIONS OF  
RADIOACTIVE DEPOSITS**

**Semiannual Progress Report for June 1 to  
November 30, 1956**

**This report is preliminary and has not been edited or  
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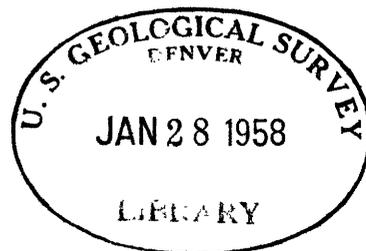
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UNITED STATES, DEPARTMENT OF THE INTERIOR  
GEOLOGICAL SURVEY,

GEOLOGIC INVESTIGATIONS OF RADIOACTIVE DEPOSITS

SEMIANNUAL PROGRESS REPORT

June 1 to November 30, 1956

December 1956



Trace Elements Investigations Report 640\*  
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**40455**

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

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## INTRODUCTION

This report is a statement of progress during the six-months period from June 1 to November 30, 1956, on investigations of radioactive materials in the United States and Alaska, undertaken by the U. S. Geological Survey under the sponsorship of the Division of Raw Materials and the Division of Research of the Atomic Energy Commission.

The shift in emphasis of the Geological Survey's program from the search for minable deposits of uranium as such toward the understanding of geologic conditions favorable for uranium concentration, which was discussed in previous Semiannual Reports (TEI-590 and TEI-620) was continued during the period. No exploration drilling was done, and the Geological Survey's effort was directed toward a comprehensive understanding of the factors involved in uranium geology and the publication of reports that will make available to the public the information obtained in the various studies. Many investigations have progressed to the point where final reports have been completed or are in preparation for future publication with the permission of the Atomic Energy Commission; for other studies, particularly those of a continuing nature, it will be several years before final reports can be published.

Between June 1 and November 30, 1956, formal publications included twelve Geological Survey Bulletins; 37 maps; 22 publications in scientific journals; and 64 papers by Survey authors in Geological Survey Professional Paper 300, "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",** edited by Lincoln R. Page, Hobart E. Stocking, and Harriet B. Smith.

In addition, two reports were placed on open file, and one was set to the Technical Information Service Extension of the Atomic Energy Commission for wider distribution and sale to the public.

A total of 13 papers were presented at scientific meetings by members of the Geological Survey involved in the investigation of radioactive deposits.

Publications issued on the geologic investigations of radioactive deposits during the past six months are listed under the descriptions of the various projects.

HIGHLIGHTS,  
GEOLOGIC INVESTIGATIONS OF RADIOACTIVE DEPOSITS  
JUNE 1 TO NOVEMBER 30, 1956

Geologic mapping

Colorado Plateau region

In the Bull Canyon district, Montrose and San Miguel Counties, Colorado, outcrops east of the Uravan Mineral Belt indicate a widespread area of ground unfavorable for the deposition of uranium-vanadium ores. Exposures west of the Uravan Mineral Belt indicate a large area of ground favorable for uranium-vanadium deposition, but no ore bodies have yet been found in that area.

In the Slick Rock district, San Miguel and Dolores Counties, Colorado, evaluation of data on the lower part of the Mancos shale in Disappointment Valley indicates a correlation between fossil zones, lithology, and  $\text{CaCO}_3$  and pyrite content, suggesting that lithology and mineral content, as well as life forms in the seas receiving the sediments, varied with volcanic activity during the formation of the shale. It has also been found that barite formed in ore bodies contains an appreciable amount of trace elements, many of which have been considered "extrinsic" by persons studying the distribution of elements in ore deposits. Trace element content of carbonates may reflect the influence, or lack of influence, of ore solutions during formation.

Horst and graben structures are prominent features in the Placerville, Little Cone and Gray Head quadrangles, Western San Juan Mountains, Colorado. The igneous rocks of these three quadrangles are apparently associated with three distinct centers of igneous activity. The horst and graben structures appear to die out near two of the igneous centers, but there is some evidence that they cut the third center. These observations suggest a genetic relationship between the faulting and the intrusions.

Mapping of the Ute Mountains, Colorado, indicates that much of the doming visible around the Utes is due to buried intrusives of the laccolithic type. A consistent quaquaversal dip of  $2^\circ$  to  $4^\circ$  around the mountains is ascribed to the intrusion of the stocks.

South of Spanish Valley, in the northwestern corner of the Lisbon Valley area, Utah-Colorado, some persistent southwest-trending faults link the Lisbon Valley fault system with the northwest-trending folds and faults of Spanish Valley. Peculiar small collapse structures, roughly oval in plan, are numerous along the northeast side of Spanish Valley; some of these structures have displacements of at least 1,200 feet. Study of mines in the Big Indian Wash-Lisbon Valley mining district shows that lithology is not a major factor in controlling the distribution of ore and that uranium and vanadium generally are not associated in detail. Some

samples taken as examples of vanadium ore proved to contain little vanadium but several percent molybdenum.

Two northwest-trending grabens traverse the Abajo Mountains area, Utah. The northern one truncates the north edge of Shay Mountain and is known as the Shay graben. The southern one, known as the Verdure graben, truncates the south flank of South Peak. Both grabens, perhaps coincidentally, parallel a zone of favorable ground in which uranium-vanadium ores are in the Salt Wash member of the Morrison formation.

At Middle Montezuma Canyon in the Sage Plain area, Utah-Colorado, the ore deposits are in a single lens of sandstone near the middle of the Salt Wash member of the Morrison formation. The lens is locally 110 feet thick, and has an exposed length of about 13,000 feet. The ore bodies, which are at several levels within the sandstone, consist of central zones rich in carbonaceous material surrounded by thin enveloping layers of ore.

At the Orange Cliffs, Utah, uranium occurrences are most common where purple-white alteration and silicification are most abundant. This alteration feature is believed to be a regional guide to some of the geologic processes responsible for some occurrences of uranium.

Detailed mapping and sampling in the Grants area, New Mexico, show that ore is likely to be found in the Todilto limestone in areas where intraformational flexures are concentrated, especially in such areas downdip from faults which trend about N. 80° E. Ore in the Westwater Canyon member of the Morrison formation may be concentrated near the bottoms of synclines or synclinoria, especially where changes in dip produce small structural terraces. Prospecting may be aided by watching for a change from pale blue to purple in the overlying Brushy Basin shale, which is a possible indicator of mineralized ground in the Westwater Canyon member.

In the Laguna area, New Mexico, the fracture system contains a prominent cross, or tensional set bearing nearly north; a longitudinal set bearing east; and several diagonal sets, bearing northeast and northwest; the system probably developed between the beginnings of the Rio Grande trough (Miocene?) and the Recent. The presence in the area of pyrite concretions and hematite pseudomorphs after pyrite suggests a period of weak sulfide mineralization. Sulfides in the uranium ore deposits, possibly related to the vein sulfides, are probably younger paragenetically than pitchblende and coffinite.

During the report period, 18 new photogeologic maps of 7-1/2 minute quadrangles were compiled at a scale of 1:24,000 and 30 such maps were published in the Miscellaneous Geologic Investigations map series. Mapping at a scale of 1:62,500 in conjunction with the 1:250,000-scale map of the Colorado Plateau was initiated, and the equivalent of fourteen 7-1/2 minute quadrangles were interpreted and partly transferred to base maps.

## Central region

Reconnaissance geologic mapping and detail studies have been essentially completed in the Southern Powder River Basin, Wyoming, and show a distinct spatial relationship between the boundary of red sandstone in the Wasatch formation and the uranium deposits of the area.

In the Hulett Creek mining area, Crook County, Wyoming, the structure of the Inyan Kara group is dominated by a northwest-trending ellipsoidal lens about 8,000 feet long, 3,000 feet wide, and a maximum of 45 feet thick in the upper sandstone of the group, by northeast-trending normal faults, and by a flat asymmetric anticline that plunges northeast. The mined ore deposits are of the carnotite-tyuyamunite or uraninite-coffinite type and are near the base of the upper sandstone of the Inyan Kara group.

Recent mapping in the Jewel Cave SW quadrangle in the Southern Black Hills, South Dakota, indicates that the collapse structures in that area are the result of the removal, in solution, of gypsum from the Minnelusa formation. In this area there has been little or no solution of the underlying Pahasapa limestone, though in other parts of the Black Hills solution of parts of the Pahasapa has resulted in the subsidence and collapse of the overlying formations.

Mapping of structures within the Wind River formation in the Gas Hills area of the Wind River Basin, Wyoming, shows that two periods of normal faulting have affected the uranium deposits. The older faulting contemporaneous with the deposition of the Wind River formation may have afforded barriers to the flow of uranium-bearing solutions.

Post-Miocene southward regional tilting in the Clarkson Hill area, Natrona County, Wyoming, is thought to have made adjustments in the movement of ore-solutions within the Wind River formation. Because of differences in the amount of tilting or original dip, the dip of the Wind River formation was reversed by regional tilting in the Gas Hills area but not in the Clarkson Hill area. Attendant adjustments of ground water movement may explain why uranium occurs in the Gas Hills, but not in significant quantities in the Clarkson Hill area.

Each of the two major groups of uranium deposits in the Ralston Buttes district, Colorado, is located where a northwest-trending Laramide breccia-reef system splits into a complex network of faults and fractures. The ore deposits are hydrothermal veins and most appear to be localized where faults and fracture zones cut Precambrian metamorphic rocks that are rich in hornblende, biotite, or biotite and garnet. Pitchblende, the principal uranium mineral, is associated with base-metal sulfides in a gangue of carbonate minerals, potash, feldspar, and quartz. Some veins contain as much as 0.14 percent vanadium oxide in an unknown mineral.

Uranium deposits in the western half of the Maybell-Lay area, Colorado, occur near the axis of an asymmetrical syncline cut by high-angle faults of post-Miocene age. These relationships indicate that ore deposition may have been controlled by stratigraphic and structural traps.

An ore body of moderate size was discovered near Vega, Texas, in Triassic sedimentary rocks. This discovery indicates the possibility that a large uranium region may exist in eastern New Mexico and northwestern Texas.

### Pacific region

Five uranium deposits have been found in the Turtle Lake quadrangle, Washington. Uraninite and possibly coffinite have been identified from the Midnight deposit, the largest deposit in the quadrangle, and coffinite has been identified from the Lowley Lease deposit. Only secondary uranium minerals have been identified from the other deposits.

### Geologic topical studies

#### Colorado Plateau region

Stratigraphic studies of the Triassic rocks of the Colorado Plateau show that the Moenkopi formation in the San Rafael Swell, Capitol Reef and Circle Cliffs areas can be divided into five units, some of which can be traced to other areas of southeastern Utah. In the Defiance Uplift of northeastern Arizona, the Wingate sandstone is divided into two members, the Rock Point member below and the Lukachukai member above. Correlations show that the unit that is called the Lukachukai member at Ft. Wingate in west-central New Mexico is probably a lateral equivalent of the Rock Point member.

During the report period lithologic studies were made of 60 samples of acid-leached, silt-free sand from the Salt Wash, Recapture, Brushy Basin and Westwater Canyon members of the Morrison formation. Each sample was analyzed by the flame photometer method for sodium, potassium, and calcium. The method yielded mathematically significant results for sodium and potassium, but not for calcium. In another study, reconstituted feldspar computed in terms of albite, orthoclase and anorthite was found to be present in larger quantities in the southern and southeastern parts of the Colorado Plateau than in the northwestern part. The Recapture and Westwater Canyon members have significantly higher feldspar contents than the Salt Wash and Brushy Basin members.

Preliminary studies of the distribution of trace elements in the Todilto limestone of northwest New Mexico show that vanadium and lead occur in above-background amounts in rather broad zones away from uranium deposits, and that

uranium, fluorine, and selenium show promise of a similar relationship. If these relations are confirmed by further work, they may be useful as guides to ore.

By far the greater part of the uranium resources of southeastern Utah is in the Chinle formation of Triassic age and the Morrison formation of Jurassic age. It appears that, regardless of the origin of the uranium-bearing solutions, favorable ground for significant uranium deposits is related to sedimentary features. Low-grade uranium ore and uraniferous rock in tuffaceous siltstone and mudstone beds in the Brushy Basin member of the Morrison formation may be much more widespread in southeast Utah than has generally been recognized, and may possibly represent appreciable potential reserves of uranium.

At all of the productive uranium deposits in the Entrada sandstone in the eastern part of the Colorado Plateau, the ore is associated with a green chromium-bearing sandstone. The presence of a green layer in the Entrada near Delta, Colorado, suggests that vanadium-uranium mineralization may have occurred in that area and permits speculation on the possibility of a belt of this type of mineralization in the eastern part of the Plateau.

The initial piercement of the diatremes on the Navajo and Hopi reservations, Arizona, was probably along a fracture propagated by a high pressure aqueous fluid in a manner analogous to the formation of artificial hydraulic fracture systems induced in certain oil well operations. Gas rising at high velocity along the fracture would become converted to a gas-solid fluidized system by entrainment of wall-rock fragments. The first stages of widening of the vent are probably accomplished mainly by simple abrasion of the high velocity fluidized system on the walls of the fracture. As the vent widens its enlargement may be accelerated by inward spalling of the walls.

#### Central region

Metatorbernite, uranophane, bassetite, uranocircite, saleite, fluorescent hyalite, and minerals similar to metazeunerite, abernathyite, and zippeite have been identified in weathered parts of the deposits in the Dripping Spring quartzite, near Globe, Arizona. Purple fluorite close to, but not in contact with, uraninite has been noted at several deposits.

Regional alteration and addition of carbonate in "red beds" of Permian age on anticlinal structures in the Anadarko syncline, southern Oklahoma, are supplemented by uranium mineralization along joints on or near the axis of the Cement anticline. Tyuyamunite and carnotite are disseminated in sandstones and concentrated in poorly defined pockets along the joints. A preliminary study of the deposit on the Cement anticline indicates that jointing along similar anticlinal structures in the Anadarko syncline is favorable for the concentration of uranium minerals.

## Alaska

The most promising known uranium deposits in Alaska are near Bokan Mountain, in an area containing several types of uranium occurrences. The Ross-Adams deposit is the most thoroughly explored and probably best deposit in the area. It consists chiefly of a uranium thorianite and urano-thorite-rich ore body in granite.

### Research and Resource studies

Analysis of the tectonics of western United States reveals that most of the uranium deposits are within a single large tectonic unit, the Cordilleran foreland. Tectonic structures within the foreland show an overall pattern, are analogous in size and configuration, and have a similar geologic history.

Study of the mineralogy of many uraniferous veins in the United States reveals that uraninite is early in the sequence of mineralization and that the texture of uraninite is almost universally colloform--a texture interpreted by many as a result of precipitation from colloidal suspension.

Analytical data on the oil and uranium content of the Chattanooga and Antrim shales indicate a direct positive relationship between uranium and oil content.

Work in progress on the distribution of uranium deposits in terrestrial sedimentary rocks as related to lithofacies, paleogeography, and environmental features of the host rocks indicates that the uranium deposits in Jurassic rocks are: (1) confined largely to formational intervals where the ratio between sandstone and shale ranges between 4:1 and 1:4 and not in intervals consisting predominantly of sandstone or shale, and, (2) in areas of fluvial sedimentation near the source of the sediments.

### Geophysical Investigations

#### Colorado Plateau region

During the past season 1,170 gravity stations were established in about 2,000 square miles of the east-central and south-central Plateau. To date 4,035 stations have been established in an area of 9,000 square miles.

Temperature measurements were made in deep boreholes in Disappointment Valley, Colorado, and in the Big Indian and Temple Mountain areas, Utah, to determine thermal gradients and to permit computing heat flow. Measurements were also made in boreholes cutting two large uranium deposits in northwest New Mexico. No demonstrable thermal effects associated with the deposits were found.

### Central region

Both ground and airborne surveys in the Texas Coastal Plain indicate that the radioactivity reflects stratigraphic and lithologic changes and possibly other geologic features. Areal mapping and detailed mapping of ore deposits is in progress to provide information necessary to the correlation of the geology and geophysical measurements.

Preliminary results of detailed isoradioactivity surveys and geologic mapping suggest that the uranium mineralization is related in time and space to silicification that has acted upon certain tuffaceous sandy members of the Jackson formation, possibly prior to the deposition of the overlying Catahoula tuff.

### General investigations

Preliminary results, based on borehole electrical and gamma-ray logs and on macroscopic examination of cores, indicate that in Karnes County, Texas, as is the Colorado Plateau, differences in the amounts and salinity of pore water may be associated with mineralized rock and adjacent barren ground.

In the Crooks Gap area, Wyoming, the final Bouguer and residual gravity maps correlate well with the known geology and provide additional information on subsurface geology. A previously unsuspected buried thrust mass was discovered and the trace of a normal east-trending fault with an approximate displacement of 1,150 feet bisecting the Crooks Gap area was extended considerably beyond its surface expression.

Preliminary Bouguer maps indicate a good correlation between gravity and known geologic features in the Black Hills, Wyoming and South Dakota. A short cooperative seismic survey in the Triangle Park area by USGS and AEC personnel indicated that the topographic depression there is not the result of slumping caused by solution of the Pahasapa limestone at depth. It did, however, detect a fault that may be associated with the Triangle Park depression.

Near Telluride, Colorado, a short seismic survey was successful in mapping the bedrock configuration of the San Miguel Valley and determining the thickness of the glacial till overlying the bedrock. The valley was

found to be U-shaped beneath the glacial till, and a deep scour was discovered approximately 1-1/2 miles west of the town of Telluride.

Seismic refraction and reflection measurements made near Maybell, Colorado, delineated fault patterns in the Browns Park formation, but the reflection measurements were not successful in determining the thickness of the Browns Park formation.

Extensive tests were made in the Radiation Detection laboratory at Denver on the performance of the thermoluminescence unit. Comparative data were obtained on natural and artificial glow curves as well as on half-life decay and buildup factors for irradiated samples. A general appraisal of the results indicates a complex pattern associated more with crystalline structure and sample impurity than with radiation damage.

Gamma-ray logging for subsurface geologic and radiometric information was done during the report period in the Edgemont, South Dakota, and Karnes County, Texas, areas. A group of simulated drill holes containing various grades and thicknesses of uranium ore was constructed at the Denver Federal Center for calibrating gamma-ray logging equipment.

The acquisition of approximately one curie of cobalt-60 will make possible studies of subsurface soil densities and the effect of radiation damage in minerals and rocks. The effects of this damage have been observed by thermoluminescence. Equipment for measuring soil density is being designed.

#### Airborne surveying

In the Pine Ridge Escarpment and Pine Mountain areas, Wyoming, the Wind River formation can be correlated with a high radioactivity background and to some extent it is possible to differentiate sandstones from shales. In northern Michigan the characteristic radioactivity patterns of the "Republic granite" and the Cambrian sedimentary rocks can be recognized. Many small features can be delineated on a few adjacent flight lines but their meaning cannot be understood without more detailed geologic information.

#### Geochemical investigations

Experiments with plants grown in desert soil plots which have been carried on for the past four seasons were terminated during the report period. An unusual content of strontium (1,500 ppm Sr) was found in the ash of plants growing in plots to which strontium ore had been added. The Sr absorption by vegetation rooted in other types of radioactive deposits is being investigated.

The Chattanooga shale and five other fine-grained sedimentary rocks have been studied to determine elemental associations with uranium and with carbonaceous fractions separated from the rocks. The elements B, P, V, Fe, Co, Ni, Cu, Zn, As, Mo, Ag, Sn, Pb, U, La, and Ce were found to be concentrated in the carbonaceous fraction separated from one or more of these rocks. Uranium was found concentrated in only one organic fraction--that from a coaly shale. Except for U, La, and Ce none of the elements concentrated in the organic matter is dominantly lithophile; almost all the other elements characteristically form complex compounds which might be fixed with organic material.

Preliminary results of a study on leaching of uranium from uraniferous ores by petroleum show large increases in uranium content of the oil. Work is under way to show whether the increase is mechanical or chemical in nature.

### Mineralogic investigations

The ores in the Lisbon Valley area, San Juan County, Utah, are almost completely unoxidized and are alike mineralogically. The major uranium mineral is uraninite; montroseite probably is the most abundant vanadium mineral. The sulfides, pyrite, sphalerite, galena and chalcopyrite, though scarce, are present in most of the mines. Molybdenum in an as yet unidentified mineral is present in most of the mines.

Glauconitic mica occurs as interstitial clay in a bed of fine-grained sandstone in the upper part of the Brushy Basin member of the Morrison formation of Late Jurassic age near Uravan, Colorado. This mica, similar to other material ordinarily called glauconite, is interesting because the Morrison formation is generally regarded as nonmarine in origin, whereas glauconite commonly forms in a marine environment.

In the Gas Hills area of the Wind River Basin, Wyoming, secondary enrichment occurred at the water table. Closely related to the uranium both in origin and in oxidation-migration-history are Mo, Se, As, and several other trace elements.

The close association of the uranium deposits in the Texas Coastal Plain with altered volcanic ash, extensive caliche deposits, intense silicification, opal and chalcedony, and saline carbonate ground waters strongly suggests a genetic relation between these features and a probable ground water origin.

The crystal structures of carnotite and its analogs have been solved. Vanadium occurs in 5-fold coordination with  $V_2O_8^{6-}$  groups in the structure, showing that carnotite is essentially a metavanadate, rather than an orthovanadate as previously supposed.

## Analytical service and research on methods

During the report period the Washington and Denver laboratories received 13,353 samples and completed work on 11,998 samples. On December 1, 1956, 8,263 samples were on hand for analysis.

### Radioactivity

A total of 3,865 radiometric and radiochemical determinations were made during the report period. Spectrographic and chemical determinations of the lead content of granite sample G-1 were made because divergent results of approximately 27 and 50 ppm have been reported. In an inter-laboratory test the results ranged from 38 to 60 ppm, with a mean of 48.9 ppm which may be inferred to be the mean lead content of the remaining bottles of G-1. These results confirm but do not solve the 27-50 ppm dilemma.

Studies are being made to obtain a method of determining uranium in ores by radioactivity which will be independent of the state of equilibrium. Three different approaches to this problem are being tested.

### Spectrography

The Washington and Denver spectrochemical laboratories completed 134,895 qualitative, semiquantitative, and quantitative determinations on 2,044 samples during this report period. There was a marked increase in the diversity of the chemical and physical properties of the samples submitted. In addition, earlier results on more than 1,000 samples were re-evaluated as part of a study on "The distribution of elements in Colorado Plateau ores and sandstones".

### Chemistry

A total of 10,458 chemical determinations were made on 5,148 samples. Five counting standards were prepared and the lead content of standard granite G-1 was determined. Eleven visiting chemists received training. A rapid method was developed for determining mineral and organic carbon in Colorado Plateau samples. Colorimetric methods for determining cobalt, nickel, and molybdenum in high uranium samples are being studied. Several separation and concentration procedures are being investigated for application to the determination of less than 1 ppm  $\text{ThO}_2$  in basic rocks.

## Mineralogy

Five hundred and seventy samples were processed for mineralogical and petrographic study and identification during this report period in the Denver laboratory; the Washington laboratory processed 1,748, for a total of 2,318. Thus, the sample load reached the level attained in calendar year 1954. Specialized treatment of samples, however, has gradually increased. Improved methods for separation of minerals have been employed and improved methods for isolation of uranium-bearing minerals have been introduced. The same methods allow for approximate estimations of uranium content or radioactivity.

### Program sponsored by Division of Research, AEC

#### Physical behavior of radon

Radon concentrations in the water and gas phases of several natural mixtures of water and gas were found to deviate from laboratory-determined equilibrium concentration ratios. This is believed due to insufficient mixing of the phases, and where the water phase has less than the equilibrium concentration of radon and is increasing in temperature, the existence of separate water and gas phases underground may be inferred.

#### Uranium in natural waters

Dustfalls from the Colorado Plateau region were found to have negligible effect on uranium content of Front Range waters in Colorado and Wyoming. The uranium content of the Weber River in its canyon near Ogden, Utah, was found to increase systematically downstream by uraniumiferous ground water issuing from fractured Precambrian rocks; results agree with radon increase reported by Rogers and Tanner.

#### Organic geochemistry of uranium

A conglomeratic sandstone from the Dirty Devil No. 4 mine, San Rafael Swell, Utah, was found to contain as much as 0.5 percent tungsten. Tiny carbonaceous pellets in the sandstone have essentially the same uranium content as the rock in which they are imbedded.

Analysis of three oils isolated from sediments of the Temple Mountain area shows them to contain 0.5, 32, and 73 ppm uranium.

File irradiation of coals shows them to be extremely stable; humic acid, however, is converted into a substance having the composition of a lignite.

A fluorescing pigment, tentatively identified as a phthalic acid derivative, was isolated from a paraffinic crude oil collected in the Uintah Basin, Utah. Carbon isotope analyses of a number of gilsonites indicate that all probably derived from a single source reservoir.

#### Distribution of uranium in igneous complexes

Results of leaching experiments on rocks of the Boulder Creek batholith of Colorado indicate that the amount of leachable uranium increases with the uranium content of the rock. The average percentages of uranium leached from the rocks are: quartz diorites, 27; granodiorites, 40; quartz monzonites, 61; and granites, 73.

Sphene is variable in uranium content although in general the average uranium content is higher in sphene from the more siliceous rocks. The average uranium content in apatite increases from the quartz diorites to quartz monzonites and there appears to be a sharp decrease in uranium content of apatite from granites. In zircon, the average uranium content progressively increases from the quartz diorites to the quartz monzonites.

#### Synthesis and solution chemistry of uranium-bearing minerals

Field studies in the Wyoming-South Dakota area indicated that the idea of a primary unoxidized uranium ore modified by exposure to oxygen as the water table drops is generally applicable to this area. The main difference between the uranium ores of this area and those of the Colorado Plateau is the increased mobility of uranium in the Wyoming-South Dakota area owing to the absence of vanadium capable of fixing the secondary minerals.

Mineral synthesis studies disclosed that many uranium and vanadium minerals may be formed only over a narrow pH range, while carnotite may be precipitated over a wide pH range.

#### Isotope geology of lead

Additional analyses of galena support earlier observations that the Coeur d'Alene lead mines and the Belt terrane of the surrounding region are pervaded by a primitive variety of ore-lead of specific isotopic composition. The new data also suggest a supplementary hypothesis: that where uranium is concentrated, this ordinary lead can be modified drastically by additions of radiogenic  $Pb^{206}$  and  $Pb^{207}$ . These data add the Coeur d'Alene to the growing list of districts where uranium deposits are known to contain anomalously uraniumogenic sulfide-lead, older in apparent age than the radiogenic lead in associated uraninite. The interpretation of these two radiogenic components will complicate the calculation of

isotopic ages for Coeur d'Alene uraninite, but the one analysis available provisionally continues to indicate a Precambrian age for uraninite from the Sunshine mine under all alternative age calculations.

### Nuclear geology

Measurements of the natural variations in the isotopic abundance of copper are being continued. A considerable amount of time was spent in instrumentation and development of techniques on a neutron activation method for isotopic analysis. Preliminary experiments are encouraging and justify further work. The magnetic susceptibility balance was completed for zircon. Neutron irradiation of fresh zircon for periods up to 120 days showed no significant change in the lattice parameters.

### Geochronology research

Approximately 20 samples of igneous rocks and 25 samples of uranium, thorium and lead ores were prepared for isotopic analysis. The 12-inch solid sample mass spectrometer was placed in operation and initial tests of the instrument showed excellent results.

### Natural radioactivity of the atmosphere

The basic instruments for determining the rate of diffusion of radon through rock cores have been assembled, although some accessory equipment is not yet in operation. Core cuts of various rock types have been sealed in plastic cylinders and connected between an ionization chamber containing a known amount of radon and an evacuated chamber. The diffusion time is read from a strip chart record. Diffusion rates will be determined for several rock types under various conditions of pressure, temperature, and water saturation.

### Thermoluminescence of radioactive minerals

A thermoluminescence apparatus has been designed for "activating" thermoluminescence over a temperature range of  $-190^{\circ}$  to  $500^{\circ}$  C with ultraviolet or X-radiation. "Glow curves" or "decay curves" can be obtained from this apparatus on the same temperature range. Sources for quartz with known composition have been established and considerable effort has been made to obtain "thermoluminescence-pure calcite".

## Nuclear magnetic resonance

A survey of the literature indicates that nuclear magnetic resonance methods may possibly be useful in mineral structure studies but only as a subsidiary technique.

## Geochemistry of thorium

Two analytical methods are under development for the quantitative determination of thorium in rocks down to 1 ppm. One is a further development of a spectrophotometric method, the other entails a fairly rapid chemical concentration of thorium from the rock and its quantitative measurement by the X-ray fluorescence spectrometer. As little as 5 micrograms of thorium can be detected in 2 to 30 mg of concentrate. The procedure for concentrating the thorium is not yet fully tested.

Twenty samples from Laramide intrusives from the Front Range mineral belt, Colorado, which are unusually high in thorium content, were analyzed for thorium. The thorium content tends to parallel the uranium content, except in the latest differentiates where the Th/U ratio is abnormally high.

Work was started on the stability of thorium complexes in water solutions. Starting with soluble thorium nitrate, precipitation studies over a range of pH 3.5 to 7.5 show that  $\text{Th}(\text{OH})_4 \cdot \text{Th}(\text{NO}_3)_4$  precipitates at the lowest pH and  $7\text{Th}(\text{OH})_4 \cdot \text{Th}(\text{NO}_3)_4$  precipitates at the highest pH.

In a study of the distribution and geologic relations of thorium deposits in the Powderhorn district, Gunnison County, Colorado, an area of about 20 square miles in the northwestern part of the Gateview quadrangle was mapped, and 50 thorium-bearing veins in the area were examined. About 90 percent of the thorium-bearing limonitic quartz-carbonate-barite veins in the area studied have a northwesterly trend and are discordant to the foliation of enclosing Precambrian rocks.

## Geologic thermometry of radioactive minerals

Several sulfide-bearing uranium deposits from the Colorado Plateau contain two phases from the system  $\text{Fe}_2\text{S}_2\text{-FeSe}_2$ , a sulfide-rich phase and a selenium-rich phase, which may be valuable for temperature determinations. The lack of exsolution or intergrowths of galena in galena-clausthalite from the roscoelite-type deposits indicates that the system  $\text{PbS-PbSe}$  would not be useful as a temperature-sensitive solid solution series. The  $\text{FeS-ZnS}$  system of Kullerud has been applied to deposits containing sphalerite associated with iron sulfides and by projecting the data of this system the temperature of formation of several sphalerites from the Colorado Plateau were estimated to be less than  $138^\circ\text{C}$ . Additional work was initiated on the use of the  $\text{Cu}_2\text{S-CuS}$  system, and on the unit cell size variation of uraninite as possible indicators of temperature of formation.

## GEOLOGIC MAPPING

Colorado Plateau region

Early in 1947 geologic mapping was started in southwestern Colorado as part of the uranium investigations on the Colorado Plateau. Subsequently, the original program was expanded 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; Red House Cliffs, Utah; and Deer Flat, Utah. During the report period field and office work continued in the following areas: Bull Canyon district, Colorado; Slick Rock district, Colorado; Uravan district, Colorado; Western San Juan Mountains, Colorado; Ute Mountain, Colorado; Sage Plain, Utah and Colorado; La Sal Creek area, Colorado and Utah; Lisbon Valley, Utah and Colorado; Moab-Inter-river area, Utah; Orange Cliffs area, Utah; San Rafael Swell, Utah; Circle Cliffs area, Utah; Elk Ridge area, Utah; Abajo Mountains, Utah; East Vermillion Cliffs area, Arizona; Grants area, New Mexico; Laguna area, New Mexico; and Hopi Buttes, Arizona.

Summaries of the results from the following projects that are nearing completion will be reported in the next semiannual report: Moab-Inter-river area, East Vermillion Cliffs, Elk Ridge area, San Rafael Swell, La Sal Creek area, and Uravan district.

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

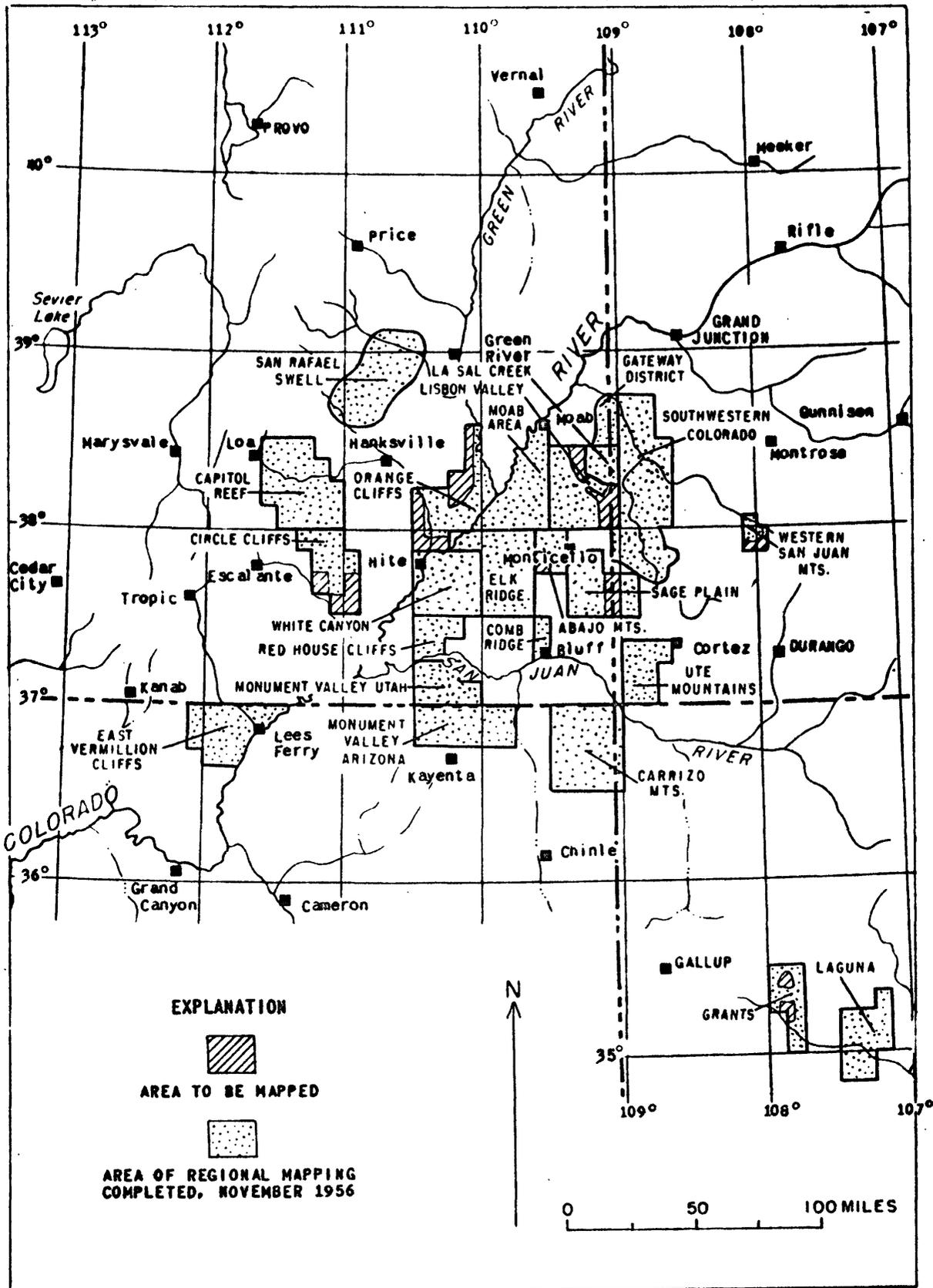


FIG. 1.--INDEX MAP OF PART OF THE COLORADO PLATEAU SHOWING LOCATION OF MAPPING PROJECTS.

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Bull Canyon district, Montrose and  
San Miguel Counties, Colorado

By

R. M. Wallace and C. H. Roach

The major geologic objective during the report period was an understanding of the favorability and thickness of the Salt Wash member of the Morrison formation of Jurassic age throughout the Bull Canyon district. Three typical uranium-vanadium mines in the Salt Wash member in Bull Canyon were mapped. One of these mines is in a deposit of unoxidized ore minerals, another is in oxidized ore minerals, both in the upper part of the Salt Wash. The third mine is in a deposit of unoxidized ore minerals near the base of the Salt Wash member.

East of the boundary of the Uravan Mineral Belt (fig. 2) mapping indicates a large increase in the ratio of red sandstone beds to light gray sandstone beds, and a decrease in the number and thickness of green mudstone layers. The total thickness of the Salt Wash member here and in other parts of the district is within a few feet of the district average of 330 feet. In the Jo Dandy area, however, the Salt Wash member is between 205 and 275 feet thick where exposed on the edge of Paradox Valley; away from the valley it is more than 400 feet thick in places. These thick sections probably are the result of deposition in small basins adjacent to the salt structures.

The large number of mudstone lenses and layers intercalated in the sandstone units east of the boundary of the Uravan Mineral Belt, plus the absence of the other lithologic guides described by Weir (1952) strongly suggest that this area is not a favorable place for prospecting for uranium and vanadium ore.

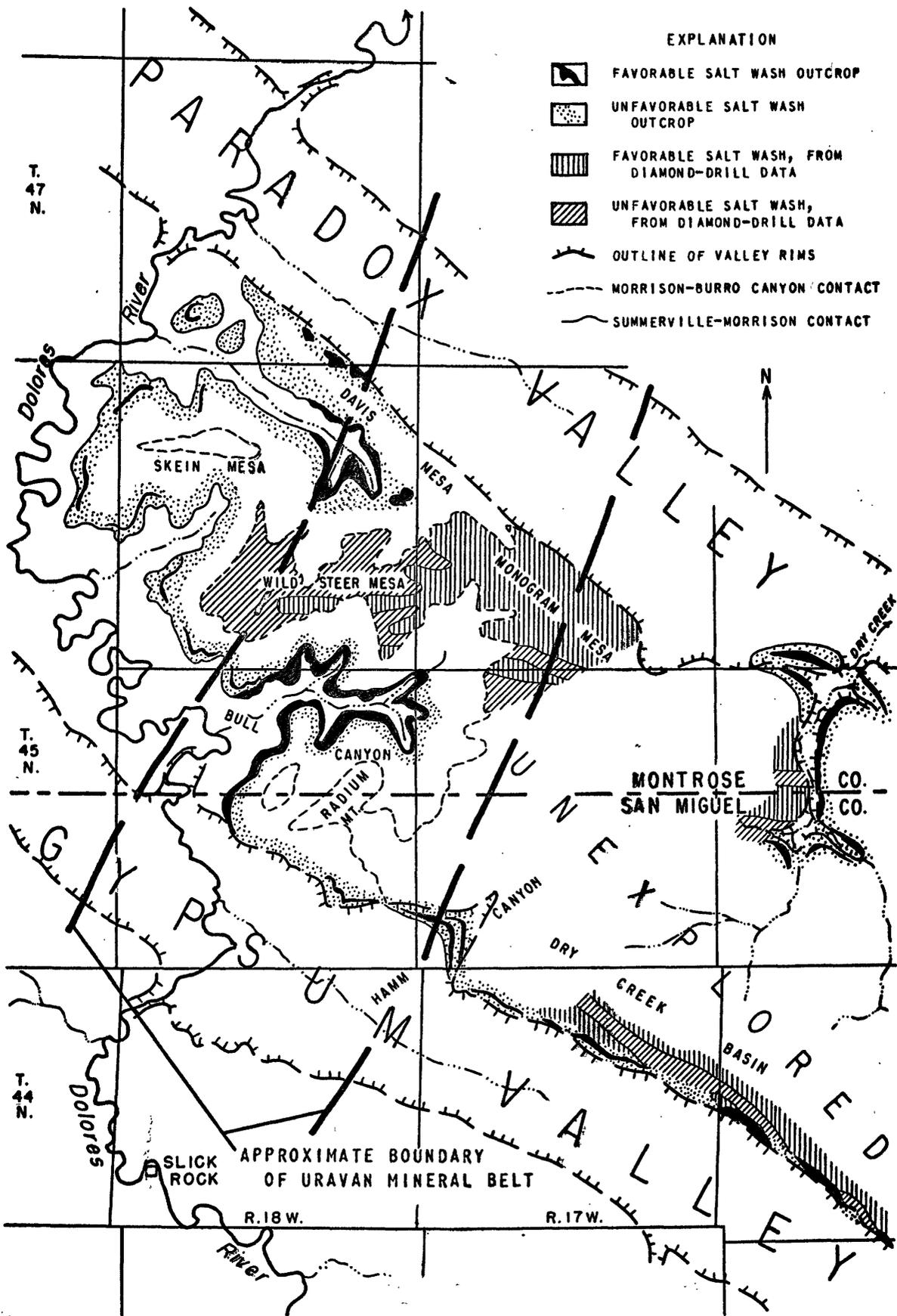


FIG. 2.--GENERALIZED MAP SHOWING PARTS OF THE SALT WASH MEMBER OF THE MORRISON FORMATION FAVORABLE AND UNFAVORABLE FOR URANIUM-VANADIUM DEPOSITS, BULL CANYON DISTRICT, MONTROSE AND SAN MIGUEL COUNTIES, COLO.

Sedimentary features in the Salt Wash exposures in the eastern area indicate that during deposition of the member the streams flowed generally eastward; the direction of flow commonly was between N. 80° E. and S. 80° E. A variation of more than 10° in any one place is rare. In the southeastern part of Dry Creek Basin, however, the stream flow was southeast parallel to Gypsum Valley.

Study of the Salt Wash outcrops and drill cores indicates that the area west of the Mineral Belt boundary is favorable for prospecting for uranium-vanadium ores. To date, however, no ore bodies have been found, and few drill cores contained more than a trace of uranium and vanadium ores. The Salt Wash member here contains thick, light-gray sandstone lenses containing abundant carbonaceous trash, bordered above and below by thick green mudstone layers. The general areas of lithologies that are favorable hosts for the deposition of uranium-vanadium minerals are shown in figure 2.

The compilation and study of the mine data from the Bull Canyon mines is now in progress and will be completed during the next report period. Isopach and structure contour maps of the Monogram Mesa-Wild Steer Mesa area will be completed.

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Slick Rock district  
San Miguel and Dolores Counties, Colorado

By

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

Stratigraphic studies

Study of the cores from hole DVR-1 shows that the Early Greenhorn, Late Greenhorn, Later Carlile, Earlier Niobrara, and Later Niobrara in the lower 855 feet of the Mancos shale in the southeastern part of Disappointment Valley (fig. 3) are generally calcite-rich according to acid bottle tests and six chemical determinations, by N. L. Archbold of the Geological Survey, that ranged from 15.6 to 38.1 percent  $\text{CaCO}_3$ . The Earlier Carlile, however, is calcite poor according to acid bottle tests and two chemical determinations by N. L. Archbold that ranged from 0.6 and 2.4 percent  $\text{CaCO}_3$  (fig. 4).

In addition the Early Greenhorn, Late Greenhorn, Later Carlile, and Earlier Niobrara zones contain sparse to abundant pyrite, whereas the Earlier Carlile and Later Niobrara contain very sparse to no pyrite (fig. 4). Moreover, the abundance of pyrite in the Mancos core is directly associated with thin claystone layers; the middle part of the Earlier Carlile and the Later Niobrara intervals contain very few claystone layers (fig. 4). The claystone layers are probably bentonitic and are interpreted as representing volcanic ash falls.

It is suggested that volcanic activity during the earlier part of Mancos time influenced life forms by affecting the composition of the sea water; this may explain the correlation of some of the fossil zones with claystone and pyrite-rich intervals. Finally, the zones of abundant calcite in the Mancos may be related to periods of volcanic activity, but this correlation is tenuous.

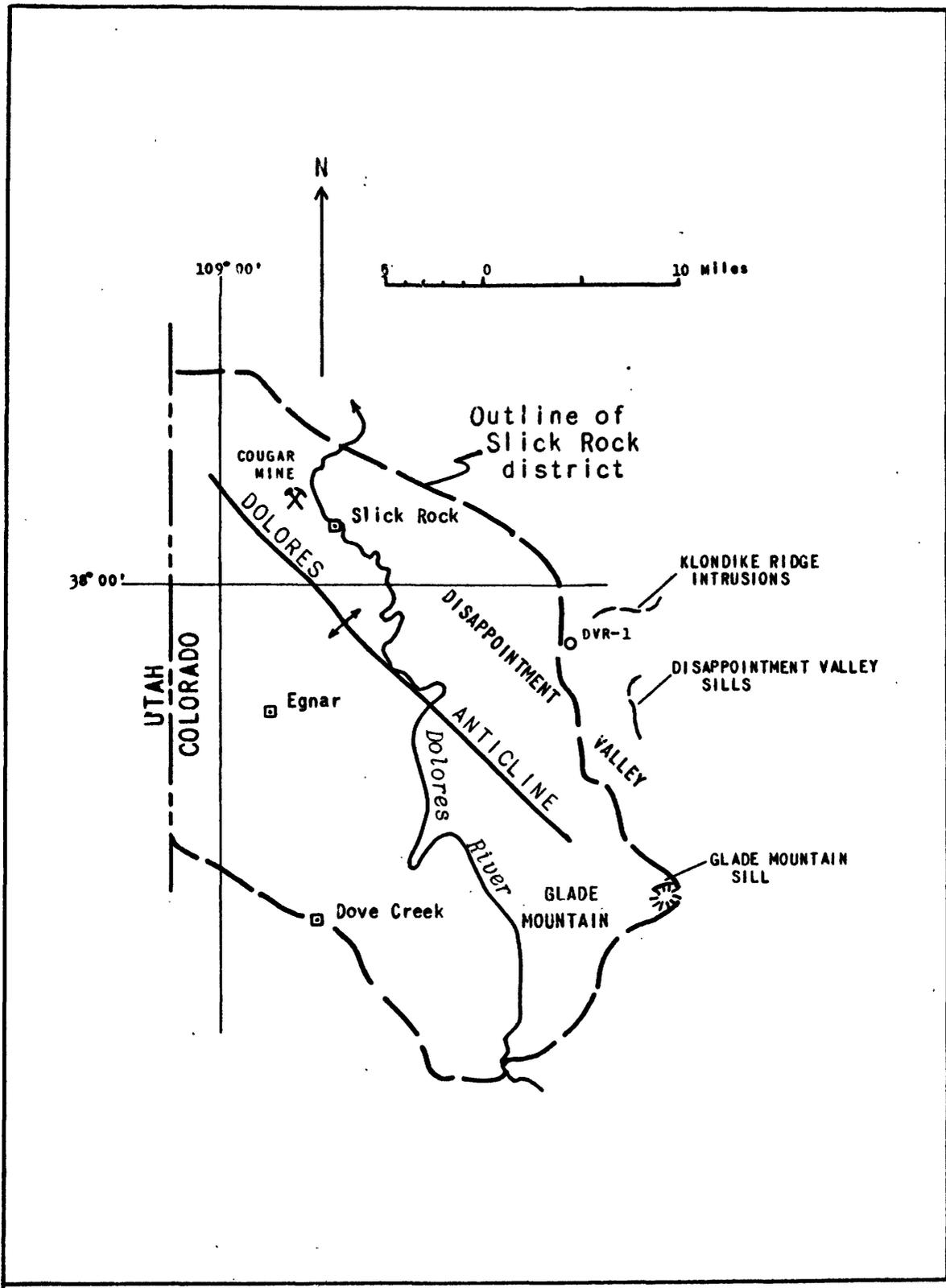


FIG. 3.--LOCATION MAP OF SLICK ROCK DISTRICT, COLORADO, SHOWING AREAS REFERRED TO IN TEXT.

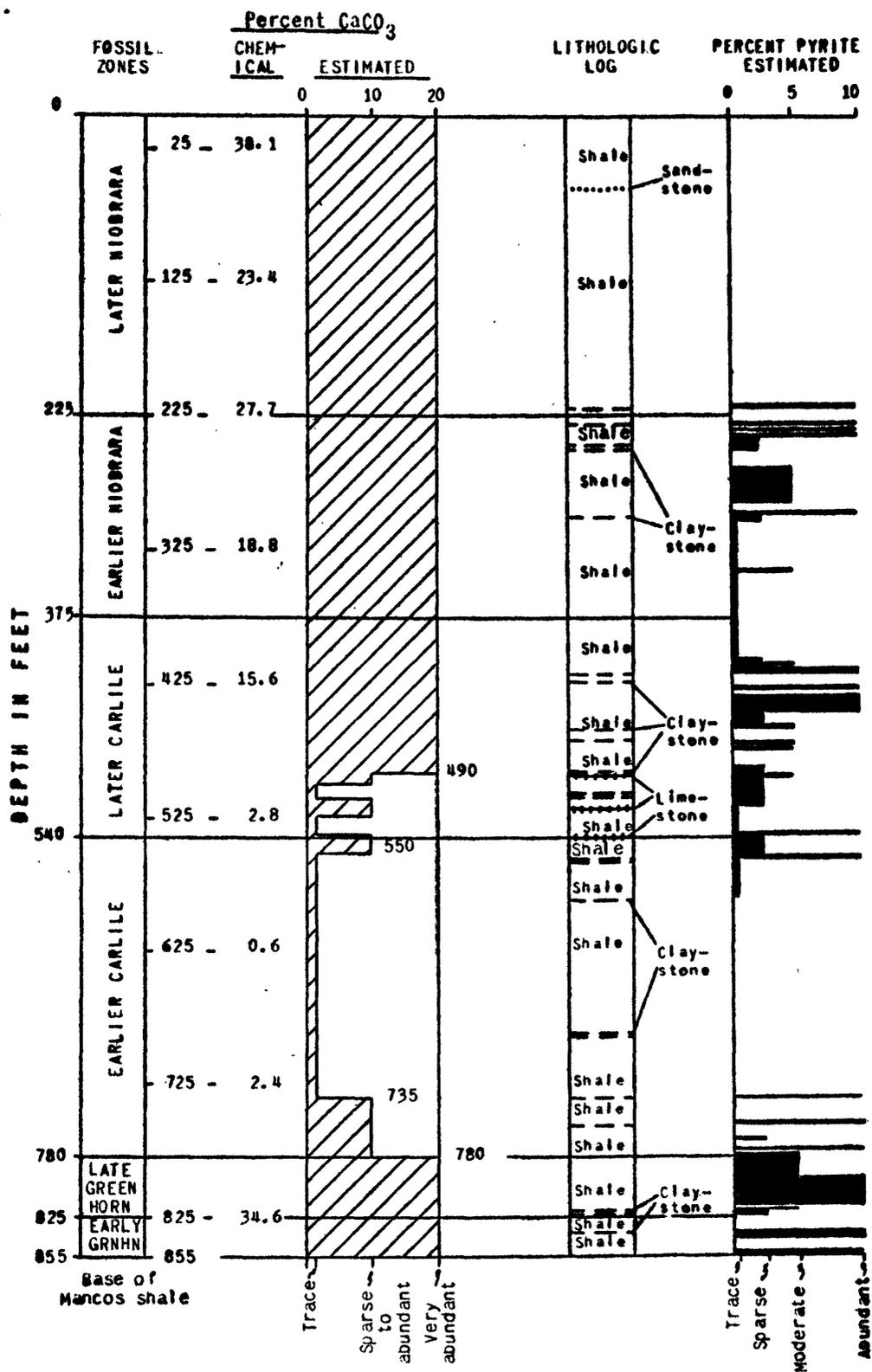


FIG. 4.--DIAGRAM SHOWING FOSSIL ZONES, LITHOLOGY, AND CaCO<sub>3</sub> AND PYRITE CONTENT OF THE LOWER PART OF THE MANCOS SHALE.

Mineralogic studies

Semiquantitative spectrographic analyses have been made of five purified carbonates and sulfates from the Slick Rock district. The only impurities in the barite from the Mancos shale are .05-.1 percent Sr and .0001-.0005 percent each Al and Cu. Barite from an ore roll in the Cougar mine (sample C-29, TEI-620, fig. 4, p. 44) contains .1-.5 percent Sr and .01-.05 percent each Al and Cu, and in addition .1-.5 percent Fe, Ca, and Si; .01-.05 percent Pb, Zr, V, and Mg; .001-.005 percent Ti, Y, Ni, Mn, Mo, and Cr; .0005-.001 percent Ag; and .0001-.0005 percent Yb. The barite from the ore roll is pale yellow and is more abundant in ore than in barren rock next to ore (TEI-620, p. 44; see also Bergin and Chisholm in TEI-620, p. 191). All but six (Al, Ca, Si, Zr, Ti, and Mn) of the eighteen trace elements detected in barite from the Cougar mine ore roll have been suggested by Shoemaker and others (TEI-446, 1955) to be extrinsic elements in ore deposits of the Morrison formation.

Some of the trace elements in three samples of calcite, one from the Mancos shale, one from altered mudstone in the Burro Canyon formation, and one from unaltered mudstone in the Salt Wash member of the Morrison formation show interesting relations. The Fe, Mg, and Mn in calcite from the Mancos and Salt Wash range from .1 to 1 percent each whereas in the calcite in the Burro Canyon they range from .01 to .1 percent. Similarly, the Sr and Ag in calcite from the Mancos and Salt Wash range from .01 to .05 percent and .00001 to .00005 percent respectively, and range from .001 to .005 percent in calcite from the Burro Canyon. All these elements apparently replace Ca in the calcite structure, and seem to enter the structure in amounts proportional to each other regardless of total

amount in each type of calcite. Because this constant ratio of trace elements in each type of calcite may reflect crystallization of the mineral in environments unaffected by ore-forming processes, studies of the trace element composition of calcite formed near uranium-vanadium deposits in the Salt Wash member of the Morrison formation are underway.

It is hoped that trace element studies of carbonates and sulfates from sedimentary rocks will help clarify genesis of uranium-vanadium deposits in the sediments, and may provide additional criteria for use in exploration.

Continuing studies of heavy minerals in sandstone strata, largely in the Morrison formation of the Slick Rock district, confirm earlier conclusions on alteration in sedimentary formations described in TEI-620 (p. 40-45) (figs. 5 and 6).

#### Geochemical studies of alteration

Recognition of alteration along fractures in otherwise unaltered Navajo sandstone, Carmel formation, Entrada sandstone, Summerville formation, and Salt Wash member of the Morrison formation resulted in sampling of rocks to determine if the alteration is similar to that previously assumed to be related to deposition of the ore bodies. Zones of fractures showing alteration seem to parallel the principal favorable trends in the Salt Wash member, and generally underlie the favorable areas. Chemical and spectrographic analyses of the samples collected in this study are pending, but results of determinations of eU have been received.

Figure 7 shows five examples where samples were taken close to each other in altered (generally very light brown) sandstone and unaltered

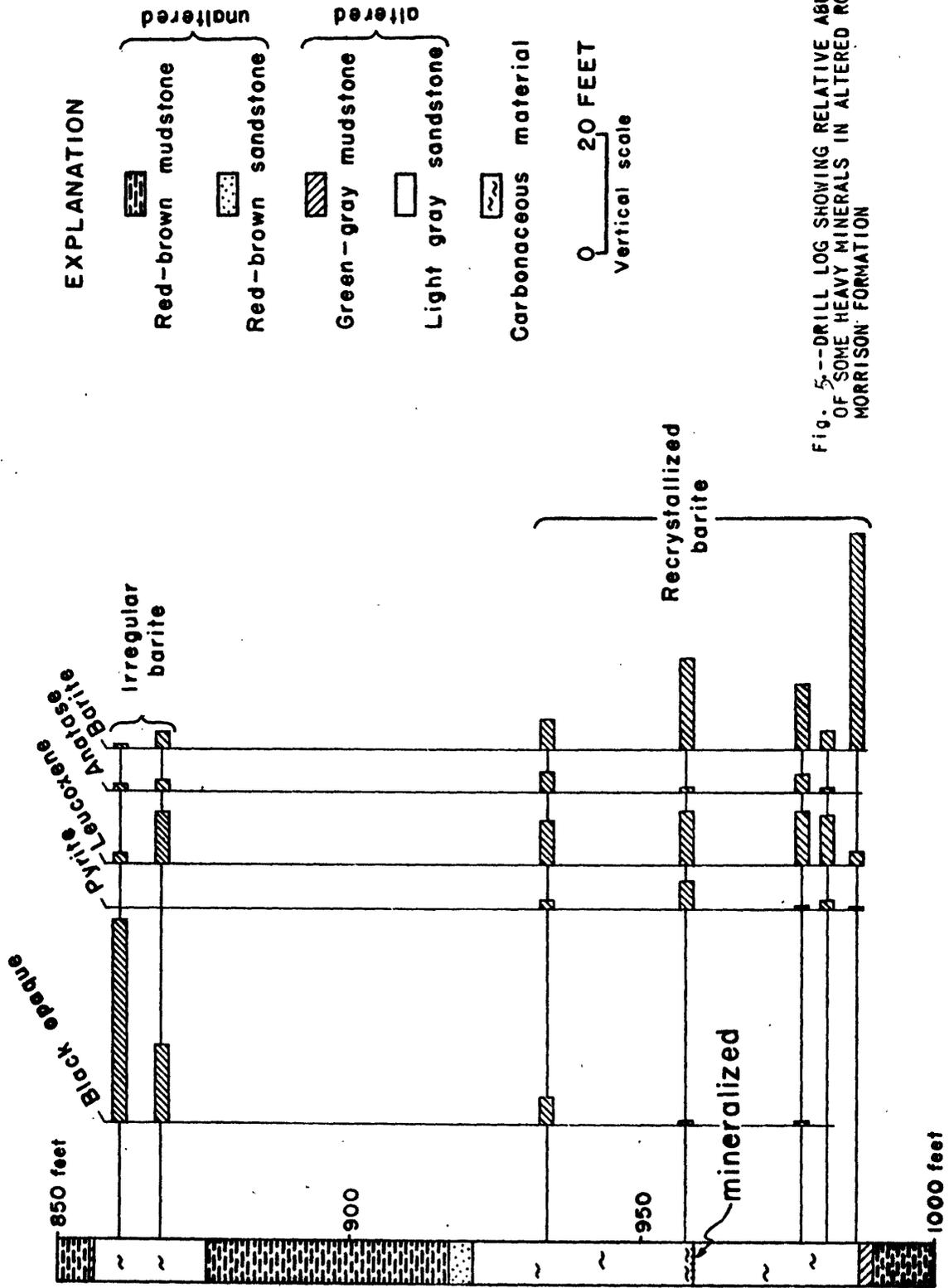


Fig. 5--DRILL LOG SHOWING RELATIVE ABUNDANCES OF SOME HEAVY MINERALS IN ALTERED ROCKS, MORRISON FORMATION

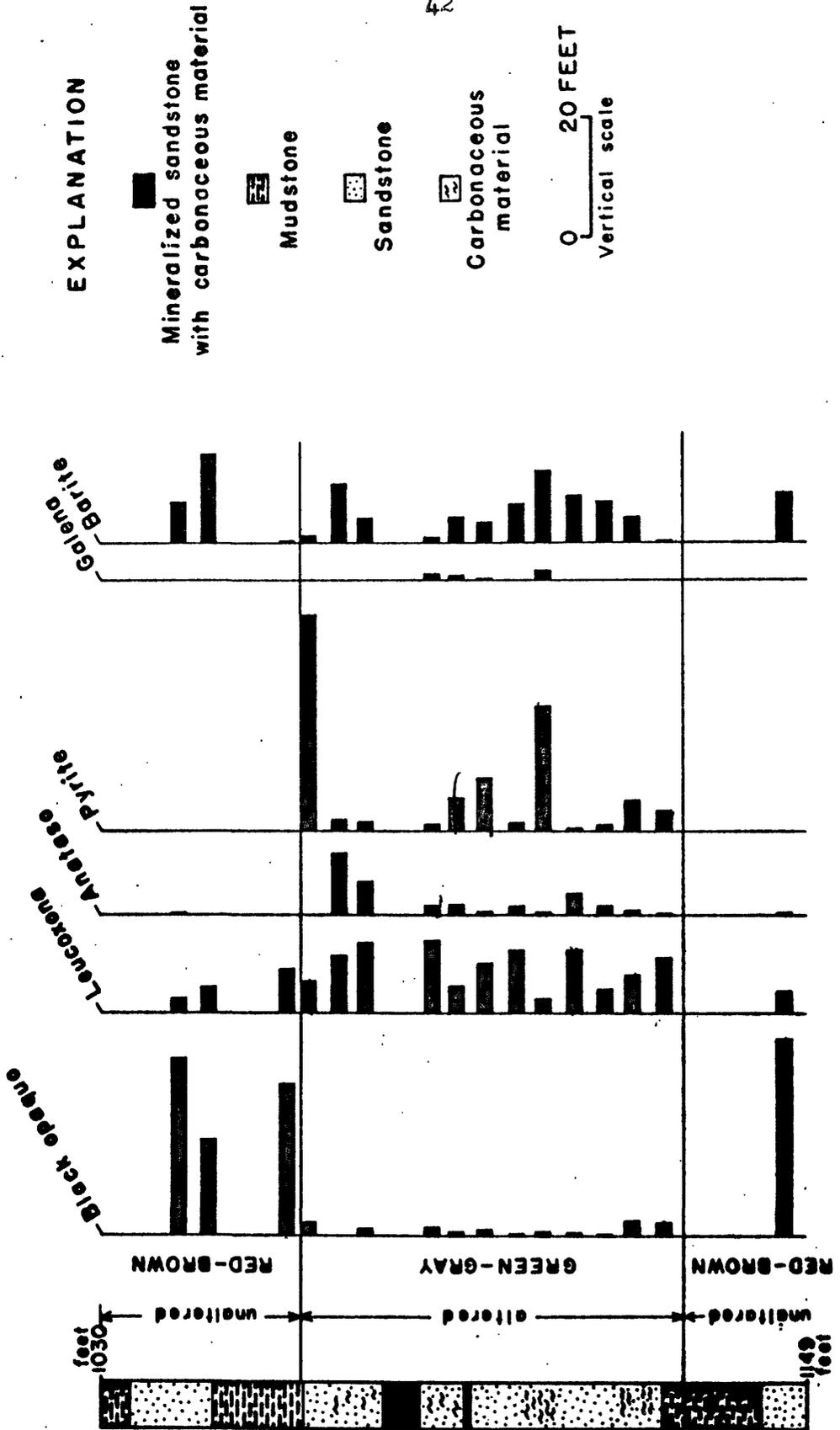
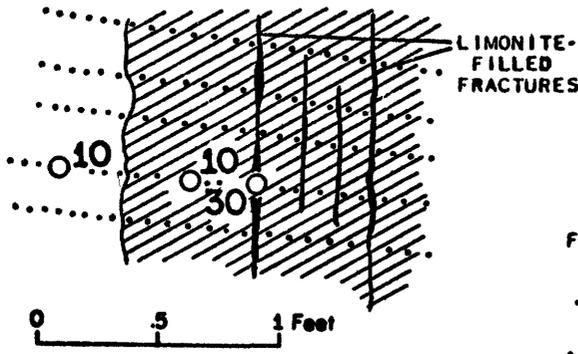
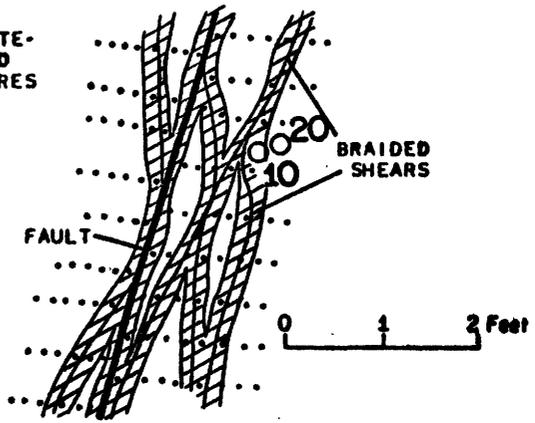


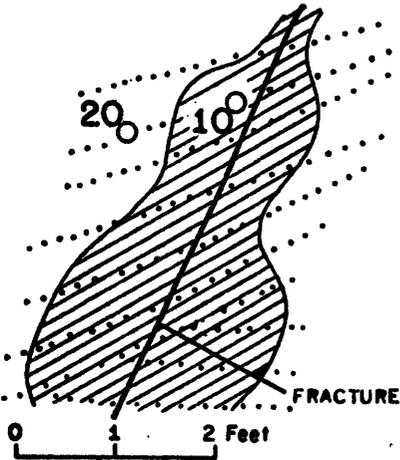
FIG. 6--DRILL LOG SHOWING RELATIVE ABUNDANCES OF SOME HEAVY MINERALS IN ALTERED AND UNALTERED ROCKS, MORRISON FORMATION



NAVAJO SANDSTONE

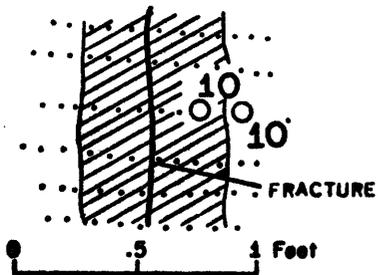


CARMEL FORMATION

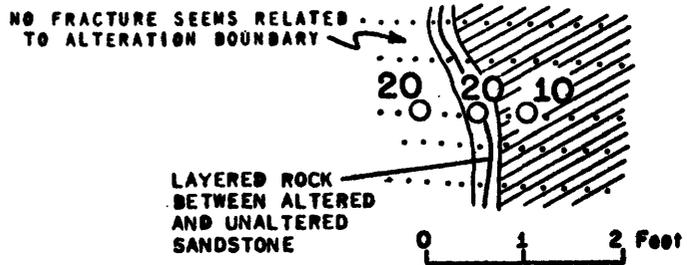


ENTRADA SANDSTONE

LIMONITE RICH ZONE ALONG NEARBY FAULT IN ALTERED ENTRADA SANDSTONE HAS 6 PARTS PER MILLION eU



SALT WASH SANDSTONE



SALT WASH SANDSTONE

FIG. 7.--URANIUM CONTENT (eU) IN SOME ALTERED AND UNALTERED SANDSTONES IN THE SLICK ROCK DISTRICT, COLORADO.

(reddish-brown) sandstone respectively. Alteration is clearly related to fractures in four examples. Although no difference in eU content between altered and unaltered rocks is indicated in the Navajo sandstone and in one Salt Wash sandstone example (10 ppm eU in all rocks), eU is lower in altered rock (10 ppm eU) than in unaltered (20 ppm eU) Entrada sandstone, Carmel formation, and in one Salt Wash sandstone example. In addition, limonite concentrations in fractures of faults that seemingly controlled alteration contain distinctly higher amounts of eU (30 ppm eU, fig. 7). Although the data do not warrant the conclusion that fractures controlled localization of ore deposits in the Slick Rock district, assuming the eU represents only uranium, it is possible that the solutions causing the alteration leached uranium from the sediments, and later deposited this uranium in amounts higher than normal for unaltered sedimentary rocks.

#### Igneous rocks

The discovery of a diorite porphyry sill(?) in the southeast corner of the Slick Rock district at an altitude of 9,000 feet on Glade Mountain extends the area of known igneous intrusions farther south of the adjoining Klondike ridge area than the previously known sills in southeastern Disappointment Valley (fig. 3). The coarse gravels containing boulders of volcanic rock overlying the Glade Mountain sill may be of glacial origin; comparison of rock types in the gravels with volcanic rocks in the San Juan Mountains to the east may help date the time of major uplift of Glade Mountain and the contiguous Dolores anticline (fig. 3).

### Ore deposits

Mapping in the Cougar mine (fig. 3) has shown that roll ore bodies are oriented parallel to current lineation in elongate sand-filled scours in the upper sandstone unit of the Salt Wash member of the Morrison formation. Moreover, the rolls are localized near either edge of a sand-filled scour, within the elongate sand lens, so that in cross section the "mirror image" rolls, generally of the C-form type, are convex away from each other (fig. 8). From this, and earlier ideas on formation of roll ore bodies, it is concluded that the roll ore bodies formed at the edges of an ore solution flowing through the permeable sandstone, and ore was precipitated at an interface between the ore solution and connate water trapped against the impermeable edges of the elongate sandstone lenses.

The following reports on the significance of roll ore bodies in forming uranium-vanadium deposits and the relation of alteration to ore deposits were published during the report period:

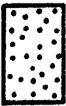
Shawe, D. R., 1956, Significance of roll ore bodies in genesis of uranium-vanadium deposits on the Colorado Plateau, in Page, L. R., Stocking, H. E., and Smith, H. B., Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U. S. Geol. Survey Prof. Paper 300, p. 239-241.

\_\_\_\_\_, 1956, Alteration related to Colorado Plateau ore deposits (abstract): Geol. Soc. America Bull. (69th Annual Meeting - GSA, November 1956).

E X P L A N A T I O N



ALTERED  
MUDSTONE



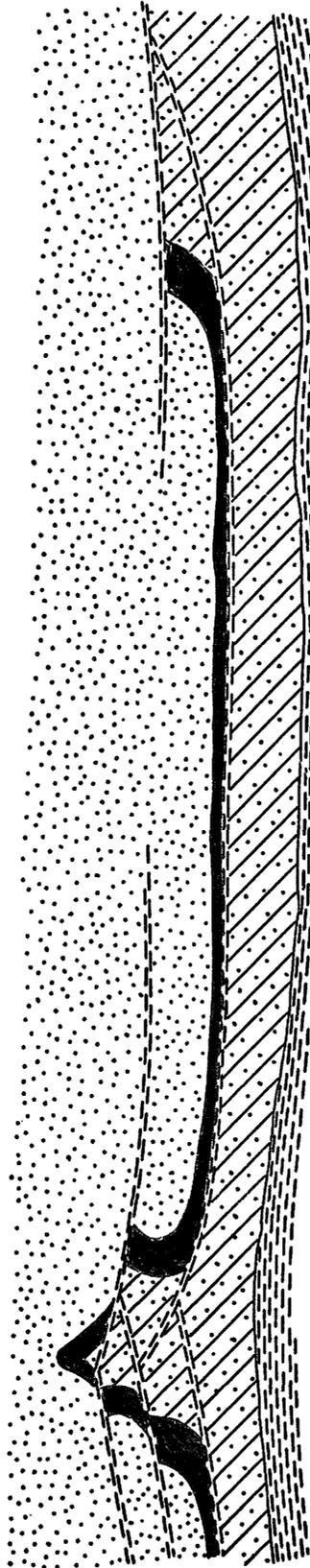
POSTULATED ZONE OF  
MOVING ORE SOLUTION.  
NOW BARREN SANDSTONE



POSTULATED ZONE OF  
TRAPPED CONNATE WATER.  
NOW BARREN SANDSTONE



POSTULATED POSITION  
OF SOLUTION INTERFACE.  
NOW MINERALIZED ROCK



0 5 10 Feet

HORIZONTAL AND VERTICAL SCALE

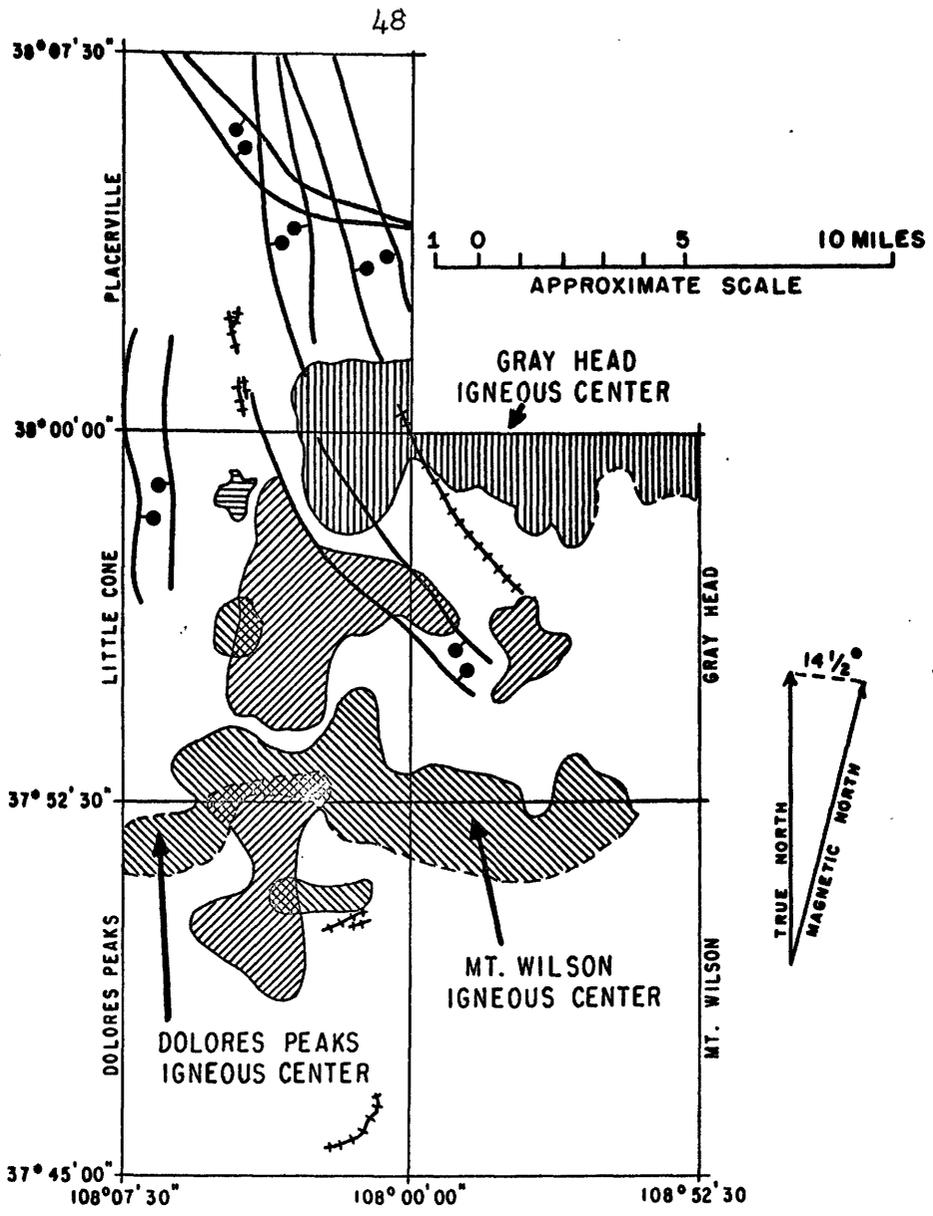
FIG. 8.--DIAGRAMMATIC CROSS SECTION OF ROLLS IN SANDSTONE LAYERS NEAR THE BASE OF THE ORE-BEARING UNIT OF THE SALT WASH MEMBER OF THE MORRISON FORMATION, COUGAR MINE, SLICK ROCK DISTRICT, COLORADO.

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

The large deposits of vanadium in the Placerville district, Colorado, that contain enough uranium to be of byproduct value are being studied in five 7-1/2 minute quadrangles (Placerville, Little Cone, Gray Head, Dolores Peaks, Mt. Wilson), comprising about 300 square miles in the Western San Juan Mountains, San Miguel and Dolores Counties, Colorado (fig. 9). The primary objective of this study is to determine the relationships between the vanadium-uranium deposits, the base and precious metal deposits, and the extrusive and intrusive igneous rocks of the San Juan volcanic province. Areal mapping has been completed for the Placerville and Little Cone quadrangles, is about 70 percent complete in the Gray Head quadrangle, and is about 30 percent and 10 percent complete in the Dolores Peaks and Mt. Wilson quadrangles, respectively.

The sedimentary rocks of the Western San Juan Mountains range in age from Permian to Oligocene(?). At the end of the Cretaceous, or early in the Tertiary, the sedimentary rocks were warped into a series of broad anticlines and synclines, and extensively eroded, so that all the Cretaceous rocks younger than the Mancos shale were removed. Upon this surface the Telluride conglomerate of Oligocene age was deposited.

During the Miocene, extrusive igneous rocks were deposited on the Telluride conglomerate, and intrusive igneous rocks invaded both the sedimentary and the extrusive rocks. Normal faulting accompanied and followed the igneous activity, with the development of a horst and graben system in the Placerville, Little Cone, and Gray Head quadrangles.



EXPLANATION

-  AREA OF BASALTIC ANDESITE, DIABASE, AND DIORITE
-  AREA OF MICROGRANOGABBRO AND ASSOCIATED ROCKS
-  AREA OF QUARTZ-LATITE AND ASSOCIATED ROCKS
-  RECENT(?) BASALT FLOW
-  LAMPROPHYRE
-  GRABEN STRUCTURE, SHOWING DOWNTHROWN SIDE OF FAULTS

FIG. 9.--SKETCH MAP OF A PART OF THE WESTERN SAN JUAN MOUNTAINS SHOWING GRABEN STRUCTURES, SOME OF THE AREAS UNDERLAIN BY IGNEOUS ROCKS, AND THEIR RELATIONS TO CENTERS OF IGNEOUS ACTIVITY.

Three periods of glaciation followed in the Pleistocene, and one last surge of igneous activity produced a basalt flow some time during the Quaternary, perhaps as young as Recent(?).

The concepts of the horst and graben structures, and of multiple centers of igneous activity have been previously reported (TEI-390, p. 111-112; TEI-440, p. 28-30; TEI-490, p. 40-41; TEI-590, pp. 31-32; TEI-620, p. 47-50). During this report period, areal mapping extended the fault system (fig. 9) from the Placerville quadrangle into the Little Cone and Gray Head quadrangles, and indicated that these systems do not cut the Mt. Wilson igneous center. A similar relationship is suggested for the Dolores Peaks center and the fault system. There is some suggestion, however, that the fault systems do cut the Gray Head center. These observations suggest a genetic relationship between the faulting and the intrusions.

Additional areas underlain by igneous rocks were mapped during the period in the Little Cone and Gray Head quadrangles (fig. 9). The area underlain by rocks of the general quartz-latitude and lamprophyric types was largely extended, and the areas underlain by microgranogabbro sills and/or laccoliths were also extended. Basalt and minette dikes were found to conform to a general system, in which the basalts trend generally westerly, the minettes northwesterly to northerly.

The following report on uranium-vanadium deposits in the Western San Juan Mountains was published during the report period:

Bush, A. L., 1956, Vanadium-uranium deposits in the Entrada sandstone, western San Juan Mountains, Colorado (abstract): Geol. Soc. America Bull. (69th Annual Meeting - GSA, November 1956).

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

Field mapping and systematic sampling of the igneous and sedimentary rocks in the Ute Mountains area were completed during the 1956 field season.

Much of the doming visible at the surface around the mountains is due to buried intrusives of the laccolithic type which are probably intruded into shales of Triassic age (TEI-620, p. 52). This near-surface doming camouflages the structure that can be ascribed to the intrusion of the stocks; however, the presence of a consistent quaquaversal dip of  $2^{\circ}$ - $4^{\circ}$  around the Utes is believed to be the result of the stock's emplacement.

The oldest intrusives in the Ute Mountains are sills of fine-grained, very dark porphyry. These sills are commonly domed over underlying laccoliths consisting of more siliceous porphyries. In the southern part of the mountains the sills and laccoliths are cut by quartz monzonites (the most silicic rocks in the Ute Mountains). In the northern part of the mountains quartz diorites intrude the laccoliths and sills. With the possible exception of a complexity, which has not been fully evaluated, in the northern part of the area the field data suggest a basic to acid differentiation sequence. This concurs with the conclusions of Shoemaker and Newman (Shoemaker, E. M., and Newman, W. L., written communication).

A study of several miles of the contact between the Cretaceous Burro Canyon formation and the Cretaceous Dakota formation indicated that although the contact is disconformable throughout the Ute Mountains area, no angular unconformity is present.

A detailed study of the contact between the Cretaceous Burro Canyon formation and the Jurassic Morrison formation suggests that this contact is transitional and intertonguing. The Burro Canyon in places in the northern part of the area is dominantly conglomeratic sandstone. In other places, especially in the southern part of the area, the Burro Canyon contains no sandstone whatsoever. It was found that although the mudstones of the Burro Canyon formation and the upper part of the Morrison formation are very similar a difference does exist. The Burro Canyon mudstones are dominantly hackly weathering, and the mudstones of the Brushy Basin member of the Morrison are dominantly frothy weathering. According to W. D. Keller this difference is probably due to different mudstone types--the hackly weathering mudstones consist primarily of illitic clay; the frothy weathering mudstones primarily of montmorillonite (Keller, W. D., written communication, 1955).

No abnormal radioactivity other than that previously reported (TEI-590, p. 32-33) was noted in the Ute Mountains area.

Lisbon Valley, Utah-Colorado

By

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

Geologic mapping of the southern part of Spanish Valley and Blue Hill and environs was completed during the period. Spanish Valley is a faulted syncline; the major fault trends northwest through the west-central part of the valley. It is a hinge fault, downthrown to the northeast, the displacement decreasing from more than 1,000 feet just west of the Grand County airport to less than 100 feet at the southeast end of the valley. The valley is filled with alluvial gravels of unknown thickness. The southwest wall of the valley is paralleled by a faulted monocline that

affects rocks of the Glen Canyon group of Triassic, Jurassic, and Jurassic(?) ages (Wingate sandstone, Kayenta formation, and Navajo sandstone). The northeast flank is characterized by normal hinge faults that trend northwesterly. Displacements toward the valley on these high-angle faults range from a few feet to the southeast to a few hundreds of feet to the northeast. The northeast wall of the valley is also a faulted monocline but faults are fewer and have displacements of only a few tens of feet. The gently dipping Navajo sandstone of Jurassic and Jurassic(?) age is sharply flexed at the rim where it dips steeply toward the valley; dips are more gentle near the valley floor. South of Spanish Valley is a complexly folded and faulted area with many normal faults that trend just north of west, as well as the more common northwesterly trending faults. A few prominent faults trend southwesterly and link the northwest-trending faults of the Spanish Valley structures with the northwest end of the Lisbon Valley fault system just south of the upper part of Cane Springs Canyon.

The geology of Spanish Valley is further complicated by the presence of peculiar small collapse structures. Figure 10a shows a portion of Spanish Valley environs and the location of some of the collapse structures. More than 50 of these collapse structures have been located. All but one lie in a narrow northwest-trending belt that is parallel to the major folds and faults of Spanish Valley. The collapses are generally roughly oval in plan, though in detail the boundaries consist of many short straight segments. A brief description of Collapse 1 N, just north of the Grand County line, northeast of the Grand County airport, serves to bring out some general characteristics (fig. 10b). Collapse 1 N is easily seen from U. S. 160 about 6 miles south of Moab; it forms a

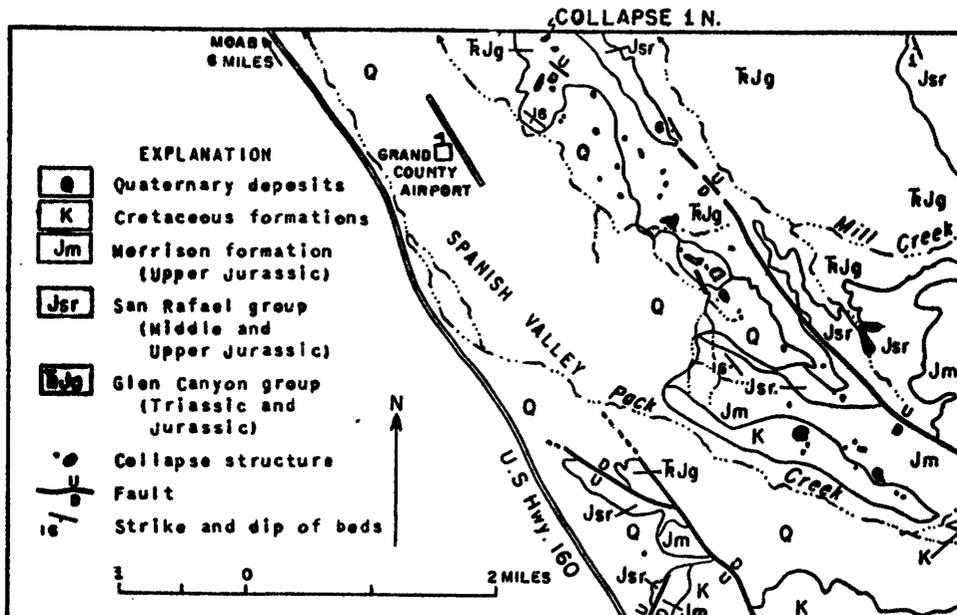


FIG. 10a--INDEX MAP OF SPANISH VALLEY AND ENVIRONS, SHOWING LOCATION OF COLLAPSE STRUCTURES.

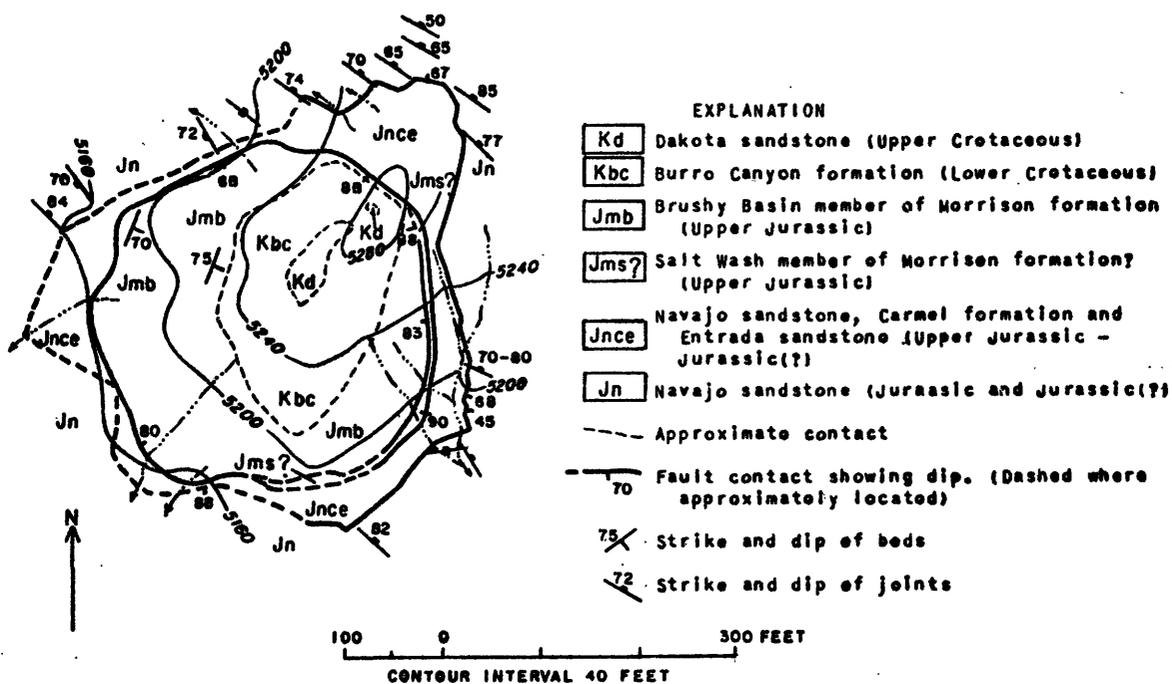


FIG. 10b--SIMPLIFIED GEOLOGIC MAP OF COLLAPSE STRUCTURE 1 N. NORTHEAST RIM OF SPANISH VALLEY, GRAND COUNTY, UTAH.

readily visible light-colored hill on the steeply dipping brown Navajo sandstone. This collapse has a maximum width and length of about 500 feet. In plan it is roughly tear-drop shaped. In places the bordering fault parallels or is a continuation of northwesterly trending joints but in general the border is at a considerable angle to any local structure. The border fault dips outward ( $45^{\circ}$ - $88^{\circ}$ ). Where the border is well-exposed there commonly is a distinctive border breccia consisting of small fragments to large blocks more than a foot across of Navajo sandstone, Carmel formation, and Entrada sandstone with minor amounts of sandstone possibly from the Salt Wash member of the Morrison formation, all of Jurassic age. These fragments are indiscriminately mixed in a sandstone matrix. Neither the border breccia nor border fault show slickensides. Inward from the border is a mappable unit composed of jumbled blocks of Navajo sandstone (Jurassic and Jurassic(?)), Carmel formation (Middle Jurassic), and Entrada sandstone (Upper Jurassic) in a sandstone matrix. This unit is bounded within by a roughly circular fault that dips steeply inward ( $80^{\circ}$ - $90^{\circ}$ ). On the east side is a fault slice containing red mudstone that is probably from the Salt Wash member of the Morrison formation (Upper Jurassic) or the Summerville formation (Upper Jurassic). Large blocks of chert from the Summerville formation and of sandstone from the Salt Wash member are conspicuous in places as float, but none of this material has been with certainty identified in place within the collapse. The fault on the inside of the red mudstone dips steeply inward ( $83^{\circ}$ - $88^{\circ}$ ) and merges north and south with the fault on the inside of the Navajo-Carmel-Entrada unit. Within this is a sequence of steeply dipping gray-green and purplish-gray mudstone representing part of the Brushy Basin

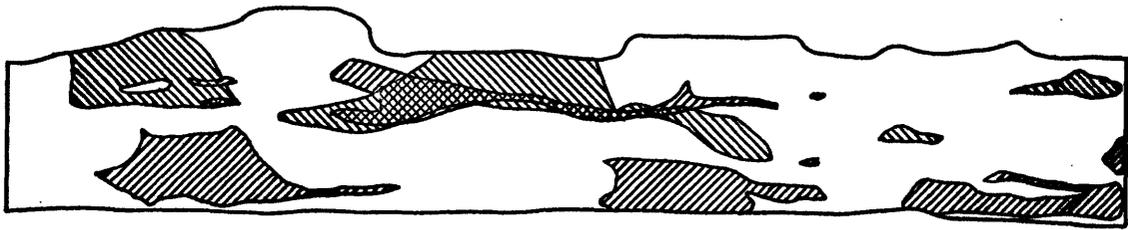
member of the Morrison formation (Upper Jurassic). The Morrison dips from  $68^{\circ}$ - $75^{\circ}$  inward. Above the Brushy Basin is a sequence of green mudstone and light brown sandstone representing the Burro Canyon formation (Lower Cretaceous). The contact between the Burro Canyon and the underlying Morrison is obscure but is believed to be normal. The thinness of the Burro Canyon formation and the Brushy Basin member is probably due in part to slippage along steeply inward-dipping bedding planes. Above the Burro Canyon are broken discontinuous slabs of the basal conglomerate of the Dakota sandstone (Upper Cretaceous). The dips here are apparently nearly flat. The stratigraphic section in the collapse represents more than 1,200 feet and is a measure of the minimum vertical displacement.

Other collapse structures along Spanish Valley are generally similar to the one described, though there are some important differences. The collapse structures range from only a few tens of feet across to more than 700 feet across. Vertical displacement differs greatly: a few hundred feet southeast of Collapse 1 N. is another collapse that involves only rocks from the Navajo and the San Rafael group. A collapse in the Ferron sandstone member of the Mancos shale (Upper Cretaceous) south of the the M4 Ranch on Pack Creek suggests that sandstone actually flowed downward within the collapse. Alteration within and outside of the collapse structures is minor and commonly consists only of dark brown sandstone (probably due to iron?) and sandstone dikes and veinlets.

Parts of the Continental No. 1 incline, the Big Buck, Mi Vida, Little Beaver, La Sal, Far West, Radon, and Cord mines were mapped in detail during the period. These are all large mines in the lower part of the Chinle formation of Upper Triassic age on the rim of Big Indian

Wash and southeastern Lisbon Valley. Figure 11 shows the lithology and ore in part of the Continental No. 1 incline, and except for the unusual abundance of vanadium is typical of many of the mines.

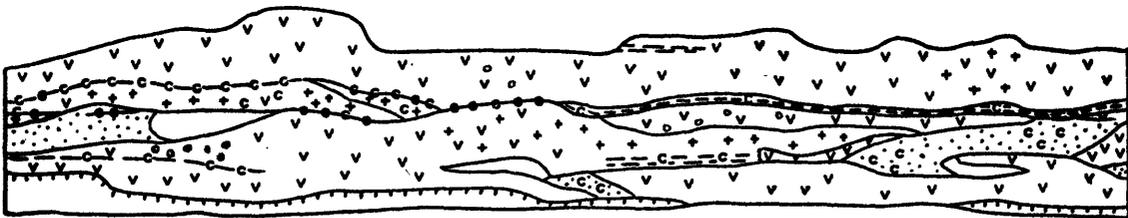
The following points were brought out by the mine studies: (1) most uranium is in sandstone, but grain size of the sandstone does not appear to be an important factor in controlling ore limits; mudstone, siltstone, and claystone are generally barren but there are many local exceptions; (2) there is rarely any discernible difference in lithology at the edge of ore or between high- and low-grade pods of ore; (3) some sandstone containing high-grade uranium has a pinkish to dark reddish tint. This color is apparently due to coloring of the calcite cement; (4) uranium and vanadium where found in the same mine are not generally associated in detail; the concentrations of vanadium tend to be elongated and follow bedding planes and the concentrations of uranium are commonly irregular; (5) molybdenum is an important accessory element; some gray streaks in sandstone, identical in appearance with vanadium, apparently contain only molybdenum minerals, and as there appears to be no obvious way of differentiating the two in hand specimen, this raises the question as to how much molybdenum-bearing rock has been misidentified as vanadium ore; (6) most ore is found at or near the contact between the Chinle formation and the Cutler formation contact but the distribution is very irregular; (7) mineralization frequently extends a few inches into the Cutler formation (Permian) and in some places a few feet into the Cutler; (8) the ore is controlled more closely by bedding in the mines in the northwestern part of the Big Indian Wash area--the Cord, Radon, and Far West mines--than in other mines in the district; (9) commonly, mudstone partings and seams are related to local variations



## EXPLANATION

-  URANIUM (MINERALIZED ROCK WITH RADIOACTIVITY GREATER THAN 2.0 m $\mu$ /hr.)  
 VANADIUM (ROCK COLORED GRAY BY VANADIUM MINERALS)

## A. DISTRIBUTION OF URANIUM AND VANADIUM



## EXPLANATION

- |  |   |
|--|---|
|  CONGLOMERATIC SANDSTONE  |  MUDSTONE PARTING  |
|  COARSE-GRAINED SANDSTONE |  CARBONACEOUS MATERIAL   |
|  MEDIUM-GRAINED SANDSTONE |  UNCONFORMITY BETWEEN CHINLE FORMATION (UPPER TRIASSIC) AND CUTLER FORMATION (PERMIAN) |
|  FINE-GRAINED SANDSTONE   |   |
|  SILTSTONE AND MUDSTONE   |   |

## B. LITHOLOGY



FIG. 11.--WALL MAP SHOWING LITHOLOGY AND DISTRIBUTION OF URANIUM AND VANADIUM MINERALIZED ROCK IN PART OF CONTINENTAL NO. 1 INCLINE, SEC. 36, T.30S., R.25E., S.L.M., SAN JUAN COUNTY, UTAH.

in grade of ore; but not in any general way; that is, the grade may be higher above or below a parting; (10) orange to reddish chert, of epigenetic origin, occurs as small nodules and stringers replacing sandstone in all ore bodies but shows no detailed relation to grade of ore; it occurs in mineralized and unmineralized rock, chiefly in the Chinle but also in the Cutler, but does not occur more than a few hundred feet from ore; (11) visible carbonaceous matter is generally rare to absent and even where locally common to abundant shows little direct relation to presence or grade of ore; some carbonized logs have been largely replaced by uraninite but most are barren; (12) the only fault mapped in an ore body (the Far West mine) is post-ore; no change in ore grade or habit has been detected near the Lisbon Valley fault (Continental No. 1 incline); (13) joints commonly have little effect on the ore; though a few are mineralized the general picture suggests that this is due to recent oxidation after opening up of the mine. Mineralogic data of these studies are reported in another section of this report.

Circle Cliffs, Utah

By

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

Mapping of the northern and central part of the Circle Cliffs area was completed by the end of the report period. This area contains nearly all the exposures of the Shinarump member of the Chinle formation, the stratigraphic unit of greatest economic interest in the Circle Cliffs.

The Shinarump is made up of two major intergrading units; an upper blanket deposit of medium-grained white sandstone that may fill small channels, and a lower unit that fills deep channels cut into the Moenkopi formation. Both units are locally gradational with, or intertongue

with, the overlying Monitor Butte member of the Chinle formation. The Shinarump is disconformable with the underlying Moenkopi formation with local angular unconformities; two units present in the upper part of the Moenkopi can be traced over most of the outcrop area except for places where they are cut out by deep channeling into the Moenkopi. The major Shinarump drainage-channel fill forms the Stud Horse Peaks and trends northwest in the northern part of the area. This drainage was braided at the north end of the peaks where it was about 8,000 feet wide. Most of the other channels, especially those to the east of this system, probably joined this major drainage. To date, the sandstone fill of the smaller channels seems more favorable for ore deposits than does the rock filling this major drainage channel.

The Sinbad limestone member of the Moenkopi formation, probably equivalent to the Timpoweap limestone of the Grand Canyon-Vermillion Cliffs region, is present in all of the area except the central-eastern part. This unit, a brown-yellow dolomite or dolomitic limestone, is underlain by a considerable thickness of red siltstone in the Capitol Reef area, but in Circle Cliffs is underlain by only a few feet of green-gray siltstone, and that only in the northern part of the area. This unit frequently fills depressions in the Kaibab formation and locally is channeled by the overlying Moenkopi siltstone. It is an excellent unit to study when tracing minor faults because its nearly continuous outcrop is practically devoid of cover.

The Salt Wash member of the Morrison formation is the unit of greatest economic importance in the Halls Creek area. It is a white pebbly sandstone composed of lenticular beds separated by mudstone. The upper part of the underlying red Summerville siltstone is similar in

lithology, but a fairly continuous limy chert bed separates the two units. The contact between the Salt Wash and the Brushy Basin members of the Morrison is placed at the base of a pebble conglomerate containing very abundant red and green chert--in contrast to the gray and black chert normally predominating in Salt Wash sandstones of this area. Uranium minerals are found locally in the Salt Wash member, generally near the base. Some exposures of this sandstone have unusually high concentrations of selenium. Areas of high selenium content are indicated by abundant growth of *Astragalus* (Loco weed).

The Dakota sandstone (Cretaceous), as mapped by C. B. Hunt and the present party, is divisible into two distinct units; the lower, a white to brown carbonaceous sandstone with minor chert pebble conglomerate, interbedded with coaly mudstone and siltstone; the upper, a brown fossiliferous (oyster shells) sandstone interbedded with gray mudstone. The upper unit is more nearly akin to the overlying marine Tununk member of the Mancos shale (Cretaceous), and the lower unit is the more typical Dakota sandstone, which here is a combination fluvial-coaly swamp deposit. None of the coaly mudstone in the Dakota is of commercial quality.

The following report on uranium ore deposits in Circle Cliffs was published during the report period:

Davidson, E. S., 1956, The Rainy Day uranium deposits, Garfield County, Utah (abstract): Geol. Soc. America Bull. (69th Annual Meeting - GSA, November 1956).

## Abajo Mountains, Utah

By

I. J. Witkind

The Abajo Mountains consist of a central igneous core flanked on the north, east, and south by domelike structures interpreted as laccoliths (TEI-620, p. 72).

Two major grabens traverse the area. The northern one, known as the Shay graben, truncates the north flank of Shay Mountain. This graben is about half a mile wide, and can be traced about N. 65° W. to the southwest beyond the limits of the Abajo Mountains area. The southern graben, known as the Verdure graben, truncates the south flank of South Peak. This graben is about half a mile wide and can be traced about N. 80° W. to the west beyond the limits of the mapped area. The northwest trend of these grabens is paralleled by a zone in which uranium-vanadium ore deposits occur in thickened sandstone lenses of the Salt Wash member of the Morrison formation. This zone of ground favorable for ore deposits is about 4 miles wide and trends N. 80° W. across the northeast corner of the mapped area (TEI-490, p. 38). Whether this parallelism of the grabens and the favorable ground is fortuitous or meaningful is unknown as yet.

The Carmel formation of the San Rafael group (Late Jurassic) may be separated into two units in the Abajo Mountains area by a tongue of the Entrada sandstone. Baker (1933, p. 48) discussing the Moab district, considers the Carmel to consist of 20 to 70 feet of soft red thin-bedded sandstone, mudstone, and sandy shale beds separating the underlying Navajo and the overlying Entrada sandstones. However, the sequence is well-exposed along Harts Draw (fig. 12) in the Abajo Mountains where the

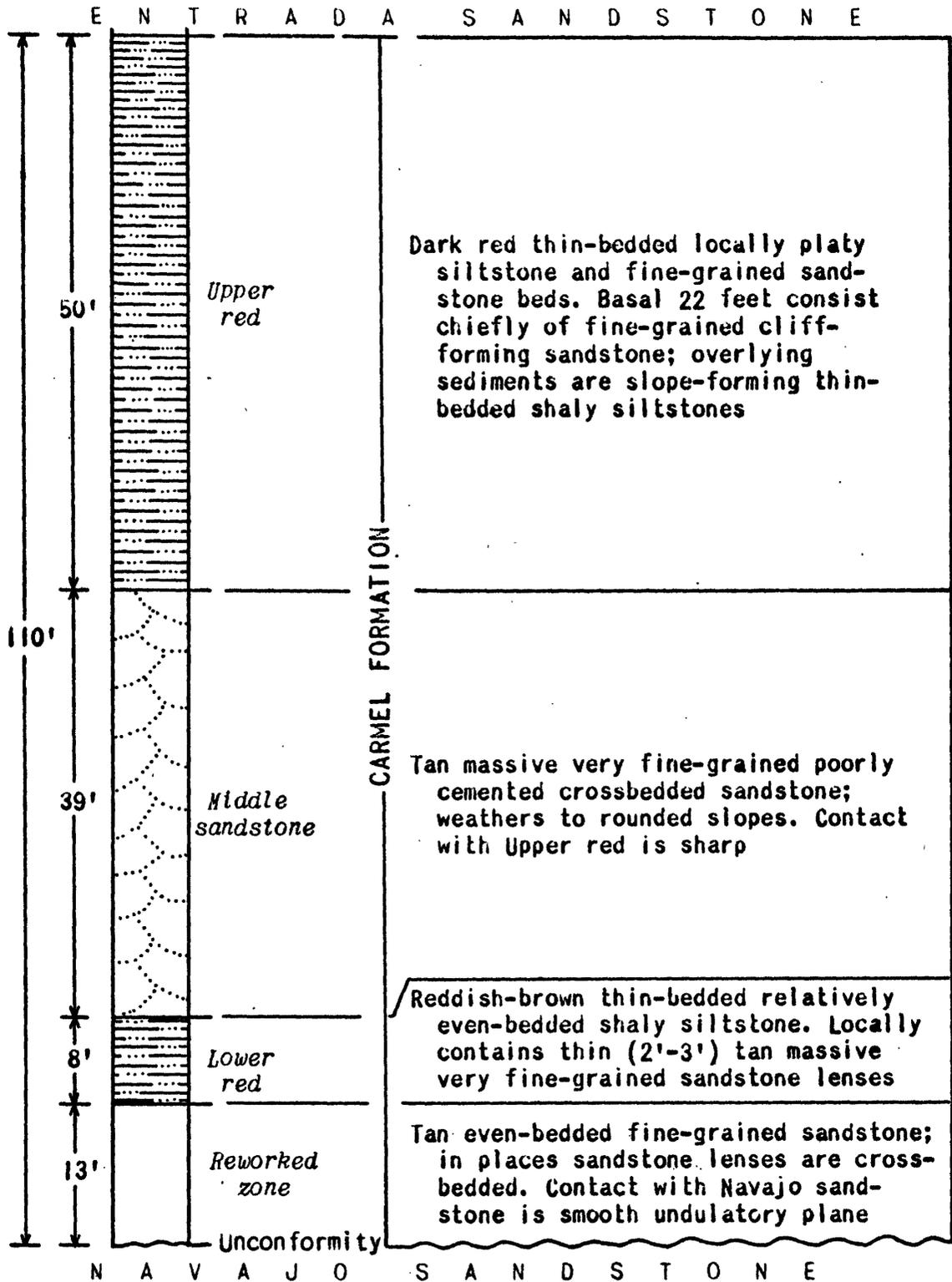


FIG. 12.--STRATIGRAPHIC SECTION OF THE CARMEL FORMATION AT HART'S DRAW, ABAJO MOUNTAINS AREA, UTAH,

Carmel formation probably consists of two red siltstone units separated by a massive crossbedded sandstone, The lower part of this Carmel sequence is a fine-grained sandstone that may represent reworked Navajo sandstone. To the north, the uppermost red unit thins and grades out and in the Lisbon Valley area the massive crossbedded sandstone cannot be distinguished from the Entrada (Weir, G. W., oral communication).

#### Reference

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

Sage Plain area, Utah and Colorado

By

L. C. Huff and F. G. Lesure

Detailed mapping of the uranium-vanadium ore deposits in Montezuma Canyon and sampling for geochemical studies occupied most of the field season. Geologic mapping of the six quadrangles surrounding Montezuma Canyon was field checked at critical places in preparation for publication. Most of the other uranium mines and prospects in the Sage Plain area were revisited to examine new work and to check the mine names shown on the maps.

The Middle Montezuma mine group (fig. 13) was mapped on a scale of 1:7,200 to show the relationships between the ore bodies, the ore-bearing sandstone, and the contacts of the Salt Wash member of the Morrison formation of Jurassic age. Nearly all of these mines and prospects 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 length of 13,000 feet. At both ends the lens grades into thinner sandstones separated by tongues of mudstone. The shape of this lens is shown in

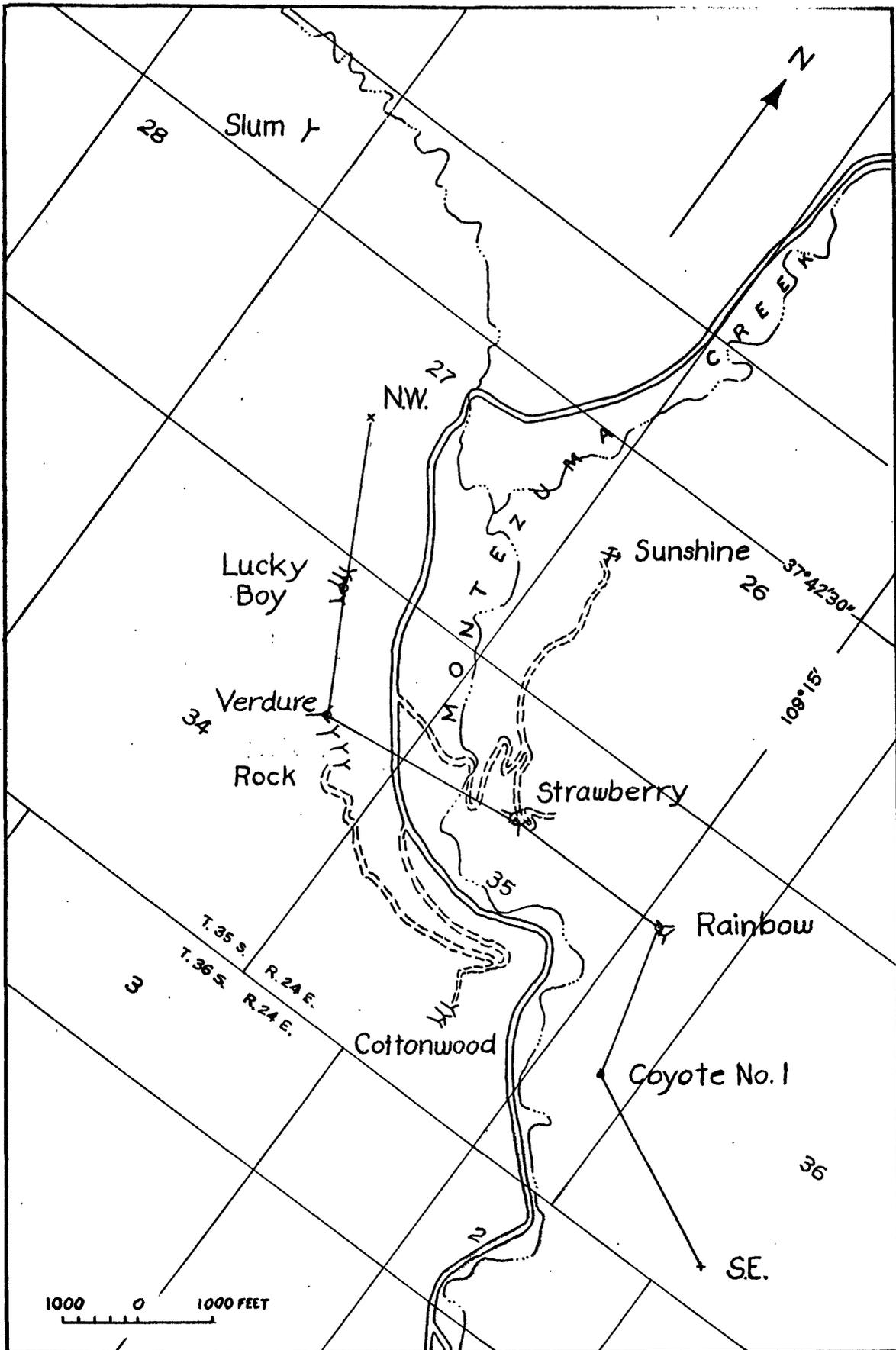


FIG. 13.--INDEX MAP OF MIDDLE MONTEZUMA CANYON, SAN JUAN COUNTY, UTAH, SHOWING LOCATION OF PRINCIPAL URANIUM-VANADIUM MINES, AND THE LINE OF SECTION (FIG. 14 ).

somewhat simplified form in an accompanying cross-section (fig. 14). Some ore deposits like the Lucky Boy and the Coyote No. 1 are near the edges of the lens whereas others like the Strawberry, Rainbow, and Verdure are more centrally located. Some ore deposits like the Verdure and the Rainbow are near the top of the sandstone lens; the Strawberry deposit is near the middle of the lens; and other ore deposits like the Coyote No. 1 and the Lucky Boy are near the base of the sandstone host rock.

Mine mapping on a scale of 1:240 revealed a systematic zoning of minerals in the ore deposits. The zones are most easily recognized in small uranium-vanadium deposits. The small deposits 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 definite zones termed the ore zone, the brown zone, and the gray zone. The ore zone is a layer or "shell" of sandstone impregnated with uranium-vanadium minerals. The brown zone, which occurs on one side of the ore layer or "shell", is an iron-stained, porous sandstone commonly containing abundant carbonaceous material or abundant plant fragments. The gray zone, which occurs on the other side of the ore layer from the brown zone, is a light gray sandstone tightly cemented with carbonate and commonly freckled with limonitic specks. Radiometric study and preliminary analyses of these zones indicate a sharp reduction in the quantity of ore minerals in both the brown and gray zones as compared to the ore zone.

The ore zone is typically a continuous curved layer or "shell" of rounded or ellipsoidal shape that completely envelops the brown zone and is in turn completely enveloped by the gray zone (figs. 15 and 16). The

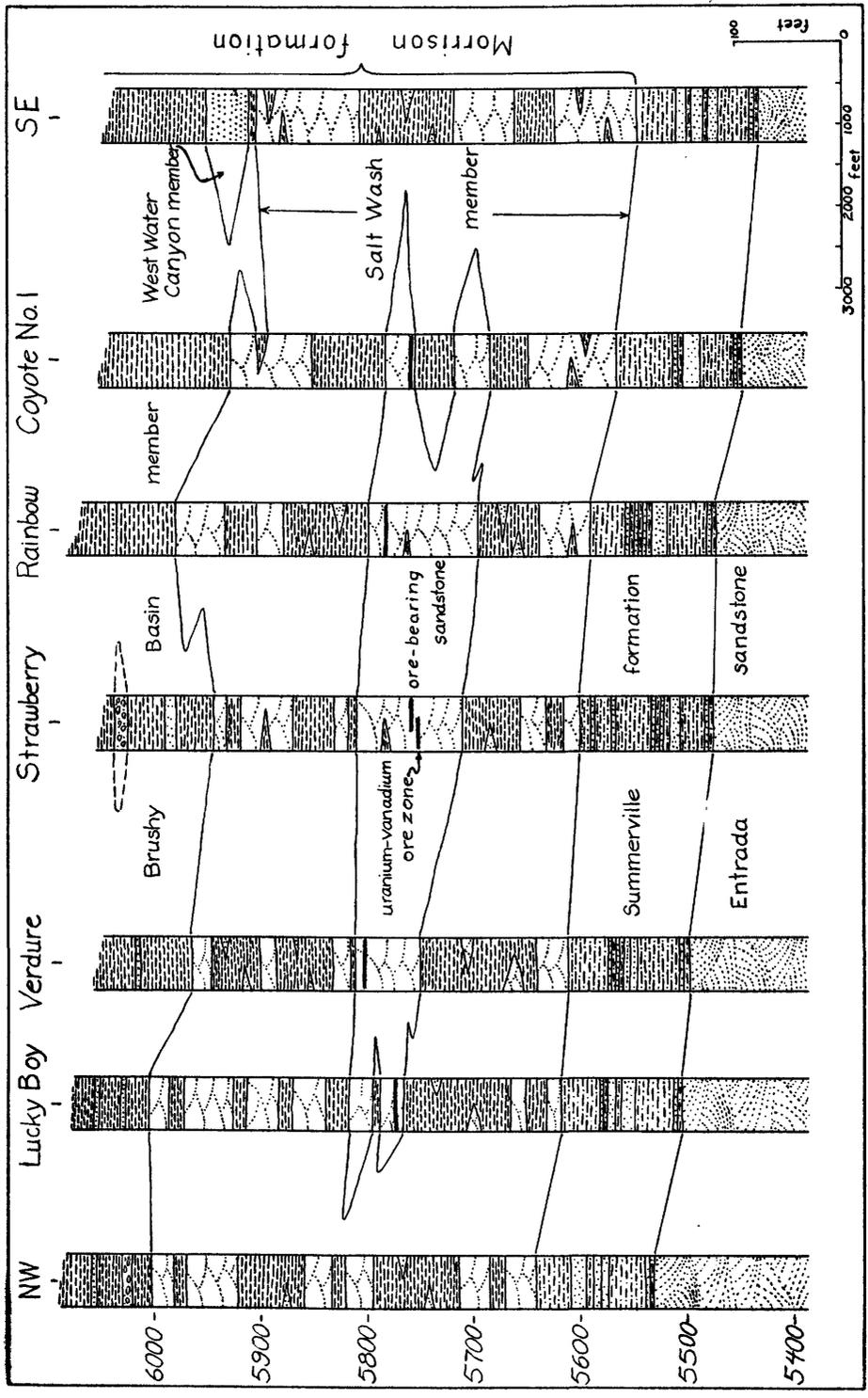


Fig. 14. --STRATIGRAPHIC SECTIONS IN MIDDLE MONTEZUMA CANYON SHOWING LOCATION OF ORE BODIES WITHIN THE ORE-BEARING SANDSTONE.

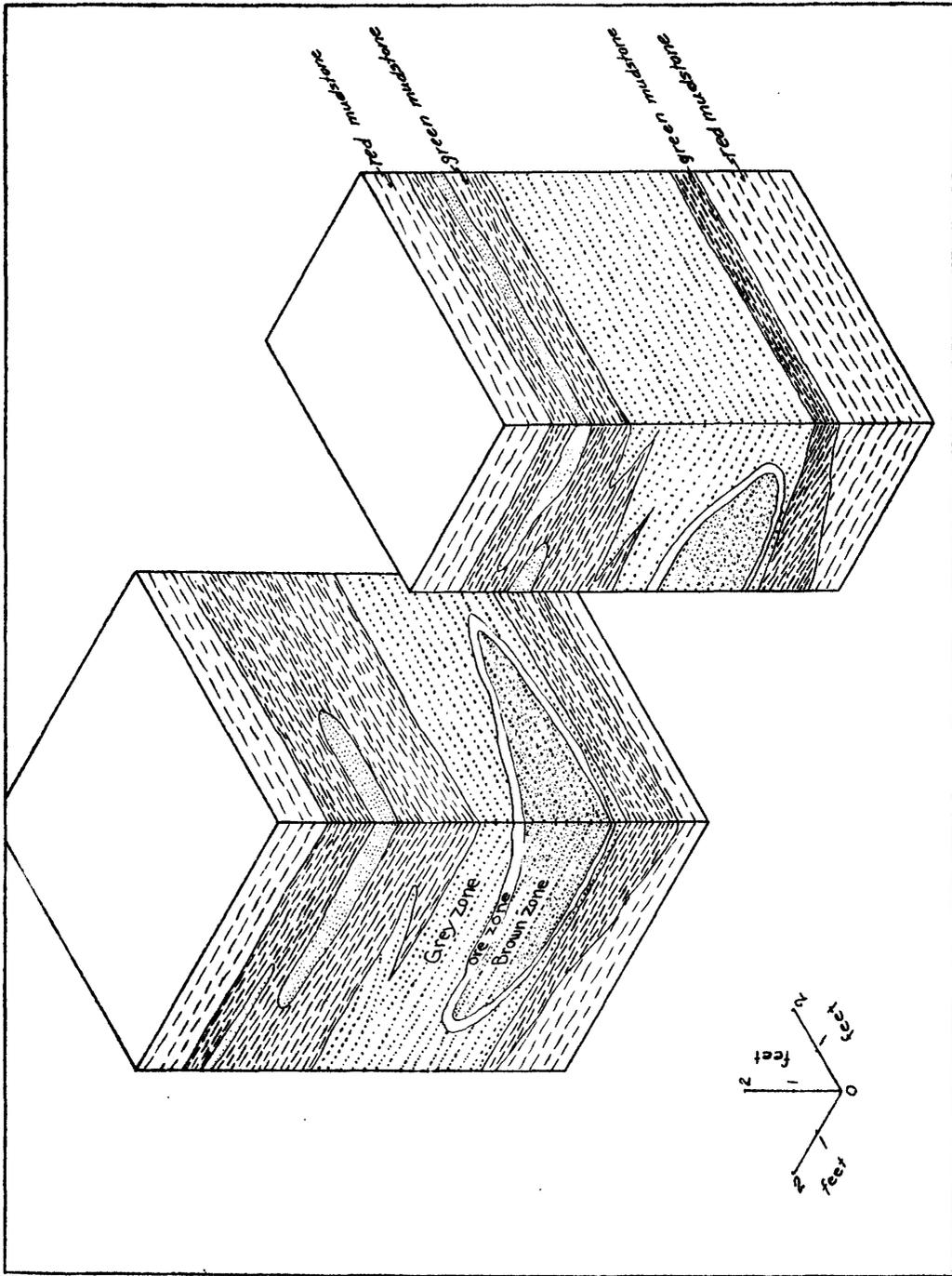


Fig. 15.--GENERALIZED BLOCK DIAGRAM OF A SMALL URANIUM-VANADIUM DEPOSIT, MOAB URANIUM CLAIM, UPPER MONTEZUMA CANYON, SAN JUAN COUNTY, UTAH.

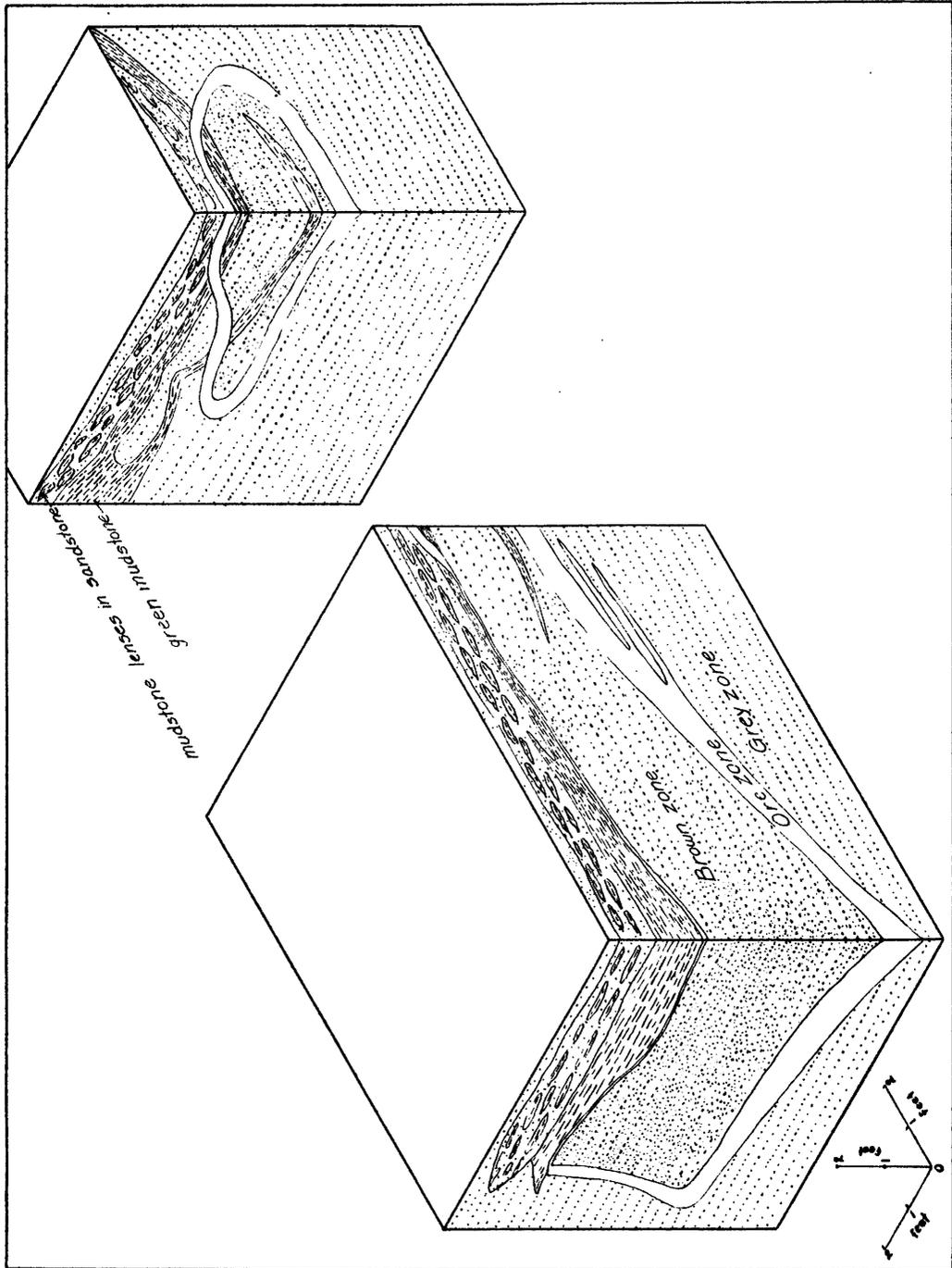


Fig. 16.--GENERALIZED BLOCK DIAGRAM OF A SMALL URANIUM-VANADIUM DEPOSIT, BLUE JAY NO. 3 CLAIM, MONUMENT CANYON, SAN JUAN COUNTY, UTAH. NOTE THINNING OF UPPER MINERALIZED ZONE BENEATH MUDSTONE LAYER.

ends or sides of the ore zone have the characteristic roll forms of the ore that have been described elsewhere on the Plateau. The ore zone tends to be thinnest where close to the mudstone and thickest where both contacts are either along the ends or on the top or bottom of the ore lens (figs. 15 and 16).

In homogeneous, well-sorted sandstone, the ore has a smoothly curved roll form (fig. 15) but both mudstone layers and logs create local irregularities in the shape of the zone (fig. 16). In many deposits the ore layer follows closely a sandstone-mudstone contact. Logs or other concentrations of organic debris commonly form local projections of the ore surface. Several ore-bearing logs were observed close to but completely outside a roll surface.

Orange Cliffs, Utah

By

F. A. McKeown, P. P. Orkild, and R. W. Hallagan

Strip mapping of all Triassic formations in the Orange Cliffs has been completed. Since June a Kelsh plotter has been used for photo-geologic mapping concurrently with field mapping. The chief reason for using the Kelsh was to map post- and pre-Triassic rocks that are in areas of difficult accessibility; however, it is expedient to map all contacts including certain bleached zones and joints with it. Plane-table, inspection, and altimeter methods combined with the Kelsh mapping in specific field checks provide multiple crosschecks during compilation of the maps. Though most of the map compilation and study of samples and data remains to be done, some tentative inferences may be made regarding the relationships of the observed geologic features and the occurrence of uranium deposits.

The apparent regional relationship of uranium occurrences with purple-white alteration (TEI-590, p. 44-49), recognized by Finch (1953) is further confirmed by mapping in the Orange Cliffs area. Further, silicification in the form of red chert (TEI-590, p. 44-49) is nearly coextensive with the purple-white alteration. Figure 17 shows approximately the areas where purple-white alteration is common, and the location of most of the known occurrences of uranium; it also shows the area that contains thick bleached zones in the Moenkopi formation. These bleached zones are the same or similar to the red-buff alteration (TEI-590, p. 44-49) that commonly occurs along fractures and faults in the Moenkopi and Cutler formations in the southern part of the Orange Cliffs area. Petroleum and much iron sulfide occur in the thicker parts of some of the bleached zones. Bleached rock is also common in the part of the Moenkopi formation that overlies the generally petroliferous White Rim member of the Cutler formation. Much gypsum occurs as veinlets and as thin contorted beds that are coextensive with the thick bleached zones. Figure 18 shows in vertical section the position of the two types of alteration.

The distribution of uranium occurrences, purple-white alteration, silicification, and red-buff alteration, i.e., bleaching, may be fortuitous. However, incomplete compilation of structural and stratigraphic data indicates that the area of red-buff alteration occurs where the Moenkopi formation is gypsiferous, weathers to a lighter reddish-brown color than is normal, has more fine-grained clastics, and is thicker than to the south; also a pre-Chinle structurally low area is present.

Interpretation and correlation of the alteration, stratigraphic, and structural features is not yet justified. The alteration features,

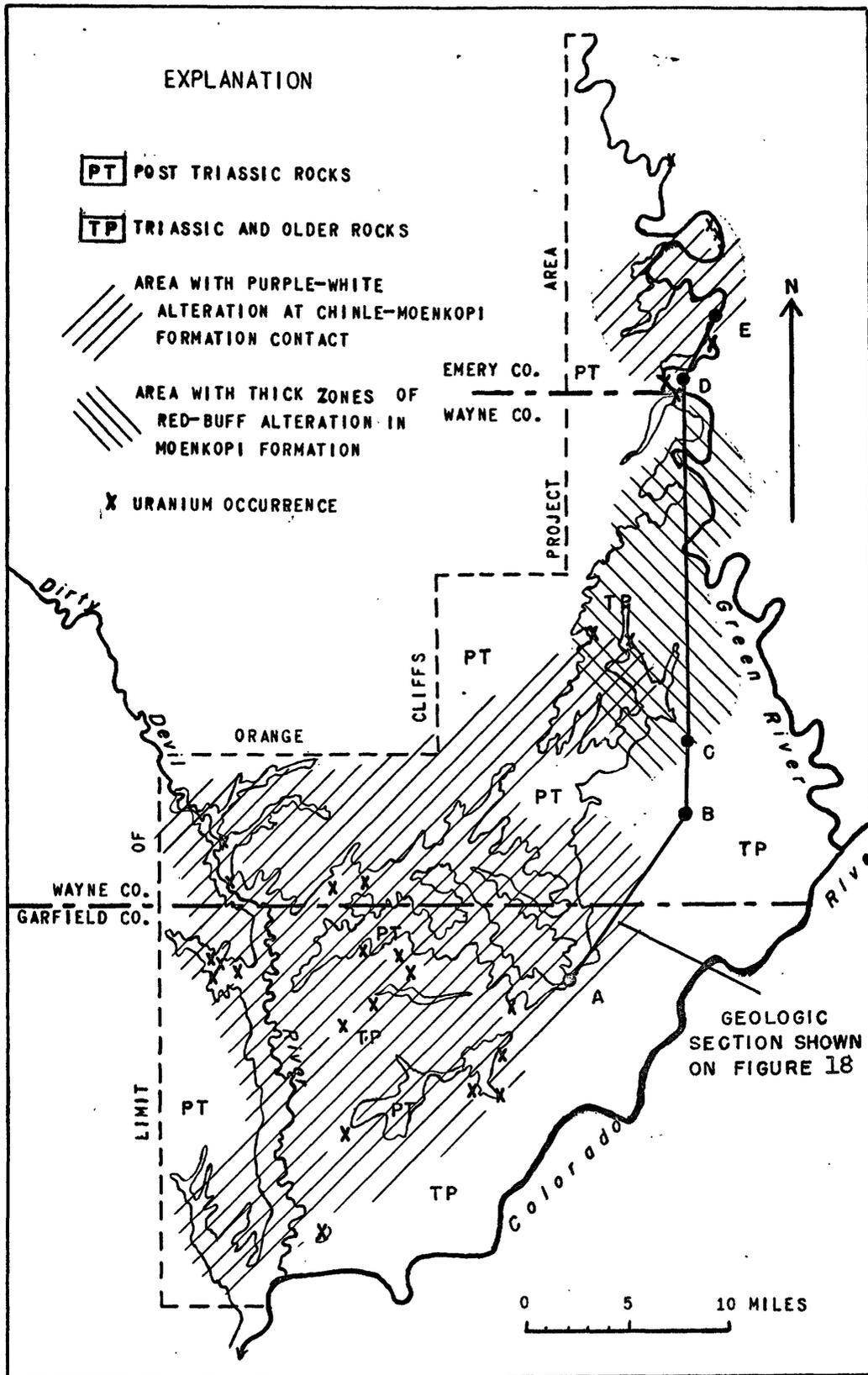


FIG. 17.—INDEX MAP OF THE ORANGE CLIFFS AREA, UTAH, SHOWING LINE OF SECTION FOR FIGURE 18.

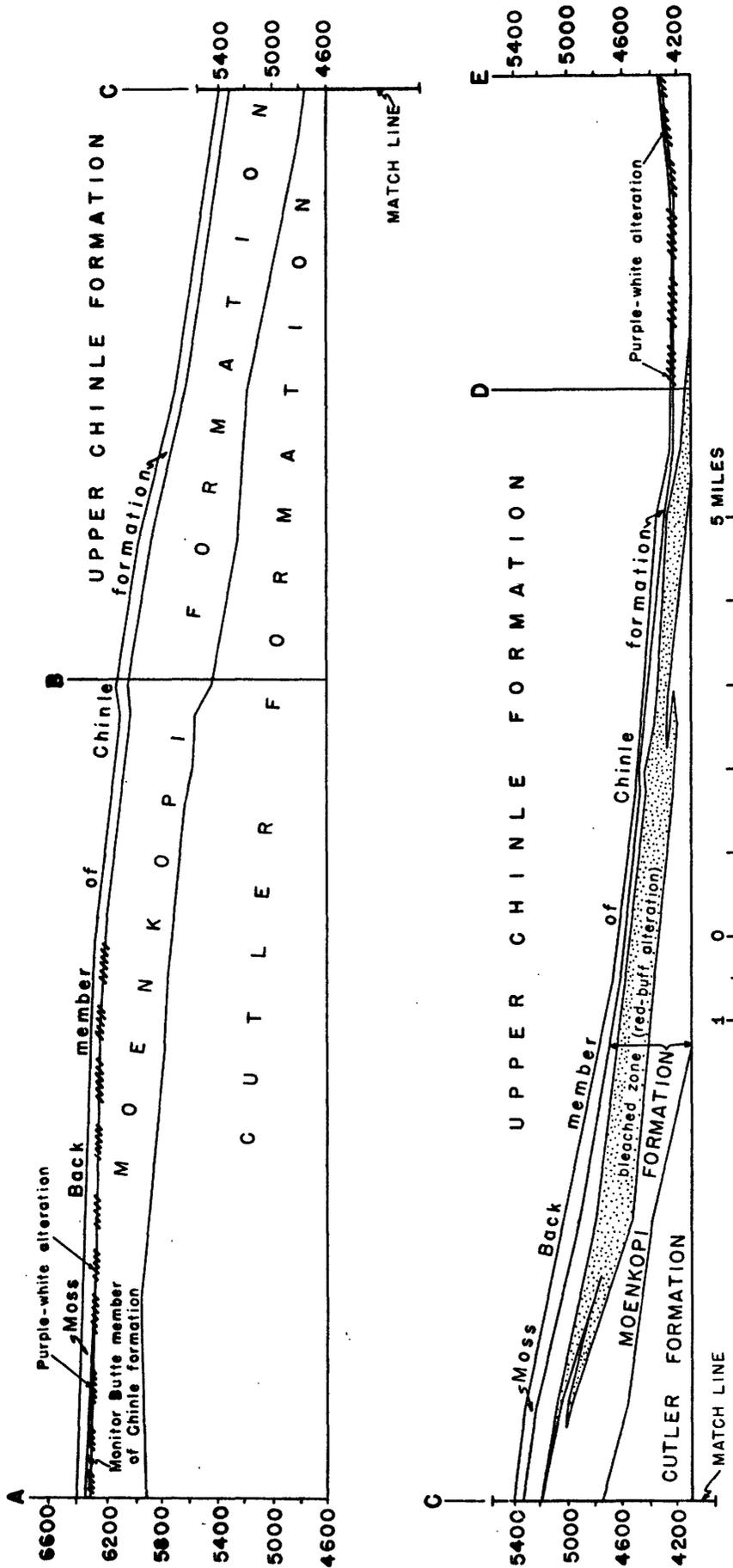


Fig. 18--DIAGRAMATIC CROSS SECTIONS SHOWING STRATIGRAPHIC POSITIONS OF RED-BUFF AND PURPLE-WHITE ALTERED ZONES IN THE MOENKOPI FORMATION, ORANGE CLIFFS AREA, UTAH.

however, are believed to be possible regional guides to areas where uranium deposits may occur, and may also provide clues to the problems relative to the origin of the deposits.

#### Reference

Finch, W. I., May 1953, Geologic aspects of the resource appraisal of uranium deposits in pre-Morrison formations of the Colorado Plateau: U. S. Geol. Survey, TEI-328A, Issued by the U. S. Atomic Energy Comm., Tech. Inf. Service, Oak Ridge.

Grants area, New Mexico

By

R. E. Thaden and E. S. Santos

Areal mapping of the 360 square miles in the Grants project area is essentially complete. Compilation on an enlarged Army Map Service planimetric base has been abandoned in favor of a preliminary Geological Survey topographic base, available in a few months for the area south of 35° 15' N. and for the area north of that line by July or early August 1957.

Lateral changes in the lithic character of the sedimentary units across the area are very rapid and are related to the southern margin of the San Juan basin and the bounding Zuni highland. The Morrison formation of Late Jurassic age (and its lateral partial equivalents) thickens and is composed of increasingly coarse sediments toward the west side of the basin, but southward from the town of Grants it pinches against an increasingly thicker Bluff sandstone. The field relations indicate that not only does the Morrison pinch against the Bluff, but it is also cut out entirely by pre-Dakota erosion south of a point three miles south of the U. S. Highway 66 overpass. In this vicinity, the Dakota sandstone also thins abruptly against the Bluff and the Mancos shale, which is

largely shale with six discontinuous sandstone lenses in its lower part near Ambrosia Lake, but largely sandstone in the southern part of the mapped area. The Todilto limestone also becomes sandy in its lower part south of the town of Grants and is a quartzite pebble conglomerate south of the mapped area.

Recent detailed mapping in the Poison Canyon area, together with data gathered elsewhere, indicates that the following general interpretations may be helpful in formulating a workable hypothesis to explain the formation and position of the ore deposits:

1. Faults trending N. 30° W. and N. 30° E. are perhaps the oldest faults in the area, predating the ore deposits.
2. Faults trending N. 80° E. may have formed next, also predating the ore.
3. Faults trending about N. 45° E. may be pre-ore, but if so, have had renewed movement in relatively recent times. Several such faults offset the late Pliocene flows emanating from the Mt. Taylor volcanic center.
4. Uranium-bearing fluids (gases or liquids) from an unknown source may have used the N. 80° E. faults as channelways before migrating as linear fronts updip or, more likely, downdip in the sedimentary rocks.
5. The ore precipitated under reducing conditions in certain favorable units and at certain favorable localities within these units. Many ore bodies formed in the Todilto limestone at, or near, areas of abundant small anticlines. There is a pronounced tendency for ore bodies to form where the anticlines are of such magnitude as to involve the top few feet of the underlying Entrada sandstone. Such folds trapped not only the migrating mineral-bearing fluid, but also petroliferous or humic

fluids that had previously migrated through the Todilto. The petroleumiferous or humic fluids may have acted as precipitants of the primary ore minerals.

Many groups of ore bodies in the Todilto are in zones trending about N. 80° E. Each body is also elongated either N. 80° E. or down-dip (generally northerly). Certain ore bodies or parts thereof, however, may conform to the shape and orientation of individual anticlines on or near which the ore precipitated, or to the orientation of other pre-existing fault sets (e.g., N. 30° W., N. 30° E.).

Favorable localities for ore bodies in the Morrison formation appear to be structural synclines or synclinoria, and traps developed where the earliest faults have placed the ore-bearing Westwater Canyon sandstone member against less permeable rocks, particularly where the Westwater Canyon dips toward such faults. The large amount of organic material in the Westwater Canyon sandstone member, probably carbonized fluids derived from plants, has apparently migrated downdip like the ore-bearing fluids to structural traps. This organic material is now found in association with the ore and probably was the main precipitant of the primary ore minerals.

At the Poison Canyon mine the ore is largely confined to areas of relatively flat dip, low on the flanks of a poorly defined, eastward plunging, asymmetric syncline. The syncline appears to curve from about N-S to about N. 70° E. eastward across Poison Canyon, to be about 1,500 feet in width, and to flatten from about 35 feet amplitude at the west end of Poison Canyon to about 20 feet where it disappears below the cliff of Dakota sandstone. It may be a fold reflecting a nearly easterly trending strike fault at depth which displaced the northern block at least 700 feet to the east.

There are many possible sedimentary controls for ore, but most are of unknown significance. It is obvious that the presence of organic material in the Todilto limestone and in the Westwater Canyon sandstone member of the Morrison formation is an important ore control. Consistent with the structural controls enumerated above, the ore bodies formed in the Westwater Canyon where the unit is thick as in the Ambrosia Lake area and also where the unit begins to tongue and become clayey as in the Poison Canyon area. Ore has not been found in the Westwater Canyon where the sandstone is in many tongues or where it is less than about 100 feet thick. An interesting fact observed in the Poison Canyon area which might be useful as a guide in prospecting for ore is that the Brushy Basin shale member, normally pale bluish, becomes increasingly purplish in zones and streaks near the ore.

6. Probable minor post-ore leaching has formed halos of Ca, Mn, Ni, Y, and V elements above and also downdip from the Morrison ore bodies.

Laguna area, New Mexico

By

R. H. Moench, J. S. Schlee, and F. S. Hensley

Field mapping in the Laguna area has provided much data concerning the inter-relationships between the ore deposits, fold structures, fracture system and igneous rocks, as well as the relationships of the major ore-bearing units--the Jackpile sandstone unit of the Morrison formation and Todilto limestone--to the pre-Dakota folds.

The more important results of the recent field season include:

(1) Pre-Dakota folds (TEI-590, p. 60) trend in two general directions. The largest folds trend northeast to east; lesser folds are at about right angles to this direction, or slightly west of north. It is suspected that

the major system contains folds that are considerably larger--with breadths of several miles and heights of several hundred feet--than those actually mapped. Minor folds and linear structures in the Todilto limestone conform to the two major directions, 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.

(2) With local variations the fracture pattern is remarkably consistent throughout the area. A north-south set of joints is nearly ubiquitous; most faults, diabasic dikes, and veins of relict pyrite (see 4) follow this direction. A second joint set, striking nearly east, is persistent and locally contains relict pyrite. A number of joint sets bisect the north- and east-trending joint sets.

From structural evidence it is interpreted that the fracture system developed over a period of time ranging from the development of the Rio Grande trough (Miocene?) to the Recent. The north-south set is probably a cross set, resulting from tension; the east-west set is probably a longitudinal set, the northeast and northwest sets are diagonal, and probably occupy shear positions in relation to the regional stresses.

(3) The igneous rocks are divided, for convenience, into three series--the diabasic sills and dikes, the Mt. Taylor volcanics, and the later flows and related volcanic plugs.

The diabasic (gabbroic, dioritic, local aplitic veins) sills and dikes are possibly the oldest of the three series, though their actual age relations to the Mt. Taylor volcanics are not known. Structural evidence indicates that the diabasic rocks probably were intruded during an early

stage (Miocene?) in the development of the Rio Grande trough. From linear features on the tops and bottoms of the sills, and the relation of country rock "splits" and inclusions, the sills, at least locally, were intruded from the east of their present exposure--from the region of the Rio Grande trough, and not from Mt. Taylor.

The Mt. Taylor volcanics (Hunt, 1937) contain a rhyolite-trachyte series, overlain by a latite series, all cut by dikes of a porphyritic andesite series (Hunt, 1937, p. 58-63). During the recent field season rocks of these series were sampled for further petrographic and geochemical studies, to determine their relationships to the other igneous rocks in the region.

The later flows range in age from slightly later than the porphyritic andesite series of Mt. Taylor to the time of the development of the present level of stream erosion. Fifteen types of later flows are recognized, distinguished on the basis of composition, and relative age as determined by stratigraphic position and their relation to erosion surfaces past and present. Probably the compositions range from dacites(?) to olivine basalts. Pelecypods in a limestone found between two of the more important flows may provide a clue as to age.

(4) There is some evidence for minor sulfide mineralization contemporaneous with the development of the regional fracture system. Pyrite, mainly as hematite pseudomorphs after pyrite, is locally abundant as veins generally less than 2 inches thick in the north-south joints and faults, and locally in the east-trending and diagonal joints. Pyrite concretions, locally abundant in the Bluff, Entrada and Dakota sandstones, commonly are aligned along the north- and east-trending fractures. The relationship between the vein sulfides and the sulfides in the uranium deposits, and

between the latter and the black uranium minerals is not known. Megascopic examination suggests that the sulfides are paragenetically later than the black uranium minerals.

(5) The bulk of the Jackpile sandstone, the uppermost unit in the Morrison formation and the main ore-bearing unit in the area, is confined to a broad belt that extends northeast to east across the central part of the area. The lowermost Morrison arkosic sandstone, possibly correlative with the Westwater Canyon member, locally thickens within this belt. It is tentatively interpreted that the deposition of sandstones of the Westwater type and the Jackpile type was controlled, in part, by the contemporaneous development of the pre-Dakota fold system. Knowledge of this belt should delineate favorable areas for prospecting.

(6) The structural types of uranium deposits were described in a previous report (TEI-590, p. 60). Additional work has revealed that in the Sandy mine area the zone of mineralization--consisting of many small deposits--is confined to the crest and steep flank of a monoclinial fold. Most of the individual deposits in the Entrada sandstone and Todilto limestone are localized by minor folds. The Entrada deposits are in the form of rolls, having an S-shape in section, and apparently are independent of crossbedding structures. Sulfides and possibly pitchblende or coffinite occur locally along north-striking joints so that the sulfide and uranium deposition may not be widely separated in time.

The blanketlike ore bodies of the Jackpile mine occur about one-third of the distance upward from the base of the Jackpile sandstone. The bodies are crudely lenticular in section, but strongly layered. The ore appears to be mainly in the better sorted and more crossbedded sandstone. Because

of lack of marker beds pre-Dakota fold structures have not been recognized in the Jackpile mine, but the main ore body is elongated about parallel to the minor (north-northwest) direction of the pre-Dakota fold system. A post-Dakota structural terrace passes through the south end of the Jackpile mine but is not parallel to the elongation of the ore body. As in the Sandy mine area the diabasic sills are later than the ore and there is some evidence for some jointing prior to the mineralization.

### Reference

Hunt, C. B., 1937, Igneous geology and structure of the Mt. Taylor volcanic field, New Mexico: Prof. Paper 189-B.

Photogeology

By

W. A. Fischer

Photogeologic mapping of the Colorado Plateau area continued largely as in previous report periods with the Kelsh plotter being used in conjunction with high-altitude photography (approximately 1:60,000 scale), although the amount of effort devoted to this project was decreased. Initiation of photogeologic mapping at a scale of 1:62,500 contributory to the Survey's 1:250,000-scale mapping program of the Colorado Plateau was delayed by lack of photography, which was not delivered until late August, but this work is now in progress and the equivalent of approximately fourteen 7-1/2 minute quadrangles in southwestern Colorado have been interpreted and have been transferred or are in process of transfer to base maps. Part of the summer field season was spent obtaining stratigraphic information preliminary to interpretation and compilation of geology for the 1:250,000 mapping program.

Two photogeology studies in close cooperation with field projects continued through the report period. Kelsh-plotter procedures were used to compile photogeologic maps of the Orange Cliffs area, central Utah, which served as preliminary maps for final field geologic study of formations ranging from Permian to Cretaceous in age. The photogeologist assigned to this project participates directly in the field investigations. Similar photogeologic methods were employed in conjunction with the Inyan Kara project, Wyoming, where detailed mapping of the Inyan Kara group of Cretaceous age is being carried out.

During the report period, 18 maps of 7-1/2 minute quadrangles were completed at a scale of 1:24,000, and 30 such maps, completed in this and previous report periods, were published by the Geological Survey in the Miscellaneous Geologic Investigations map series. These maps are listed below by number and title:

- I-169 - Lees Ferry SE quadrangle, Coconino County, Arizona
- I-170 - White Canyon-4 quadrangle, San Juan and Garfield Counties, Utah
- I-171 - Paria Plateau SW quadrangle, Coconino County, Arizona
- I-172 - Mount Peale-4 quadrangle, San Juan County, Utah
- I-173 - Mount Peale-6 quadrangle, San Juan County, Utah
- I-174 - Mount Peale-8 quadrangle, San Juan County, Utah, and Montrose County, Colorado
- I-176 - Mount Peale-16 quadrangle, San Juan County, Utah, and San Miguel County, Colorado
- I-177 - Emery-8 quadrangle, Emery County, Utah
- I-178 - Orange Cliffs-13 quadrangle, Garfield County, Utah
- I-179 - Virgin SE quadrangle, Washington County, Utah, and Mohave County, Arizona
- I-180 - Carlisle-1 quadrangle, San Juan County, Utah
- I-181 - Bluff-3 quadrangle, San Juan County, Utah
- I-182 - Paria Plateau NW quadrangle, Coconino County, Arizona
- I-183 - Mount Peale-7 quadrangle, San Juan County, Utah
- I-184 - Navajo Mountain-13 quadrangle, Kane and San Juan Counties, Utah, and Coconino County, Arizona
- I-185 - Navajo Mountain-15 quadrangle, San Juan County, Utah, and Navajo County, Arizona
- I-186 - Tidwell-10 quadrangle, Emery County, Utah
- I-187 - Orange Cliffs-11 quadrangle, Wayne and Garfield Counties, Utah

- I-188 - Orderville Canyon NW quadrangle, Kane and Washington Counties, Utah
- I-189 - Lees Ferry SW quadrangle, Coconino County, Arizona
- I-190 - Emmett Wash NE quadrangle, Coconino County, Arizona
- I-191 - Paria Plateau SE quadrangle, Coconino County, Arizona
- I-192 - Emmett Wash NW quadrangle, Coconino County, Arizona
- I-193 - Tanner Wash NW quadrangle, Coconino County, Arizona
- I-194 - Jacob Lake NE quadrangle, Coconino County, Arizona
- I-195 - White Canyon-3 quadrangle, San Juan and Garfield Counties, Utah
- I-198 - House Rock Spring NE quadrangle, Coconino County, Arizona
- I-199 - House Rock Spring SE quadrangle, Coconino County, Arizona
- I-227 - Tidwell-11 quadrangle, Emery County, Utah
- I-228 - Paria Plateau NE quadrangle, Coconino County, Arizona

### Central region

#### Southern Powder River Basin

By

W. N. Sharp and A. B. Gibbons

Field work in the Southern Powder River Basin terminated in October, after reconnaissance geologic mapping was essentially completed in about 2,000 square miles of the basin. Study of specific uranium deposits may require additional mapping in the spring of 1957.

The zone of dominantly red sandstone lenses in the Wasatch formation, that trends northward along the central part of the basin (TEI-590, p. 148-151), is completely delineated. The zone extends about 80 miles from the Sundquist mesa escarpment, 10 to 12 miles north of Douglas, to a northern limit 6 to 8 miles north of Pumpkin Buttes (fig. 19), and ranges from 4 to 20 miles in width.

All major uranium mines and deposits in the Powder River Basin are near or at the edge of this red sandstone zone. All are at a color change from red to drab in a specific sandstone lens. The map (fig. 19) shows the location of the major mines of the Basin relative to the boundary of the red zone. The consistent association of major deposits with the

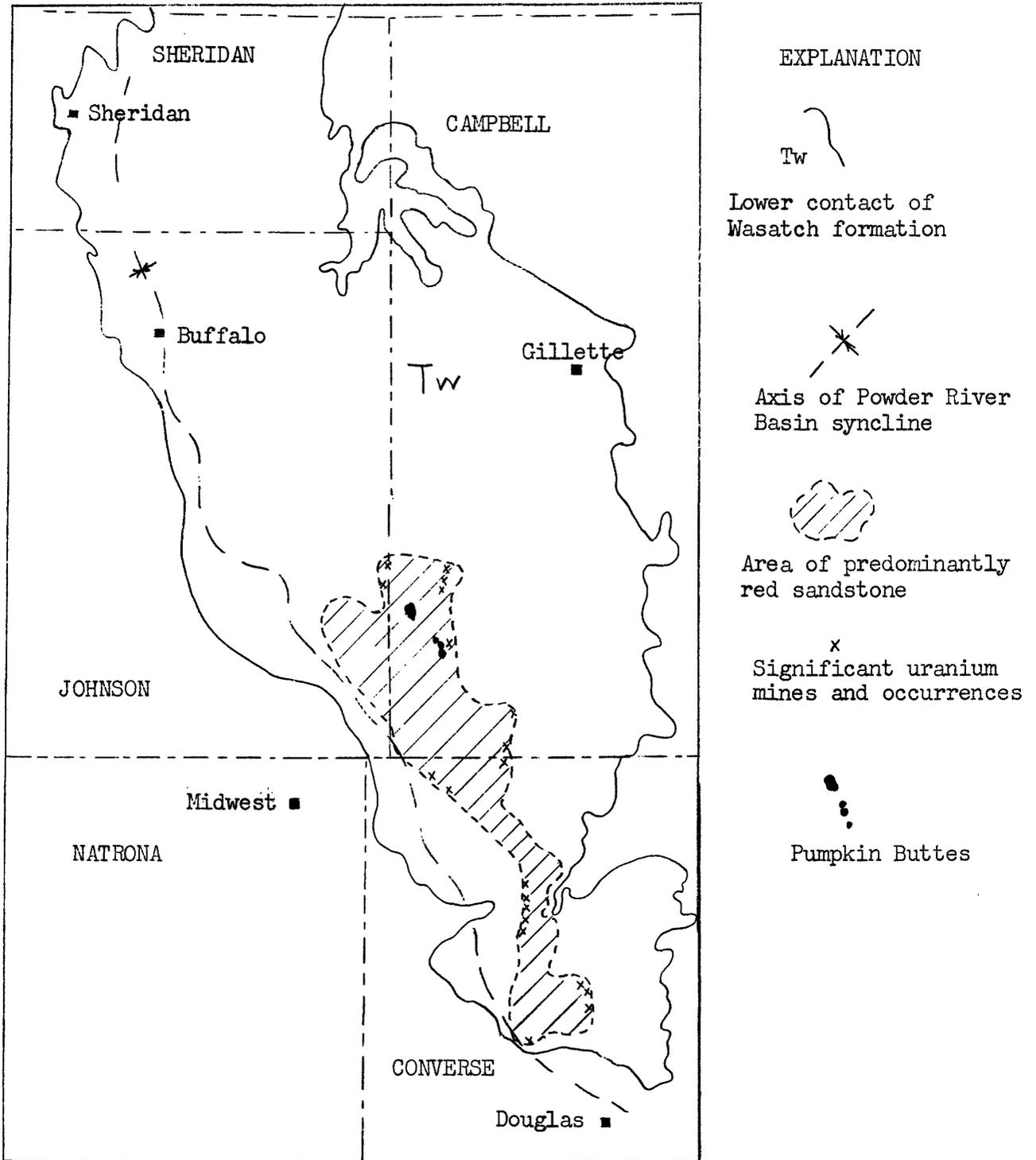


Figure 19--Geologic map of the Powder River Basin, Wyoming, showing extent of red sandstone in Wasatch formation

0 6 12 18 miles

periphery of the red zone should greatly aid future prospecting in the Basin.

The pattern of physical features and the geochemical mechanism that is deduced from these field data, both general and detailed, indicates that the Wasatch formation outside the red zone and its border probably will be nonproductive of uranium. A few local occurrences of uranium minerals in carbonaceous shale, sandstone, and coaly beds away from the red zone are present, as are expected, but all such occurrences should be very small.

Possible regional and local controls that have caused the association in the Powder River Basin of uranium in minable deposits with the boundary of the red hematitic area, as well as with other local components of the sandstone lenses such as coaly material and accretionary calcite, are being studied. The structure pattern for the Southern Basin is being developed from mapping data and may show a relationship to the red zone and uranium deposits.

#### Northern Black Hills

##### Carlile quadrangle, Wyoming, by M. H. Bergendahl and G. A. Izett

Field studies in the Carlile quadrangle, Crook County, Wyoming, were completed during this report period. Discussions of the general geology and preliminary results of field studies may be found in TEI-590, p. 159-165 and TEI-620, p. 179.

The bulk of the rocks exposed in the Carlile quadrangle belong to the Inyan Kara group, a complex sequence of sandstone, siltstones, and mudstones of Early Cretaceous age (TEI-590, p. 161). As a result of field studies during this report period, the uppermost formation of the

Inyan Kara group--the Fall River formation--was informally subdivided into four units that can be traced throughout much of the northern Black Hills. These units are, in ascending order: a thin-bedded siltstone unit 30 to 35 feet thick, a claystone and silty claystone unit 42 to 47 feet thick, a massive, very fine-grained sandstone 30 to 50 feet thick, and a fine-grained sandstone and clayey siltstone unit that ranges from 7 to 40 feet in thickness, but may be absent locally.

Geology of the Hulett Creek mining area, Crook County, Wyoming, by  
C. S. Robinson and H. D. Goode

The Hulett Creek mining area includes about 2 square miles in the southwest corner of the Devils Tower 2 SE quadrangle (fig. 20) and extending about 1/2 mile into the adjacent quadrangle to the west. The area is about 20 miles west of Hulett and 45 miles north of Moorcroft, Wyoming.

Stratigraphy.--The stratigraphic units exposed in the Hulett Creek area are the Inyan Kara group and the overlying Skull Creek shale, both of Early Cretaceous age. The Inyan Kara group is divided into two parts, each of which has a characteristic lithology. Only about 11 feet of the lower part is exposed at Hulett Creek; this consists of clayey sandstone and sandy claystone (see fig. 21). The total thickness of the unit in the area is 150 to 200 feet. The upper part of the Inyan Kara group is divided into five lithologic units. In ascending order these are (1) a lower sandstone and siltstone unit; (2) a lower shale and siltstone unit; (3) a middle sandstone unit; (4) an upper shale and siltstone unit; and (5) an upper sandstone unit. These units are shown and described in figure 21.

The Skull Creek shale crops out around the margins of the Hulett Creek area and in small isolated patches on the divides. The formation in adjacent

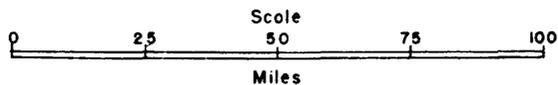
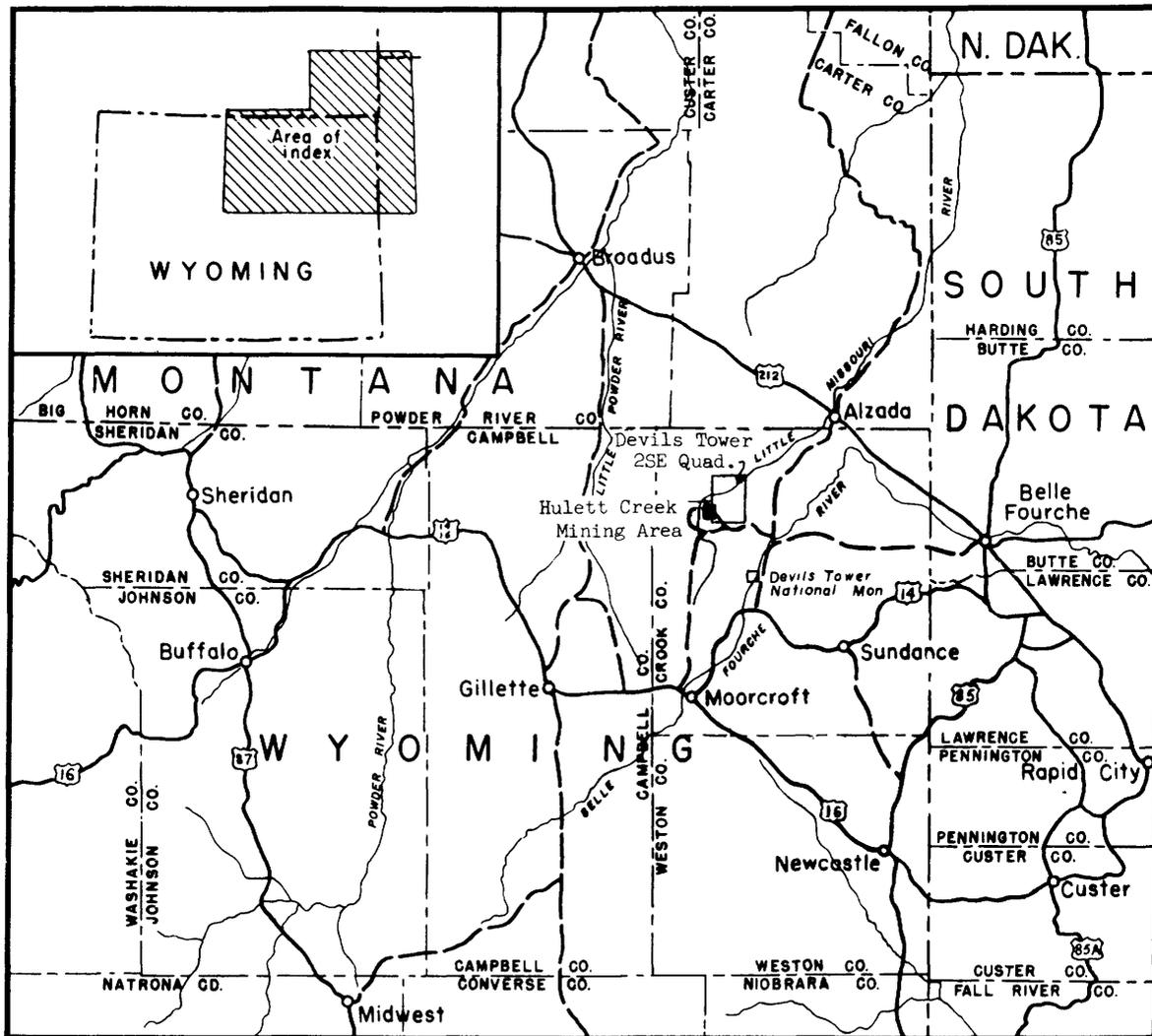


FIG. 20

MAP SHOWING LOCATION OF DEVILS TOWER 2SE QUADRANGLE AND HULETT CREEK MINING AREA

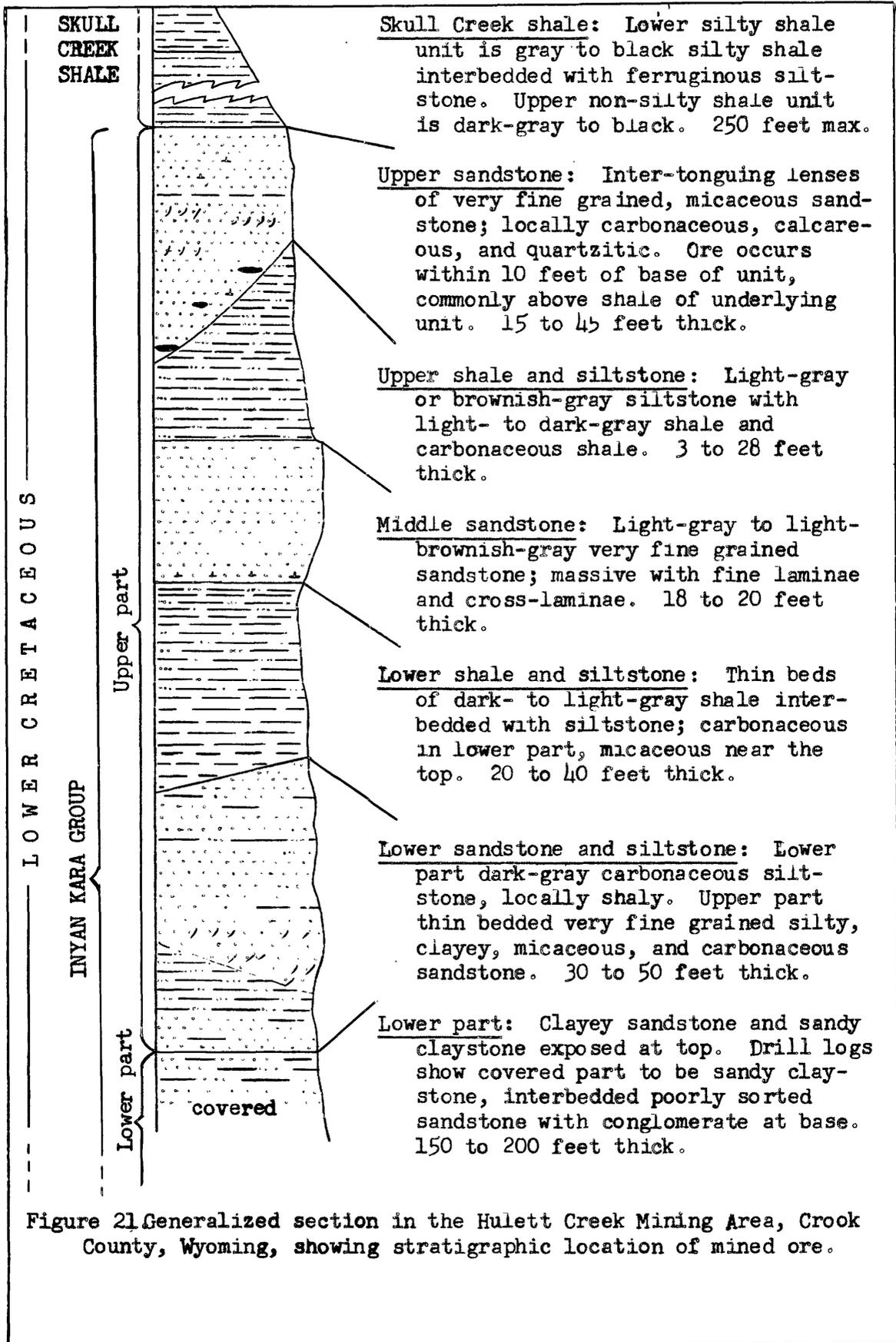


Figure 21 Generalized section in the Hulett Creek Mining Area, Crook County, Wyoming, showing stratigraphic location of mined ore.

areas is about 250 feet thick but only about 100 feet remains in the Hulett Creek area. Two lithologic units have been differentiated in the area; a lower unit about 45 feet thick consisting of gray to black shale interbedded with ferruginous siltstone, and an upper shale unit consisting of dark-gray to black shale that contains a few beds, 1 to 4 inches thick, of very fine-grained sandstone or siltstone.

Structure.--The Hulett Creek area is at the western margin of the Black Hills just east of the Black Hills monocline, which essentially forms the boundary between the Black Hills to the east and the Powder River Basin to the west. A gentle north-plunging asymmetrical anticline cut by a series of northeast-trending normal faults crosses the Hulett Creek area. The anticline is about a mile wide and a mile and a half long.

The flanks of the anticline dip from  $2^{\circ}$  to  $5^{\circ}$ , the west flank in general being steeper than the east, and are crenulated by several minor folds of diverse orientation. The north end of the anticline passes into a structural terrace that dips  $3^{\circ}$  to  $5^{\circ}$  northwest.

A series of normal faults ranging in length from less than 100 feet to more than 1 mile and striking N.  $45^{\circ}$  to  $60^{\circ}$  E. and dipping  $50^{\circ}$  to  $90^{\circ}$  NW or SE cut across the Hulett Creek area. The rocks on the northwest sides of the major faults are downthrown, and the stratigraphic throw ranges from a foot or less to 60 feet.

The sandstone units display a well-developed set of joints. These joints are particularly conspicuous in the cliff-forming middle sandstone where they strike about N.  $40^{\circ}$  E. and dip  $80^{\circ}$  to  $90^{\circ}$  NW or SE, and strike N.  $40^{\circ}$  W. and dip vertically.

Ore deposits.--The uranium deposits mined in the Hulett Creek area have come from the upper sandstone unit in the Fall River formation, although the Homestake Mining Company during the past summer was exploring a possible deposit in a conglomeratic sandstone at the base of the Fuson-Lakota formations undivided.

The sandstone lens that contains the ore deposits is elliptical in plan with the long axis trending northwest. This unit consists of a series of superimposed and interfingering sandstone lenses separated by thin shale or claystone partings. It is approximately 45 feet thick near its center and thins to 10 to 15 feet at the edges.

The mineralized areas are 200 to 1,200 feet long and 5 to 400 feet wide and their long axes trend between N. 30° and 60° W. Within the mineralized areas, the ore deposits are 5 feet to 200 feet long, 5 feet to 80 feet wide, and a few inches to 10 feet or more thick. The average thickness is probably about 3 to 4 feet. The ore deposits in general show a preferred alignment parallel to the alignment of their enclosing mineralized zones, which, in turn, are generally elongated parallel to the edges of the sandstone lens.

The deposits are either of the oxidized carnotite-tyuyamunite type or of the unoxidized uraninite-coffinite type, depending upon the position of the water table. The ore minerals fill the interstices between sand grains, coat the sand grains, or are disseminated in the carbonaceous material. The contacts of the ore deposits are gradational, except that most deposits are bottomed sharply on a clay or shale seam.

The ore deposits are made up of one or more ore bodies. The typical ore body is 1 to 4 feet thick and consists of a crossbedded carbonaceous sandstone lens impregnated with uranium and vanadium minerals mainly along

the carbonaceous seams. The ore body is bounded by a shale seam above and below, and lies near the base of the sandstone lens. An ore deposit consists of several interfingering, superimposed mineralized sandstone lenses and may be as much as 10 feet thick and 200 feet long. The ore deposits are essentially parallel to the bedding, but locally, in detail, may cut across the bedding.

In five of the six ore deposits mined to date in the Hulett Creek area, calcite- and silica-cemented sandstone concretions are associated with the ore minerals. In the sixth deposit, calcite cement probably was present once but it has been subsequently leached. There is some evidence for similar leaching in the deposits that at present contain calcite-cemented sandstone.

The calcite- and silica-cemented concretions are in general tabular and parallel to the bedding but, as do the ore deposits, may crosscut the bedding. They range from an inch or so in width, thickness, and length to continuous ledges as much as 10 feet thick and hundreds of feet in length and width. The percentage of calcite and silica cement in such ledges varies from pure silica to pure calcite. A common occurrence is a silica-cemented concretion surrounded by an envelope of calcite-cemented sandstone; the contacts between the types of cement and between cemented and uncemented sandstone are gradational through distances of an inch or less to several feet. No concretion containing silica-cemented sandstone surrounding a concretion of calcite-cemented sandstone was observed.

The ore minerals are sparse in calcite-cemented sandstone, and have not been seen in a silica-cemented sandstone. Most commonly, the ore minerals impregnate the sandstone adjacent to a calcite-cemented concretion and some form an envelope around silica- and calcite-cemented concretions.

Neither the silica- or calcite-cemented concretions nor the ore minerals occur in heavily iron stained sandstone. In the Homestake Mining Company pit no. 3, which trends northwest, the sandstone on the southwest wall of the pit is stained a bright reddish-brown. In the pit, and to the northeast, the sandstone is a light-gray to light brownish-gray. The ore, which was of the carnotite-tyuyamunite type, occurred in the light-gray sandstone in association with some calcite-cemented sandstone a few inches to a few feet northeast of the red sandstone. There were no ore minerals or calcite in the bright-red sandstone. The contacts between the red and gray sandstone are gradational and very irregular.

There is no apparent relationship between folding and the location of the ore deposits, but there is some evidence that the location of at least one of the deposits is related to the faulting.

The ore deposit of pit no. 5 of the Homestake Mining Company is adjacent to and on the downthrow side of a fault having a stratigraphic throw of 40 to 50 feet. The upper sandstone, in which the ore occurs, has been downfaulted opposite the lower shale and siltstone unit and dips downward towards the fault. Along the fault is 1 to 4 feet of clay gouge. The sandstone on the downthrown side is cemented both by silica and calcite for a distance of 2 to 6 feet from the fault. The ore minerals impregnate the sandstone lenses up dip, or away from the fault. It seems possible that the ore-bearing solutions migrating down the dip were partly blocked by the impervious shale and siltstone unit on the upthrown side or by the gouge along the fault. Thus, the silica, calcite, and uranium minerals were concentrated in the sandstone on the downthrown side.

Strawberry Hill quadrangle, Wyoming, by R. E. Davis

The Strawberry Hill quadrangle covers an area of approximately 53 square miles in north-central Crook County, Wyoming (fig. 22). Field mapping was started in the area in July 1956; previous work by the U. S. Atomic Energy Commission and by prospectors and private industry showed many areas of anomalous radioactivity in the quadrangle. During the summer of 1956 two mines--the Busfield mine, operated by the Sodak Uranium and Mining Company, and the Vickers mine, operated by Hilmer-Tessem Uranium Corporation--produced uranium ore of the coffinite-uraninite type. The location of the mines, which are in sec. 26, T. 56 N., R. 66 W., is shown in figure 22.

The Strawberry Hill quadrangle is being mapped by the Geological Survey in order to (1) provide a geologic map of the area in sufficient detail to aid in further exploration for uranium deposits; (2) relate uranium mineral occurrences, insofar as possible, to stratigraphy, lithologic character of the rocks and structure; (3) study the known uranium deposits in detail; and (4) find geologic guides to uranium occurrences.

The Strawberry Hill quadrangle is on the northwest flank of the Black Hills uplift, and the exposed sedimentary rocks include, in ascending order, the Morrison formation of Late Jurassic age, the Lakota and Fuson undivided and the Fall River formations, Skull Creek shale, Newcastle sandstone, and Mowry shale, of Early Cretaceous age.

Structural features include several pronounced domes and anticlines superimposed on a gentle regional dip to the northwest. In some of these flexures the structural relief and dissection are great enough to afford good exposures of the entire Fall River formation; in other more gentle flexures the rolling ground surface closely reflects the dip slopes of the

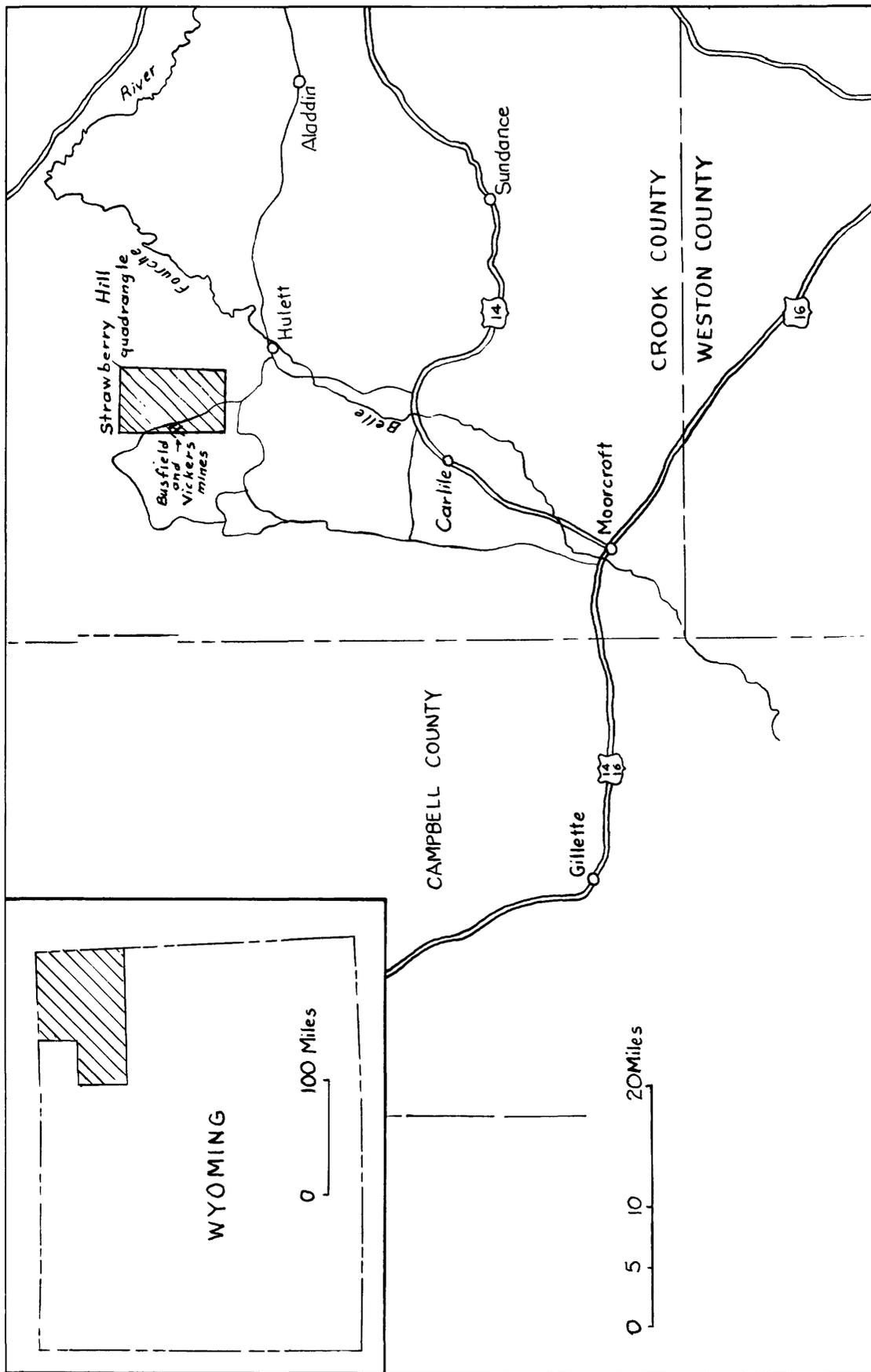


FIGURE 22 -INDEX MAP SHOWING LOCATION OF BUSFIELD AND VICKERS MINES AND STRAWBERRY HILL QUADRANGLE, WYOMING.

beds in the upper part of the Fall River formation.

Uranium deposits occur in the sandstones of the upper one-third of the Fall River formation. The deposit of coffinite-uraninite ore at the Busfield mine occurs at or near the undulating lower surface of a channel fill, or at least a local thickening, of the uppermost sandstone unit of the Fall River. The ore horizon is from 35 to 40 feet below the Fall River-Skull Creek contact which is exposed for a short distance at the top of the east side of the large open pit. The upper 30 feet of the sandstone is highly oxidized, and the unoxidized state of the ore zone is due to precipitation under a reducing environment at a local perched water table--considerably above the regional water table--held up probably by the compact shaly siltstone and claystone that immediately underlie the sandstone. Concentrations of carnotite-type minerals occur in the oxidized zone above but are not mined. The ore occurs in concentrations of thin black carbonaceous sand layers that appear to parallel the planes of crossbedding and as disseminations in the surrounding sandstone.

A new deposit of "black ore", for which no mineral identifications are as yet available, was drilled and stripped during the latter part of the summer. The deposit is approximately 3,000 feet northwest of the Busfield deposit. Ore shipments from this deposit, known as the Vickers mine, were begun in September. The ore zone, which averages 3 to 4 feet in thickness, is in the upper sandstone unit of the Fall River formation. In this area the sandstone is only about 18 feet thick and is covered by 20 to 30 feet of Skull Creek shale. The sandstone has none of the characteristics of deposition in a channel evident at the Busfield mine. It is a thin-bedded, regularly bedded succession of sandstones and

siltstones. In general, little oxidation of the ore has taken place, due probably to the presence of a perched water table above the dense siltstone below the ore-bearing sandstone and to the compact thick cover of Skull Creek shale. As at the Busfield mine, unoxidized uranium minerals are associated with concentrations of carbonaceous layers parallel to the bedding planes in the sandstone.

Both deposits are at least spatially related to a relatively low flexure--an anticline or a slightly elongated dome--which trends east-northeast. The Busfield deposit lies on the south flank of this fold, and the Vickers deposit is close to the west end of the fold. Genetic relationships between the uranium deposits and the structure have not been determined.

#### Southern Black Hills

During 1956 geologic mapping was completed in the Burdock, Cascade Springs, Dewey, and Jewel Cave SW quadrangles. The area mapped in the Edgemont region to date is indicated on figure 23.

#### Cascade Springs quadrangle, by E. V. Post

The thickness and lithology of the Lakota sandstone varies abruptly in the eastern part of the Cascade Springs quadrangle and the western part of the Angostura Reservoir quadrangle. Here the thickness of the Lakota ranges from 447 feet on the west to 209 feet, 1-1/4 miles to the east. The gross lithology of the formation also changes in this distance from 72 percent sandstone and 28 percent mudstone on the west to only 38 percent sandstone and 62 percent mudstone on the east of this small area.

Part of the local thickening of the Lakota is the result of filling of channel scours cut as much as 180 feet deep into the underlying Unkpapa

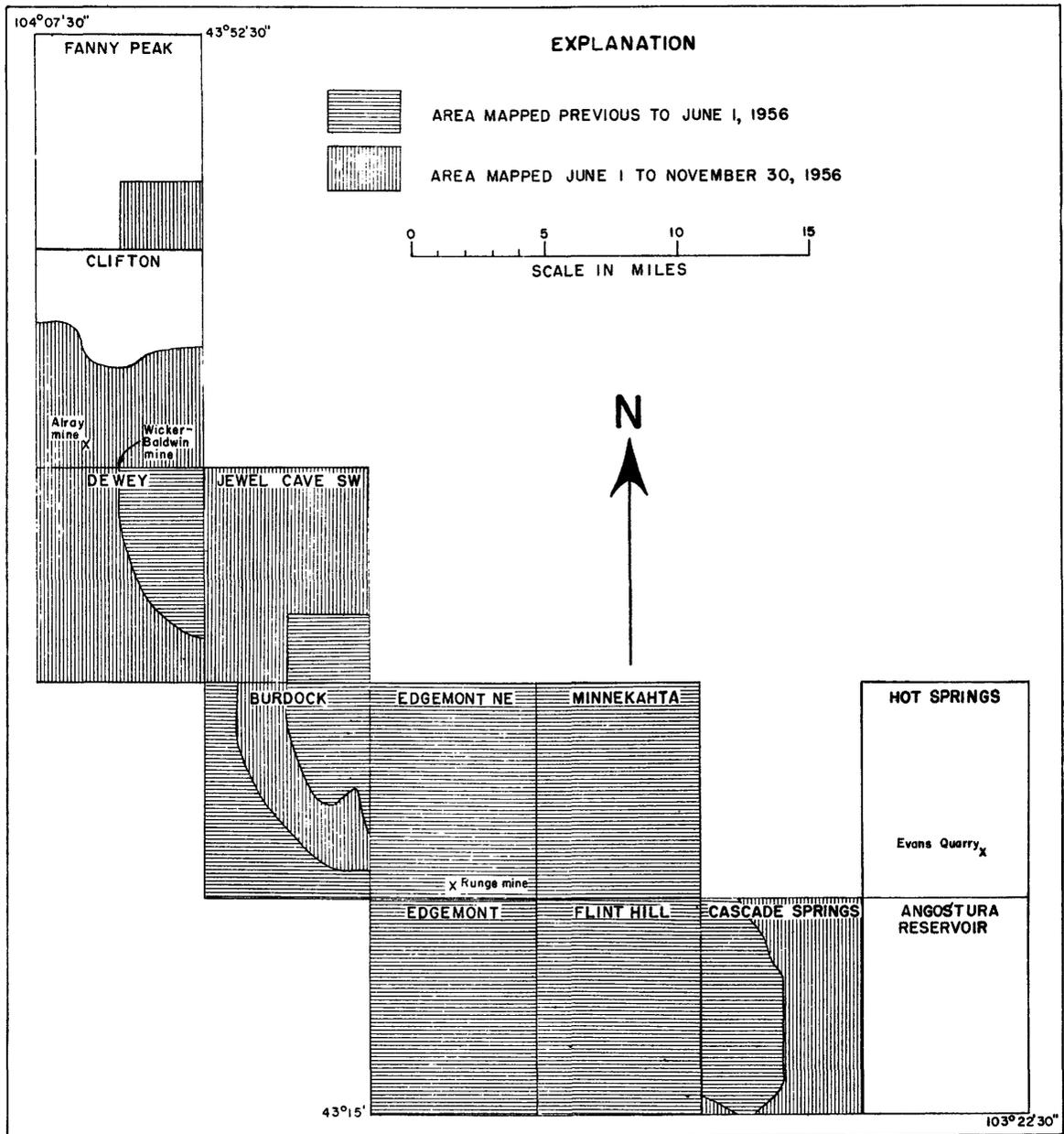


FIGURE 23— INDEX MAP SHOWING AREAS MAPPED PRIOR TO JUNE 1, 1956, AND JUNE 1 TO NOVEMBER 30, 1956, SOUTHERN BLACK HILLS, WYOMING AND SOUTH DAKOTA

sandstone. The Unkpapa sandstone is as much as 230 feet thick in the northeast part of the Cascade Springs quadrangle, but is approximately 50 feet thick to the south where the Lakota is 447 feet thick.

Over the greater part of the Cascade Springs quadrangle the Lakota sandstones and mudstones are devoid of carbonaceous material and pyrite; sparse fragments of carbonized wood and carbonized leaf and twig casts occur locally. The absence of commercial uranium deposits in this area, is perhaps attributable to the general lack of significant quantities of carbonaceous debris and pyrite.

Two occurrences of uranium minerals in the Inyan Kara group have been observed in the Cascade Springs quadrangle. One of these occurrences is the Canyon Lode deposit on the east side of Cedar Canyon, SE $\frac{1}{4}$  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 containing abundant pyrite concretions. This sequence of rocks is about 75 feet thick and is the basal unit of the Fall River formation. Nine tons of ore-grade rock reportedly have been shipped from this deposit. A grab sample of ore collected at this locality assayed 0.88 percent  $U_3O_8$ .

At the other occurrence, yellow uranium minerals are present at the top of the basal unit of the Fall River formation at the top of the cliff south of Angostura Reservoir in the south center of sec. 10, T. 9 S., R. 5 E. No analyses of this material nor indications of the extent of the deposit are available.

Several radioactivity anomalies in the Spearfish formation of Triassic(?) age have been examined in the Cascade Springs quadrangle. Two anomalies (one in the SE corner of sec. 9, T. 8 S., R. 5 E., and one

in the SE $\frac{1}{4}$  sec. 29, T. 8 S., R. 5 E.) are associated with a 1 $\frac{1}{2}$  foot-thick dark-gray to black mudstone that is approximately 54 feet above the base of the Spearfish formation. This mudstone underlies the second gypsum bed above the base of the formation. The anomalies ranged from 2 to 90 times background, the anomaly at the second locality being the larger. Radioactivity anomalies in the black mudstone are relatively local in extent; the unit as a whole does not exhibit anomalous radioactivity.

High radioactivity, ranging up to 35 times background, was noted at a bleached and disturbed zone in the Spearfish formation on the south side of Highway 87 in the SW $\frac{1}{4}$  SE $\frac{1}{4}$  sec. 20, T. 8 S., R. 5 E. This disturbed zone is approximately 15 feet wide and extends vertically up the face of the road cut. Bedding in the zone is obliterated. The rock consists of a mass of disoriented fragments of siltstone, gypsum, and black mudstone. The siltstone, which is the major constituent, has been bleached to a moderate greenish-gray from the normal reddish-brown color of the Spearfish formation. The black mudstone has been derived from the 1 $\frac{1}{2}$ -foot unit that underlies the second gypsum bed in the Spearfish formation.

The highest radioactivity was recorded at fragments of black mudstone, some of which are coated with a yellowish-green fluorescent mineral. Both the black mudstone and the yellowish material give a positive flux test for uranium.

An attempt was made to correlate the base of the Fall River sandstone as mapped in the Cascade Springs quadrangle with the type section of the Fall River at Evans Quarry in the Hot Springs quadrangle. Exposures of the Evans Quarry sandstone and adjacent stratigraphic units were studied in the southern part of the Hot Springs quadrangle and the northwestern

part of the Angostura Reservoir quadrangle.

Little similarity was noted between the Fall River in the eastern part of the Cascade Springs quadrangle and the type Fall River at Evans Quarry. The thick Evans Quarry sandstone pinches out within one mile southwest of the quarry, and thus is not present in the eastern part of the Cascade Springs quadrangle. Primarily because of the lack of exposures, it has not been determined whether the Evans Quarry sandstone is: (1) a stratigraphic equivalent of the basal Fall River in the Cascade Springs quadrangle, (2) a deposit older than the basal Fall River in the Cascade Springs area, or (3) a unit higher in the Fall River that has filled a channel cut in, and possibly through, the earliest Fall River deposits. Detailed geologic mapping of the Hot Springs and Angostura Reservoir quadrangles may find the answer to this problem.

Clifton quadrangle, by N. P. Cuppels

Rocks exposed in the Clifton quadrangle range in age from the Permian Minnekahta limestone to the Late Cretaceous Carlile shale. A prominent hogback forming the Elk Mountains is underlain by the Lower Cretaceous Inyan Kara group and occupies one-half of the quadrangle.

The Inyan Kara group is 350 feet thick in the area mapped, and an erosionally truncated surface of the group forms the dip slope of the Elk Mountains. A conglomeratic sandstone at the base of the Lakota is exposed over much of this slope but is buried in many places beneath erosional remnants of thin-bedded sandstones and siltstones of the upper Lakota.

The thin-bedded sandstones tend to be discontinuous except for a granule sandstone 10 to 15 feet thick near the top of the Lakota. A sequence of variegated mudstones and siltstones 10 to 30 feet thick

above the granule sandstone probably represents the Fuson interval. The overlying Fall River sandstone is 125 feet thick and consists of laminated carbonaceous siltstones intercalated with thin-bedded sandstones at the base, a rim-forming massive sandstone above the siltstones and thin sandstones, and a sequence of dark-colored mudstones and siltstones at the top of the formation.

No commercial uranium deposits have been found in the Clifton quadrangle. The Alray Mining Company has driven a tunnel 275 feet into the Fall River rim sandstone to explore anomalous radioactivity near the abandoned town of Clifton. Fifteen feet from the working face, the tunnel crosses a well defined color boundary. West of the boundary the sandstone is uniformly gray and is homogeneously well-cemented. The sandstone on the east side of the boundary, however, is dominantly yellow, poorly cemented, and is spotted with patches of white, brown, and red oxides of iron and gray siliceous concretions. Zones of anomalous radioactivity start at the color boundary and extend into the yellow sandstone. Silica having a yellow fluorescence is associated with the zones of anomalous radioactivity.

On the surface, the color boundary is relatively sharp and trends northward for more than a mile. Exposures of the rim sandstone east of the boundary have a uniform yellow color which contrasts sharply with the light-gray color of the same sandstone west of the boundary. A radiometric survey of this boundary failed to detect other areas of anomalous radioactivity.

Another striking color change in the rim sandstone can be seen  $1\frac{1}{2}$  miles southeast of the Alray mine. Here, the color changes from yellow to red along a knife-edge boundary that appears to be unrelated to

structure or texture of the rim sandstone. Both the red and yellow colorations are very uniform in the sandstone with the area of red coloration forming a northeast-trending zone 300 feet wide and 2,000 feet long. No anomalous radioactivity could be detected near this color change.

Dewey quadrangle, by D. A. Brobst

The rocks of the Inyan Kara group in this quadrangle average about 300 feet in thickness and are exposed over about 16 square miles. It appears from geologic mapping that the rocks of the Inyan Kara group continue westward from the hogback of Elk Mountain onto the Dewey structural terrace. The sandstones dip from  $3^{\circ}$  to  $13^{\circ}$  west on the dip-slope of the hogback but the dips are only  $1^{\circ}$  to  $2^{\circ}$  west on the terrace. The Fall River channel sandstones of the type found in the Wicker-Baldwin mine extend onto the terrace at shallow depth, especially in the northern half of the quadrangle. The extension of favorable host rocks into structurally favorable areas, such as the change in dip on the Dewey terrace, suggests that the eastern margin of the terrace might be worthy of careful prospecting.

The Dewey fault is probably best interpreted as a series of en echelon faults extending for about 7 miles across the southeast corner of the quadrangle and passing through the town of Dewey. At the east boundary of the quadrangle, the vertical displacement is about 350 feet. Near the southwest corner of the quadrangle, the vertical displacement is 120 feet. The horizontal component of movement appears to be negligible. The same series of faults has been traced to the northeast for another 7 miles across the Jewel Cave SW quadrangle.

Channel sandstones, by D. A. Brobst

The distribution of channel sandstones at three different stratigraphic levels of the Inyan Kara group is shown in figures 24, 25, and 26. The boundaries of the channels are shown approximately at the 20-foot isopach. The arrows indicate the direction of flow based on many readings of the direction of cross-beds. The vertical relationships of these sandstones are shown diagrammatically in figure 27.

A complex channel sandstone in the lower part of the Lakota formation (fig. 25, and A in fig. 27) has been traced from the south border of the Flint Hill quadrangle to the southern part of the Clifton quadrangle, a distance of nearly 30 miles. The channel sandstone dips beneath the surface at both ends. The thickest parts of the channel sandstone are about 160 to 200 feet thick. The channel deposits southeast of the Burdock quadrangle are chiefly fine- to very fine-grained sand. North of Burdock, the channel contains scattered pockets of conglomerate consisting of abundant gray to brown pebbles of chert. The conglomerate becomes increasingly abundant in the northern part of the Dewey quadrangle and in the adjacent parts of the Clifton quadrangle.

In this area, conglomerate of the channel complex is continuous but varies considerably in thickness from place to place. Where the conglomerate thins, the upper part of the channel fill is dominantly a fine- to medium-grained sandstone. Although the complex is commonly light brown to buff, it becomes light gray to white in large areas of the Clifton quadrangle, particularly in exposures that are closest to the Skull Creek shale. The channel complex is a composite of many lithologically distinct sub-units which vary widely in texture. Ten of these sub-units were sampled for size analyses from an outcrop 111 feet thick.

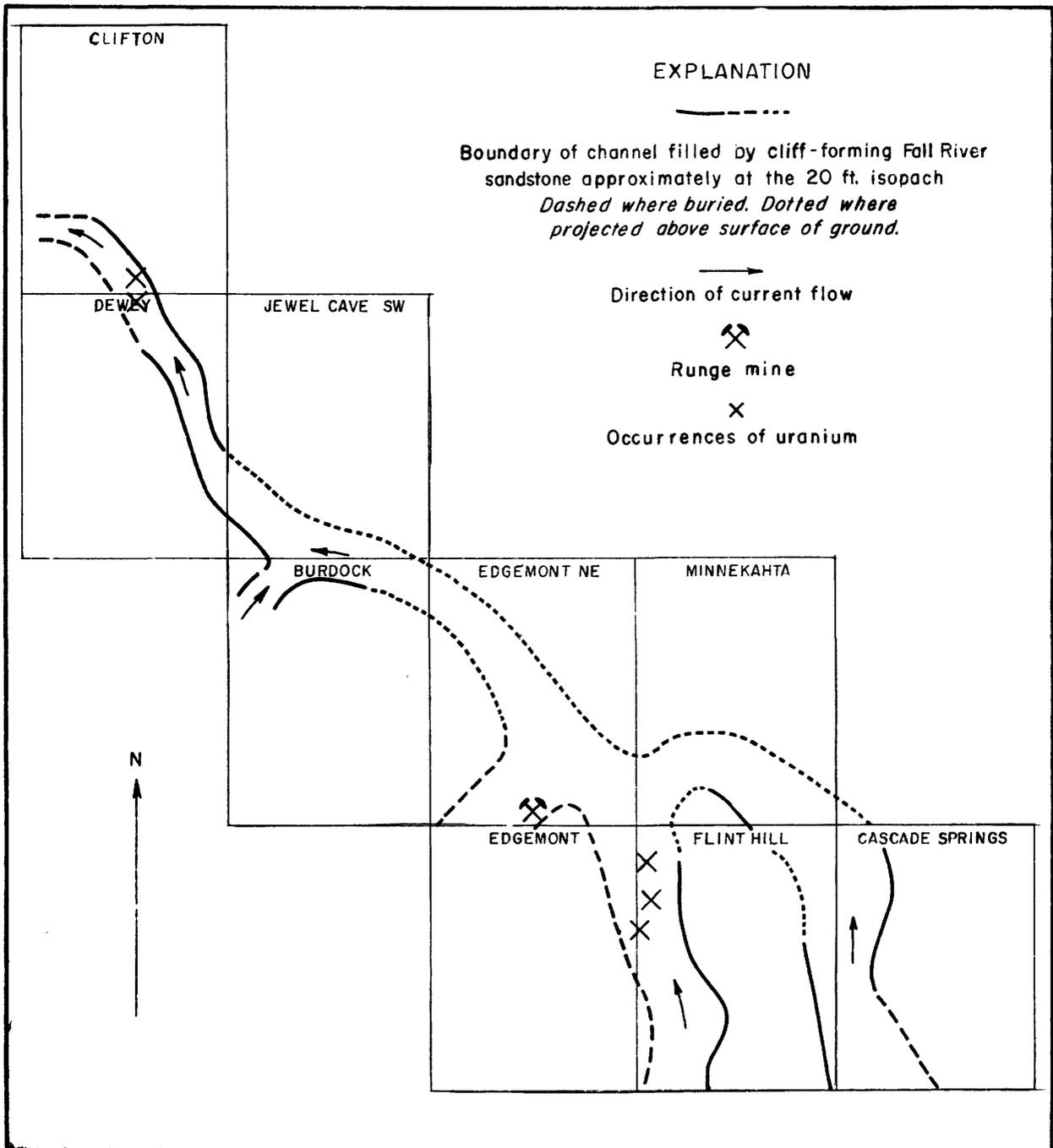


FIGURE 24—MAP SHOWING DISTRIBUTION OF CHANNEL  
SANDSTONE IN THE FALL RIVER FORMATION

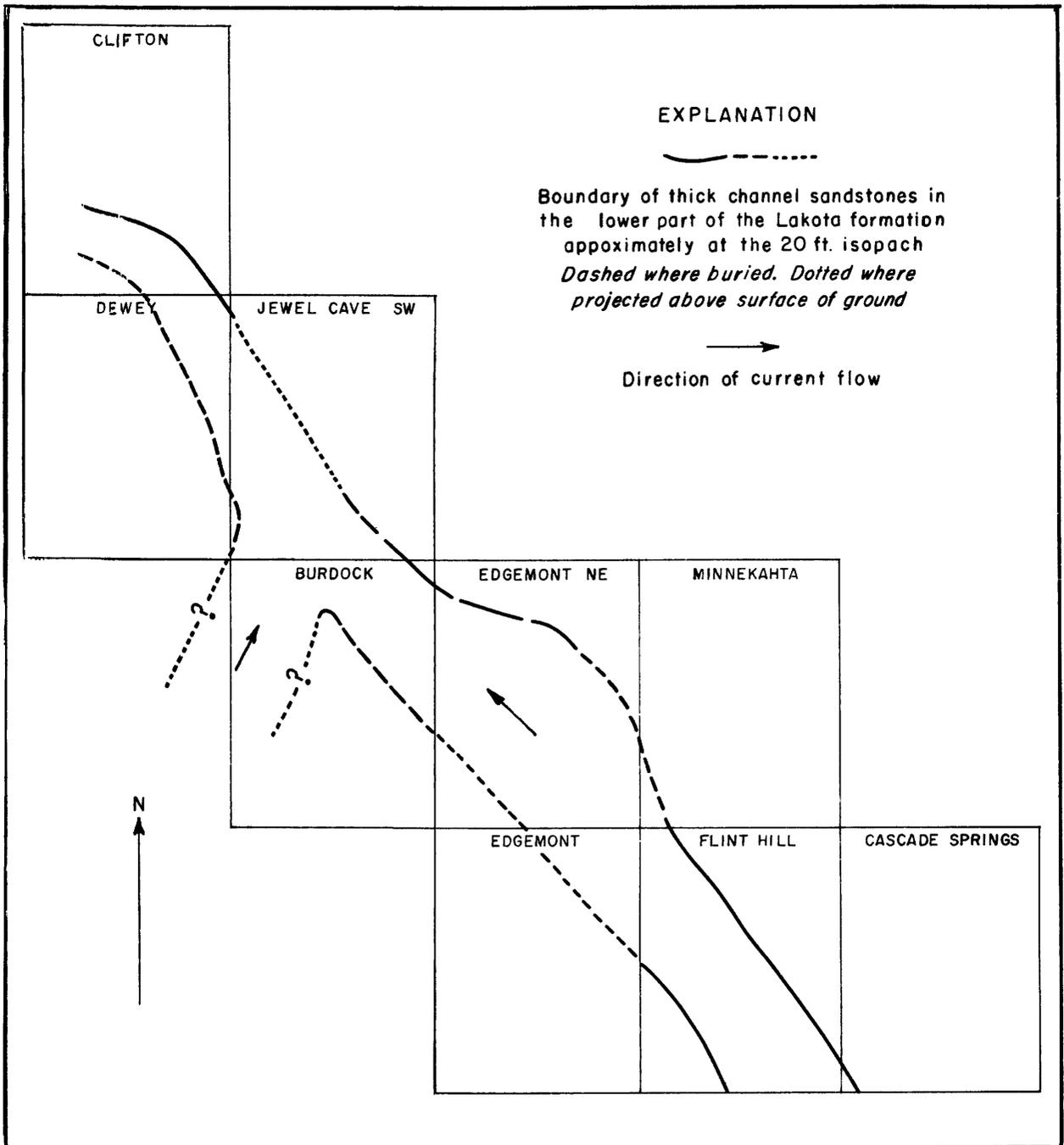


FIGURE 25.— MAP SHOWING DISTRIBUTION OF THICK CHANNEL SANDSTONES IN THE LOWER PART OF THE LAKOTA FORMATION

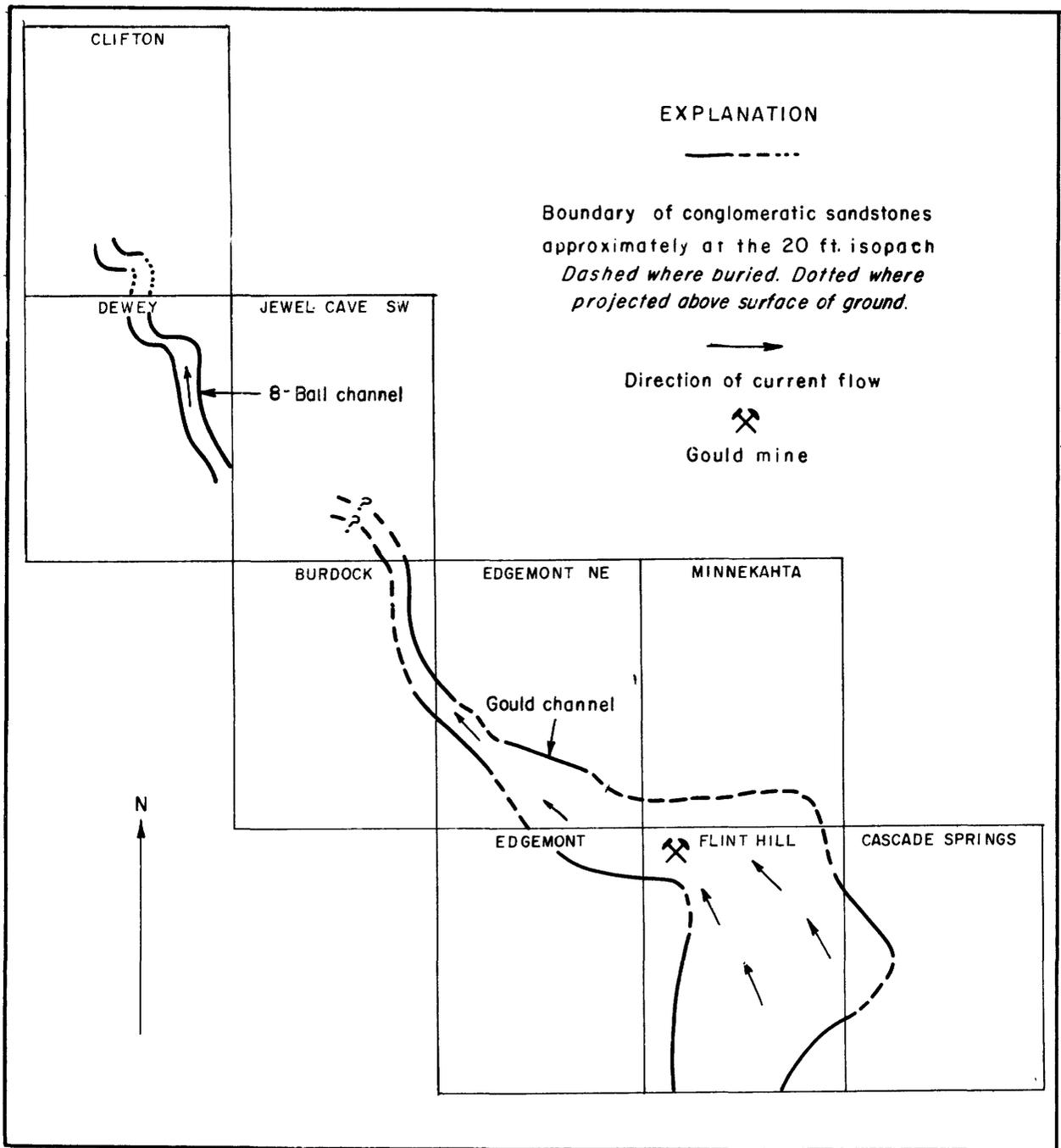


FIGURE 26.- MAP SHOWING DISTRIBUTION OF CONGLOMERATIC SANDSTONES IN THE GOULD AND 8-BALL CHANNELS

0 5 10 15 Miles

SKULL CREEK SHALE

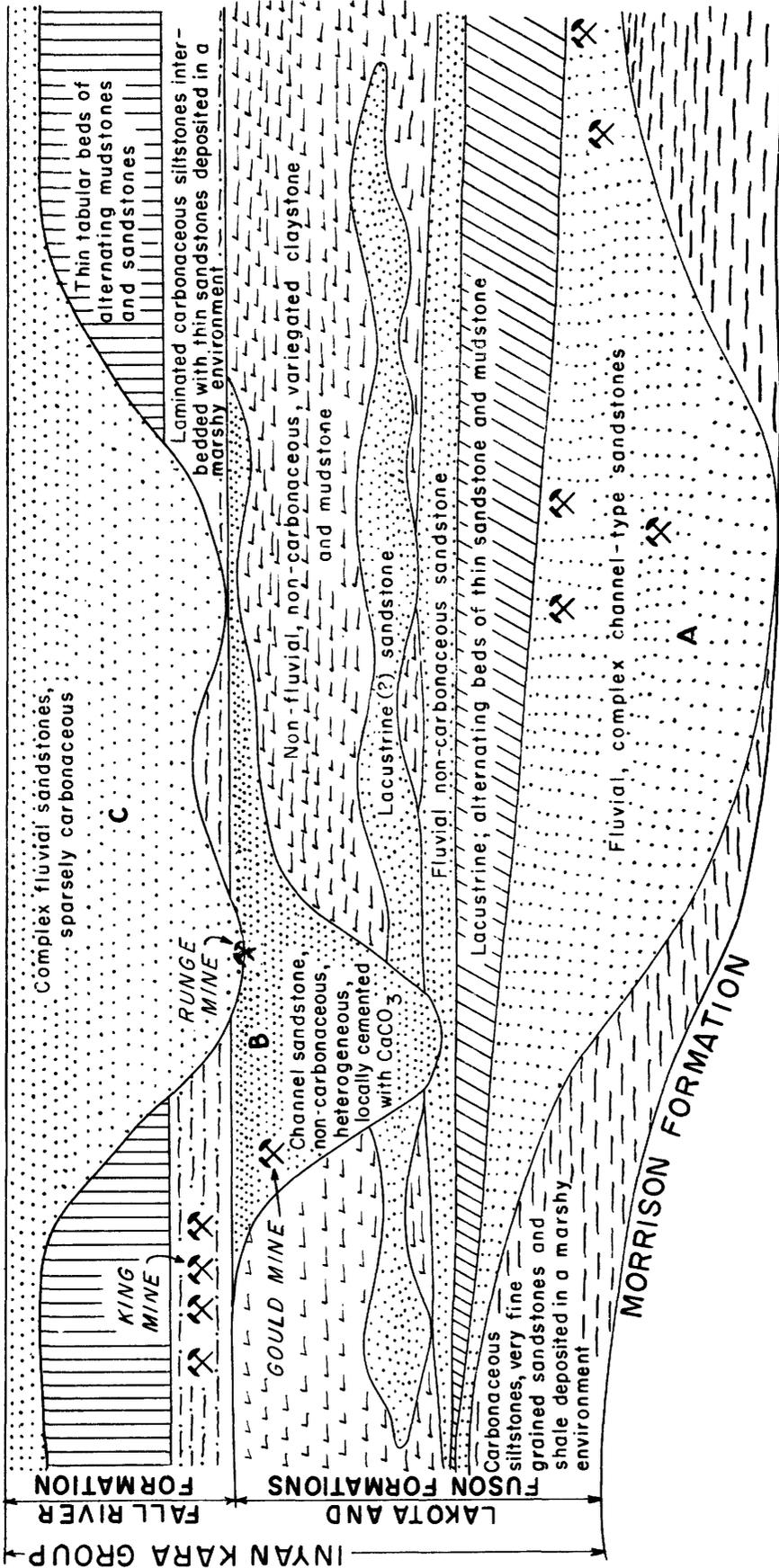


FIG. 27-DIAGRAMMATIC SKETCH OF INYAN KARA ROCKS IN THE SOUTHERN BLACK HILLS, FALL RIVER COUNTY, SOUTH DAKOTA

Results of the analyses show that the median grain size ranges, between sub-units, from 0.10 mm to 1.70 mm and averages 0.35 mm for all sub-units sampled. The coefficients of sorting of the sub-units range from 1.10 to 2.92. These results demonstrate that whereas sorting is good within the sub-units, the overall sorting of the conglomerate is relatively poor.

Incomplete data from a drill core suggest that this large channel is joined by another from the southwest in the northern part of the Burdock quadrangle. The drill core contained some conglomerate suggesting the possibility that some of the abundant conglomerate in the Dewey and Clifton quadrangles might have entered the stream system from this or other tributaries in the vicinity.

The Gould channel (fig. 26, and B in fig. 27) is in the upper part of the Fuson-Lakota formations undivided. It extends for about 25 miles from the Flint Hill quadrangle to the southern part of the Jewel Cave SW quadrangle. To the north the channel fill is truncated by erosion; in the south it dips underground. The channel fill attains a maximum thickness of 50 feet in the north and 110 feet in the south and contains fine to coarse sandstone, clay galls, and conglomerate. The Gould mine, one of the larger uranium deposits of the southern Black Hills, is in this channel.

The 8-Ball channel (fig. 26), named for sandstone exposures in sec. 8, T. 6 S., R. 1 E., Custer County, South Dakota, has been traced across the Dewey and Clifton quadrangles. The channel fill contains fine to coarse sandstone and is locally conglomeratic. The conglomerate contains gray chert pebbles as large as half an inch in diameter. The maximum thickness observed is 40 feet. This channel fill appears to occupy

the same stratigraphic position as the Gould channel to the south. The geologic mapping in the Jewel Cave SW quadrangle, however, suggests that the two channels may not be correlative.

A complex channel sandstone in the Fall River formation extends for more than 30 miles from the Cascade Springs quadrangle to the Clifton quadrangle (fig. 24, and C in fig. 27). The main parts of the channel system are one to two miles wide. The thickness of the deepest parts of the channel ranges from 110 feet in the Cascade Springs quadrangle to at least 60 feet in the Clifton quadrangle. The channel sandstone dips beneath the surface of the ground both to the north and to the south. The northeast edge of the channel in the Minnekahta, Edgemont NE, and Jewel Cave SW quadrangles has been removed by erosion, but data from the north and south ends suggest that the reconstructed channel would have the configuration shown in figure 24.

The sandstone in this channel forms cliffs nearly everywhere along its length. The sandstone is fine- to coarse-grained, although medium-grained facies predominate. Conglomerate similar to that of the other channels has not been seen. Scattered thin layers of clay have been incorporated in the sandstone. This unit is characterized by spheroidal concretions of calcareous sandstone that range in size from a few inches to 6 feet in diameter. The concretions are white inside, but weathered surfaces are generally dark brown. On canyon walls the concretions stand out in low relief. Carbonaceous and lignitic material is common.

Uranium is associated with this channel complex in many places, notably the Livingston group in the Flint Hill quadrangle, the Runge mine in the Edgemont NE quadrangle, the Wicker-Baldwin mine in the Dewey quadrangle, and the Alray mine in the Clifton quadrangle.

Runge mine, by F. R. Shawe

The Runge mine is in the south-central part of the Edgemont NE quadrangle, Fall River County, South Dakota. The underground workings were mapped at a scale of 1:240, the mine was sampled, and field inter-relationships of ore, sub-ore, and barren rock were studied.

The ore now being mined at the Runge mine is at the bottom of a 60-foot-thick sandstone that is in the lower part of the Fall River formation. Exploratory drilling prior to the opening up of the mine indicated ore-grade mineralization at a horizon lower than that of the present mining operations (Gott, 1956).

In the mine area, the Fall River formation strikes a little north of west and dips  $2^{\circ}$  to  $10^{\circ}$  southwesterly.

The deposit is primarily of the black ore type. Uraninite and coffinite are the only ore minerals that have been identified, though at least one other black uranium-vanadium mineral and one yellow radioactive mineral are present. Some black material that is either weakly radioactive or nonradioactive is also present. All of the black minerals are here referred to as "black ore". Pyrite and possibly marcasite, and red iron oxides are found with the "black ore" minerals. All of the minerals are interstitial to sand grains of the sandstone. Analysis of a few samples of radioactive material shows a ratio of about 2 to 3 equivalent uranium to uranium.

The "black ore" is concentrated in small pods and lenses, in narrow bands that resemble diffusion bands, and along joint planes. Many of the pods and lenses are zoned, but the zoning is not systematic. The core of a pod or lens may be either "black ore" rimmed by pyrite or the reverse. Pyrite (and marcasite?) and "black ore" are intergrown in many places.

Several alternating pyrite-"black ore" zones may be present in a single pod or lens. Carbonate cement is associated with many of these zoned pods and lenses and may be either in the core or at the rim. The pyrite has been wholly or partly oxidized to red iron oxides in some places, particularly near the top of the ore-bearing zone.

Carbonate-cemented material seems to be most abundant near the bottom of the deposit and highly radioactive material seems to be just above the highly cemented carbonate material.

Mineralogical and petrographic studies of the ore and sub-ore materials are being continued.

Wicker-Baldwin mine, by D. A. Brobst

The Wicker-Baldwin mine in the NE $\frac{1}{4}$  sec. 16, T. 42 N., R. 61 W., Weston County, Wyoming, was mapped in detail. The mine is in the Fall River channel sandstone shown on figure 24. This was the only mine being operated in the Dewey quadrangle during the summer of 1956. The uranium occurs chiefly with scattered irregular lenticular pods of black clay and lignitic material ranging from 6 inches to 10 feet thick. Many of the lignitic pods contain scattered masses of pyrite or marcasite as much as one inch across. The uranium mineralogy of these pods is unknown. Carnotite-type minerals coat sand grains in scattered local concentrations measured in inches across in the lignitic zones. Other materials in these zones include clay gall conglomerate with a matrix of friable white sandstone, lenses of rusty-brown sandstone, lenses of white sandstone with irregular diffusion bands of brown iron oxides, and lenses of gray pyritic clay. All of these units are randomly distributed in the zones. Some of the sandy units are crossbedded. The great variation and irregularity of the lithology of these zones and the local trends of

the enclosing sandstones suggest that these sediments were deposited on the fill-side of a bend in the channel.

Light-yellow, generally medium-grained, sandstones enclose and separate the lignitic zones. The enclosing rocks contain many spheroidal concretions of white calcareous sandstone as large as 6 feet across. Many of these concretions terminate against adjacent lignitic zones. At the mine the channel sandstone is at least 60 feet thick. The sandstone strikes N. 32° W. and dips 8° SW.

Solution of gypsum in the Minnelusa formation, by W. A. Braddock

Many collapsed blocks of relatively small dimensions, breccia pipes, and extensive zones of brecciated sandstone and limestone have been observed in the southern Black Hills. These features are known to occur in the Pahasapa, Minnelusa, Opeche, Minnekahta, Spearfish, Sundance, and Lakota formations. Because some of the collapse features have resulted from the removal in solution of parts of the Pahasapa limestone and the subsequent subsidence or collapse of overlying formations, it had been concluded that they all originated in the same manner. Results of recent mapping in the Jewel Cave SW quadrangle, however, indicate that the collapse structures in that area are the result of the removal, in solution, of gypsum from the Minnelusa formation.

The evidence that the brecciation and subsidence in the Jewel Cave SW quadrangle were caused by the leaching of gypsum in the Minnelusa formation is as follows:

(1) In the SW 1/4 sec. 20, T. 5 S., R. 2 E., there is 43 feet of gypsum in the upper 120 feet of the Minnelusa formation. The gypsum is not present in the next exposures to the northeast. In the area where the gypsum is present there is no brecciation nor any evidence of

subsidence in any of the Minnelusa sandstones. Conversely there is extensive brecciation and subsidence in the areas where there is no gypsum. The relationship of brecciated sandstones and breccia pipes to gypsum-deficient areas is illustrated by figure 28.

(2) The gypsum in the Minnelusa is restricted to the upper half of the formation. The brecciation and subsidence are likewise restricted to the upper half of the formation. The absence of any disturbance in the beds in the lower part of the formation indicates that there has been little or no solution of the underlying Pahasapa limestone.

#### Geophysical investigations, by R. A. Black

Regional gravity measurements were begun in August 1956 to obtain information about subsurface igneous and sedimentary structures in the Black Hills. A total of 1,127 gravity stations were occupied during this initial survey. Detailed gravity measurements at station spacings of 1/2 to 1 mile were made in ten quadrangles that include most of the belt of the Inyan Kara group of Cretaceous age, which contain the uranium-bearing rocks in the Southern Black Hills. Sufficient additional gravity stations were occupied to obtain a regional picture of the gravity field in the Southern Black Hills, including the area of Precambrian outcrop.

Preliminary Bouguer maps on a scale of 1:24,000 have been prepared and terrain corrections are now being made where necessary. Although it is too early to attempt any detailed correlation between the gravity data and geology data, inspection of the preliminary contour maps indicates that excellent correlation exists.

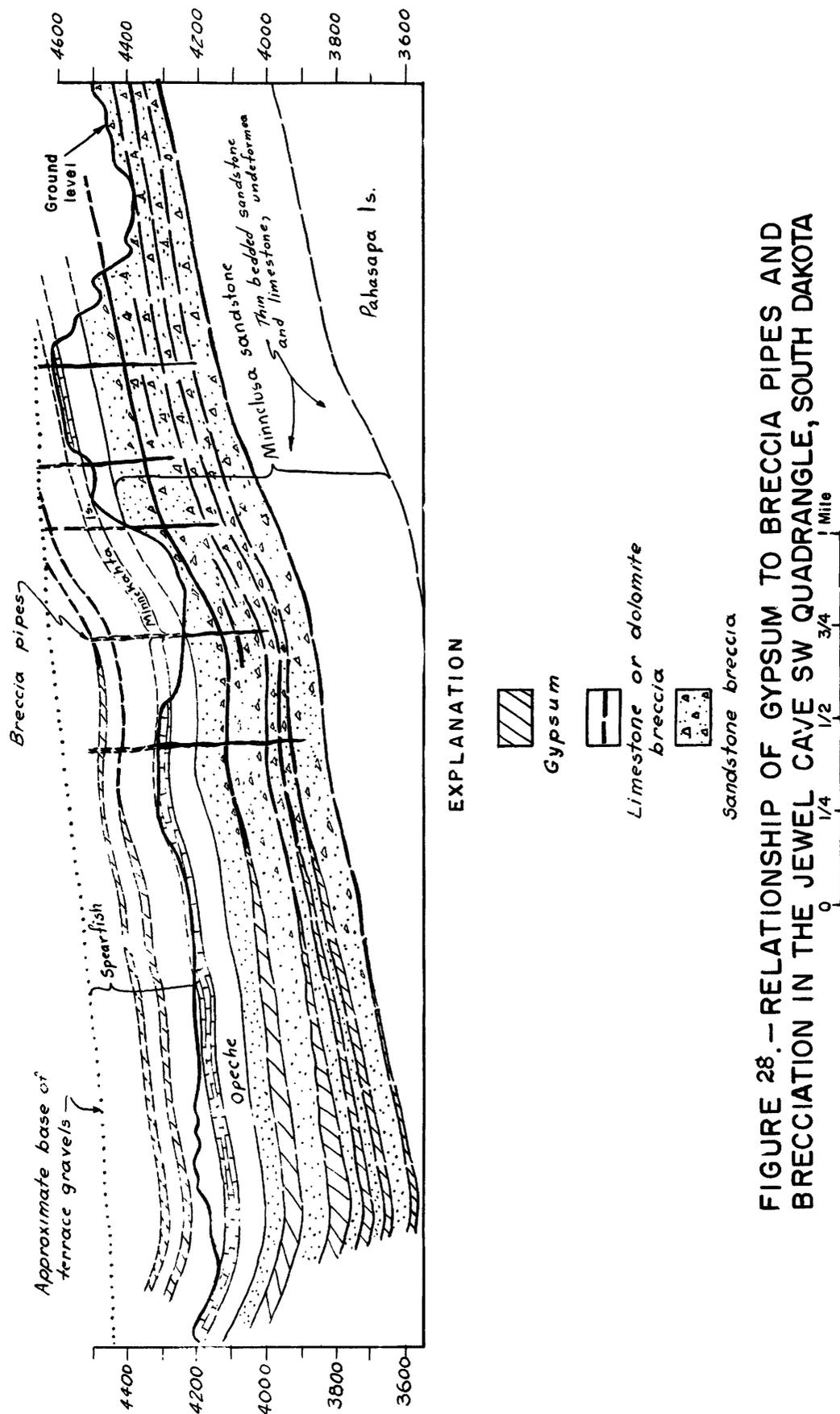


FIGURE 28. — RELATIONSHIP OF GYPSUM TO BRECCIA PIPES AND BRECCIATION IN THE JEWEL CAVE SW QUADRANGLE, SOUTH DAKOTA

A cooperative seismic reflection survey was made prior to proposed drilling in the Triangle Park area of the Black Hills by the Geological Survey and the AEC to investigate a possible slump due to solution of the Pahasapa limestone at depth. The seismic survey revealed that the Triangle Park topographic depression was not due to slumping, but showed a fault, traced for approximately 1-1/2 miles, that may be associated with the topographic depression in Triangle Park.

Good quality reflections were obtained from the Minnekahta and Pahasapa limestones in Triangle Park, and in other test areas in the southern Black Hills at depths ranging from 350 to 1,200 feet. It seems probable from the test results that reflection methods can prove useful in the southern Black Hills in delineating local structures and providing control for the interpretation of gravity data in this area. Refraction methods were also tested over the Dewey fault with excellent results.

#### Reference

Gott, Garland B., 1956, Inferred relationship of some uranium deposits and calcium carbonate cement in Southern Black Hills, South Dakota: U. S. Geol. Survey Bull. 1046-A.

Cave Hills, Harding County, South Dakota

By

G. N. Pipiringos and W. A. Chisholm

Field work in the Cave Hills, Harding County, South Dakota was completed in September 1956. Previous work in the area was reported in TEI-590, p. 240-247, and TEI-620, p. 243-254. A final report on the program will be included in the next Semiannual Report.

Gas Hills area, Fremont and  
Natrona Counties, Wyoming

By  
H. D. Zeller

During the report period mining began on many newly discovered uranium deposits in the Gas Hills area, and drilling outlined a considerable number of other large deposits. The recently found deposits are restricted to the upper coarse-grained facies of the Wind River formation of Eocene age, and occur in arkosic fluviatile sandstones and conglomerates. In the unoxidized zones uraninite is the principal uranium mineral (TEI-540, p. 183) and in the oxidized zones uranium phosphates and hydrous uranium oxides are the most important ore minerals. Selenium and arsenic are associated with pyrite in the unoxidized ore of the newly discovered deposits.

The Wind River formation, which dips gently to the south in the Gas Hills area, rests with angular discordance on rocks of Paleozoic and Mesozoic ages and is overlain by tuffaceous rocks ranging in age from middle Eocene to Miocene. Subsurface information indicates that the pre-Wind River topography was a surface of considerable relief carved on the folded anticlinal and synclinal structures of the older rocks. Ancient valleys filled with fluviatile sandstones and conglomerates of the Wind River formation may have afforded channelways for the uranium-bearing solutions.

Two periods of normal faulting affecting the uranium deposits are recognized in the Gas Hills area: (1) faulting of early Eocene age contemporaneous with the deposition of the Wind River formation; (2) faulting of post-Miocene age in which movement appears to have continued into Pleistocene and Recent times. The earlier faults generally trend in a

northeasterly direction and the more recent faults trend more east-west to northwesterly. One of the larger structural features formed by the more recent faults in secs. 16, 17, 20, and 21, T. 33 N., R. 89 W., Fremont County, is a small belt of horsts and graben. The largest of the graben may have a vertical displacement of over 300 feet.

Though the evidence thus far is inconclusive, it appears that the more recent faults in the eastern part of the area have cut the ore bodies and thus are post-ore whereas the older faults are pre-ore and may have afforded barriers to the flow of uranium-bearing solutions. There is evidence that secondary enrichment has occurred adjacent to the more recent faults, where dammed up ground waters have precipitated uranium near the top of small perched water tables. The present water tables are controlled in part of the area by recent faults, and the ground water near two deposits contains up to 5,000 ppb uranium.

At the Lucky Mc mine an average of 5 feet of lignitic coal and carbonaceous shale of early Eocene age contain an average of .5 percent uranium. A two-foot lignitic coal in this sequence contains up to 1 percent uranium.

#### Geophysical investigations, by R. A. Black

Seismic refraction measurements to delineate major and minor fault trends in the Gas Hills area were successfully concluded in June 1956. The reversed-profile method and air-shooting techniques were used. Overlapping spreads were shot over known faults to obtain a continuous bedrock velocity, and offsets in the bedrock velocity segments of the time-distance curve were taken as indications of faulting. Similar offsets in the bedrock velocity along traverses where no control

was available were interpreted as indications of fault traces if the following three conditions were satisfied: (1) each of the time-distance curves plotted for a reversed profile showed offsets in the bedrock velocity; (2) when the offset portions of the time-distance curves were migrated toward their respective shotpoints, they tended to superimpose; and (3) the offset in the time-distance curve shot from the upthrown side of the fault appeared as a decrease in apparent velocity as it approached the velocity corresponding to the overburden velocity, and the offset for the reverse time-distance curve appeared as an increase in velocity as it approached a negative apparent velocity.

Reversed time-distance curves across the Lucky Mc fault in the Gas Hills area are shown in figure 29. Two faults, both with small throws, are indicated by the offsets at 575 feet and 825 feet on the time-distance curves.

Experimental shallow reflection measurements were also made in the Gas Hills area. The Survey's shallow reflection equipment was used by standard field methods, including both hole and single air shots and inline and split spreads and several different arrangements of multiple geophones. Air shooting with charges ranging from 1 to 10 pounds produced no recognizable reflections and the best records were obtained from 5-pound shots in holes 60 to 80 feet deep. The best results were obtained with a multiple pattern of three inline geophones spaced 10 feet apart, parallel to a line from the station to the shot point, hole offsets of 50 to 75 feet from the nearest geophone, and 50-foot station spacings. Although reflections could be recognized on the unmixed records, mixing cleaned up the records and made the reflections easier to recognize.

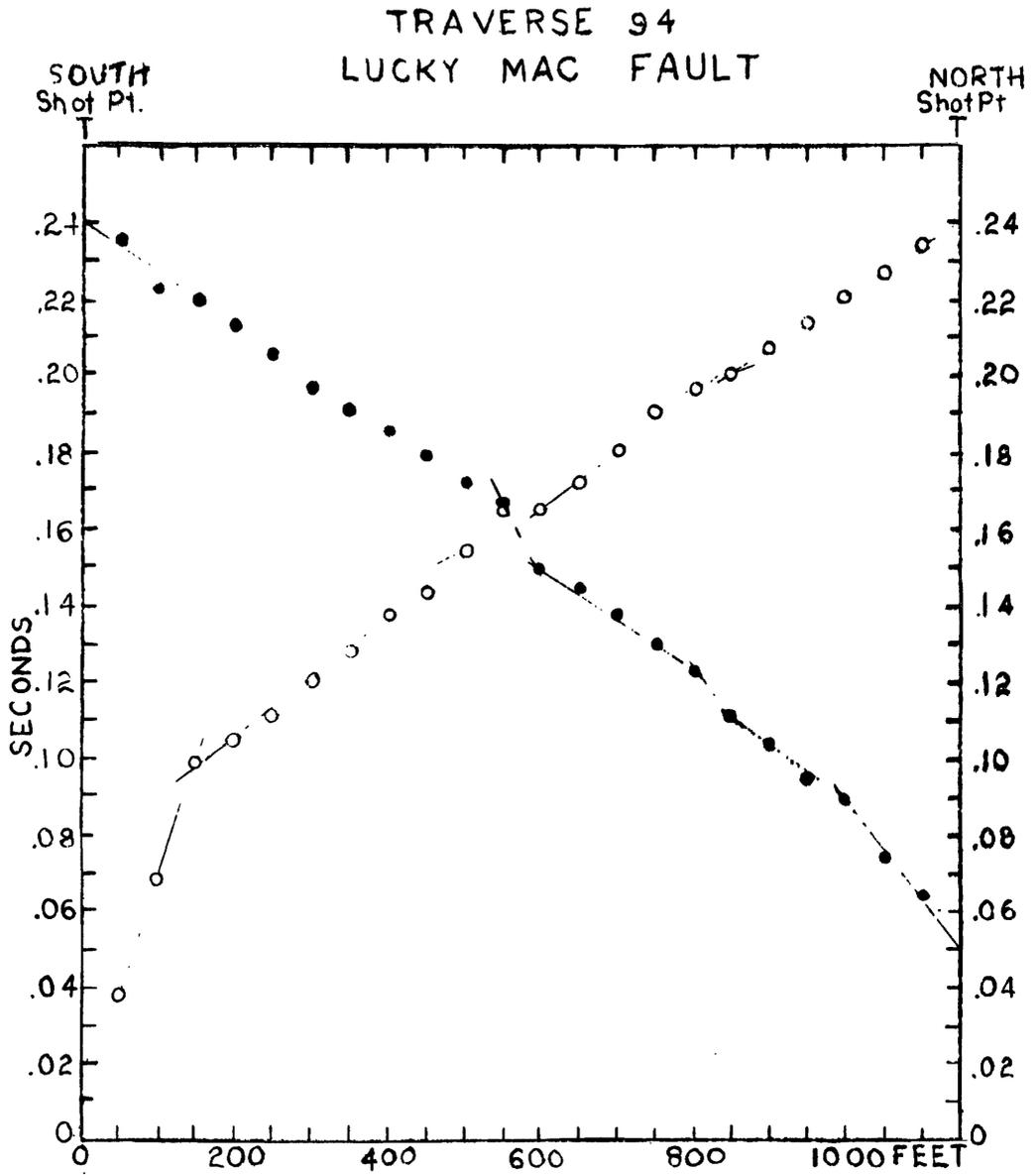


Figure 29.--Time-distance curves for a reversed seismic refraction traverse showing two small faults in the Gas Hills area, Wyoming.

The location of shot holes was critical. With light drilling equipment it was impossible to drill holes to much more than 20 feet in the Wind River sandstones, and no reflections were obtained from shots detonated in these shallow holes. Where it was possible to drill the holes to depths of 60 to 80 feet in alluvium, records of good quality were obtained. Four good reflection horizons, the deepest at approximately 1,200 feet, were recorded at four points spaced 1,300 feet apart and correlated by the character of the reflecting wave. Because of the lack of geologic control, however, no attempt has been made to identify the reflecting horizons.

Mineralogic studies, by R. G. Coleman

Study of the mineralogy and geochemistry of the Gas Hills uranium deposits shows that the uranium was deposited in two distinct environments: (1) uraninite-coffinite-iron sulfides formed under reducing conditions, and (2) uranium deposition in and near phosphate zones under partially reducing conditions. These primary ore types are generally in radioactive equilibrium. Recent fluctuations of the water table resulting from erosion and the concurrent oxidation of much of the ore near the surface together with downward leaching of uranium produced some enrichment at the interface between the oxidized and unoxidized ore, and also at mudstone-sandstone contacts. The oxidized ores and the enriched zones are strongly out of equilibrium. Radiochemical studies indicate that much of the redistribution of the uranium during the erosional period took place in recent times, at least in part within the last 16,000 years. The reduced ores containing uranium oxides and iron sulfides show enrichment of Mo, As, and Se when compared to the barren sandstone. During oxidation Mo and Se do not follow uranium but become

dispersed. The arsenic usually becomes enriched in the uranium phosphates and arsenates. The uranium in the oxidized zone occurs as a complex suite of secondary minerals; approximately 20 distinct mineral species have been identified from these deposits. The unoxidized ores average about 0.01 percent Se which is most abundant in pyrite and/or marcasite. The consistent Se content of the unoxidized ores indicates that these deposits might be an economic source of this metal.

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

Zeller, H. D., Soister, P. E., and Hyden, H. J., 1956,  
Preliminary geologic map of the Gas Hills uranium  
district, Fremont and Natrona Counties, Wyoming:  
U. S. Geol. Survey Mineral Investigations Field  
Studies Map MF-83.

The following publication was also released during the period:

Denson, Norman M., Zeller, Howard D., and Stephens, James G.,  
Water sampling as a guide in the search for uranium  
deposits and its use in evaluating widespread volcanic  
units as potential source beds of uranium, in  
Contributions to the geology of uranium and thorium  
by the U. S. Geological Survey and Atomic Energy  
Commission for the United Nations International  
Conference on the Peaceful Uses of Atomic Energy,  
Geneva, Switzerland, 1955: U. S. Geol. Survey  
Prof. Paper 300, p. 673-680.

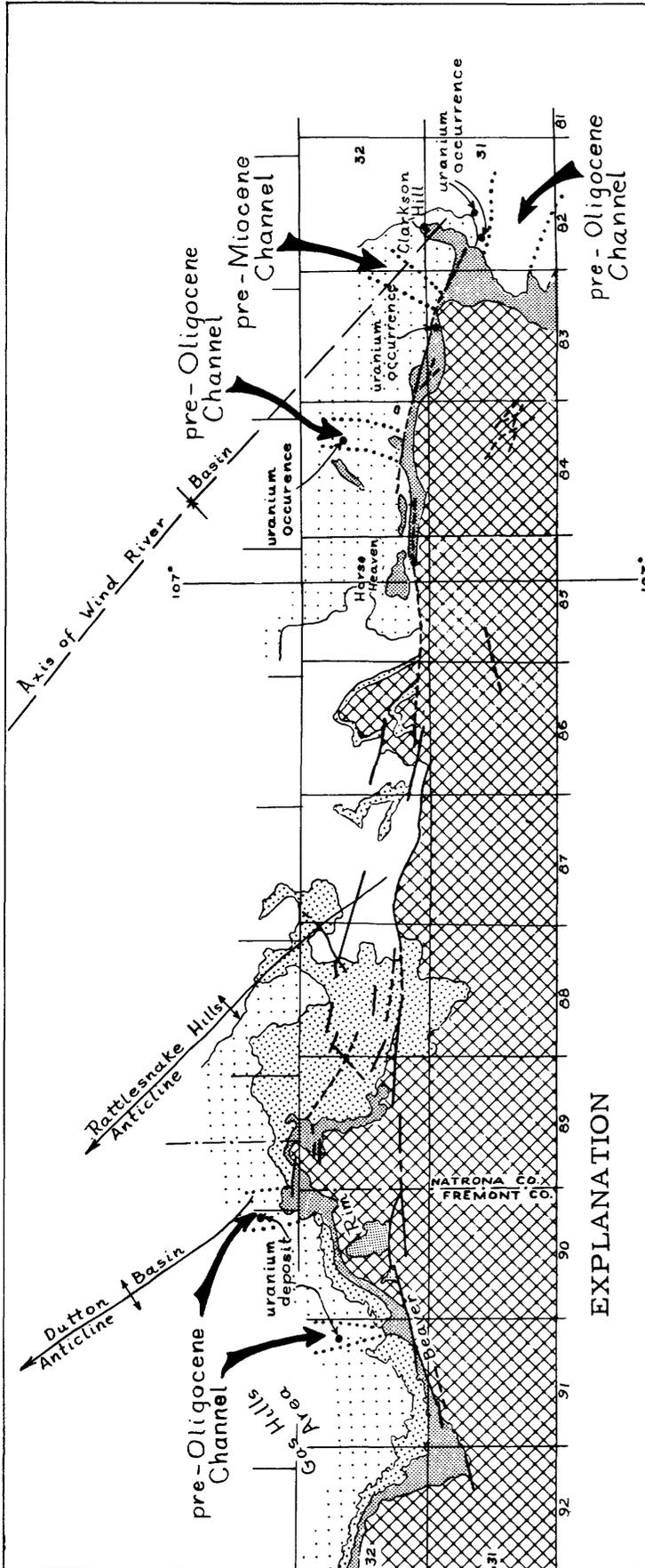
Hiland-Clarkson Hill area,  
Natrona County, Wyoming

By  
E. I. Rich

Previous reconnaissance mapping in the Hiland-Clarkson Hill area (TEI-590, p. 171-174; and TEI-620, p. 186-188) shows that the southeastern part of the Wind River structural basin is geologically similar to the Gas Hills area, about 30 miles to the west, where commercial deposits of uranium are found in the upper coarse-grained facies of the Wind River formation. Detailed geologic mapping during the 1956 field season was concentrated in the vicinity of Clarkson Hill, a high mesa in the extreme southeastern end of the Wind River basin (fig. 30), in order to determine, if possible, why uranium occurs in one area but not in significant quantities in the other.

Although field data have not been fully compiled significant geologic relationships have been discovered that bear on this apparent selective accumulation of uranium.

Along the southeastern border of the Wind River structural basin, the basal conglomerate of the Oligocene White River formation, ranging in thickness from 12 to 120 feet, unconformably overlies the upper facies of the lower Eocene Wind River formation. There are no middle and upper Eocene rocks such as occur in the Gas Hills. The conglomerate is composed of granitic boulders as much as 20 feet in diameter, pebbles and cobbles of Paleozoic sandstones, basic igneous rocks, and green Precambrian quartzite. Detailed mapping of the basal conglomerate in the White River



EXPLANATION

- Miocene - Middle Miocene rocks
- Oligocene - White River formation
- Eocene - Middle and Upper Eocene rocks
- Wind River rocks
- Pre-Wind River rocks
- Normal fault
- Formation contacts
- Projected trace of channels

Fig. 30

Generalized Geologic Map Showing Relationship of Uranium Occurrences to Oligocene and Miocene Channels in the Clarkson Hill and Gas Hills Areas

by

Ernest I. Rich

Adopted from Geologic Map of Wyoming

formation has outlined two pre-Oligocene channels cut into the Wind River formation (T. 32 N., R. 84 W., and T. 31 N., R. 82 W.). Areas of higher background count are in the Wind River formation adjacent to these channels. One of the occurrences in T. 31 N., R. 82 W., contains a small pocket, about 1 foot in diameter, of commercial grade uranium in a carbonaceous siltstone lens. In the Gas Hills area two pre-Oligocene channels cut through middle and upper Eocene rocks and some of the best uranium deposits occur below and in line with these channels (Zeller, personal communication, 1955).

During the last field season in the Clarkson Hill area, it was discovered that middle Miocene rocks fill a broad channel cut into the White River formation in T. 31 N., R. 83 W. North of and in line with this channel a small uranium occurrence containing a maximum of .21 percent eU and .12 percent U is present in a carbonaceous siltstone and sandstone zone in the White River formation.

The occurrence of uranium below and in line with the trends of pre-Oligocene and pre-Miocene channels is thought to occur too frequently in the Gas Hills and Clarkson Hill areas to be mere coincidence.

Strata of the Wind River formation, with northward dips ranging from  $1^{\circ}$  to  $5^{\circ}$ , are unconformably overlain by strata of the White River formation that dip  $1^{\circ}$  to  $15^{\circ}$  southward or southwestward. Structural relationships indicate that the White River formation originally had a gentle north dip, but the region has subsequently undergone post-Miocene southward tilting that was sufficient to reverse the dip of the White River strata but not the somewhat steeper dip of the Wind River formation.

Similar southward post-Miocene regional tilting occurred in the Gas Hills area (Zeller, personal communication, 1955), but there the Wind

River formation now dips southward indicating that the original northward dip of the strata must have been less than the amount of the southward tilting. This reversal of dip in the host rocks of the Gas Hills area may have had the effect of stopping or reversing the ground water movement from a northward (basinward) to a southward (mountainward) direction. In many places it can be demonstrated that after tilting occurred, commercial grade ore was deposited by ground water in favorable fault or stratigraphic traps at or near the present water table.

In contrast, in the Clarkson Hill area the ground water movement in the Wind River formation has not been stabilized or reversed by regional tilting. Because the southeastern part of the Wind River basin is relatively narrow, any uranium-bearing solutions moving through the Wind River formation would tend to be carried northeastward toward the axis of the basin or entirely out of the basin area. The ground water movement prior to tilting may have leached most of the soluble uranium from the overlying Oligocene and Miocene rocks or have provided an escape-way for other possible ore-bearing solutions. After tilting, the post-Wind River rocks had a southward dip so that movement of solutions within these rocks would be south or southwestward. The change in direction of ground water movement in post-Wind River rocks may possibly have prevented not only further trapping of uranium-bearing water in the areas where the Wind River formation is now exposed but may also have caused leaching of previously-formed uranium deposits below the unconformity at the base of the White River formation. This may be the explanation for some of the areas of abnormally high background in the Wind River formation.

If this hypothesis is correct, any significant deposits of uranium would probably be near the axis of the basin rather than along the margins.

Supporting this interpretation is the fact that water of higher uranium content does occur along the axis of the structural basin, whereas those water samples collected from the Wind River, White River, and Miocene rocks along the southeastern margin of the basin contain abnormally small amounts of uranium as compared with water samples from corresponding rocks in the Gas Hills and other areas where data are available.

The equivalent uranium in the rock samples collected from the Wind River formation in the Clarkson Hill area is consistently higher than the chemical uranium, thus indicating the possible antiquity of the accumulation or a slow post-depositional leaching by ground water.

Ralston Buttes, Colorado

By

D. M. Sheridan

Field investigations in the Ralston Buttes district, Colorado, were completed during the report period. The work consisted of completion of areal mapping at a scale of 1:20,000 and of detailed mine mapping at scales of 1:120 and 1:1,200.

The general geology of the district and the economic geology of the uranium deposits are discussed below.

#### Geologic setting

The Ralston Buttes district is one of the most significant uranium-producing districts east of the Continental Divide in Colorado. The district is on the eastern flank of the Colorado Front Range and coincides with the Ralston Buttes 7-1/2 minute quadrangle (about 58 square

miles in area), shown on the accompanying geologic map (fig. 31). The district lies southeast of the northeast-trending Front Range Mineral Belt.

### Rocks

Precambrian metamorphic and igneous rocks form about 90 percent of the bedrock of the Ralston Buttes district (fig. 31); sedimentary rocks of Paleozoic and Mesozoic age crop out in the northeastern part of the district. Not shown on the map are thin Tertiary dikes and sills of leucosyenite and monzonite. Quaternary deposits, also not shown on the map, include thick deposits of gravel mantling pediments in the northeastern corner of the district, and thin alluvial deposits in the valleys.

On the map the Precambrian rocks have been grouped on the basis of predominant lithologic character into seven units: (1) granodiorite, (2) quartzite unit, (3) amphibolite unit, (4) mica schist unit, (5) deformed schist, (6) gneiss unit, and (7) deformed quartz monzonite gneiss. Not shown on the map are dikes, sills, and irregular bodies of Precambrian pegmatite, aplite, and hornblende metasyenite. With the exception of some of the pegmatites, all of the Precambrian rocks have been metamorphosed and contain assemblages of minerals characteristic of the sillimanite zone of regional metamorphism.

The granodiorite occurs in several areas in the western and northwestern parts of the district and is similar in texture and lithology to the Boulder Creek granite, as mapped elsewhere in the Front Range by Lovering and Goddard (1950, p. 25, 27, pl. 2). The quartzite unit crops out in the northwestern part of the district in a syncline plunging gently northeastward. The amphibolite unit crops out in a semicircular

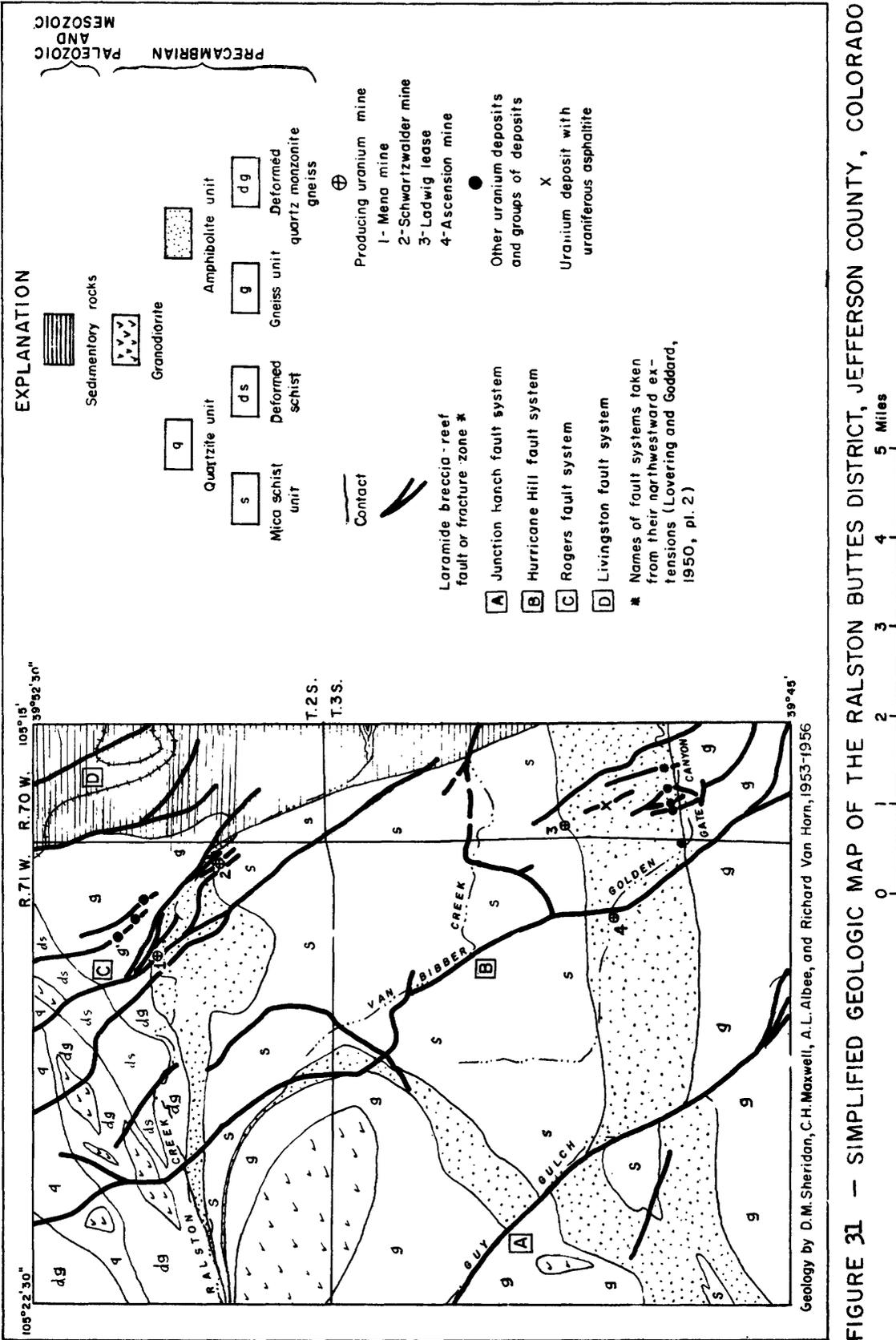


FIGURE 31 - SIMPLIFIED GEOLOGIC MAP OF THE RALSTON BUTTES DISTRICT, JEFFERSON COUNTY, COLORADO

belt in the northern, western, and southern parts of the district and separates a central area of mica schist from the gneiss unit. Rocks in the amphibolite unit include layered lime-silicate gneiss, inter-layered hornblendic and biotitic gneisses, and lesser amounts of quartz gneiss and muscovite-biotite schist. The mica schist unit consists predominantly of muscovite-biotite-quartz schist, but porphyroblasts of sillimanite, garnet, and andalusite are common. The contact between the mica schist unit and the amphibolite unit is commonly marked by an irregular zone of garnetiferous biotite-quartz gneiss and magnetite-bearing quartz gneiss. The gneiss unit includes quartz monzonite gneiss, plagioclase-biotite gneiss, and lesser amounts of amphibolite, garnet-biotite schist, and quartz gneiss. Map units of deformed schist and deformed quartz monzonite gneiss, shown in the northern part of the district, represent a belt of cataclastic deformation.

The sedimentary rocks in the northeastern part of the quadrangle range in age from Pennsylvanian to Cretaceous.

#### Precambrian structure

The major trend of lithologic layering and schistosity in the Precambrian terrain is easterly to northeasterly. Several broad arcuate patterns of folding are evident (see fig. 31). The rocks have been complexly folded but nearly everywhere the schistosity is parallel to the compositional layering. In some areas a slip cleavage crosses the layering and schistosity at various angles. Conspicuous lineation is caused by minor folds, drag folds, tiny chevron folds, mineral alignment, warps, crinkles, and streaking. Two prominent trends of the linear structures are S. 70° W. and N. 70° W. Cataclastic deformation has caused textural changes in the rocks in a northeast-trending belt in the northern part of the district.

### Laramide faults and fracture zones

Northwesterly trending Laramide faults and fracture zones cut both the Precambrian rocks and the younger sedimentary rocks in the Ralston Buttes district. In the Precambrian terrain these Laramide structures are marked characteristically by fault breccias and fracture zones. The structures are southeastward extensions of the Laramide "breccia reefs" or "breccia dikes" that extend for many miles northwestward across the Front Range Mineral Belt (Lovering and Goddard, 1950, p. 79, pl. 2). The traces of breccia-reef faults and fracture zones are shown on the geologic map (fig. 31). These have been grouped into four major fault systems, according to names given to their northwestward extensions by Lovering and Goddard: (A) Junction Ranch, (B) Hurricane Hill, (C) Rogers, and (D) Livingston fault systems.

A generalized zoning of the character of the fault breccias along these breccia-reef systems was recognized from northwest to southeast in the Ralston Buttes district. In the northwestern part of the district the breccia reefs commonly consist of fault breccia cemented by quartz, fluorite, and hematite. Most of the breccia reef structures in the remainder of the district are characterized by fault breccias cemented by ankerite and potash feldspar.

### Uranium deposits

The uranium deposits in the Ralston Buttes district are hydrothermal veins in Laramide fault breccias and related fractures. Pitchblende and secondary uranium minerals are associated with base-metal sulfides in a gangue of carbonate minerals (typically ankerite), potash feldspar, and quartz. In addition to the deposits associated directly with fault breccias, one deposit occurs in a fracture zone along and near a pegmatite and

another deposit occurs in fractures cutting a quartz vein.

All of the known uranium deposits in the district are in Precambrian terrain and are grouped in two main areas: the Golden Gate Canyon area in the southeastern part of the district and the Ralston Creek area in the northeastern part. The locations of four producing mines and nine other uranium deposits and groups of deposits are shown on the map. The uranium deposits near Golden Gate Canyon are associated with the complexly branching southeastward extension of the Hurricane Hill breccia-reef system, and the uranium deposits along Ralston Creek are associated with a similar complexly faulted area along the Rogers breccia-reef fault system. Although radioactive anomalies have been found along the Junction Ranch fault system, no potentially significant uranium deposits have been discovered in surface exposures along this structure in the Ralston Buttes district. The Livingston fault system cuts sedimentary rocks in the Ralston Buttes district and no uranium deposits are known in its vicinity within the district.

The uranium deposits range in thickness from thin mineralized veinlets less than an inch thick to major ore shoots as much as 6 to 8 feet thick. Commonly the uraniferous material occurs in lenses or shoots that are discontinuous along strike. Individual ore bodies range in size from small pods or lenses containing 50 tons or less to large shoots containing over a thousand tons of ore.

Pitchblende is the main uranium mineral of the deposits in the Ralston Buttes district. Secondary uranium minerals at some of the deposits are torbernite, metatorbernite, uranophane, autunite, uranopilite, and meta-autunite. Base-metal sulfides associated with the pitchblende in these deposits are not present in sufficient quantities

to be valuable constituents of the ore. The suite of metallic minerals includes pitchblende, pyrite, chalcopyrite, bornite, chalcocite, covellite, sphalerite, galena, tetrahedrite-tennantite, marcasite, malachite, azurite, and hematite. Samples from some of the deposits contain as much as 0.14 percent vanadium oxide but the mineralogic nature of the vanadium has not yet been determined. Native bismuth occurs at one pitchblende deposit. Pyrrhotite and molybdenite(?) have been observed near some of the pitchblende deposits but may not belong to the same period of mineralization. Uraniferous asphaltite is associated with base-metal sulfides in a carbonate-bearing fault breccia in the Golden Gate Canyon area. The asphaltite may be related to oil seepage in the vicinity, with the oil presumably coming from sedimentary rocks underlying a westward-dipping reverse fault which crops out east of the district.

The detailed paragenesis of minerals at the Union Pacific prospect in Golden Gate Canyon has been discussed by Adams and Stugard (1956), who found that pitchblende preceded the sulfide mineral deposition. Preliminary microscope studies of material from other pitchblende deposits in the district suggest that this same paragenetic sequence is generally consistent. Post-mineral movement is common in some of the deposits.

Maps and descriptions of some of the uranium deposits in the Ralston Buttes district have been published in reports by Adams, Gude, and Beroni (1953) and by Adams and Stugard (1956). A brief description of the Schwartzwalder mine is given at the end of this report.

Factors controlling uranium deposition in the district

Field and laboratory investigations suggest that most of the pitchblende deposits in the Ralston Buttes district were controlled primarily by favorable structural environment and favorable host rocks.

Each of the two known uraniumiferous areas near Golden Gate Canyon and Ralston Creek is located where a major northwesterly trending Laramide breccia-reef system consists of a complex network of faults and fractures rather than a single relatively simple fault. In the Ralston Creek area the complexity of faulting is also characterized by numerous changes in trend of the faults along their strike. The combination of these geologic conditions--splitting of a fault into a complex network and changes of trend of the faults--has been favorable for uranium deposition, apparently because ample open space was provided by these conditions.

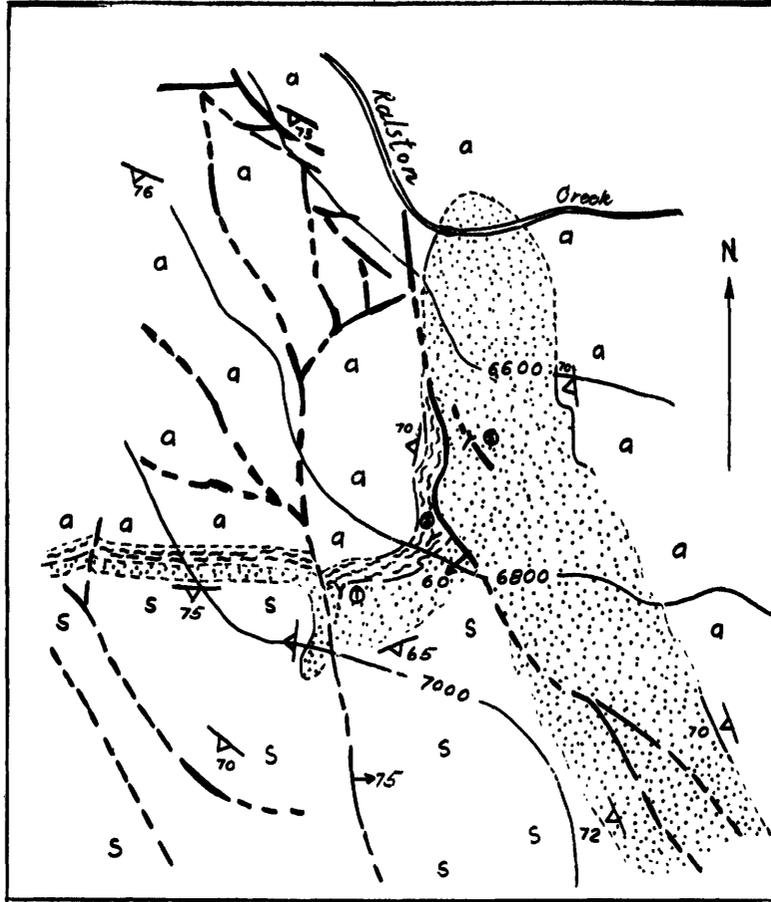
The other major factor in the localization of the uranium deposits is a favorable host rock. Precambrian rocks in the district that seem to have been favorable include rocks rich in hornblende, biotite, or garnet and biotite. Such rocks occur predominantly in the amphibolite unit (fig. 31) and along the garnetiferous zone between the amphibolite unit and the mica-schist unit, but lesser amounts of the more favorable rocks are also found in the gneiss unit. Most of the pitchblende deposits in the district occur where Laramide breccia-reef faults and related fractures cut layers of favorable host rocks. Adams and Stugard (1956) first recognized the importance of wall rock control in deposits along Golden Gate Canyon, and concluded that wall rocks rich in ferrous iron are the most favorable.

The favorability of certain wall rocks for pitchblende deposition may be explained by their chemical character or by their physical character. Certain minerals, such as biotite or hornblende, may react with mineralizing solutions in such a way as to cause the deposition of the uranium as pitchblende. The hornblende-rich and garnetiferous gneisses, on the other hand, are relatively more competent than the muscovite-rich schists and yield more open spaces when brecciated. It is not known whether the chemical or physical nature of these rocks was of more importance in ore deposition, but it is likely that both characteristics are involved in the genetic history of the uranium deposits in the Ralston Buttes district.

#### The Schwartzwalder mine

The Schwartzwalder mine, located in the Ralston Creek area (fig. 31), is the largest producing mine in the Ralston Buttes district. Originally discovered by Mr. Fred Schwartzwalder of Arvada, Colorado, the mine is currently being operated by the Denver-Golden Oil and Uranium Company. The mine has been operated from three levels, and a lower fourth level is being planned. Production of pitchblende ore from the mine started in 1953.

The mine is in the complexly faulted area along the Rogers breccia-reef fault system. The geology of the surface area at the mine is shown in figure 32. The amphibolite unit, consisting of layered lime silicate gneiss, amphibolite, and quartz gneiss, crops out in the northern part of the area. Muscovite-biotite-quartz schist in the southern part of the area is separated from the amphibolite unit by a zone of garnetiferous biotite-quartz gneiss and fine-grained biotite-quartz-muscovite schist. The Precambrian rocks have been folded tightly into an anticline and



Geology by D.M. Sheridan, 1956

### EXPLANATION

- |   |   |   |
|---|---|---|
| <p><span style="border: 1px solid black; padding: 2px;">a</span><br/>Amphibolite unit</p> <p><br/>Fine-grained biotite-quartz-muscovite schist</p> <p><br/>Garnetiferous biotite-quartz gneiss</p> <p><span style="border: 1px solid black; padding: 2px;">S</span><br/>Muscovite-biotite-quartz schist</p> | <p><br/>Contact<br/><i>Dashed where inferred</i></p> <p><br/>Breccia reef fault, showing dip<br/><i>Dashed where inferred</i></p> <p><br/>Strike and dip of compositional layering</p> <p><br/>Portal of adit:-<br/>① Upper (orig.) level<br/>② Minnesota level<br/>③ Charlie level</p> | <p><b>NOTE</b><br/>Overburden not shown</p> |
|---|---|---|

FIG. 32.--GEOLOGIC MAP OF SURFACE AREA, SCHWARTZWALDER MINE, RALSTON BUTTES DISTRICT, COLORADO

0 200 400 600 Feet

Contour Interval 200 feet  
Datum's approximate mean sea level

syncline which plunge steeply to the southwest. The Precambrian rocks are cut by Laramide breccia-reef faults that trend northward and northwestward across the area. These faults belong to a complex branching network of faults in the footwall of the main Rogers breccia-reef fault, which lies 500 feet north of the area shown in figure 30. and dips steeply to the northeast.

Pitchblende associated with base-metal sulfides occurs in veins that occupy the Laramide fault breccias. The known uranium mineralization in the Schwartzwalder mine area has occurred principally where the Laramide faults and fractures cut the garnetiferous-biotite-quartz gneiss and the adjacent discontinuous layer of fine-grained biotite-quartz-muscovite schist. One pitchblende-bearing vein, however, occurs in the amphibolite unit immediately north of the area shown in figure 30. No uranium mineralization is known southward along the faults in the muscovite-biotite-quartz schist.

The principal known veins are shown at a larger scale in the preliminary geologic section (fig. 33). From west to east these are the Nebraska, Kansas, Colorado, Walder, Illinois, and Washington veins. The Nebraska, Kansas, and Colorado veins dip northeastward, and the Illinois and Washington veins dip westward. The movement along the Colorado and Nebraska structures has apparently been reverse fault movement. Not named on the section is the Ralston Creek vein (or "Flat vein"), which dips at a low angle southwestward from its junction with the Colorado vein in the upper level.

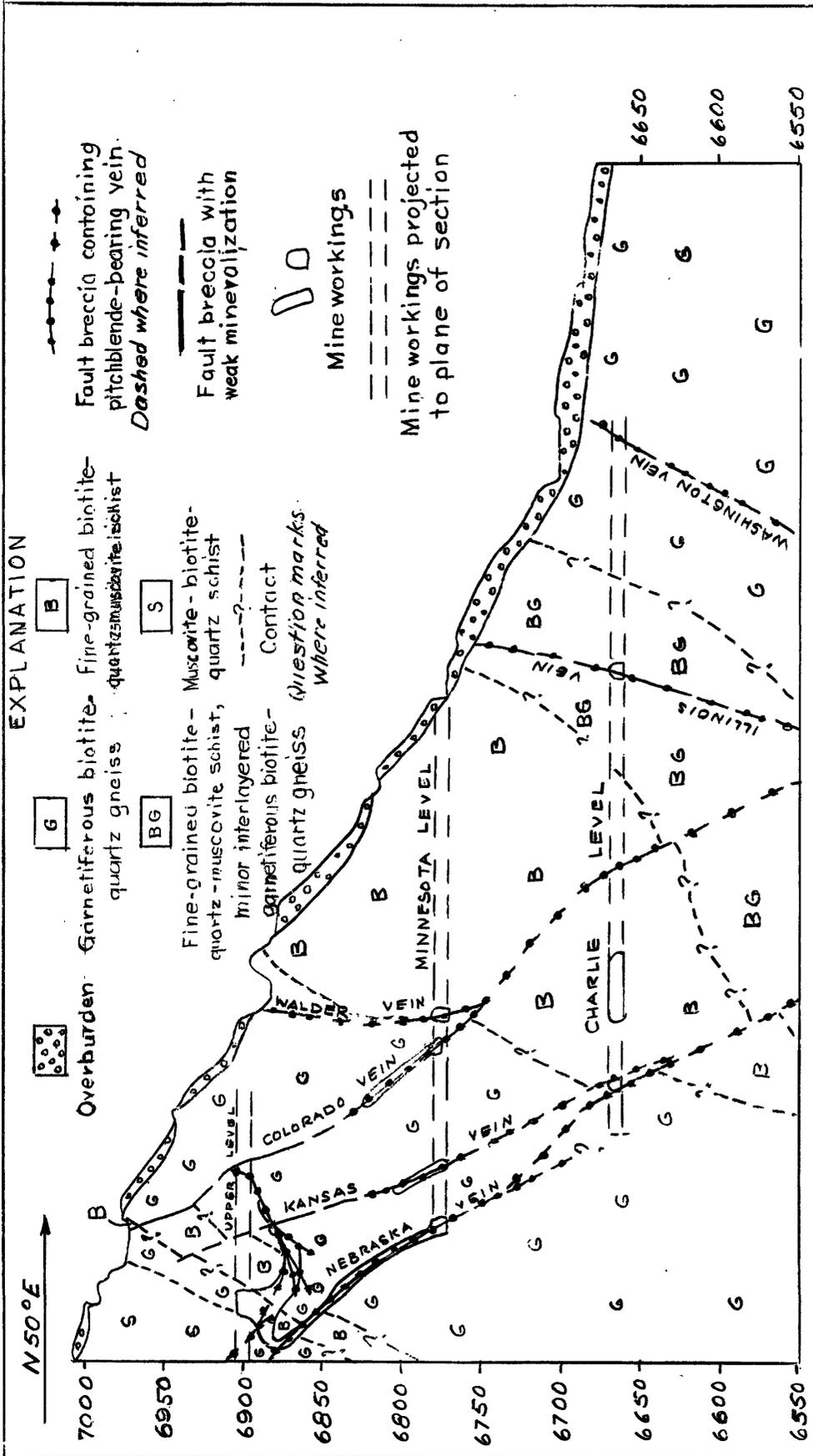


FIG. 33. --PRELIMINARY GEOLOGIC SECTION, SCHWARTZWALDER MINE, RALSTON BUTTES DISTRICT, JEFFERSON CO., COLORADO  
 Geology by D.M. Sheridan, November 1956

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- Adams, J. W., and Stugard, Frederick, Jr., Summary of wall-rock control of certain pitchblende deposits in Golden Gate Canyon, Jefferson County, Colorado, in Page, L. R., Stocking, H. E., and Smith, H. B., (1956), 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. Prof. Paper 300, p. 113-116.
- Adams, J. W., Gude, A. J., 3rd, and Beroni, E. P., 1953, Uranium occurrences in the Golden Gate Canyon and Ralston Creek areas, Jefferson County, Colorado: U. S. Geol. Survey Circular 320.
- Lovering, T. S., and Goddard, E. N., 1950, Geology and ore deposits of the Front Range, Colorado: U. S. Prof. Paper 223.

Colorado Front Range  
By  
P. K. Sims

A summary of the general geology of the Central City and adjoining mining areas in the Colorado Front Range was given in TEI-390, p. 100-107, and a report on the distribution, structure, mineralogy, paragenesis, and origin of the uranium deposits was given in TEI-440, p. 75-87, and TEI-590, p. 200-202. An evaluation of the uranium potential of the region was given in TEI-490. Evidence for a quartz bostonite magma source for the uranium was presented in TEI-620, p. 217-220.

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

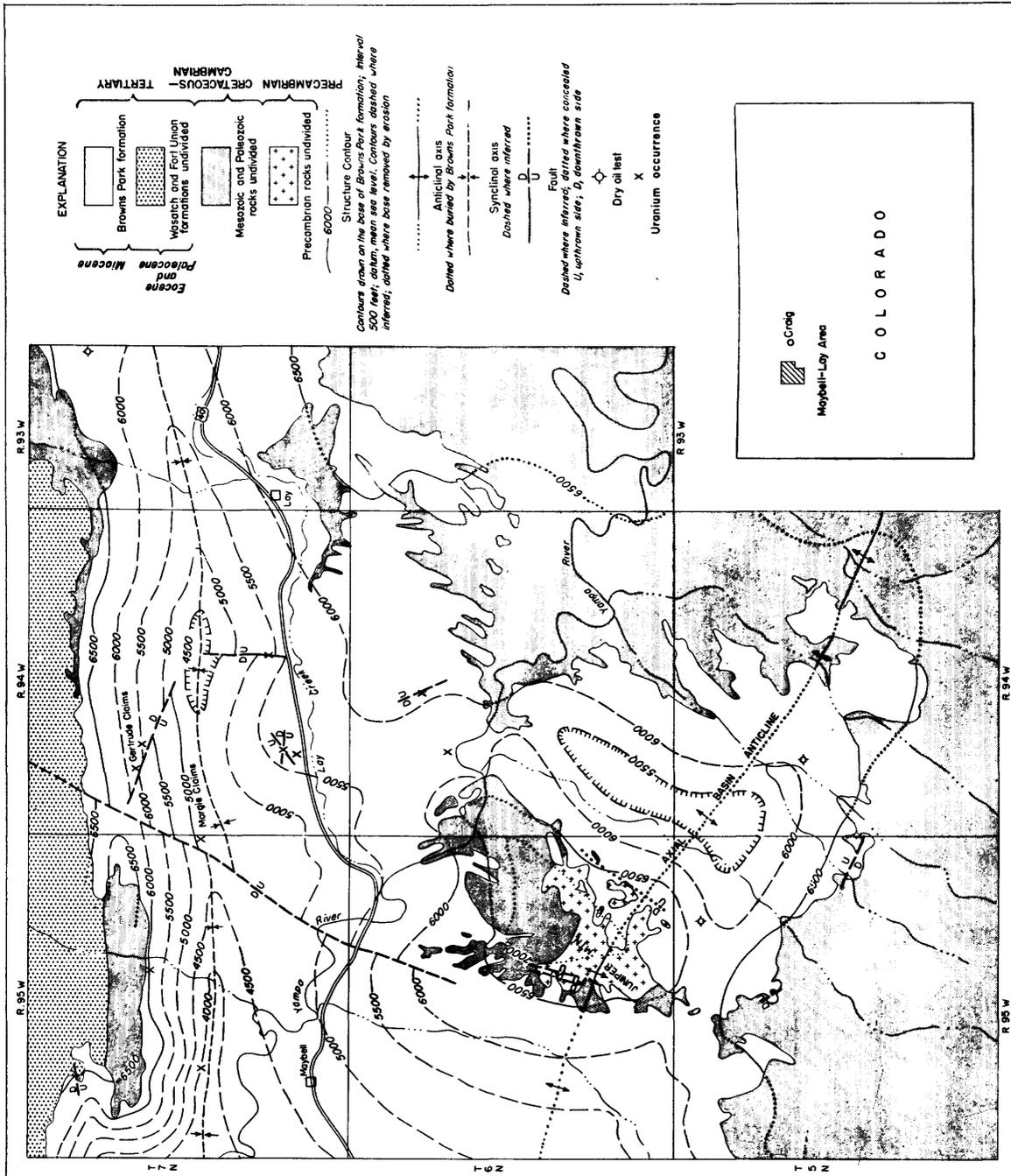
- Harrison, J. E. and Wells, J. D., 1956, Geology and ore deposits of the Freeland-Lamartine district, Clear Creek County, Colorado: U. S. Geol. Survey Bull. 1032-B.
- Sims, P. K., 1956, Uranium deposits in the Front Range, Colorado: The Mines Magazine, v. 46, no. 3, p. 77-79.

Maybell-Lay area, Moffat County, Colorado  
By  
M. J. Bergin

The Browns Park formation of Miocene age and the underlying rocks ranging in age from Cretaceous to Eocene were mapped on aerial photographs at a scale of 1:20,000 during the report period, over an area of about 180 square miles in the eastern part of the Maybell-Lay area, Moffat County, Colorado (fig. 34). During the 1955 and 1956 field seasons a total of about 400 square miles have been mapped (figs. 34 and 35). Samples were collected for grain size and heavy mineral analyses from the Browns Park sandstone, siltstone and shale in a stratigraphic section on Cedar Mountain (fig. 34), where the formation is more than 900 feet thick. The caprock on Cedar Mountain is a basalt flow 15 to 30 feet thick. At one locality it is overlain by 7 feet of sandstone similar to that below the basalt, indicating that the flow is of Browns Park age. The basalt probably is related to the igneous rocks of the Elkhead Mountains about 25 miles to the northeast.

The Margie and Gertrude claims (see fig. 35), where the ore being shipped from open pits 50 feet deep averages at least 0.22 percent uranium, were studied in detail. At these localities uranium minerals occur as disseminated material in soft, friable, porous, very fine-to medium-grained, massive to crossbedded sandstone ranging from 5 to 30 feet in thickness and separated by beds of claystone and hard calcareous sandstone 1 to 5 feet thick. The uraniferous zones are irregularly shaped elongate bodies ranging from 1 to 19 feet in thickness; the largest is reported to be approximately 1,000 feet long and 200 to 300 feet wide. The zones are usually concordant to the regional bedding of the host rock.





Geology modified from Sears, J.D., USGS Bull. 751, p.11, 1924

**FIGURE 35 GENERALIZED GEOLOGIC MAP SHOWING CONFIGURATION OF THE BASE OF THE BROWNS PARK FORMATION IN THE MAYBELL-LAY AREA, MOFFAT COUNTY, COLORADO**

At the Margie claims three zones containing meta-autunite, tyuyamunite, and an unnamed uranyl phosphate mineral are being mined from oxidized sandstone adjacent to and in the east wall of a high-angle fault of post-Browns Park age. Ore in medium dark gray unoxidized sandstone is also mined from the west wall adjacent to the fault but at that place no uranium minerals have as yet been identified. The fault strikes N.  $5^{\circ}$  W. and dips  $77^{\circ}$  to  $84^{\circ}$  NW. The displacement is unknown because of the lack of key beds. The offset on the contact of the oxidized and unoxidized sandstone shows a reverse movement of about 30 feet, and striations on the fault plane indicate a lateral movement with the east wall moving south and down at angles of  $20^{\circ}$  to  $30^{\circ}$  from the horizontal.

In the Gertrude mine two mineralized zones containing meta-autunite, uranophane, and liebigite are mined from sandstone between beds of claystone and hard calcareous sandstone in the oxidized zone. Large quantities of limonite, jarosite, and gypsum are associated with the ore zones as well as with barren rock in both the Gertrude and Margie mines. Studies and analyses of uranium content, associated elements, composition, grain size, and heavy minerals of the host rock are in progress (see also TEI-620, p. 190-199).

Approximately 100 tons of ore averaging at least 0.22 percent uranium have been mined from clayey sandstone gouge along a high-angle fault cutting the Browns Park formation in sec. 27, T. 7 N., R. 94 W. Meta-autunite occurs as disseminated material and as fracture coatings in the gouge zone which ranges from 2 to 6 feet thick. The fault strikes N.  $20^{\circ}$  E. and dip  $78^{\circ}$  W., but the amount and direction of displacement are not known.

The association of uranium deposits with synclinal folds and faults and with relatively impervious hard calcareous sandstone and claystone beds indicates that uranium-bearing solutions moving through the Browns Park formation may have been concentrated by favorable stratigraphic and structural traps. Possible uranium precipitating agents may have been calcium carbonate and iron sulfides. Hydrogen sulfide in natural gas rising from buried older sediments has also been suggested as a possible precipitating agent (Grutt, E. W., Jr., personal communication).

All commercial uranium deposits discovered to date in the Browns Park formation in the Maybell-Lay area occur near the axis of an asymmetrical syncline or in proximity to high-angle faults (fig. 35). Geologic mapping during the report period has shown that the synclinal structure with which the deposits are associated continues to the east and that a similar structure is present in the vicinity of Cedar Mountain (fig. 34). Numerous high-angle, northwest-trending normal faults with displacements of 50 to 400 feet were also mapped in the Browns Park formation in the eastern half of the Maybell-Lay area. Uranium occurrences are indicated by water samples with abnormally high uranium contents, and in addition several occurrences are present in the Browns Park and Wasatch formations in the area shown on figure 34. 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. 34). Both areas are from 100 to 250 feet below the restored Wasatch-Browns Park contact and could be reconcentrations of uranium from the Browns Park formation which once covered the area. The occurrences are significant because they indicate that the Wasatch formation, which is of large areal extent in northwestern Colorado and

southwestern Wyoming, may contain uranium deposits.

It is believed that additional prospecting along faults, near the axes of the synclines, and in areas where water samples contain abnormally high amounts of uranium (shown in fig. 34) may lead to the discovery of additional uranium deposits in the Browns Park formation.

Thomas Range, Utah

By

M. H. Staatz

Results of previous geologic work in the Thomas and Dugway Ranges in central Juab and Tooele Counties, Utah, were given in the last semi-annual report (TEI-620, p. 223-224). During this report period, most of the effort was devoted to: (1) measuring and studying the stratigraphic sequence of the Paleozoic rocks in the Dugway Range, (2) areal mapping in the Dugway Range, (3) detailed study of individual mining properties in the Dugway mining district, and (4) mapping new properties and keeping abreast of the work in the uraniferous fluorspar and uranium deposits in the western part of the Thomas Range.

The sequence of Paleozoic rocks in the Dugway Range is different in part from that in the Thomas Range, and includes rocks ranging in age from Lower Cambrian to Mississippian. Sections were measured of these rocks to familiarize the field party with the stratigraphic details and the thickness of these units, and to determine the formations to be used in mapping. Stratigraphic sections were measured on rocks also present in the Thomas Range to determine variance in thickness and stratigraphic details.

During the report period the Paleozoic sedimentary rocks in the Dugway Range 15-minute quadrangle were mapped on a scale of 1:24,000, completing field work on the project involving an area of about 323 square miles.

The Dugway mining district is a small, principally lead-silver district, although a little zinc, copper, and gold have been recovered. About two-thirds of this mining district lies within the Dugway Range quadrangle, and one-third in the Dugway Proving Ground SW quadrangle to the north. At present no mines are operating. The ore deposits consist of narrow fissure veins in quartzite and somewhat larger replacement veins in dolomite. The dumps of the various properties as well as all the accessible underground workings in the Dugway Range quadrangle were checked with a Geiger counter. No abnormal radioactivity was noted.

On Spor Mountain in the western part of the Thomas Range, the newly-discovered pipes of the Dell No. 5 and the Floride No. 5 mines were mapped. These uraniferous fluorspar pipes contain between 0.02 and 0.03 percent uranium. Additional sampling was done on some of the other uraniferous fluorspar pipes.

Tunnels 20 feet long driven into the uraniferous ore body at the Good Will property, about 1 mile east of Spor Mountain, were sampled during the period. The chief ore mineral at this property is beta-uranophane; the deposit is in a lens of tuffaceous sandstone in a series of volcanic rocks.

Tucumcari-Sabinoso area, New Mexico

By

R. L. Griggs

The uranium occurrences and the significant geologic features of the Tucumcari-Sabinoso area have been summarized in preceding semi-annual reports (TEI-590, p. 191-195; TEI-620, p. 209-212).

During the period covered by this report, mapping on a scale of 1:62,500 was continued, and a total of thirteen 15-minute quadrangles had been completed at the close of the field season. Within this area about 2,000 feet of nearly flat-lying sedimentary rocks of Triassic, Upper Cretaceous, and Tertiary age are exposed. The entire sequence has been subdivided into 14 stratigraphic units (see TEI-620, p. 209-212) which are delineated on the map of the thirteen quadrangles.

A significant uranium discovery was made 50 miles east of the project area during the report period. A moderate-sized ore body was discovered by personnel of the AEC on the Hart-Mansfield ranch, 12 miles northwest of Vega, Oldham County, Texas. The ore occurs in a gray sandstone in the Triassic Dockum group. This sandstone is correlative with part of the Santa Rosa sandstone of the Tucumcari-Sabinoso area, and the discovery indicates the potentiality of a large region in eastern New Mexico and northwestern Texas where very little prospecting has been done.

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 (fig. 36). The oldest rocks in the area are Precambrian in age and include phyllite, quartzite, dolomite, limestone, and argillite. These rocks have been tentatively separated into four formations along the northern boundary of the quadrangle; in this vicinity, the Precambrian rocks are overlain by a medium-gray marble that is probably Paleozoic in age.

The metamorphic rocks in the southeastern part of the quadrangle (fig. 36) are largely hornfels, limestone, and phyllite. The age of these rocks is unknown, except that they are older than the Loon Lake batholith, and they have not yet been correlated with the metamorphic rocks along the northern margin of the quadrangle.

The Precambrian and Paleozoic(?) rocks were intruded by the Loon Lake batholith, probably Cretaceous in age. The batholith consists largely of quartz monzonite and granodiorite and is cut by many small dikes of alaskite and a few lamprophyre dikes.

In the Turtle Lake quadrangle, the batholith has been separated into three major units: porphyritic quartz monzonite, **equigranular** quartz monzonite, and granodiorite. In the northern part of the quadrangle, the batholith consists largely of porphyritic quartz monzonite containing large phenocrysts of potash feldspar and less than five percent biotite, and **equigranular** quartz monzonite containing about three percent biotite.

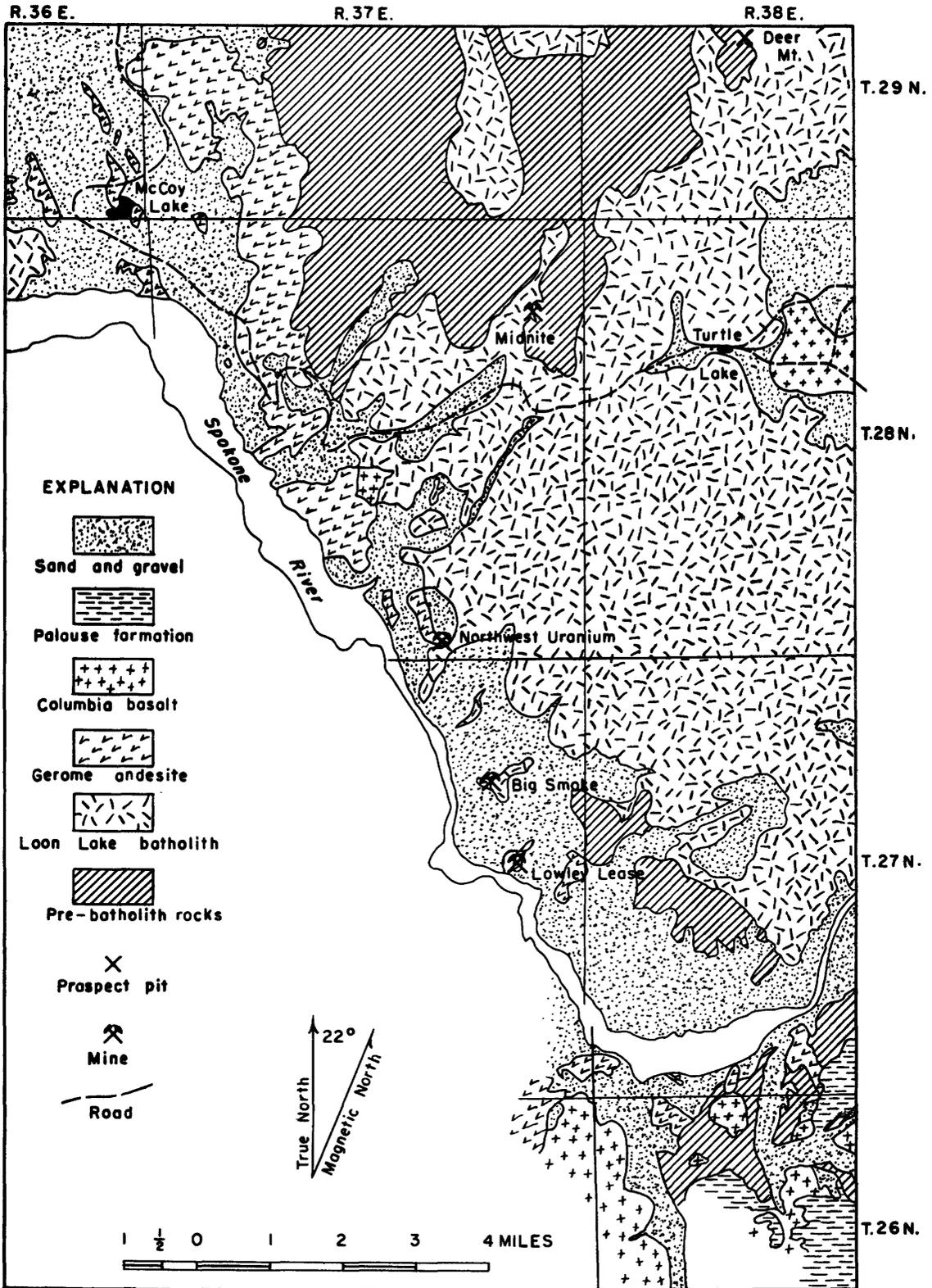


Fig. 36—Generalized geologic map of part of the Turtle Lake quadrangle, Washington

In the southern part of the quadrangle, the batholith is largely equigranular granodiorite containing as much as 20 percent biotite and hornblende in approximately equal amounts.

Post-batholith rocks include Oligocene andesitic flows, dikes, sills, and pyroclastic rocks with associated sandstone, conglomerate, and carbonaceous shale; Miocene basalt flows; Pleistocene Palouse loess; and Pleistocene gravel and sand. Plant fossils collected from the pyroclastic rocks in the vicinity of the Northwest Uranium mine have been identified as of probable Oligocene age. The pyroclastic rocks are probably part of the Oligocene Gerome andesite.

Uranium deposits have been found at five localities in the Turtle Lake quadrangle. The largest deposit is at the Midnight mine (fig. 36). The uranium occurs in several large ore bodies near the contact of the porphyritic quartz monzonite and Precambrian phyllite and schist. The uranium appears to be largely in intensely faulted zones in the phyllite and schist. The ore bodies above the water table contain only secondary uranium minerals coating fractures and grain boundaries in the metamorphic rocks, and, locally, in the adjacent quartz monzonite. Diamond drilling has indicated that the ore bodies below the water table contain black uranium minerals coating fractures in the metamorphic rocks. No black uranium minerals have been observed in the quartz monzonite. Uraninite, and possibly coffinite, have been identified from core samples of the black ore by Robert G. Coleman, U. S. Geological Survey.

The uranium deposits at the Lowley Lease and Deer Mountain (fig. 36) are apparently similar to the **Midnight** deposits. Only relatively sparse uranium minerals have been observed at these deposits.

The uranium minerals at the Lowley Lease are in an intensely faulted zone at the contact of biotite-hornblende granodiorite and a dark-gray to reddish-brown quartzite. Coffinite was identified in one specimen from this deposit.

The uranium deposits at the Northwest Uranium mine and the Big Smoke mine are in the Oligocene pyroclastic and sedimentary rocks. The rocks include interbedded tuffs, tuffaceous sandstones and conglomerates, sandstones and conglomerates which contain little or no volcanic debris, and carbonaceous shales. The beds generally strike northwest and dip gently southwest. Shallow bulldozer cuts expose secondary uranium minerals in carbonaceous shale, and in sandstone and conglomerate. Drilling has indicated a large, relatively low-grade uranium deposit with a highly irregular outline. The top of the ore body is from about 30 to 90 feet below the surface of the ground, and the thickness of the ore ranges from about 2-1/2 feet to about 40 feet and averages about 5 to 10 feet. The ore is apparently not confined to a single bed or horizon in the rocks.

The northwest end of the ore body is cut off by a steeply dipping, northward-trending fault. The west side of the fault moved down, and although low radioactivity was found in a single drill hole west of the fault, insufficient information is available to determine definitely whether all of the movement was pre- or post-mineralization.

The only uranium mineral identified from surface exposures is of the metatorbernite group, but the principal mineral in the ore body may be finely disseminated uraninite.

Uranium minerals are exposed in only one bulldozer cut at the Big Smoke mine. The uranium minerals appear to be in carbonaceous shale and

tuffaceous sandstone that have been intensely sheared by a northward-trending fault along the contact between the sedimentary rocks and biotite-hornblende granodiorite.

Similar pyroclastic and sedimentary rocks occur south of the Spokane River, but no radioactivity anomalies have been detected south of the river.

Jarbridge, Nevada-Idaho  
By  
R. R. Coats

During the report period, work on the Jarbridge quadrangle, Nevada-Idaho, was chiefly in the field, including study of the distribution of radioactivity in the rhyolitic rocks and collection of samples for laboratory work.

Mapping of the quadrangle is now completed, about 70 square miles having been mapped this summer. About one-fourth of the quadrangle was mapped on a scale of 1:24,000, and the rest on a scale of 1:48,000. Six distinct series of volcanic rocks were found and mapped; they ranged in age from late Miocene to early Pliocene, according to provisional dating thus far, and in composition from rhyolite to quartz-latitude. In a general way, it may be said that the content of uranium and some other trace elements, chiefly beryllium, niobium, zirconium, tin, lead, and fluorine, increases with decreasing age, although the trends are irregular.

Argillically altered rhyolitic rocks examined underground near quartz veins are slightly less radioactive than the unaltered equivalents. It has not yet been determined whether this decrease in radioactivity reflects an actual removal of uranium from the wall rocks.

Eastern region

Mauch Chunk, Pennsylvania

By

Harry Klemic and J. C. Warman

Geologic mapping of the Pohopoco Mountains and East Mauch Chunk 7-1/2-minute quadrangles was started in July 1955, and continued in 1956. Narrow strips of the adjoining Nesquehoning, Weatherly, and Mauch Chunk 7-1/2-minute quadrangles are included in the area studied because of proximity to uranium occurrences along the Lehigh River. Field work is about 85 percent completed. Stratigraphic sections were studied, and preliminary petrographic studies of samples of the rocks have been completed (TEI-620, p. 212-214).

Stratigraphy

The stratigraphic units in the area range in age from Middle Devonian to Early Pennsylvanian; of these units only the Pottsville formation of Pennsylvanian age and the Cherry Ridge member of the Catskill formation of Late Devonian age are known to contain uranium deposits. A description of the formations follows.

Hamilton formation (Middle Devonian).--The lowest stratigraphic unit in the mapped area is assigned tentatively to the Hamilton formation (Willard, 1939). The base of the formation is not exposed, but the portion seen is about 1,400 feet thick. The rocks are dark-gray shale, locally silty or finely arenaceous. Southeastward-dipping, closely spaced cleavage masks the bedding. Brachiopod, pelecypod, coral, trilobite, and crinoid fossils have been collected, and their more precise identification should assist in recognizing Hamilton subdivisions and in locating the Hamilton formation-Portage group contact.

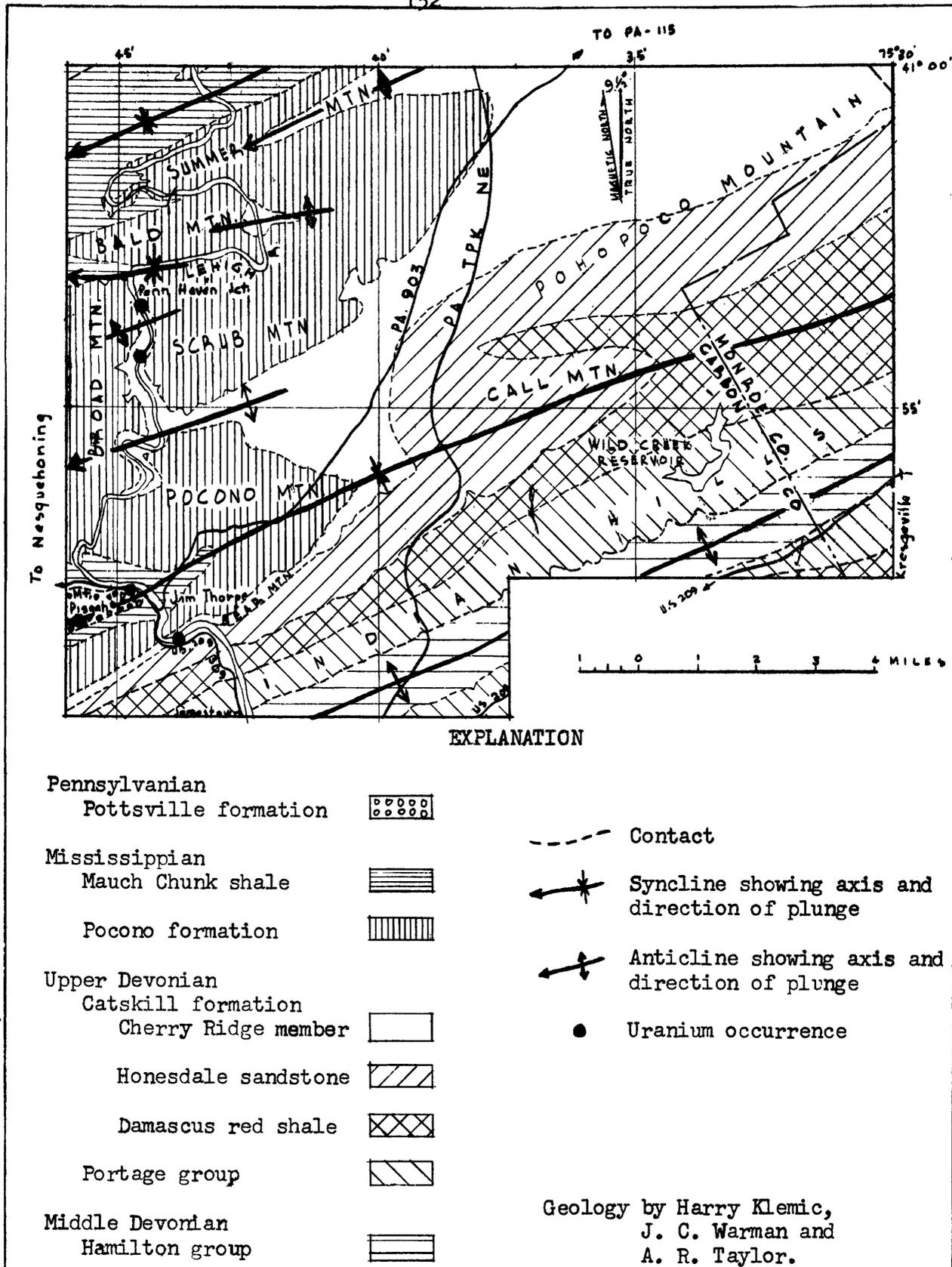


FIGURE 37 PRELIMINARY MAP OF AREAL GEOLOGY OF NORTHERN HALF OF MAUCH CHUNK QUADRANGLE AND ADJOINING AREAS.

Portage group (Upper Devonian).--Overlying the Hamilton formation is a sequence of about 3,100 feet of gray and brown sandstone and shale that is assigned tentatively to the Portage group (Willard, 1939, p. 207). In general the sandstones and shales of the group have well developed bedding planes, and the rocks are lighter in color and more coarse-grained in the upper part of the unit. At the base gray to dark-gray shale with closely spaced cleavage planes and indistinct bedding resembles Hamilton lithology, and the contact between these units is poorly defined. Marine fossils including brachiopods, corals, trilobites, and crinoids are abundant in some beds. As in the case of the Hamilton formation, subdivision of the Portage and location of its base await identification of the fauna. The uppermost rocks containing marine fossils in this area are mapped as the top of the Portage group.

An occurrence of galena, sphalerite, pyrite, and chalcopyrite was found in rocks of the Portage group near the south-central part of the area. The sulfide minerals occur in quartz-encrusted fracture fillings almost perpendicular to beds that are nearly vertical and slightly overturned. Only minor amounts of these minerals were found, but some of the galena crystals have faces as much as half an inch across.

Catskill formation (Upper and Middle Devonian).--The Catskill formation consists of about 5,900 feet of non-marine rocks overlying the marine Portage group. A subdivision of the Catskill into three units (Willard, 1936)--the Damascus red shale, the Honesdale sandstone, and the Cherry Ridge red beds--has been used by the authors in this area.

At the base of the Catskill and immediately overlying the Portage is a sequence of red sandstone and shale sparsely interbedded with gray and greenish-gray sandstone and shale. Except for a few fossil plant

remains, these rocks are unfossiliferous. This sequence of predominantly red rock is the Damascus red shale (Willard, 1939, p. 291) which is about 3,100 feet thick in this area.

Overlying Willard's Damascus red shale is the Honesdale sandstone (Willard, 1939, p. 291) composed of about 1,900 feet of unfossiliferous gray and brown sandstone. A few thin beds of red shale and sandstone occur near the base of this unit and some of the uppermost beds are reddish gray. Willard's Honesdale is generally coarser-grained than any of the underlying rocks in this area, and contains some conglomerate and conglomeratic sandstone beds.

The uppermost 900 feet of the Catskill formation is the Cherry Ridge red beds (Willard, 1939, p. 284). This is a sequence of predominantly red or reddish-gray beds of shale, sandstone and conglomerate, with some gray units interbedded with the red. Along the northern boundary of the quadrangle the uppermost red shale of Willard's Cherry Ridge is missing and the gray quartzitic sandstone of the Pocono formation of Mississippian age is in contact with the red sandstone of the Cherry Ridge. Willard's Cherry Ridge unit near Penn Haven Junction, except for some red shale in the upper part, is gray rather than the usual red.

Pocono formation (Lower Mississippian).—Overlying the Catskill formation is about 1,100 feet of gray sandstone, conglomerate, and shale of the Pocono formation. The upper part of the Pocono is commonly coarser-grained than the lower part (Winslow, 1887). Plant fossils are common, and locally thin coaly partings are found.

Mauch Chunk shale (Upper Mississippian).—The Mauch Chunk shale (Winslow, 1887) overlies the Pocono formation and is composed of about 2,200 feet of red sandstones and shales, although gray and brown sandstones

are interbedded with red sandstone and shale near the base of the formation. Traces of malachite or chrysocolla occur in a thin layer of gray shale near the base of the Mauch Chunk in the north part of the quadrangle. Although these occurrences of copper in gray shale are not radioactive, they are similar to occurrences of copper which include small amounts of uranium in Upper Devonian rocks in other parts of Pennsylvania.

Pottsville formation (Lower Pennsylvanian).---About 900 feet of gray conglomerate and sandstone with some interbedded red sandstone and shale comprise the Pottsville formation (Winslow, 1887) overlying the Mauch Chunk formation. The top and some intermediate units of the Pottsville are coarsely conglomeratic. Gray sandstone and conglomerate lenses are interbedded at the base of the formation. Carbonaceous material is abundant in some beds and some of this material resembles fossil logs which are elongate to the southwest.

#### Structure

Southwest-plunging anticlines and synclines are the major structural features in the northern half of the Mauch Chunk quadrangle. Some of these folds in Upper Devonian and Mississippian rocks terminate eastward in the central or western part of the area, but the Call Mountain syncline and the anticline south of Indian Hills persist across the area.

No major faults have been recognized in the area. Bedding plane faults are numerous, and, although displacement along individual faults appears to be minor, the aggregate adjustment was sufficient to prevent more severe faulting even in the tightly folded rocks in the western part of the area.

Cleavage is well developed in shaly layers between sandstone beds. Minor faults with little displacement are found in intraformational structures. Jointing is prevalent in more competent beds. Roll-type structures are common in thick sandstone beds in the Catskill, and occur locally in other formations.

#### Uranium occurrences

The uranium occurrences in the area are in lower beds of the Cherry Ridge member of Devonian age in the gorge of the Lehigh River (fig. 35). In areas away from the river these beds are generally covered by overburden. No additional uranium occurrences have been found within the quadrangle; however, buff shale at the base of the Mauch Chunk formation is slightly radioactive in two places in the northern part of the area. Assays of samples from these localities are not completed. Rocks in the lower Cherry Ridge member and upper Honesdale sandstone would appear to be favorable ground for prospecting on the basis of known uranium occurrences; however, reconnaissance in some of the area underlain by these rocks has failed to disclose additional uranium occurrences. Uranium has been found in rocks exposed in roadcuts in what are believed to be beds of the Cherry Ridge member in the Stoddartsville quadrangle a few miles north of the mapped area. A yellow secondary uranium mineral, either renardite or dewindite, and an interstitial black cubic mineral, probably uraninite, have been found at one of these occurrences.

#### References

Willard, Bradford, 1936, Continental Upper Devonian of Northeast Pennsylvania: Geol. Soc. America Bull., v. 47, no. 4, p. 571, 584-595.

\_\_\_\_\_, 1939, The Devonian of Pennsylvania: Pa. Geol. Survey Bull. 19-G, p. 133.

Winslow, Arthur, 1887, The Lehigh River section: Pa. Geol. Survey Ann. Report, pt. 4.

Phosphate deposits and their "leached zones"  
in northern Florida

By

G. H. Espenshade and C. W. Spencer

The program of core drilling to obtain stratigraphic data and phosphate samples from the Hawthorn formation at selected localities in northern peninsular Florida was ended in early June. The last drill hole (No. 46) was completed since preparation of a short preliminary report on the program (TEI-620, p. 271-278); the data obtained from this hole, however, do not change the preliminary report.

The drill samples have since been studied in the laboratory on a part-time basis. Completion of these studies and preparation of final reports on the project are scheduled for the next six months.

## GEOLOGIC TOPICAL STUDIES

Colorado Plateau region

General stratigraphic studies

By

L. C. Craig and Carl Koteff

General stratigraphic analysis of formations other than the major uranium-bearing formations was continued during this report period. 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 characteristics in stratigraphic units not previously studied may permit delineation of new areas favorable for the development of new uranium mining districts.

During the report period work was started on the Paleozoic of the Colorado Plateau. Tentatively the Paleozoic study will be divided into two parts, lower and upper. The top of the lower Paleozoic is placed at the top of the Mississippian for the following reasons: (1) outcrop information is and will be sparse for the geologic section from the top of the Mississippian down to the Precambrian as compared with the section from the top of the Mississippian to the top of the Permian; (2) this twofold division recognizes a natural grouping: the Pennsylvanian and Permian rocks in the Colorado Plateau represent a transition from marine to continental sedimentation and contain many facies changes and exceptional thickness irregularities. In contrast, the lower Paleozoic units are relatively thin formations of marine origin; (3) the Mississippian limestone appears to be the most extensive correlative rock unit in the Plateau, and provides a convenient reference and division line for the twofold study of the Paleozoic section.

Field work for the lower Paleozoic study has consisted of brief examinations of the section at Glenwood Canyon and in the San Juan Mountains, Colorado, and the Uinta Mountains, Utah.

Methods for recording data on the Paleozoic were adapted, for the most part, from the methods developed by E. D. McKee and associates for the Paleotectonic Map project of the Geological Survey. Variations on McKee's methods were found necessary for the purposes of this study. Work on a bibliographic card file, a cross-reference file, and accompanying index maps was started; some isopach and lithofacies data were recorded. Stratigraphic reference sections were made for twelve areas in and around the Colorado Plateau for the lower Paleozoic. Except for the Grand Canyon area, the lower Paleozoic is exposed only on the margins of the Plateau, and most of the more reliable information obtained has been from the published literature on these particular areas. The sections for the Colorado Plateau proper are mainly from published drill hole information, and are considered somewhat less reliable than the sections from the areas bordering the Plateau. A preliminary isopach map for the Leadville limestone and equivalents of Mississippian age was started.

A number of problems have been recognized:

1. Differentiation of the lower Paleozoic formations from published drill hole information have proven difficult.

2. Preliminary isopachs of the Leadville limestone-Madison limestone showed large thickness discrepancies in northwestern Colorado and northeastern Utah. It is suspected that overlying units are not differentiated in places from the Leadville-Madison rocks.

3. The age of the Ignacio quartzite in southwestern Colorado has been questioned. Recent work (Barnes, 1954) suggests that it is Devonian instead of Cambrian in age.

The study of the Upper Cretaceous rocks of the Colorado Plateau was started and first attention was directed to the San Juan Basin and some adjacent areas. The methods used for the Cretaceous study will be modifications of methods developed through the preliminary study of the Paleozoic rocks. A bibliographic card file was started. Tentative standard reference sections have been made for the Cretaceous column in various areas of the Plateau.

Uranium mineralization in the Mesa Verde group of Black Mesa, northeastern Arizona, appears to be associated with a particular stratigraphic sequence. The mineralization is in an area of intertonguing marine and continental deposits. It is possible that the distribution of continental and marine sediments may prove significant in predicting other areas of uranium potential in beds of Late Cretaceous age.

The following report on Jurassic strata was published during the report period:

Craig, L. C., and Dickey, D. D., 1956, Jurassic strata of southeastern Utah and southwestern Colorado, in Geology and economic deposits of east-central Utah: Intermountain Assoc. Petroleum Geologists, Field Conference Guidebook, p. 93-104.

#### Reference

Barnes, Harley, 1954, Age and stratigraphic relations of Ignacio quartzite in southwestern Colorado: Am. Assoc. Petroleum Geologists Bull., v. 38, no. 8, p. 1780-1791.

## Triassic studies

By

J. H. Stewart, F. G. Poole, and R. F. Wilson

During the report period studies of the Triassic rocks were extended into northwestern New Mexico and into northwestern Colorado and northeastern Utah. In addition, specific study was made of correlations of the Moenkopi formation in southeastern Utah and of the Wingate sandstone between southeastern Utah and west-central New Mexico.

Moenkopi formation in southeastern Utah and west-central Colorado

The Moenkopi formation in the San Rafael Swell, Capitol Reef, and Circle Cliffs areas (fig. 38) can be divided into five units; some of these units can be recognized in other areas of southeastern Utah. The five units are well defined in the Capitol Reef area where the Moenkopi is thicker than in any other area in southeastern Utah. In Capitol Reef, the Moenkopi units (fig. 39) are, in ascending order: (1) a lower slope forming unit of horizontally- and ripple-laminated siltstone, about 50 to 100 feet thick; (2) the Sinbad limestone member, 100 to 150 feet thick; (3) a ledge forming unit of siltstone and cross-stratified sandstone, 200 to 300 feet thick; (4) an upper slope forming unit of structureless or horizontally-laminated siltstone unit about 200 feet thick; and (5) a cliff-forming unit of horizontally- and ripple-laminated siltstone about 125 feet thick.

Eastward from the vicinity of Capitol Reef in the Dirty Devil River area (fig. 39), all but the highest cliff-forming unit can be recognized. The Sinbad limestone member is thin and discontinuous in the Dirty Devil River and Orange Cliffs areas. Along the Green River, the ledge forming unit loses its identity by interfingering with siltstone, becoming inseparable from the overlying upper slope forming unit. The easternmost

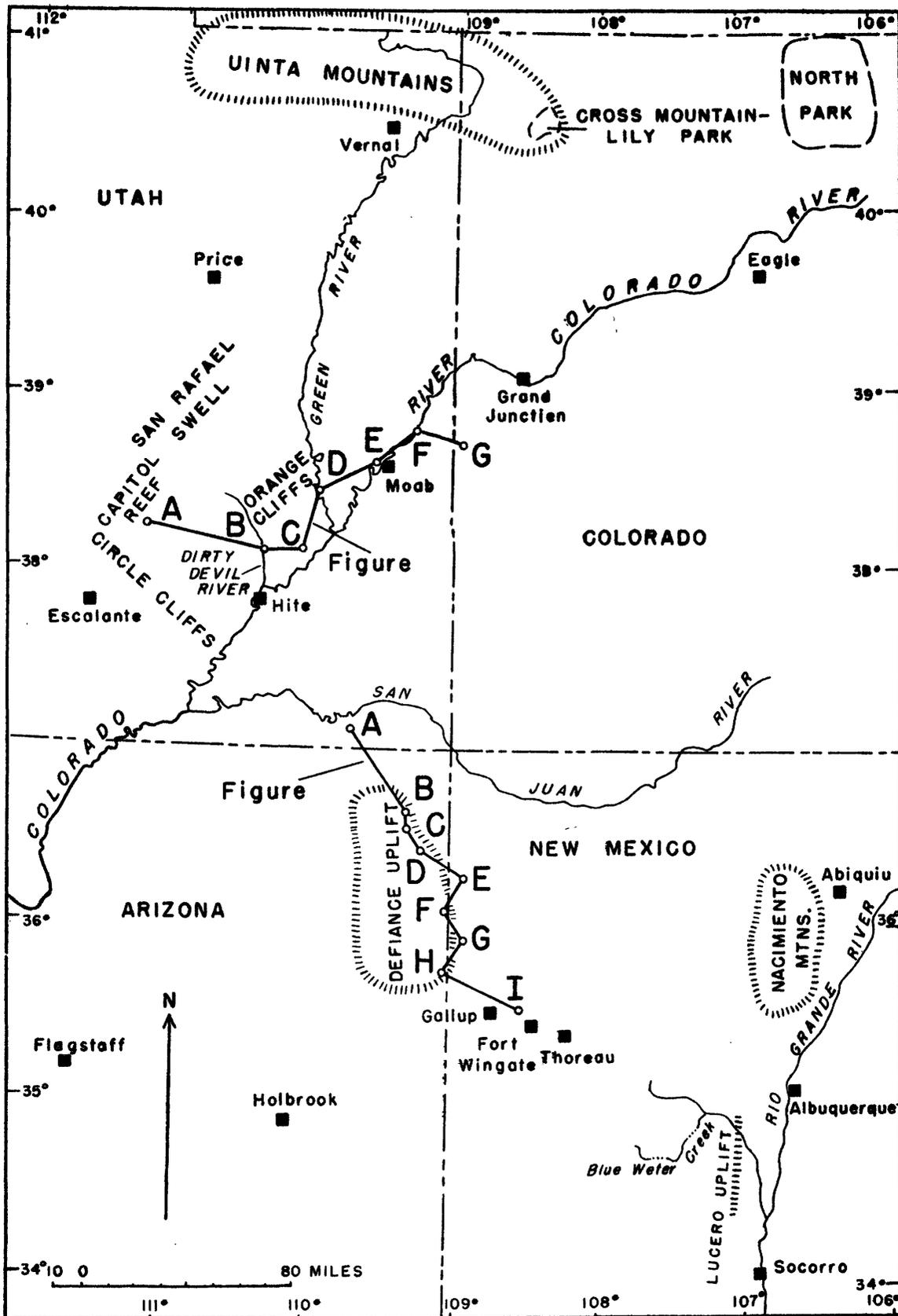


Fig. 38—INDEX MAP SHOWING LOCATION OF FIGURES 39 AND 40 AND LOCALITIES MENTIONED IN TEXT.



extension of the Sinbad limestone member is along the Green River.

Along the Green River, the Hoskinnini tongue of the Cutler formation is present. There it is separated from the White Rim sandstone member of the Cutler formation by a thin unit of yellowish-gray siltstone and fine-grained sandstone that is lithologically similar to some rocks in the Moenkopi formation. A short distance east of the Green River this thin unit pinches out and the Hoskinnini is in contact with the White Rim sandstone member. In west-central Colorado, a unit probably correlative to the Hoskinnini tongue is included with the Moenkopi formation (fig. 39).

In west-central Colorado and east-central Utah, the Moenkopi formation has been divided into four members by E. M. Shoemaker and W. L. Newman (written communication). The highest member has a small distribution and is not shown on figure 39; the other three members are referred to as the lower, middle, and upper members. The lower and upper members are mostly reddish-brown siltstone, whereas the middle member consists mostly of pale red conglomeratic sandstone. Fossils collected by G. A. Williams and E. M. Shoemaker at a locality about 10 miles north of Moab probably came from the upper member and may be of the same age as those in the Sinbad limestone member. This fossil evidence suggests that the lower and middle members of the Moenkopi formation of west-central Colorado and east-central Utah are probably equivalent in time to the lower slope forming unit in the Capitol Reef area.

#### Wingate sandstone between southeastern Utah and west-central New Mexico

During this report period an investigation was continued of the correlation of the Wingate sandstone between southeastern Utah and the type locality at Ft. Wingate in northwestern New Mexico, utilizing outcrops

along the north and east sides of the Defiance uplift in northeastern Arizona. The results of this investigation are shown in figure 40.

In southeastern Utah the Wingate sandstone consists of light brown, fine- to very fine-grained sandstone predominantly composed of planar sets of high-angle medium- to large-scale cross-laminae. It is believed to be wind-deposited. The Wingate is underlain by a reddish-brown horizontally bedded siltstone unit, the Church Rock member of the Chinle formation. South of Laguna Creek in northeastern Arizona, the Church Rock member is assigned to the Wingate sandstone and called Rock Point member. In northeastern Arizona the unit equivalent to the Wingate sandstone of southeastern Utah is called Lukachukai member.

At Poncho House, on Comb Ridge in southeastern Utah, the Church Rock member of the Chinle formation is 180 feet thick. Its equivalent in northeastern Arizona, the Rock Point member of the Wingate sandstone, thickens southward to 460 feet near Round Rock and to 573 feet near Lukachukai. South from Lukachukai the Rock Point thins progressively to approximately 310 feet at Ft. Defiance, Arizona. At least part of this thinning is due to pre-Entrada erosion, for south of Lukachukai the Rock Point is overlain, apparently at progressively lower levels, by the medial silty member of the Entrada sandstone (fig. 40).

South of Round Rock, the Rock Point member contains several beds of cross-laminated sandstone, similar in composition and appearance to the Lukachukai member of the Wingate sandstone. Some of these beds in the upper part of the Rock Point at Lukachukai are tongues of the Lukachukai member; when traced northward toward Round Rock they merge with the Lukachukai member. Several beds are not continuous with the Lukachukai member along the existing northwest line of outcrop, and either merge with



the Lukachukai member in a northeast direction, or do not represent tongues, but are merely lentils of wind-blown sand in the Rock Point member. Some of these sandstone beds are fairly persistent along the outcrop. The lowest cross-stratified unit at Chee Dodge is probably correlative with cross-stratified units at Todilto Park and Ft. Defiance, and may merge eastward into the larger cross-stratified mass of Wingate sandstone at Ft. Wingate (fig. 40).

At Ft. Wingate, the Wingate sandstone is largely composed of cross-stratified sandstone with lesser amounts of horizontally stratified sandstone and siltstone. The entire Wingate at Ft. Wingate has been placed in the Lukachukai member by Harshbarger, Repenning, and Irwin (in press). However, the Lukachukai member at Ft. Wingate is probably not equivalent to or continuous with the type section of the Lukachukai member at Los Gigantes, but rather is equivalent to the Rock Point member in the Defiance uplift area.

At its type section at Los Gigantes, the Lukachukai member is 480 feet thick. It thins rapidly southeastward to 250 feet at Lukachukai and pinches out between Lukachukai and Toadlena. Part of the southeastward thinning of the Lukachukai member is due to its intertonguing relationship with the underlying Rock Point member, as the base of the Lukachukai member rises in the section in a southward direction. However, much of the thinning of the Lukachukai member is probably due to pre-Entrada erosion, for the medial silty member of the Entrada sandstone overlaps the Lukachukai member south of Lukachukai.

#### Triassic rocks in northwestern New Mexico

The Triassic rocks in northwestern New Mexico consist of a unit tentatively considered to be the Moenkopi formation of Early and Middle(?)

Triassic age and of the Chinle formation and Wingate sandstone of Late Triassic age.

The Moenkopi formation(?) consists of grayish-red structureless and ripple-laminated siltstone and interstratified lenses of pale red, fine-grained, cross-stratified, locally conglomeratic sandstone. The Moenkopi(?) is 36 feet thick at a measured section near Ft. Wingate, 26 feet thick near Thoreau, 212 feet thick in the Lucero uplift, and 101 feet thick 16 miles northeast of Socorro. The Moenkopi(?) is absent in the Nacimiento Mountains. C. T. Smith (1954) in the Thoreau area includes the Moenkopi(?) in the Chinle formation and V. C. Kelley and G. H. Wood (1946) include it as part of the Shinarump conglomerate in the Lucero uplift area. If present correlations prove correct the Moenkopi formation extends much farther eastward than previously realized.

The direction of dip of the cross-strata in the Moenkopi(?) of New Mexico, is in general northwesterly, indicating northwestward flowing streams, and a possible southeastern source for this unit.

The Chinle formation in the west-central part of New Mexico consists of (1) a possible correlative of the Shinarump member, (2) a lower member, (3) the Petrified Forest member, and (4) the Owl Rock member. In the Nacimiento Mountains and Abiquiu areas, the Chinle formation consists of (1) the Aqua Zarca sandstone member, (2) the Salitral shale tongue, (3) the Poleo sandstone lentil, and (4) the Petrified Forest member.

Near Ft. Wingate and Thoreau in west-central New Mexico, thin sandstone and conglomerate units are present at the base of the Chinle formation. These units have a peculiar mottled purple and white color. They may be correlative with the Shinarump member. The lower member of the Chinle formation in west-central New Mexico consists of variegated

claystone and siltstone and interstratified sandstone and is about 200 feet thick. The member is locally inseparable from the overlying Petrified Forest member. The Petrified Forest member consists of variegated claystone and siltstone and minor amounts of clayey sandstone. It forms the main part of the Chinle formation and is 1,400 feet thick near Thoreau. This thickness is the maximum known for this member. The Sonsela sandstone bed, a light colored conglomeratic sandstone, is present in the middle part of the Petrified Forest member in west-central New Mexico. The cross-strata in the Sonsela dip dominantly northeasterly indicating northeastward flowing streams and a source area south of west-central New Mexico.

In the northern part of the Lucero uplift, a cross-stratified sandstone unit has been named the Correo sandstone member of the Chinle formation by V. C. Kelley and G. H. Wood (1946). This unit is a local sandstone within the sequence of rocks here called the Petrified Forest member.

The Owl Rock member consists of reddish brown siltstone and pale red limestone. It is about 30 feet thick and probably reaches an eastern limit near Thoreau.

In the Bluewater Creek area of New Mexico, Caswell Silver (1948) recognized a red siltstone member of the Chinle formation. This member is lithologically identical to the Rock Point member of the Wingate sandstone. The red siltstone member is known to be present only in a small area and is not known to be physically continuous with the Rock Point. The member may represent a deposit similar to Rock Point in lithology and time of deposition but may have been laid down in a separate basin of deposition.

In the Nacimiento Mountains and Abiquiu areas the Agua Zarca sandstone member is the basal deposit of the Chinle. In the northern part of the Nacimiento Mountains, the Agua Zarca consists of purplish and grayish coarse-grained conglomeratic sandstone about 40 feet thick. In the southern part of the Nacimiento Mountains, the Agua Zarca consists of yellowish gray fine-grained sandstone and a few lenses of conglomerate and is about 100 feet thick. Cross-strata studies indicate that the Agua Zarca in the northern Nacimiento Mountains was derived from the north, whereas that in the southern Nacimiento Mountains was derived from the south. The Agua Zarca is divisible laterally, therefore, into two different lithologic units which probably were derived from different source areas. The two units interfinger in the middle part of the Nacimiento Mountains.

The Salitral shale tongue consists of greenish and reddish claystone and siltstone. It is recognized only in areas where the overlying Poleo sandstone lentil is present. The Salitral is about 120 feet thick in the middle part of the Nacimiento Mountains area, thins to the north in part by interfingering with the Agua Zarca, and is locally absent in the northern part of the area.

The Poleo sandstone lentil is composed of fine-grained sandstone and minor conglomerate and ranges in thickness from a wedge edge in the middle part of the Nacimiento Mountains to 160 feet in the Abiquiu area. As the Poleo sandstone lentil thickens to the northeast, the underlying Salitral shale tongue thins and pinches out. In the Abiquiu area the Poleo sandstone lies directly on the Agua Zarca. Cross-strata studies in the Poleo indicate a northerly direction of transportation.

The Petrified Forest member in the Nacimiento Mountains area retains its usual characteristics. In the Abiquiu area, however, the top 200 feet of the Chinle is composed of reddish-brown siltstone that does not contain any detectable amount of the swelling clays typical of the Petrified Forest member. This part of the Chinle although laterally equivalent to the Petrified Forest member to the south, probably represents an influx of material from a different source, possibly the Ancestral Rockies of Colorado.

The Wingate sandstone in New Mexico is composed of light brown, cross-stratified, fine- to very fine-grained sandstone. It has been assigned to the Lukachukai member by Harshbarger, Repenning, and Irwin (in press) but is probably laterally equivalent to the Rock Point member of the Wingate (the description of this correlation is given under the heading "Wingate sandstone between southeastern Utah and west-central New Mexico"). The Wingate sandstone is 235 feet thick at Ft. Wingate, thins to the east, and pinches or grades out eastward in the Lucero uplift area. It is not believed to be present in the Nacimiento Mountains.

#### Upper Triassic stratigraphy of northeast Utah and northwest Colorado

The Chinle formation of northeast Utah and northwest Colorado represents the Upper Triassic series. The Chinle, as defined by previous workers in this area, is composed of six distinctive lithologic units which include: (1) basal sandstone and subordinate conglomerate; (2) purple and red sandy mudstone and mottled siltstone to sandstone; (3) ocher and lavender mudstone; (4) red, pink, and green mudstone, sandstone, and mudstone pebble conglomerate; (5) brick red siltstone with minor siltstone-limestone pebble conglomerate; and (6) yellowish-orange sandstone with subordinate red and green mudstone. Lower Triassic

redbeds underlie the Chinle unconformably and Navajo (Nugget) sandstone of Jurassic and Jurassic(?) age overlies the Chinle, of earlier workers, conformably.

The basal sandstone is composed of subangular to rounded grains of quartz with minor chert and rare feldspar. The pebbles and minor cobbles occur as lenses, layers, and isolated pebbles and are rounded to well rounded. The larger pebbles and cobbles are, in general, more rounded. The pebbles and cobbles are composed predominantly of quartz with minor chert and rare quartzite and feldspar. This basal unit is cross-stratified in most places and contains many fossil log fragments. The nature and orientation of the cross-strata indicate that this unit was deposited by northwest flowing streams originating in central Colorado. This basal unit is present throughout most of northeast Utah and northwest Colorado although it is discontinuous in many areas. It averages between 20 and 60 feet in thickness. Thomas and Krueger (1946) named this unit the Gartra grit in northeastern Utah, whereas most geologists refer to it as the Shinarump conglomerate in that area and in northwest Colorado. It is believed that this unit is younger than the Shinarump of the central and southern Colorado Plateau and hence this term is undesirable for northeast Utah and northwest Colorado.

The overlying purple and red sandy mudstone and associated mottled siltstone to sandstone is the most widespread Chinle unit in northwest Colorado and is present throughout most of northeast Utah. It is nearly always associated with the basal unit and in places is part of the basal unit. It is present at the base of the Chinle formation where the basal unit is absent. This unit grades upward into the overlying unit. Swelling

clays, iridescent iron oxide, and bedded chert and jasper are common constituents of this unit. The mottled siltstone and sandstone is usually structureless and cemented with silica. According to L. G. Schultz (written communication) many of the clays contain abundant illite with subordinate mixed-layer montmorillonite which suggests possible mild volcanism following the initial late Triassic uplift.

In the Uinta Mountains, ocher and lavender colored mudstones occur between the preceding unit and upper Chinle brick red siltstone unit. The ocher beds commonly contain analcime oolites and carbonate nodules which are not characteristic of the Chinle in this area, but are typical of the Popo Agie member of the Chugwater formation in the Wind River Mountains of west-central Wyoming. The analcime was probably formed in a widespread basin or lowland and according to Keller (1952) in a marsh or connected series of playalike lakes under a particular set of chemical conditions. This unit is limited to the Uinta Mountains and averages between 70 and 100 feet in thickness. It pinches out southward and eastward.

Many geologic sections in the northern and eastern Uinta Mountains contain a red, pink, and green mudstone, sandstone, and mudstone pebble conglomerate sequence above the ocher beds. Many of the conglomerate beds contain sparse vertebrate remains. These beds differ lithologically, in many respects, from the Chinle formation in this area. This unit ranges from a feather edge to over 100 feet at Lily Park and Cross Mountain in Moffat County, Colorado. This unit appears to interfinger and be laterally equivalent to the brick red siltstone unit of the uppermost Chinle of northwest Colorado. The beds are lithologically similar to the Jelm formation of Wyoming and the Chugwater formation in North

Park, Colorado and are believed to represent the southwestern extension of these formations.

Throughout most of northwest Colorado and the eastern Uintas a brick red siltstone unit with minor siltstone-limestone pebble conglomerates represents the uppermost Chinle formation. This unit is, for the most part, structureless and varies irregularly in thickness. Southeast of Eagle, Colorado, this unit is nearly 1,000 feet thick and thins erratically northwest and pinches out in the eastern Uintas. The erratic thickness in northwest and west-central Colorado is probably due to pre-Entrada uplift and erosion. The lower Glen Canyon interval may be represented in the upper part of the uppermost Chinle in northwest and west-central Colorado. The brick red siltstone unit is very similar to the Dolores formation of southwestern Colorado and is correlated with it. This siltstone unit directly overlies the basal two units of the Chinle throughout northwest and west-central Colorado except in the eastern Uintas where "Popo Agie and Jelm beds" are sandwiched in between.

Overlying the "Popo Agie beds" with apparent unconformity in the central and western Uintas is a unit of yellowish-orange sandstone with subordinate red and green mudstone considered to be uppermost Chinle by previous workers. In places, a few of the sandstones are cross-stratified and indicate an easterly direction of transport. The unit appears to be of near shore or perhaps continental origin in the central and eastern Uintas and may be largely marine in the western Uintas. In sections where this unit was examined the lithology is more closely related to the overlying Jurassic and Jurassic(?) Navajo (Nugget) sandstone than the underlying beds. This unit grades upward into the Navajo. All

geologists who have worked in this area considered this interval a part of the Chinle formation. Kinney (1955), who mapped in the Vernal area, Utah, called this unit the upper member of the Chinle. It is possible that these beds represent the lower part of the Glen Canyon group. This unit is tentatively considered Glen Canyon and is removed from the Chinle formation.

The lower part of the overlying Navajo, or Nugget, sandstone is dominantly horizontally bedded suggesting deposition by water. The middle and upper part is cross-stratified with many large scale planar sets indicating eolian conditions with the prevailing winds blowing southwesterly.

The Triassic-Jurassic boundary in the Uinta Mountains, as in many areas, is disguised by continuous deposition.

The following reports were published during the period:

Poole, F. G., and Williams, G. A., 1956, Direction of sediment transport in the Triassic and associated formations of 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. 227-231.

Stewart, J. H., 1956, Triassic rocks of southeastern Utah and southwestern Colorado, in Geology and economic deposits of east-central Utah: Intermountain Assoc. Petroleum Geologists, Field Conference Guidebook, p. 85-92.

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#### Entrada studies

By

J. C. Wright and D. D. Dickey

This report period has been almost entirely devoted to field measurement of stratigraphic sections throughout southern Utah. This area is critical to the study of the San Rafael group over the entire Plateau because it is the area in which the widespread terrestrial and littoral sediments of Colorado, New Mexico, Arizona, and southeastern Utah merge with thick fossiliferous marine sequences which extend northward from western Utah.

The Carmel formation, as mapped by most recent workers in the San Rafael Swell and Henry Mountains area of central Utah, has been found to include a lower limestone-bearing unit and an upper gypsiferous unit. These units persist through most of southern Utah. At Mt. Carmel, the type section in southwestern Utah, both units are present and were originally included in the Carmel formation. More recently the upper

gypsiferous unit was mistakenly correlated with the Curtis and Entrada formations; the Carmel formation was then restricted to include only the lower limestone-bearing unit. Detailed stratigraphic study in an area extending 40 miles northeast from Mt. Carmel has demonstrated the correctness of the original work. Re-establishment of the relations at the type section was necessary before the study of the San Rafael group could be extended throughout the rest of the Plateau.

A number of critical sections have been measured at the south end of the San Rafael Swell and on the Waterpocket fold. In this area it also has been possible to incorporate the stratigraphic work of other U. S. Geological Survey workers (notably that of Hunt, 1953; and unpublished sections by members of the Morrison stratigraphic project). This series of sections provide close stratigraphic control for a distance of nearly 100 miles. Along much of the Waterpocket fold a three-fold division of the Entrada sandstone is possible; the upper and lower units are sandier and more resistant than the middle unit. Northward in the San Rafael Swell the upper and lower units become fine-grained and the division is much less distinct. To the south, near the Colorado River, all of the units become sandy, and division here is also difficult. Near Capitol Reef there is a thick and very distinct section of the Carmel and Entrada formations. This section may include units not well represented at the type section of the Entrada sandstone on the north end of the San Rafael Swell, and thus will be of value in establishing detailed correlations of the formation into other areas.

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## Lithologic studies

By

R. A. Cadigan

The laboratory has been engaged in petrographic and petrologic analyses of sedimentary rocks submitted by the stratigraphic studies and other Colorado Plateau district projects. During this report period this work on samples from formations of Triassic and Jurassic age consisted of routine analyses without evaluation or study of any particular results.

Previous investigations of the Morrison formation of Jurassic age were reviewed as part of the preparation of the final report. Among these was a brief geochemical study of Morrison sandstones made as a check on the mineralogical studies. Sixty samples of disaggregated, acid-leached, silt-free sand comprising 15 samples from each of the four members of the Morrison formation were analyzed for their sodium, potassium, and calcium content. These 60 samples were selected from 420 samples of Morrison sandstones each of which had been disaggregated and analyzed for mineral content by microscopic study and count of loose mineral grains mounted on a glass slide in balsam. The mounted loose grains were cut from the size fraction consisting of the half-phi size interval on the fine side of the modal grain size for each sample.

The results of the mineralogic analysis divided the grains into percentages of quartz, feldspar, tuff plus chert, and miscellaneous.

The samples selected for chemical analysis were paired by location. The samples from the Salt Wash member were paired with those of the Brushy Basin member and the samples from the Recapture member were paired with those of the Westwater Canyon member. Replicate analyses were run on some samples to check the mathematical significance of the results of the flame photometer method used in the analyses.

The tests for significant differences applied to the replicate results of potassium determinations show significant differences between two successive runs, but also significant differences between samples. This means that the differences between results of replicate analyses are unidirectional but not large enough to obscure the differences between samples; thus the mean results of the analyses of the replicated samples may be used on a comparative basis. The sodium analyses show significant differences between samples and no significant differences between replicates of the same sample, the ideal situation.

The calcium analyses show significant differences between replicates of the same samples and no significant differences between samples indicating that differences between reruns of the same sample are as great as differences between samples. A possible reason for the poor results of the calcium analysis is that there are only small amounts of calcium present (around 0.1 percent) in most samples.

The Recapture and the Westwater Canyon sands are both conspicuously and significantly higher in potassium and sodium content than the Salt Wash and the Brushy Basin sands.

The Brushy Basin sands are significantly higher in calcium content than the sands of the other three members.

To permit evaluation of the data in a petrologic sense, the three elements were reconstituted as feldspar, that is, the potassium, sodium, and calcium percentages were converted respectively to percentages of orthoclase (potash feldspar), albite (sodic feldspar), and anorthite (calcic feldspar). Table 1 gives a summary of the average

Table 1.—The mean, the standard deviation, and the expected range of the mean of the chemically reconstituted feldspar content of sands of the Morrison formation and its members ( $\bar{x}$ ) is the mean; (s) is the standard deviation

| Stratigraphic unit      | Calculated percent |     |               |     |               |     |               |     | Expected range of mean |
|-------------------------|--------------------|-----|---------------|-----|---------------|-----|---------------|-----|------------------------|
|                         | orthoclase         |     | albite        |     | anorthite     |     | feldspar      |     |                        |
|                         | ( $\bar{x}$ )      | (s) | ( $\bar{x}$ ) | (s) | ( $\bar{x}$ ) | (s) | ( $\bar{x}$ ) | (s) |                        |
| Morrison formation      | 5.4                | 3.2 | 2.6           | 2.3 | 0.6           | 0.3 | 8.6           | 4.6 | 9.8 to 7.4             |
| Salt Wash formation     | 4.0                | 1.7 | 1.2           | 1.3 | 0.5           | 0.1 | 5.7           | 1.9 | 7.1 to 4.9             |
| Brushy Basin formation  | 2.0                | 1.3 | 1.3           | 1.5 | 0.9           | 0.3 | 4.2           | 1.7 | 4.9 to 3.1             |
| Recapture member        | 8.5                | 2.3 | 3.4           | 1.3 | 0.4           | 0.1 | 12.3          | 2.5 | 13.4 to 10.6           |
| Westwater Canyon member | 7.1                | 2.4 | 4.4           | 2.8 | 0.5           | 0.3 | 12.0          | 4.6 | 14.5 to 9.5            |

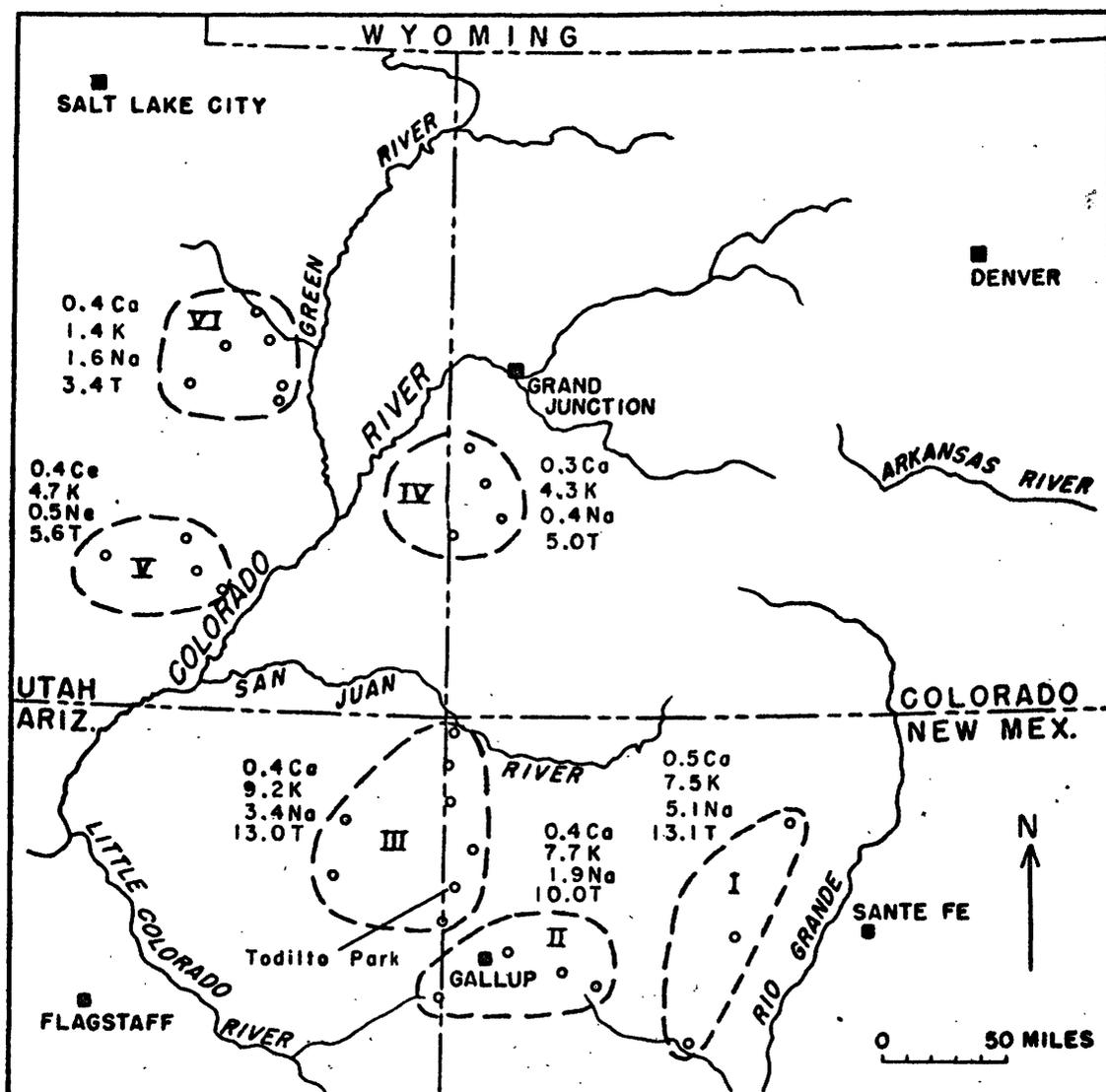
and standard deviation of the proportions and the expected range of the mean or average for each member and for the Morrison formation of the Colorado Plateau region as a whole.

As seen in table 1 in the column entitled "expected range of mean" in terms of feldspar content, the Salt Wash and Brushy Basin members are each significantly different from the other three; the Recapture and Westwater Canyon are not significantly different from each other, but are both significantly different from the Salt Wash and Brushy Basin members.

Within the sandstones of the Morrison formation, the average albite-orthoclase ratio is about one to two (1:2) with no significant differences between members. This ratio is compatible with the sodium-potassium ratio in an "average" sandstone as determined by Clarke (1924). However, using the averages in figure 41 and figure 42 the average ratio of albite to orthoclase and albite to total reconstituted feldspar is 8:5 and 8:3 in the upper Morrison and 8:3 and 8:2 in the lower Morrison. This is compatible with the evidence of a large volcanic contribution to the upper Morrison which theoretically should be higher in sodic feldspar. Area VI on figures 41 and 42 has the highest average albite ratios and therefore probably the highest proportion of volcanic detritus of any area. Unfortunately, variances in the proportions of both orthoclase and albite in the samples are too high to permit acceptance of the above ratios with a high degree of confidence.

No apparent regional ratio between albite and anorthite can be established due to the large variances caused by procedural error and the presence in the sample of other calcium minerals and possibly traces of the original calcite cement.

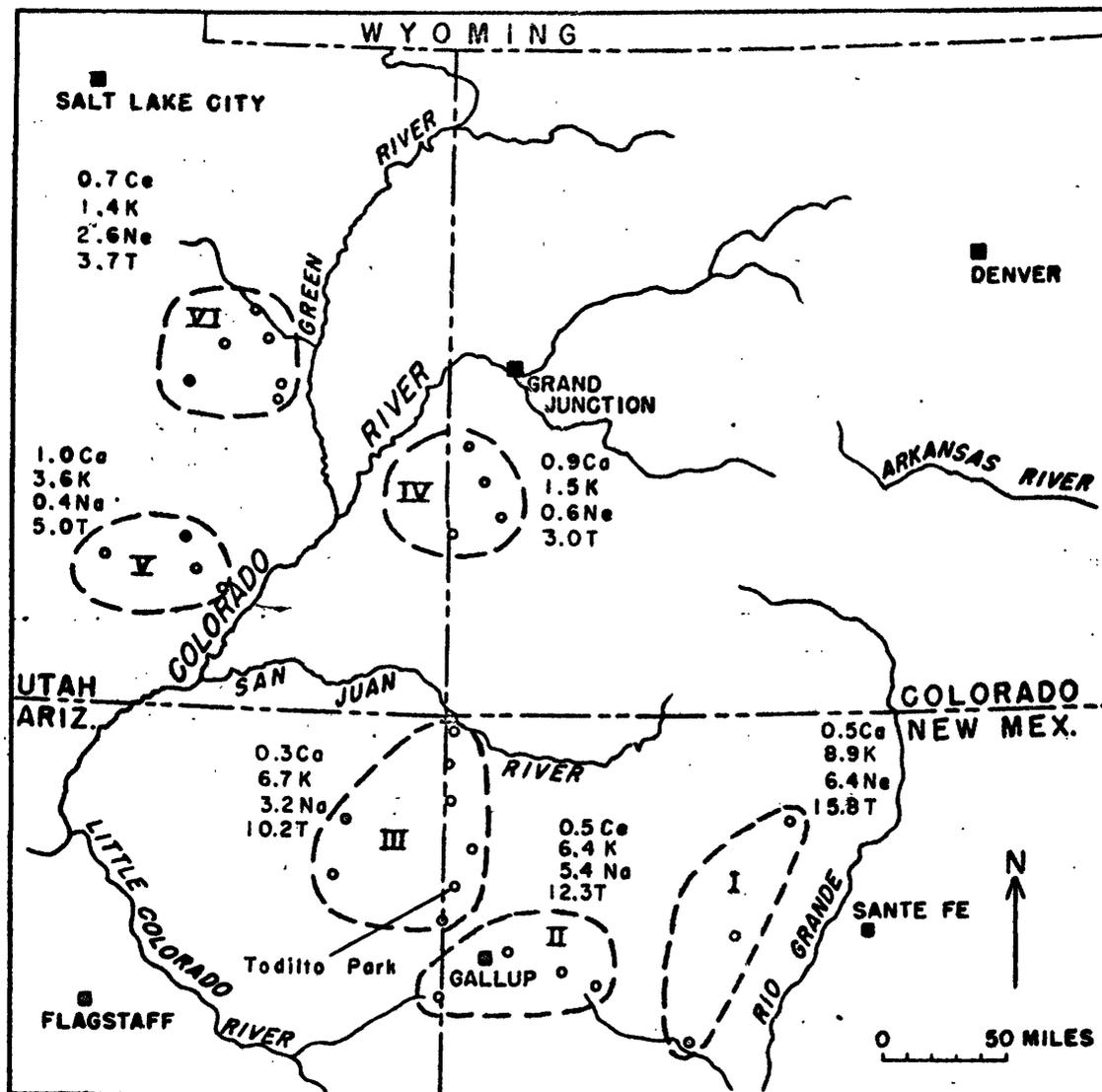
Regional distribution of reconstituted anorthite, albite, and orthoclase in the upper and lower Morrison sands is as shown on figures 41 and 42. The feldspar content is higher in the southern and lower in the northwestern parts of the Plateau which suggests a southern source of feldspar. In this respect, the geochemical study generally confirms the results of previous mineralogical studies. Two samples from the Westwater Canyon member in area III in figure 41, specifically at Todilto Park, were found to contain 0.2 percent calcium in detrital minerals. This computed in terms of feldspar would give 1.4 percent anorthite;



## EXPLANATION

- SAMPLE LOCATION
  - Ca PERCENT OF CALCIC FELDSPAR (HYPOTHETICAL)
  - K PERCENT OF POTASSIC FELDSPAR (HYPOTHETICAL)
  - Na PERCENT OF SODIC FELDSPAR (HYPOTHETICAL)
  - T PERCENT OF TOTAL FELDSPAR (HYPOTHETICAL)
- ROMAN NUMERALS DESIGNATE GROUPS OF SAMPLES USED FOR REGIONAL AVERAGING

FIG. 41.--AVERAGE PERCENT OF CHEMICALLY RECONSTITUTED CALCIC, POTASSIC, AND SODIC FELDSPARS IN DISAGGREGATED SANDSTONE SAMPLES FROM THE RECAPTURE AND SALT WASH MEMBERS, WHICH COMPRISE THE LOWER PART OF THE MORRISON FORMATION.



## EXPLANATION

- SAMPLE LOCATION
- Ca PERCENT OF CALCIC FELDSPAR (HYPOTHETICAL)
- K PERCENT OF POTASSIC FELDSPAR (HYPOTHETICAL)
- Na PERCENT OF SODIC FELDSPAR (HYPOTHETICAL)
- T PERCENT OF TOTAL FELDSPAR (HYPOTHETICAL)
- ROMAN NUMERALS DESIGNATE GROUPS OF SAMPLES USED FOR REGIONAL AVERAGING

FIG. 42.—AVERAGE PERCENT OF CHEMICALLY RECONSTITUTED CALCIC, POTASSIC, AND SODIC FELDSPARS IN DISAGGREGATED SANDSTONE SAMPLES FROM THE WESTWATER CANYON AND BRUSHY BASIN MEMBERS, WHICH COMPRISE THE UPPER PART OF THE MORRISON FORMATION.

however, the mineralogical study indicated a high (about 4 percent) content of radioactive dahllite plus apatite. This suggests that relatively high values of calcium may well indicate above average amounts of calcium phosphate minerals, rather than calcic plagioclase. The main source of apatite in the Morrison formation is probably volcanic. The significantly larger amount of calcium in the Brushy Basin correlates with the larger amount of volcanic material present in the Brushy Basin and is, therefore, probably an indicator of calcium phosphate rather than calcic feldspar.

The amounts of feldspar determined mineralogically generally averages 25 percent greater than the amounts determined chemically. As this average holds true for both the upper and lower Morrison sands, the error is probably a systematic one.

A computed correlation of the results of the geochemical determinations with those of the mineralogical determinations, sample by sample, yields highly significant correlation coefficients of  $r = 0.682$  and  $0.838$  for lower Morrison sands and upper Morrison sands, respectively.

Several other general conclusions are based on the results of this geochemical study. The study confirms the fact that calcic plagioclase constitutes probably less than 1 percent of the average Morrison sandstone. Little was observed in the mineralogical study.

Due to wide variations in albite-orthoclase ratios of individual samples in the same area and to the small number of samples used, it is not possible to differentiate particular igneous sources with a high degree of confidence. However, it seems apparent that there was a particular northwestern igneous source which affected the albite-

orthoclase ratio in area VI and possibly a southeastern source which affected the ratio in area I. These two sources were probably largely volcanic. The high total feldspar in areas I, II, and III is evidence of a granitic igneous source to the south.

The results of the 78 flame photometer analyses have been of much assistance in the Morrison sandstone investigation. In addition to adding more information to that already on hand, the geochemical analyses served as a valuable check on the 420 loose grain mineralogic analyses.

#### Reference

Clarke, F. W., 1924, Data of geochemistry: U. S. Geol. Survey Bull. 770, p. 34.

#### Regional synthesis studies

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

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

#### Northwest New Mexico, by L. S. Hilpert and A. F. Corey

Special attention has been given during the report period to the selection and processing of samples of the Todilto limestone to learn the relations of the trace elements and the thermoluminescent characteristics

to known uranium deposits. Such a program should contribute to a better understanding of the origin and controls of uranium deposits, possibly develop guides to ore, and assist in evaluating the uranium-bearing potential of the Todilto limestone in areas that are remote from known deposits.

The trace elements analyses, which were done in the Denver laboratories of the Geological Survey, have been partially completed on 45 samples. Although the samples are relatively few in number, they show that, of the elements related to uranium deposits, a few may occur in anomalously high concentrations in rather broad zones away from the deposits. These are vanadium, lead, and possible fluorine and selenium. Uranium also may be distributed in above-background amounts for fairly large distances away from what are generally considered "deposits".

Uranium, fluorine, and vanadium occur in the deposits and host rocks in sufficient quantities to permit their listing in ranges and averages in parts per million. On table 2 they are listed for the 45 samples in 4 groups, namely (1) within deposits, (2) within 100 feet of deposits, (3) more than 100 feet and less than 1 mile from deposits, and (4) more than 1 mile from deposits.

Of the three elements listed in the table vanadium shows the most uniform decrease away from deposits. It also seems to be more abundant than expected for "barren" limestone; the 14 samples selected more than 1 mile from known deposits average 35 ppm. The lowest content of any sample was 15 ppm. Both fluorine and uranium as shown on the table show lower average amounts within 100 feet of deposits than in the interval of 100 feet to 1 mile from them. This probably is the result of too few samples.

Table 2.--A preliminary listing of the ranges ( ) and averages in parts per million for uranium, fluorine, and vanadium for groups of samples of the Todilto limestone, northwest New Mexico

| Sample group relations to uranium deposits            | Number of samples | Content in parts per million |                    |                    |
|---|-------------------|------------------------------|--------------------|--------------------|
|   |                   | Uranium <u>a/</u>            | Fluorine <u>b/</u> | Vanadium <u>c/</u> |
| Within deposits                                       | 12                | (9-2,900)<br>600             | (80-1,400)<br>290  | (30-1,500)<br>500  |
| Within 100 feet of deposits                           | 8                 | (4-29)<br>15                 | (70-150)<br>100    | (150-700)<br>365   |
| More than 100 feet and less than 1 mile from deposits | 11                | (4-90)<br>20                 | (60-280)<br>150    | (30-700)<br>225    |
| More than 1 mile from deposits                        | 14                | (1-10)<br>4                  | (30-220)<br>120    | (15-70)<br>35      |

a/ Fluorimetric analyses

b/ Colorimetric analyses

c/ Semiquantitative spectrographic analyses

Lead and selenium occurred in most of the samples in less than or immediately above analytical threshold amounts. The lead was determined by semiquantitative spectrographic methods, having a detection threshold of about 10 ppm. Selenium was determined by colorimetric methods, having a threshold of about 0.5 ppm.

For the same four sample categories as used for uranium, fluorine, and vanadium, the samples containing detectable amounts of lead ranged from 15 percent of the samples from "barren" rock through 30 and 60 percent, respectively, of the samples from the intermediate categories, to 75 percent of the samples from deposits. This is a surprisingly uniform relationship and compares favorably with the similar relations shown by vanadium.

Selenium appears to be much more spotty in distribution. It ranges from 30 percent of the samples having detectable amounts in the "barren" rock through 75 and 25 percent, respectively, of the two intermediate groups, to 100 percent of the samples from deposits.

Obviously, more sample results are necessary before the relationships can be firmly established for any of these elements to the uranium deposits. On the basis of the samples now analyzed, however, vanadium and lead seem to occur in greater than background amounts in rather broad zones around uranium deposits in the Todilto limestone, and uranium, fluorine, and selenium show indications of having a similar relationship.

The following report on the appraisal of uranium ore deposits in northwest New Mexico was published:

Hilpert, L. S., and Freeman, V. L., 1956, Guides to uranium deposits in the Morrison formation, Gallup-Laguna area, New Mexico, 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. 299-302.

Utah and Arizona, by H. S. Johnson, Jr., and William Thordarson

Most of this report period was devoted to field investigations of the uranium-bearing sedimentary rocks in the Moab, Monticello, and White Canyon districts of Utah and the Monument Valley district of Utah and Arizona. Although uranium occurs in minor amounts in other formations in these districts, by far the greater amount of indicated, inferred, and potential reserves are in the Chinle formation of Triassic age and the Morrison formation of Jurassic age. Whatever the origin of the ore-bearing solutions, significant ore deposits and ground especially favorable for them appear to be related to sedimentary features such as facies

changes and local pinchouts on the flanks of salt anticlines, regional pinchouts of blanketlike sandstone units, and the traces of ancient channel systems and channels. Appreciable potential reserves of low-grade uranium ore and uraniferous rock may be present in the Brushy Basin member of the Morrison formation in tuffaceous siltstone and mudstone beds. These beds are thought to contain minor amounts of carbonaceous material and were probably deposited in ponds and small lakes. Figure 43 shows areas of ground inferred to be relatively favorable for significant uranium deposits in part of southeast Utah.

On the southwest flank of the Lisbon Valley anticline significant uranium deposits appear to be clustered in a narrow northwestward-trending belt of ground in the basal unit of the Chinle formation. The lower part of the Chinle in this area is greenish-gray in color and may correlate with the Moss Back member of the Chinle. Channels in the ore-bearing unit within the favorable belt trend northwesterly and essentially parallel the anticlinal axis in such a way as to suggest the deflection of basal Chinle streams by the structure.

North and northeast of the Lisbon Valley fault, which approximately coincides with the long axis of the Lisbon Valley anticline, the nearest exposures of basal Chinle are about 10 miles away in Lackey Basin on the south flank of the La Sal Mountains. In Lackey Basin the lower 100 feet or more of the Chinle is composed of conglomeratic quartzose grit and mottled purple, red, and white siltstone and sandstone which apparently is equivalent to the basal grit and mottled siltstone and sandstone unit present at the base of the Chinle over much of Grand and Emery Counties, Utah, and known in the San Rafael Swell as the Temple Mountain member of the Chinle formation. No greenish-gray rocks like the ore-bearing unit

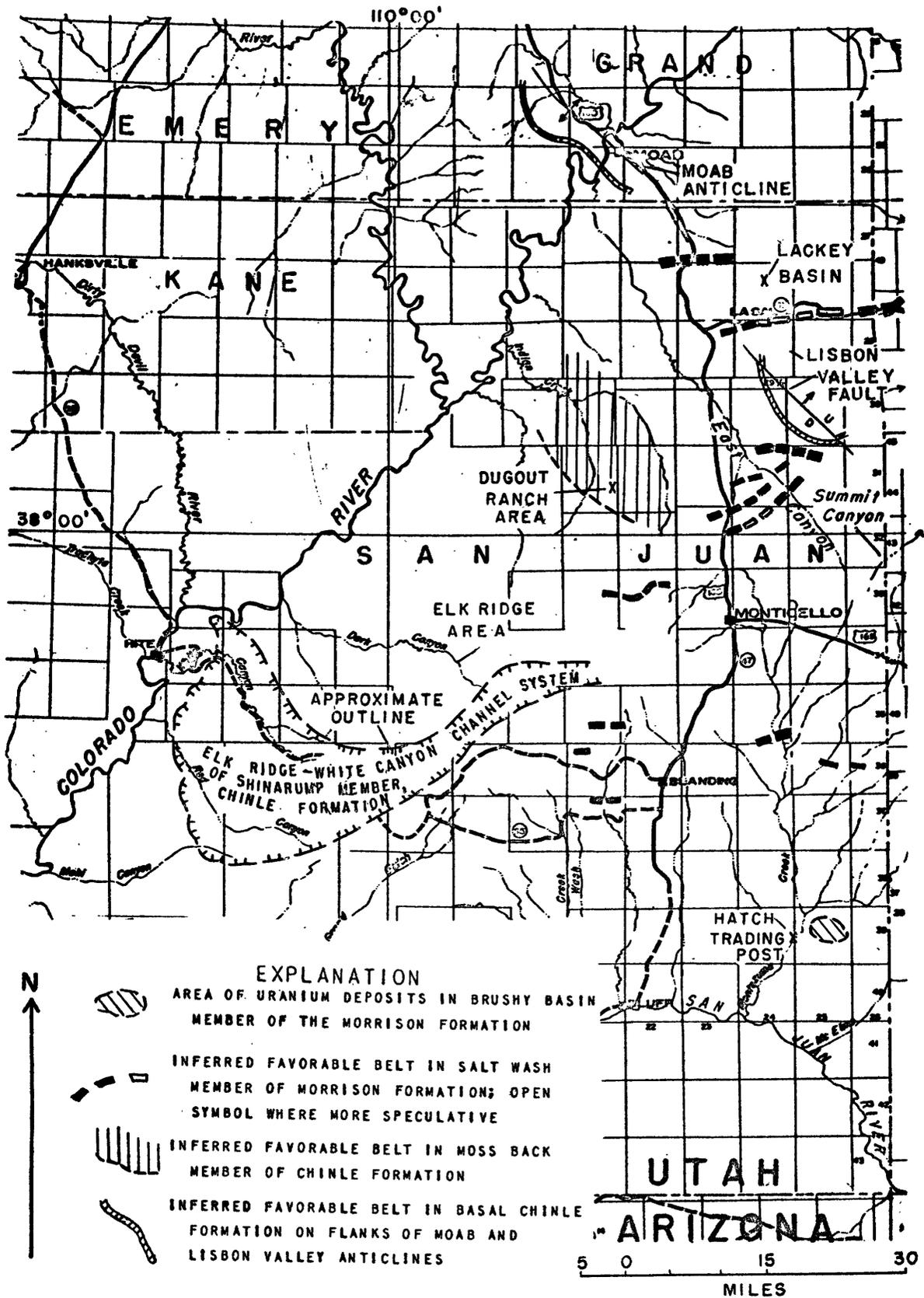


FIG. 43.--MAP OF SOUTHEASTERN UTAH SHOWING AREAS OF GROUND INFERRED TO BE RELATIVELY FAVORABLE FOR URANIUM DEPOSITS IN THE CHINLE AND MORRISON FORMATIONS.

at Lisbon Valley are present in the Chinle outcrop in Lackey Basin.

Somewhere between the axis of the Lisbon Valley anticline and Lackey Basin the Chinle loses the greenish-gray Moss Back type rocks. In this respect the Chinle of the Lisbon Valley area seems to be similar to that between the Moab anticline and the first exposures of basal Chinle a few miles up the Colorado River to the northeast of Moab, Utah. There too, all exposures of the Chinle northeast of the anticlinal axis are lacking in greenish-gray Moss Back type rocks whereas these greenish-gray rocks are well represented on the southwest flank of the Moab anticline. It seems reasonable that the Lisbon Valley and Moab anticlines (which are known to have risen intermittently during Triassic time) may have acted as barriers keeping greenish-gray Moss Back type sediments largely on the southwest side of the two anticlinal axes, and that the pinchout or facies change in the basal Chinle on the southwest flank of the Lisbon Valley anticline may be largely responsible for the belt of ore-bearing ground there. By analogy to the Lisbon Valley area, the basal Chinle on the southwest flank of the Moab anticline is also inferred to be favorable for significant uranium deposits. Exposures of basal Chinle are lacking here, however, and so far there has been insufficient exploration on the southwest flank of the Moab anticline to prove or disprove this concept.

In the vicinity of the Dugout Ranch near the north end of Elk Ridge, San Juan County, Utah, the thick blanketlike sandstone unit characteristic of the Moss Back member of the Chinle formation on Elk Ridge gives way northward to thin lenticular sandstones which are relatively favorable for significant uranium deposits. This change from blanketlike Moss Back to the more favorable non-blanketlike deposits is thought to be possibly

related to the regional pinchout of the Moss Back a few miles farther to the northeast.

Significant uranium deposits in the Shinarump member of the Chinle formation in the White Canyon district of Utah appear to be essentially confined to a channel system (herein called the Elk Ridge-White Canyon channel system) formed by westward flowing streams which probably had their source somewhere to the east in predominantly granitic terrain of the ancestral Uncompahgre Highland. Near the mouth of Red Canyon in the western part of the White Canyon district, the Elk Ridge-White Canyon channel system appears to coalesce with relatively uniform fine- to medium-grained micaceous sandstone beds that are also part of the Shinarump member. The lithology and sedimentary trends of the fine- to medium-grained Shinarump suggest a source somewhere to the south of Arizona. The greater abundance of interbedded mudstone-sandstone lenses and carbonaceous material in the lower channel-fill units of the Elk Ridge-White Canyon channel system seems to make it much more favorable host rock for significant uranium deposits than the Shinarump beds which were derived from the south. Consequently, potential reserves of uranium ore in the White Canyon district are expected to occur largely within the boundaries of the Elk Ridge-White Canyon channel system.

Reconnaissance in the Monument Valley district of Utah and Arizona suggests that ground relatively favorable for significant uranium deposits is confined to a poorly defined west- to west-northwestward-trending belt or channel system in the Shinarump member of the Chinle formation in the more northerly part of the district. Comparison of the largest pebbles found in Shinarump channels throughout the postulated belt indicates a decrease in maximum pebble size from east to west and suggests that the

Shinarump streams which filled these channels had a source somewhere to the eastward and flowed in a west to northwest direction. In the southern part of the Monument Valley district the Shinarump occurs mostly as a thin blanket of clean, very uniform sandstone and is completely absent locally. It seems possible that in Monument Valley, as in the White Canyon district, there may have been a coalescing of channel systems or "fans", one coming from the south and one from a source somewhere to the eastward. In both districts the eastern source streams seem to have been the more vigorous, and the eastern source system is characterized by deeper channels, greater maximum pebble size, more interbedded mudstone, more variable lithology in general, and more and bigger uranium deposits than are present in the Shinarump that came from the south.

Significant uranium deposits in the Salt Wash member of the Morrison formation in southeastern Utah are clustered in several eastward- to northeastward-trending belts of relatively favorably ground thought to represent the trace of ancient stream channels or channel systems on the Salt Wash fan. These belts are up to a mile or so wide and are characterized by thicker sandstone lenses, greater lenticularity and intermixing of sandstone and mudstone beds, and more and bigger vanadium-uranium deposits than are common in the Salt Wash outside the belts. Some of these belts of favorable ground can be easily recognized on the outcrop because of the abrupt piling up of thick sandstone lenses within the belt. Others are only vaguely defined and are hard to distinguish. In any event, reconstructions of Salt Wash drainage patterns are of considerable help in the attempt to outline ground relatively favorable for significant uranium deposits in the Morrison formation.

Probably some of the most favorable ground for uranium deposits in the Salt Wash member of the Morrison formation in southeastern Utah is along the easterly projection of two or three favorable belts passing through East Canyon in the Monticello district. There is some evidence that the streams making up these belts were deflected south-eastward by the positive area of the Lisbon Valley anticline and that the belts may join similar eastward-trending belts of favorable ground in the Slick Rock district of Colorado. If this is so, the ground between East Canyon in the Monticello district and Summit Canyon in the Slick Rock district should have fairly large potential uranium reserves in deposits up to several tens of thousands of tons in size.

In the vicinity of Hatch Trading Post in southern San Juan County, Utah, uranium occurs at several localities in 1- to 2-foot thick beds of light green to greenish black tuffaceous mudstone and siltstone in the Brushy Basin member of the Morrison formation. No megascopic uranium minerals are visible in the fresh rock, but yellow secondary minerals form within a few weeks when the rock is exposed to air. The uranium content appears to vary directly with the color of the rock, the darker colored rock containing the most uranium; and the color of the rock may be due in part to the presence of very finely divided carbonaceous material. According to E. B. Gross (oral communication, 1956) the uranium is present largely as microscopic blebs of coffinite along fractures and disseminated through the rock. In many respects the uranium deposits in the Brushy Basin near Hatch Trading Post appear to be similar to uranium-bearing rock in the Brushy Basin near Green River, Utah. Deposits of this type may be much more widespread in the Brushy Basin than has generally been realized and may represent appreciable

potential reserves of low-grade uranium ore and uranium-bearing rock.

At the beginning of deposition of the Burro Canyon formation, the specialized geologic conditions at Blue Mesa no longer existed.

The following report on clays of the Morrison formation was published during the period:\*

Keller, W. D., 1956, Glauconitic mica in the Morrison formation in Colorado (abstract): 20th Internat. Geological Cong., Mexico City.

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Cloud, P. E., Jr., 1955, Physical limits of glauconite formation: Am. Assoc. Petroleum Geologists Bull., v. 39, p. 484-493.

Craig, L. C., Holmes, C. N., Cadigan, R. A., Freeman, V. L., Mullens, T. E., and Weir, G. W., 1955, Stratigraphy of the Morrison and related formations, Colorado Plateau region, a preliminary report: U. S. Geol. Survey Bull. 1009-E.

Foster, M. D., 1956, Correlation of dioctahedral potassium micas on the basis of their charge relations: U. S. Geol. Survey Bull. 1036-D.

Hendricks, S. B., and Ross, C. S., 1941, Chemical composition and genesis of glauconite and celadonite: Am. Mineralogist, v. 26, p. 683-708.

Studies of localization and origin of the  
vanadium-uranium deposits on the Colorado Plateau

By  
R. P. Fischer

Studies of problems relating to the localization and origin of the Colorado Plateau vanadium-uranium deposits continued, with special attention being paid to deposits in the Entrada sandstone along the eastern part of the Plateau region in Colorado.

The productive Entrada deposits are near Rifle, Placerville, Rico, and Durango, and all are similar in geologic habit, mineralogic character, and grade. In each area the ore occurs in one or more layers, each of

\* These publications and references are misplaced; they should follow line 5, p. 263.

which is associated with a layer of green, chromium-bearing sandstone; finely disseminated grains of a mixture of galena and clausthalite also are concentrated in narrow bands bordering ore bodies.

Because the deposits in these four areas are so similar, and because the map locations of these four areas can be connected by a nearly straight line, an examination was made of the Entrada where it crops out along this line east of Delta, Colorado. This field work resulted in the discovery of a green layer containing a trace of chromium and identical in appearance to the chromium-bearing layer near Placerville. This green layer has been traced continuously along the outcrop for several miles.

This green layer suggests that a type of mineralization occurred in the Delta area similar to the mineralization that formed the vanadium-uranium deposits in the other four areas. If this is true, it permits optimism on the possibility of finding a similar deposit somewhere along the outcrop of the Entrada in the Delta area or under cover near the outcrop. It also permits speculation on the possibility of there being a belt of this type of mineralization along the projection through these areas and perhaps even beyond them.

The following general report on the uranium deposits of the Colorado Plateau was published during this report period:

Fischer, R. P., 1956, Uranium-vanadium-copper 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. 143-154.

## Diatremes on the Navajo and Hopi Reservations

By

E. M. Shoemaker and H. J. Moore, II

Detailed field work has been started on four serpentine-bearing diatremes in the northern part of the Navajo Reservation. At two localities uranium is associated with the serpentine intrusions (TEI-590, p. 62-65).

In shape the vents vary from a roughly elliptical pipe or funnel about one-fourth by one-half mile across to an elongate sinuous dike-like opening up to one or two hundred yards in width and several miles long (fig. 44). One is localized along a nearly vertical dike, whereas from another vent a nearly horizontal tongue or sheet of serpentine and clastic debris extends for half a mile along the bedding of the enclosing country rock.

The material filling the vents is a heterogeneous aggregate composed mainly of fragments of country rock set in a matrix of comminuted serpentine. The serpentine is apparently a remnant of the explosive agent active in the formation of the vents, but it is not known whether the serpentine particles have crystallized partly from the fluid state or whether excess water and perhaps other volatile constituents may have been explosively released from or through serpentine or a more hydrous heteromorph in the solid state.

Rock fragments enclosed in the serpentine matrix range in size from microscopic to huge blocks several hundred feet across. All parts of the stratigraphic section pierced by the vents are represented among the fragments as well as a great variety of crystalline rocks derived from the basement complex that underlies the sedimentary sequence of the region.

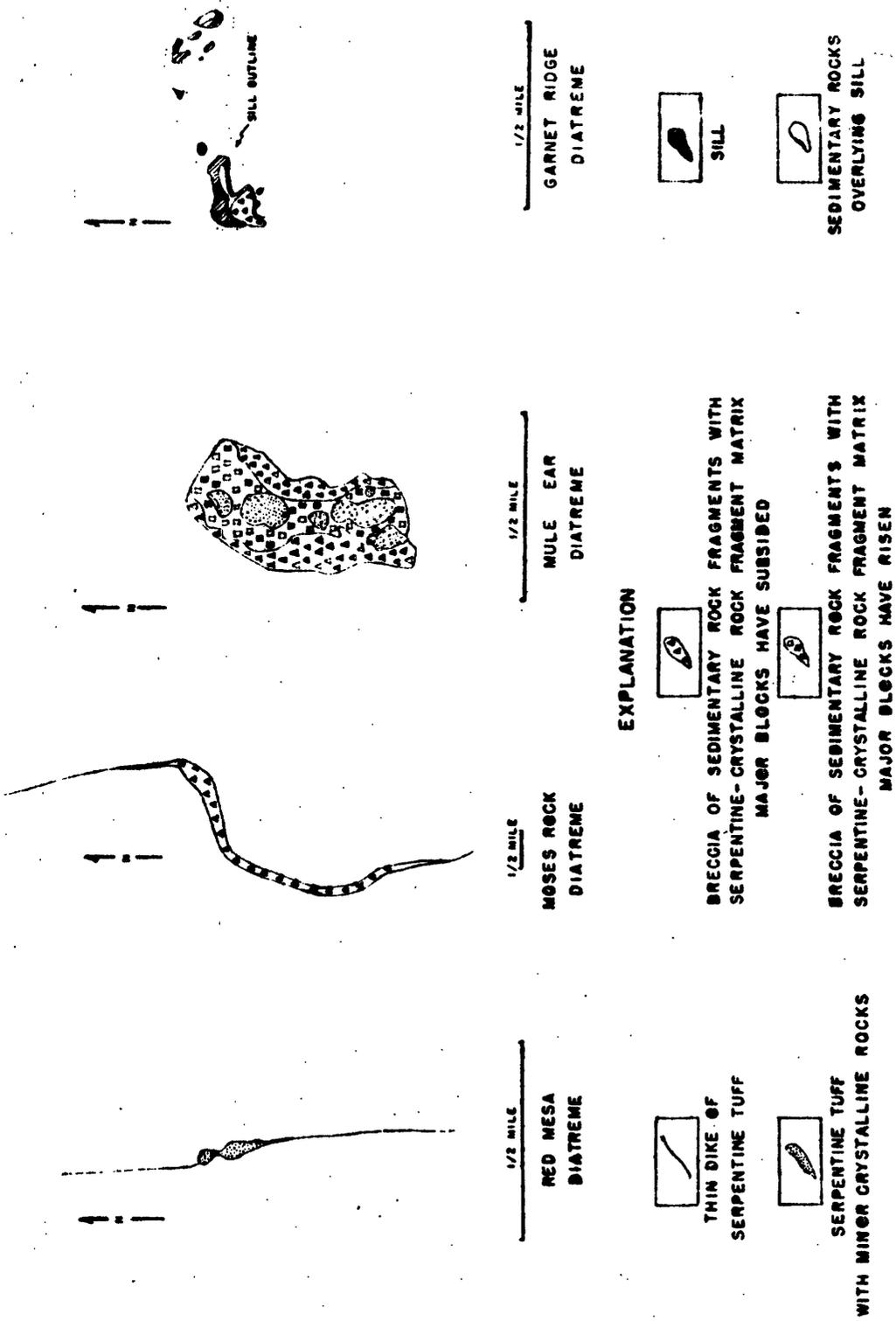


Fig. 44. --DIAGRAMMATIC PLAN VIEWS OF FOUR SERPENTINE-BEARING DIATREMES IN THE NORTHERN NAVAJO INDIAN RESERVATION

The sources of the fragments found at any one exposure have a vertical range of 7,000 or 8,000 feet in the stratigraphic section and probably at least several miles in the basement complex. The ultimate source of the serpentine matrix is not known. Small rock fragments are derived from horizons both above and below the level at which they are found in the vent, but, with the exception of the Mule Ear diatreme, fragments greater than 10 or 20 feet across are generally derived from above.

In the Mule Ear diatreme there is a crude zonal distribution of material according to its source. Several pipe-like masses composed mainly of serpentine and small crystalline rock fragments derived from great depth occur in the center of the vent. Around these "pipes" is an irregular zone made up mainly of fragments of sedimentary rocks and minor amounts of serpentine and crystalline rock debris. The majority of the large blocks in this zone have been derived from depths of a few hundred to a few thousand feet below the level of exposure. Between this zone and the wall of the diatreme the vent is also filled mainly with fragments of sedimentary rocks, but the majority of large blocks have been derived from strata several thousand feet higher than the level of exposure.

Most fragments derived from above are angular but in many cases have polished and striated faces. The fragments derived from below are more commonly rounded, especially the hard crystalline rocks derived from great depths, though some small pieces are faceted.

Nearly all fragments derived from great depth are polished and some are striated. Locally the walls of the vents are also polished and striated.

The structure of the rocks surrounding the diatremes shows clearly that the space occupied by the vents has not been created by thrusting aside of the walls but rather by excavation and removal of the country rock.

The structural data now available permit a tentative reconstruction of the mechanics of the opening of the serpentine-bearing vents. The physical reaction causing most, if not all, explosive volcanism appears to be the rapid to violent boiling of an aqueous solution or exsolution of a gaseous phase from a magma or possibly, as may be the case with serpentine, from solid rock. Exsolution of a gaseous phase from a magma would be expected to begin whenever the pressure on the magma falls below that required to keep the volatile constituents in solution. This phenomenon could be brought about by relief of the lithostatic pressure by regional stresses in the earth's crust, by upward migration of a magma into a zone of lower pressure, or by shift of the phase of equilibrium boundary due to crystallization or drop in temperature of the magma (retrograde boiling).

If it be supposed that under the present Navajo Reservation water saturated serpentine magma or solid plastic serpentine was ascending through the earth's crust along pre-existing fractures, lines of structural weakness or along new fractures caused by the intrusive masses themselves, the stage would be set for explosive eruptions. An ascending intrusion would ultimately reach a level where the pressure of the overlying rocks was sufficiently low for exsolution of gas to begin. If sufficient gas or supercritical fluid were evolved a fracture would be propagated to the surface through which the gas would escape. The resultant drop in pressure, accompanied by vesiculation or disintegration

in the upper part of the intrusion, could permit boiling to begin in successively lower and lower parts of the intrusion until some limiting depth was reached at which the pressure at the base of the fluid column became equal to the vapor pressure of the serpentine intrusion. The mechanism envisioned is closely comparable in several respects to that of a geyser.

It is not known whether the serpentine-bearing diatremes were formed by one or multiple explosion, though there is clear evidence of multiple explosion in other diatremes on the Navajo and Hopi Reservations.

The initial piercement of most of the Navajo diatremes, regardless of the ultimate shape of the vent, was probably along a more or less planar fracture of relatively short lateral extent. The propagation of the fracture by high pressure gas or fluid is analogous to the formation of artificial hydraulic fracture systems induced in certain oil well operations (Odé, 1956; Anderson, 1951). Depending on the supply and viscosity of the fluid the fracture may be propagated very rapidly.

Once the fracture is opened the gas may move along it at high velocity. Bits of serpentine and fragments of rock plucked from the walls of the fracture would become entrained converting the simple gas phase to a gas-solid fluidized system similar to some of the small scale fluidized systems of the chemical industries (Matheson, Herbst, Holt and others, 1949). The intricate mixing, rounding, and polishing of the debris in the diatremes strongly indicate fluidization. The first stages of widening of the vent are probably accomplished mainly by simple abrasion of the high velocity fluidized system on the walls of the fracture. The development of the small diatreme at Red Mesa (fig. 44) appears to have been arrested at about this stage.

As the vent widens a secondary process comes into play. Due to a pressure drop across the wall of the vent the wall will tend to spall inward. At great depths the spalling may be sudden and violent as in the case of rock bursts in deep mines, but near the surface it may be a more gentle slumping. Depending on the velocity and density of the fluidized system, large blocks spalled from the walls of the vent may tend to rise or sink. The distribution of large blocks in the Mule Ear diatreme (fig. 44) might be explained by a velocity gradient between the center and walls of the vent. In the stages of development represented at Mule Ear spalling and slumping may become the dominant process in widening the vent.

In most other diatremes on the Navajo and Hopi Reservations a complicated history of collapse subsequent to the opening of the vent is recorded by thick sequences of bedded tuff (Shoemaker, 1956). No bedded tuff is preserved in the serpentine-bearing vents of the northern Navajo Reservation, but bedded tuffs are found in serpentine-bearing vents to the south. The structural development of the serpentine-bearing diatremes in the northern Navajo Reservation appears to have been arrested in a pre-collapse stage or in the first stages of collapse.

The following report on uranium in diatremes was published during the report period:

Shoemaker, E. M., 1956, Occurrence of uranium in diatremes on the Navajo and Hopi Reservations, Arizona, New Mexico, and Utah, in 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. 179-185.

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- Matheson, G. L., Herbst, W. A., Holt, P. H., and others, 1949, Dynamics of fluid-solid systems. Fifteenth annual chemical engineering symposium: Division of industrial and engineering chemistry, American Chemical Society, Industrial and Engineering Chemistry, v. 41, p. 1099-1250.
- Odé, H., 1956, A note concerning the mechanism of artificial and natural hydraulic fracture systems: Colo. School of Mines Quart., v. 51, p. 19-29.

Central region

Dripping Spring quartzite

By

H. C. Granger and R. B. Raup

Field work on the Dripping Spring project is essentially complete. About 5,000 feet of underground workings were mapped during the report period. Other field work consisted largely of reconnaissance studies and sampling of various deposits and rock types associated with the deposits.

Mineralogy

X-ray studies of the mineralogy of weathered parts of the deposits are essentially complete although a few of the patterns have not been identified.

Metatorbernite is by far the most common secondary uranium mineral in most of the deposits. Uranophane ( $\text{CaO} \cdot 2\text{UO}_3 \cdot \text{SiO}_2 \cdot 6\text{H}_2\text{O}$ ), uranocircite ( $\text{BaO} \cdot 2\text{UO}_3 \cdot \text{P}_2\text{O}_5 \cdot 12\text{H}_2\text{O}$ ), bassetite ( $\text{FeO} \cdot 2\text{UO}_3 \cdot \text{P}_2\text{O}_5 \cdot 12\text{H}_2\text{O}$ ), and saleite ( $\text{MgO} \cdot 2\text{UO}_3 \cdot \text{P}_2\text{O}_5 \cdot 12\text{H}_2\text{O}$ ) occur in several of the deposits. It is of interest that no autunite has been identified in 25 determinations of uranite-type

minerals even though calcium-bearing minerals such as gypsum and calcite are common. Minerals with X-ray patterns very similar to metazeunerite, abernathyite and zippeite have been found at some of the deposits. Fluorescent hyalite is quite common.

Dark-purple fluorite has been noted at several deposits. Although it occurs, in some instances, within the vein-zone containing uraninite, it apparently occupies separate veinlets and the two have not been seen in contact. Sphalerite, similarly, has been noted near uraninite but not in contact nor in the same structural pattern. Galena occurs in a manner identical to the sphalerite but also is in contact with the uraninite in some places, suggesting the possibility of two galenas. One may be of radiogenic, the other of non-radiogenic origin.

#### Age determinations

L. R. Stieff and T. W. Stern of the Geological Survey (oral communication) report isotope age determinations on two uraninite specimens, as follows:

| <u>Locality</u>   | <u>Ratio</u>                              | <u>Indicated age</u> |
|-------------------|---|----------------------|
| Red Bluff deposit | $\frac{\text{Pb}^{206}}{\text{U}^{238}}$  | 585 million years    |
| Red Bluff deposit | $\frac{\text{Pb}^{207}}{\text{Pb}^{206}}$ | 725 million years    |
| Workman deposit   | $\frac{\text{Pb}^{206}}{\text{U}^{238}}$  | 830 million years    |
| Workman deposit   | $\frac{\text{Pb}^{207}}{\text{Pb}^{206}}$ | 1,100 million years  |

The two ages determined for Red Bluff uraninite are distinct and do not overlap the Workman ages. There is some evidence to indicate that the Red Bluff deposit has been subjected to different geologic events after uraninite deposition than has the Workman deposit. The discrepancies

in age may, therefore, be readily explained on a geologic basis but further studies will be necessary for final evaluation.

In the previous semiannual report (TEI-620, p. 206, 208-209) it was reported that a uraninite sample yielded an age of 730 million years by the unit cell method. It may be seen that this age lies well within the range set by isotope methods. Studies are continuing to further evaluate this potentially useful, inexpensive, and rapid method of determining age of uraninite.

Regional stratigraphic study of the Inyan Kara group and Morrison formation, Black Hills, Wyoming

By  
W. J. Mapel

Stratigraphic and petrologic studies of the Inyan Kara group and Morrison formation were begun during the summer of 1956 in Crook and Weston Counties with the purposes of correlating formational and intra-formational units, and of distinguishing regional changes in these rocks that might aid in the interpretation of their depositional history and in understanding the distribution of uranium deposits in the Inyan Kara group. Sections were measured at about 90 localities, and samples from 14 of these sections have been selected for analysis of grain size, texture, and mineralogy.

The Morrison formation is 0 to 200 feet thick in Crook and Weston Counties and consists mostly of green and dull-red claystone and some beds of grayish-white very fine-grained sandstone. The lower 50 to 70 feet are calcareous and contain numerous beds of light-gray sublithographic limestone. Locally along Oil Creek in T. 47 N., R. 62 W., Weston County, the entire formation passes laterally into fine- to very fine-grained massive light-colored sandstone that resembles the Unkpapa sandstone

of the southern and eastern parts of the Black Hills.

The Inyan Kara group, which overlies the Morrison formation, can be divided into two distinctive parts. A varied sequence ranging in thickness from 100 to 300 feet and consisting mostly of light-colored sandstone and variegated claystone makes up the lower half of two-thirds of the group. These rocks have been called the Fuson-Lakota formation undivided, or, more recently, the Lakota formation (TEI-590, p. 151, 153). Sandstone beds in this formation are fine-grained to pebbly, generally conspicuously crossbedded, and lenticular. The coarser-grained beds may occur at the base, middle, or top of the formation. The claystone is generally various shades of gray, red, or green, and commonly it is sandy. Beds of carbonaceous shale or coal are found in the basal part of the formation near Newcastle and Aladdin, but are generally absent farther west along Inyan Kara Creek and in much of the area west of the Belle Fourche River. At some places, the basal part of the formation is a thick conglomeratic cliff-forming sandstone unconformable with and easily separated from claystones in the underlying Morrison formation. At many other places, however, the basal part of the formation consists of alternating thin beds of sandstone and claystone which rest on the Morrison formation without any marked unconformity.

The Fall River formation, which makes up the upper part of the Inyan Kara group, ranges in thickness from about 120 to 140 feet. It is characterized in Crook and Weston Counties by thin-bedded fine- to very fine-grained brown-weathering sandstone interlaminated with medium- to dark-gray siltstone and shale. The formation includes at most places one or two cliff-forming beds of fine- to medium-grained sandstone that locally may be as much as 60 feet thick. Dark-brown-weathering ferruginous sandstone

seams and concretions are common in the sandstone beds, and the formation locally contains much carbonaceous material. Fossils are rare, except for plant remains, although a few nonmarine pelecypods have been found in the basal part and tabular structures of the same general nature as the marine fossil Halymenites, but differing in detail, occur locally in the middle part. The Fall River formation rests sharply on underlying rocks and the basal contact, which is easily recognized at most places, is very useful for regional and local correlations.

Regional synthesis, eastern Montana and  
North and South Dakota

By

J. R. Gill and N. M. Denson

In this report period field studies in eastern Montana and the Dakotas to determine the local and regional relationship of uranium-bearing lignite deposits to structure and stratigraphic position were completed. Preliminary results of the investigation are shown in TEI-590, p. 233-240; TEI-620, p. 235-237. More complete results of the study will be presented in the next semiannual report.

Geologic mapping during this past field season was completed in the Finger and A-Bar-B Buttes, Carter County, Montana, and in the Killdeer Mountains, Dunn County, North Dakota. Vertical control and stratigraphic data were collected on uranium-bearing lignite deposits in Billings, Golden Valley, and Stark Counties, North Dakota, and Carter, Fallon and Wibaux Counties, Montana. In addition, reconnaissance examinations were made of late Tertiary rocks in the Flaxville Highlands of northeastern Montana and the Big Badlands of south-central South Dakota.

Petrographic and geochemical investigations of the composition of uranium host and source rocks are in progress. Studies are also underway on the composition of ground waters and their role in uranium mineralization (TEI-620, p. 240-243). A synthesis of all available data, both surface and subsurface including gamma-ray and electric logs, from oil and gas test wells, is being assembled to determine relationships of uranium occurrences to regional structure.

Permian of north Texas and southern Oklahoma

By

E. J. McKay and H. J. Hyden

As part of the studies for a final report on uranium occurrences in "red bed" sedimentary rocks of Permian age (TEI-620, p. 261-264) an investigation was made of an area containing a significant uranium deposit at Cement, Caddo County, Oklahoma. The deposit is localized along joints on the axis of the Cement anticline, which is near the deeper southwest part of the asymmetric Anadarko basin (fig. 45) adjacent to the Wichita Mountains uplift. Paleozoic rocks in the basin were folded and faulted during early and late Pennsylvanian time, and folds in the overlying rocks of Permian age were localized by buried Paleozoic structures during and after Permian time. These folds have a general northwesterly trend and form traps for oil and gas. Yellow or gray areas of altered "red beds" are the surface expression of anticlinal structures in the basin. In the Cement area oil is produced from beds of Permian age within the limits of the altered zone. Production in lower Paleozoic rocks is found beyond the limits of alteration.

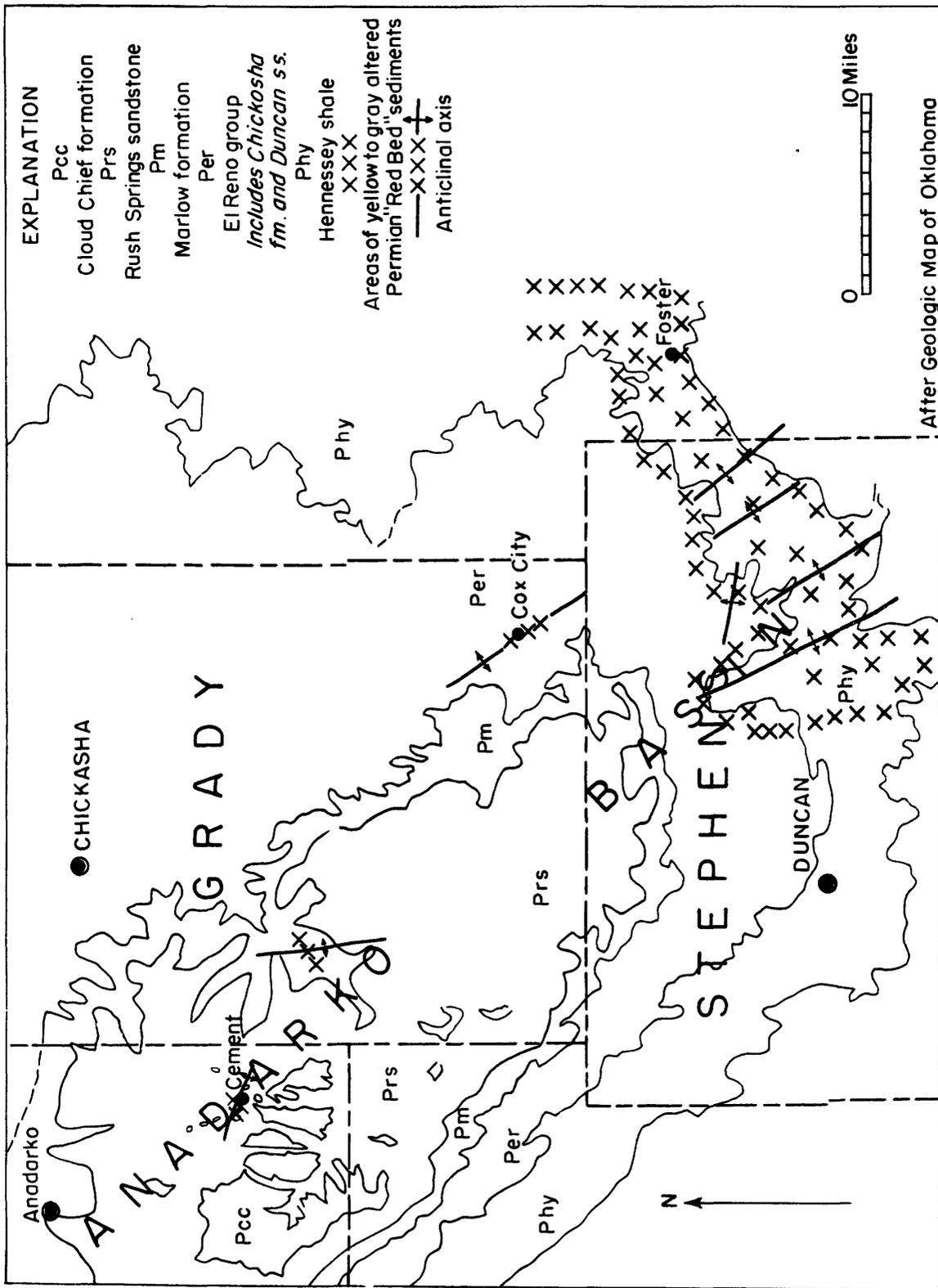


FIGURE 45-INDEX MAP SHOWING CEMENT DEPOSIT AND AREAS OF "RED BED" ALTERATION IN ANADARKO BASIN.

28

A relatively more rugged topography inside, as compared to topography outside, the basin is attributed by Paschal (1941) to the presence of resistant carbonate cemented sediments. He attributes alteration and addition of carbonate in sediments on anticlinal folds to changes in hydrodynamic conditions during folding.

The rocks exposed in the Cement area are included in the Whitehorse group of late Permian age. The gypsiferous Cloud Chief formation and the underlying festoon-bedded Rush Springs sandstone persist throughout the Anadarko Basin. Below the Whitehorse group are a widespread, but locally variable group of alternating shales, sandstones, limestones, gypsum, and anhydrite of Permian age that total about 4,000 feet of strata.

The Cloud Chief formation is about 40 feet thick in the Cement area and is composed of white finely crystalline massive gypsum. The underlying Rush Springs sandstone is 40 to 250 feet thick and is composed of fine-grained well-sorted festoon- and ripple-bedded feldspathic quartz sandstone (Reeves, 1921).

The Cement anticline structure (fig. 46a), as contoured on the base of the Cloud Chief formation, is about 11 miles long and 2 miles wide, and, independent of two domes on the axis, has a closure of 60 feet. The West Cement dome has a closure of 140 feet, is about  $1\frac{1}{2}$  miles long and  $\frac{3}{4}$  of a mile wide; the Cement dome has a closure of 60 feet, is about 3 miles long and  $1\frac{1}{2}$  miles wide. Dips range from 1 to 5 degrees and are slightly steeper on the northeast side of the axis; the anticline is slightly asymmetric in that direction. The Cobb syncline, to the north, is about 100 feet higher structurally than the Cyril syncline, to the south, and the West Cement dome is about 80 feet higher structurally than the Cement dome.

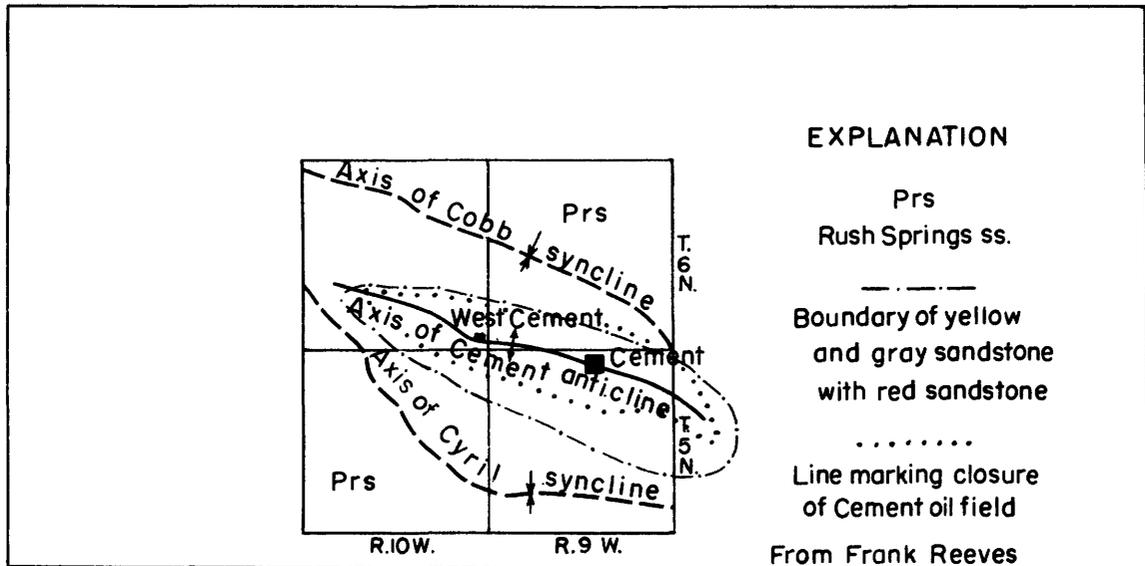


FIGURE 46a MAP SHOWING RELATION OF COLOR ALTERATION TO ANTICLINAL STRUCTURE.

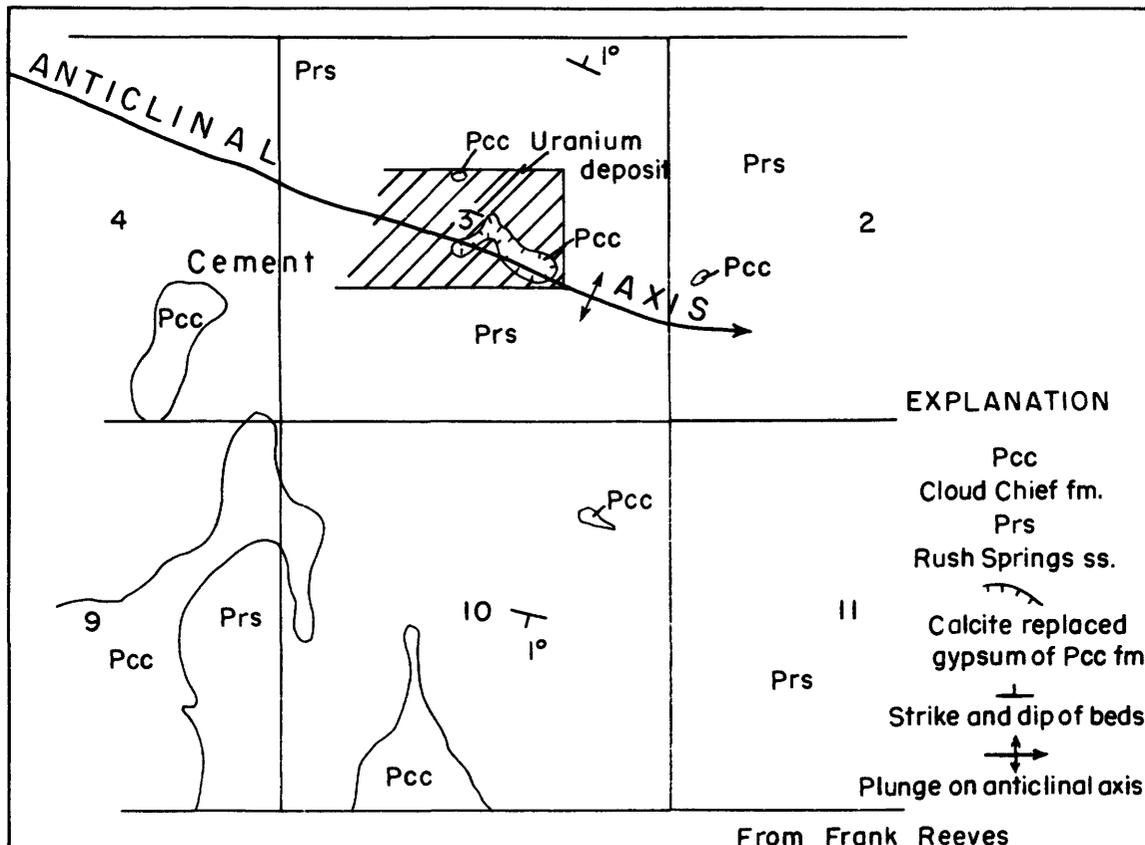


FIGURE 46b MAP SHOWING RELATION OF CALCITE REPLACED GYPSUM OF CLOUD CHIEF FORMATION AND URANIUM DEPOSIT TO ANTICLINAL STRUCTURE.

The altered yellow and gray sandstone zone includes the area of closure on the Cement anticline. The altered zone coincides with the line of closure on the northeast side and extends a mile or more beyond the line of closure on the southwest side of the anticlinal axis. Intensity of alteration, and perhaps the degree of iron mobility as well as change in oxidation state of iron, is represented by pale yellow sandstone near the color boundary with red sandstone and yellow brown sandstone near the axis of the structure. Diffusion bands of darker limonitic staining in white or gray sandstone and yellow brown sandstone mottled white are common. Non-radioactive pyrite nodules up to 6 inches across, veined with anhydrite, occur in soft yellow brown sandstone on the axis of the structure. Well defined zones of resistant gray, very limy, pyritic sandstone occur on the West Cement and Cement domes. Similar horizontal zones of carbonate cemented sandstone make well defined contacts with porous oil-bearing sandstone zones to a depth of 7,000 feet (Eisner, 1955).

Two poorly defined areas contain red sandstone on the Cement and West Cement domes. In a road cut northeast of the Cement school gym building (fig. 47) the red sandstone is soft and earthy near a color boundary with soft yellow sandstone. In the middle of the western half of sec. 6, T. 6 N., R. 10 W., both the red sandstone and the gray sandstone are cemented tightly by calcium carbonate across the color boundary.

Calcium carbonate has replaced the gypsum of the Cloud Chief formation to form a resistant cap rock (fig. 46b) on parts of the Cement and West Cement domes. Exposures have a massive appearance generally although some show contorted bedding. Near and at the base of the carbonate that replaces the gypsum, roughly lenticular bodies of yellow brown powdery

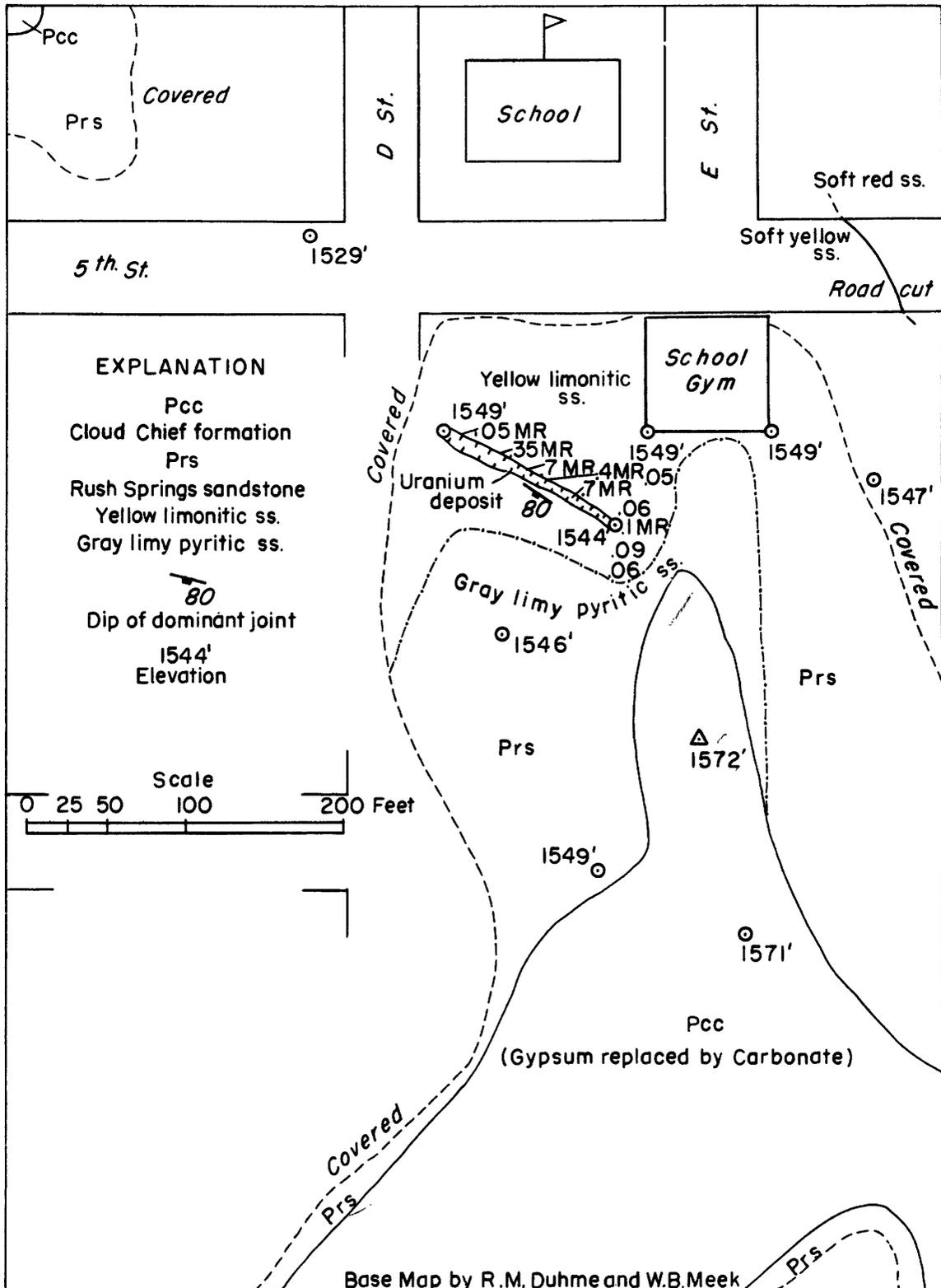


FIGURE 47-MAP SHOWING RELATION OF ORE DEPOSIT TO ADJACENT ALTERED SEDIMENTS.

to crusty gossan up to 3 feet thick and 30 feet long are present. The carbonate rock is generally gray and vuggy with a textural range from finely crystalline to half-inch crystals of calcite. Finely crystalline calcite contains fine-grained opaque minerals that oxidize to limonite.

The Cement uranium deposit (fig. 47) is on the Cement dome in the middle of sec. 3, T. 5 N., R. 9 W. It is a vein deposit controlled by a joint system trending N. 70 W. The deposit is about 150 feet long, 3 to 5 feet wide, and is worked to a depth of 3 to 6 feet. Ore minerals, tyuyamunite and carnotite, are disseminated in sandstone parallel to joints which dip about 80 degrees to the southwest. The uranium-vanadium ratio is 2:1 in ore; the average calcium carbonate is 9 percent. Concentrations of ore minerals appear to be in poorly defined pockets along the strike of the joints. Radioactivity measurements range from 0.05 to 0.8 mr/hr along the mined trench.

The sandstone in the ore zone is bleached white and stained dark brown, yellow brown, and red. White sandstone is prominent parallel to joints and is sharply defined as patches in yellow brown sandstone. Yellow sandstone is stained dark brown in diffusion bands adjacent to and away from joints. Patches of hematitic red sandstone are present parallel to the dark brown diffusion bands. Hematite nodules up to one-sixteenth of an inch across occur in yellow brown and red sandstone. The bleached white sandstone is softer than the iron stained sandstone but in places contains very hard limy concretions of goose egg size. Black specks of pin head size in bleached and yellow brown sandstone would not burn.

Interpretations of geologic relations on the Cement anticline have been made by Reeves (1921) who concluded that the process of alteration

and carbonation were caused by ascending carbonate waters associated with oil reservoirs. However, the added geologic relation of a mineral deposit associated with joints on the axis of the anticline poses the problem of defining more closely the relations between the processes of alteration, carbonation, and uranium deposition.

Tentative generalizations regarding the chronology of geologic processes are:

1. Alteration and pyritization by oil, gas and/or reducing waters associated with oil reservoirs on a possibly symmetrical anticline.

2. Folding of the anticline to present asymmetry; carbonation in areas of intense folding involving reaction and solubility of calcium carbonate, sodium chloride, sodium bicarbonate, calcium sulfate, and carbon dioxide, in ascending solutions (Seidell and Linke, 1952).

Processes 1 and 2 could be assumed to be simultaneous if alteration took place between tilted fluid contacts (Russel, 1956).

3. Fracturing in soft sediments adjacent to well indurated sediments.

4. Uranium deposition, pyritization, and hematitization from ascending solutions in joints on the Cement anticline. The presence of similar fractures and faults on other folds in the Anadarko Basin suggests that they may also be favorable for uranium prospecting.

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Reconnaissance for uranium in Alaska

By

V. L. Freeman and E. M. MacKevett, Jr.

The program on Alaska consisted of four phases: (1) geologic mapping in the area near Bokan Mountain that contains radioactive minerals; (2) examination of prospects and radioactivity anomalies reported by the public; (3) reconnaissance of favorable areas and contact with prospecting groups; and (4) operation of the radioactivity testing laboratory.

The Bokan Mountain-Kendrick Bay uranium area is in southeastern Alaska near the south end of Prince of Wales Island. Two and a half months of field work were done in this area during 1956; about 15 square miles were mapped geologically on a 1:12,000 topographic base. A plane-table map of the Ross-Adams prospect and Brunton-tape maps of many other prospects were made. Radiation surveys and sampling supplemented the mapping.

Lithologic units mapped, in order of probable decreasing age, include Paleozoic metavolcanic rocks; Paleozoic metasedimentary rocks, chiefly black slate that is locally metamorphosed to hornfels; a heterogeneous unit consisting mainly of quartz diorite and granodiorite; granite; pegmatite dikes; and fine-grained basic dikes, provisionally called andesite. The granite, which is soda-rich, occupies the central part of

the area, and most of the older units are arranged in crudely arcuate patterns around it. Faults are abundant particularly in the metamorphic rocks. The principal faults strike northwest and dip steeply and are more recent than the granite.

Several types of uranium deposits are in the area: (1) the apparently doubly tapering body that constitutes the Ross-Adams deposit, which as far as known, is unique in the area; this deposit is tentatively considered to be a late-magmatic segregation in granite; (2) deposits in pegmatites; (3) deposits in prominent faults that cut granite; and (4) deposits associated with fractures in andesite dikes. Thorium occurs in most deposits, and in some is present considerably in excess of uranium. Granite, the commonest host rock, is believed to be genetically affiliated with most uranium deposits.

The Ross-Adams ore body is a fusiform body that plunges gently to the south. Radioactive minerals from the deposit were identified by the U. S. Geological Survey as uranoan thorianite and urano-thorite; these minerals probably form most of the ore. The deposit contains minor quantities of several secondary uranium minerals near the surface. Hematite, fluorite, secondary manganese minerals, chlorite, and minor amounts of pyrite and galena are associated with the ore.

To date little analytical work has been done on the rocks and ores from the other deposits. Brannerite was identified from pegmatite on the I. and L. number 3 claim where it is associated with rare-earth bearing minerals. Uraninite was tentatively identified in minor quantities from the Little Marietta prospect, but it contained only a small part of the uranium in the sample. Many of the northwest-trending faults contain fluorite. It is commonly associated with secondary iron and manganese

minerals, and minor quantities of uranium and thorium minerals.

Of the other areas examined during this report period, the most favorable in appearance is at Skagway. During the previous period samples of radioactive rock of apparently commercial grade were received from this area and an examination showed the mineralized rock to be adjacent to a fracture in altered rhyolite(?). Other prospects were examined at Shirley Lake northwest of Anchorage, on Chichagof Island southwest of Juneau, at O'Keefe's placer claim southwest of Chandalar Lake, on Bedrock Creek near where it crosses the Steese Highway east of Miller House, near Mount Fairplay on the Taylor Highway, and near Lime Mountain in the White Mountains. None of these prospects appear to be of economic significance.

### 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.

#### The Cordilleran foreland, by F. W. Osterwald

Most of the known uranium deposits in the western United States are within a single large tectonic unit, the Cordilleran foreland (fig. 48). The western boundary of the foreland is clearly marked by the belt of folds and thrust faults of the Cordilleran geanticline extending from Canada to California; the southwestern boundary is less well marked by thrust faults and other structures related to the Mexican geosyncline and geanticline. The eastern boundary is the approximate

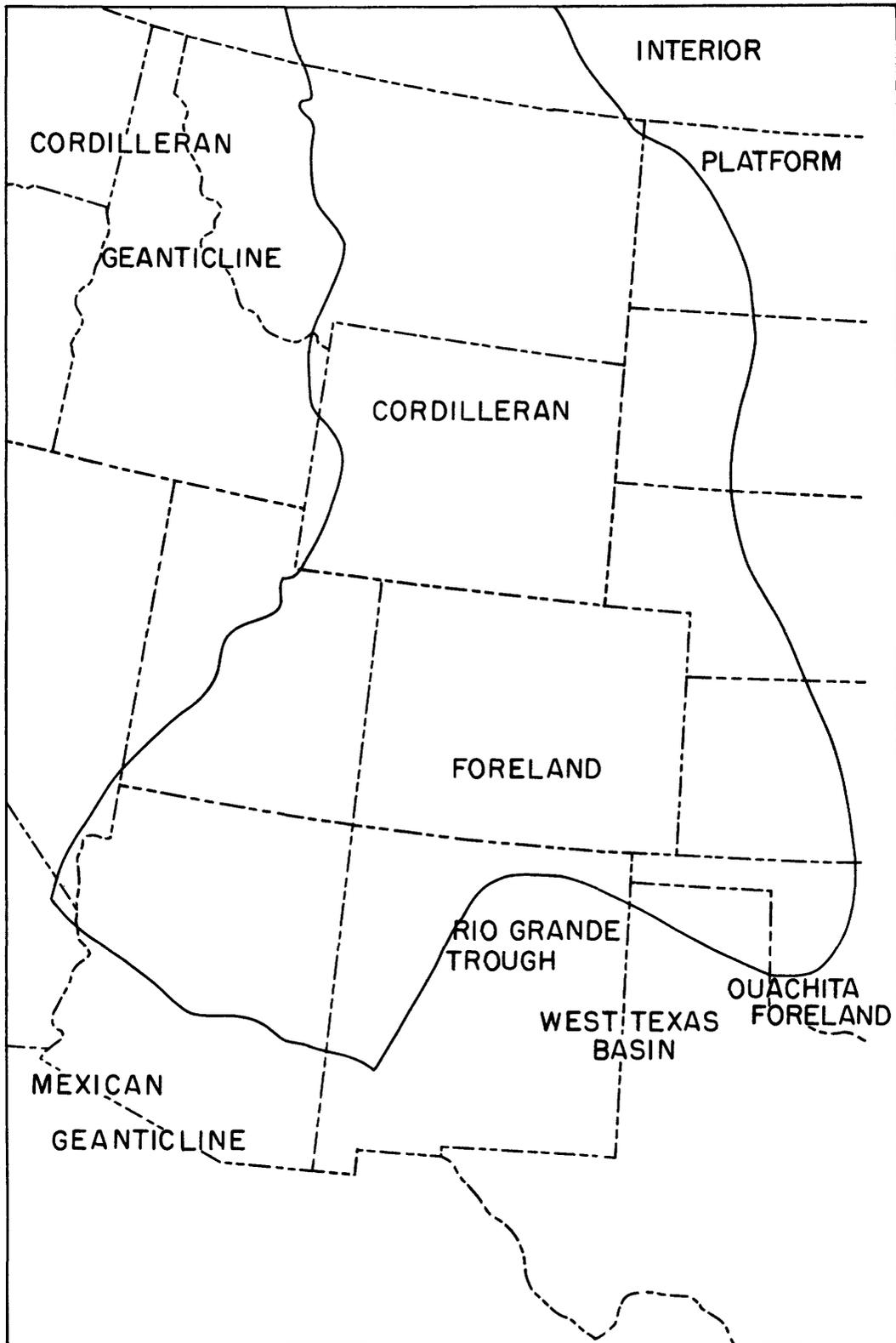


FIGURE 48—INDEX MAP SHOWING CORDILLERAN FORELAND AND ADJACENT TECTONIC UNITS.

position of the Interior platform where a pronounced change in trend of structures in the Precambrian basement rocks is revealed by geophysical data. The southeastern boundary is marked by the Ouachita foreland, the Rio Grande trough, and the West Texas Basin. The Cordilleran foreland extends northward into Canada, where its width becomes much smaller.

Designation of the Cordilleran foreland as a single, large tectonic unit is justified because:

1. The structures in the foreland fit a single tectonic pattern of northwest-, northeast-, west-northwest-, and north-trends which have existed since Precambrian time.

2. The structures of the foreland are analogous in size, configuration, and trend although the size and configuration change progressively from west to east within the foreland. In general, structures in the eastern part have less structural relief and are much less closely spaced than those in the west, but this pattern is modified by a more strongly deformed zone in south-central Colorado, related to a local deep, sedimentary basin that has existed since Paleozoic time.

3. Except for small local basins, the relatively thin sections of sedimentary rocks of Paleozoic and Mesozoic age contrast sharply with the thick sections in the tectonic unit west of the foreland.

Mineralogy of uranium-bearing veins, by G. W. Walker and J. W. Adams

A study of the mineralogy of uranium-bearing vein deposits in the United States, based largely on published data but supplemented by the examination of polished and thin sections of ore specimens from a number of widely separated vein deposits, suggests new and significant relationships, namely: (1) the primary textures of uraninite (pitchblende) in

veins are almost universally colloform—textures considered by many geologists to result from colloidal deposition, (2) idiomorphic crystals of uraninite are extremely rare, having been reported in only two vein deposits, and (3) in general, uraninite (pitchblende) is early in the paragenetic sequence and commonly was followed by brecciation before other metallic vein minerals were introduced.

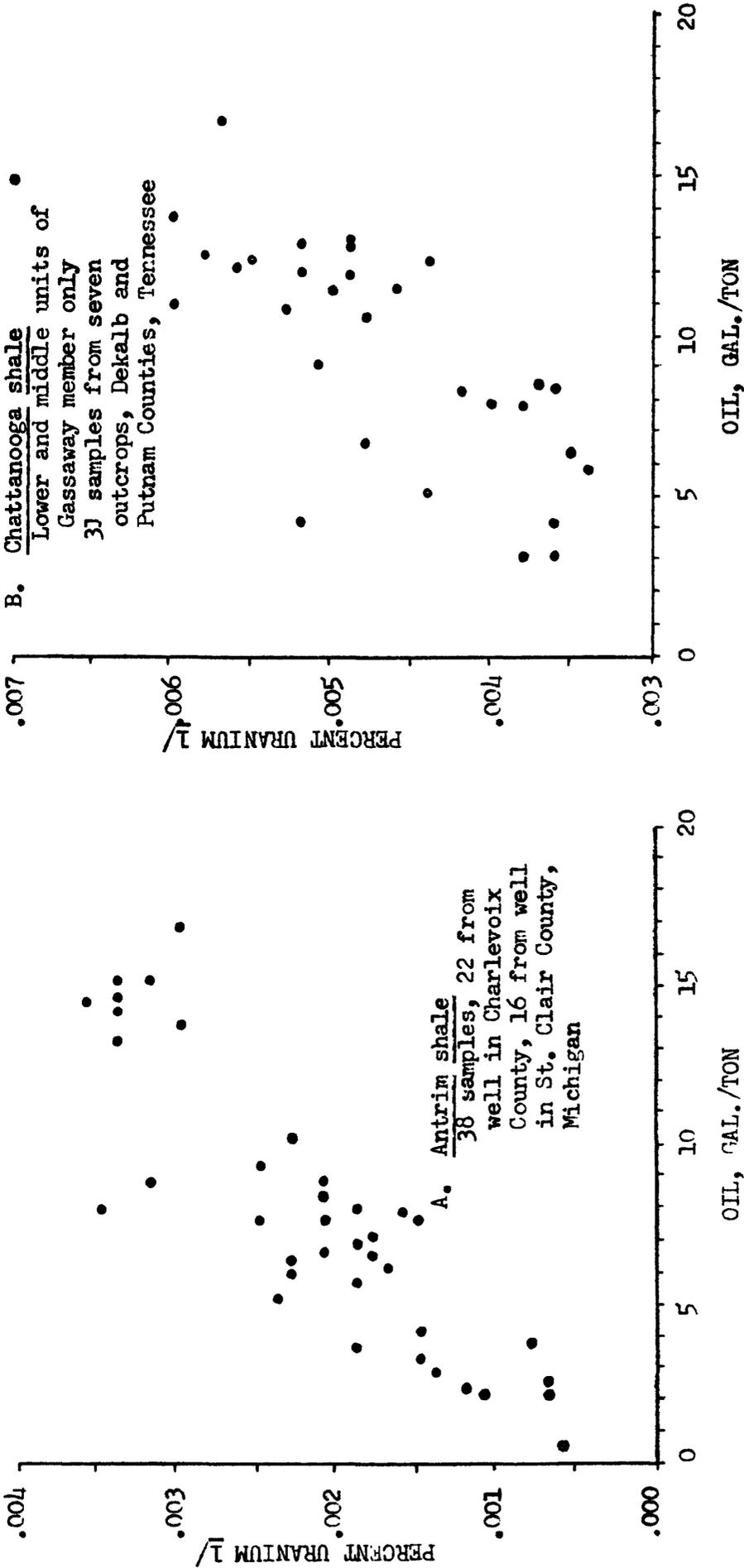
Uranium and oil content of some marine black shale, by V. E. Swanson

The positive correlation between the amount of carbonaceous matter and the amount of uranium in marine black shales has been used as a general rule-of-thumb in field studies, and subsequently was substantiated by a statistical study of laboratory analyses for organic carbon and uranium in the Chattanooga shale of Tennessee (Bates, T. F., and others, 1954). Because some of the organic material (chiefly plant debris) in these black shales is "kerogen" from which oil can be derived by destructive distillation, the possibility is being studied that a positive relationship exists between oil content and uranium content.

Since 1947, modified Fischer oil analyses and chemical uranium determinations have been made on over 600 samples of marine black shales. Incomplete analysis of these data suggests that in some shales, a crude positive correlation does exist between uranium and oil contents, as indicated in figure 49. In evaluating these diagrams, however, it should be noted that the limits of analytical error are such as to disqualify any precise correlations.

Reference

- Bates, T. F., Strahl, E. O., Short, N. M., Silverman, E. N., and Camilli, E., 1954, Mineralogy and petrography of the Chattanooga shale (abstract): Geol. Soc. America Bull., v. 65, p. 1230.



1/ Precision of uranium analyses considered to be about  $\pm 0.0005$  percent.

Figure 49. Two scatter diagrams showing relationship between uranium and oil contents in parts of the Antrim shale of Michigan (A), and the Chattanooga shale of Tennessee (B). (All analyses by Geological Survey Laboratory, Washington, D. C.)

Distribution of uranium deposits in terrestrial sedimentary rocks, by W. I. Finch and I. S. Parrish

Uranium deposits in terrestrial sedimentary rocks (sandstone and allied coarse- to fine-grained clastic rocks, luscustrine limestone, and carbonaceous rocks allied to coal) are distributed in a northeast-trending belt about 250 miles wide and 1,000 miles long beginning in northern Arizona and northwest New Mexico and ending in western North Dakota and eastern Montana (Butler and Schnabel, 1956). Although deposits in this belt occur in several physiographic provinces and in many formations ranging from Permian to Quaternary in age, this belt is entirely within a major tectonic unit, the Cordilleran foreland (Osterwald, this report). Outcrops of Tertiary intrusives within this belt are smaller and fewer in number than elsewhere in the Cordilleran foreland.

The distribution of deposits in the Morrison, Entrada, and Navajo formations of Jurassic age has been plotted on maps showing combined lithofacies, paleogeographic, and environmental features (modified from McKee and others, 1956). Most of the deposits in the Morrison formation are (1) in formational intervals where the ratio between sandstone and shale (including mudstone, claystone, and siltstone) varies between 4:1 and 1:4 and not in intervals predominantly of sandstone or shale, and, (2) in areas of fluvial deposition close to the sources of sediments but further distant from the sources than intervening areas characterized by eolian and alluvial fan deposition. This relation between lithology and environment of deposition characterizes areas in which deposits are most numerous, particularly, the central part of the Colorado Plateau region.

The distribution of deposits in the Navajo and Entrada formations and the lithofacies of the Entrada are shown on the map and accompanying cross-section of figure 50. Nearly all deposits in these formations are near the eastern edge of the basin of deposition as shown by the zero isopach line. A similar relationship to the edge of the depositional basin is shown by deposits in the Shinarump member of the Chinle formation of Triassic age (Finch, 1955).

### References

Butler, A. P., Jr., and Schnabel, R. W., 1956, Distribution and general features of uranium occurrences in the United States, 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. 39.

Finch, W. I., 1955, Preliminary geologic map showing the distribution of uranium deposits and principal ore-bearing formations of the Colorado Plateau region: U. S. Geol. Survey Min. Inv. Map MF-16.

McKee, E. D., and others, 1956, Paleotectonic maps of the Jurassic system: U. S. Geol. Survey Misc. Geol. Inv. Map I-175.

The following reports were published during the period 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:

Bell, K. G., Uranium in precipitates and evaporites: p. 381-386.

Butler, A. P., Jr., and Schnabel, R. W., Distribution and general features of uranium occurrences in the United States: p. 27-40.

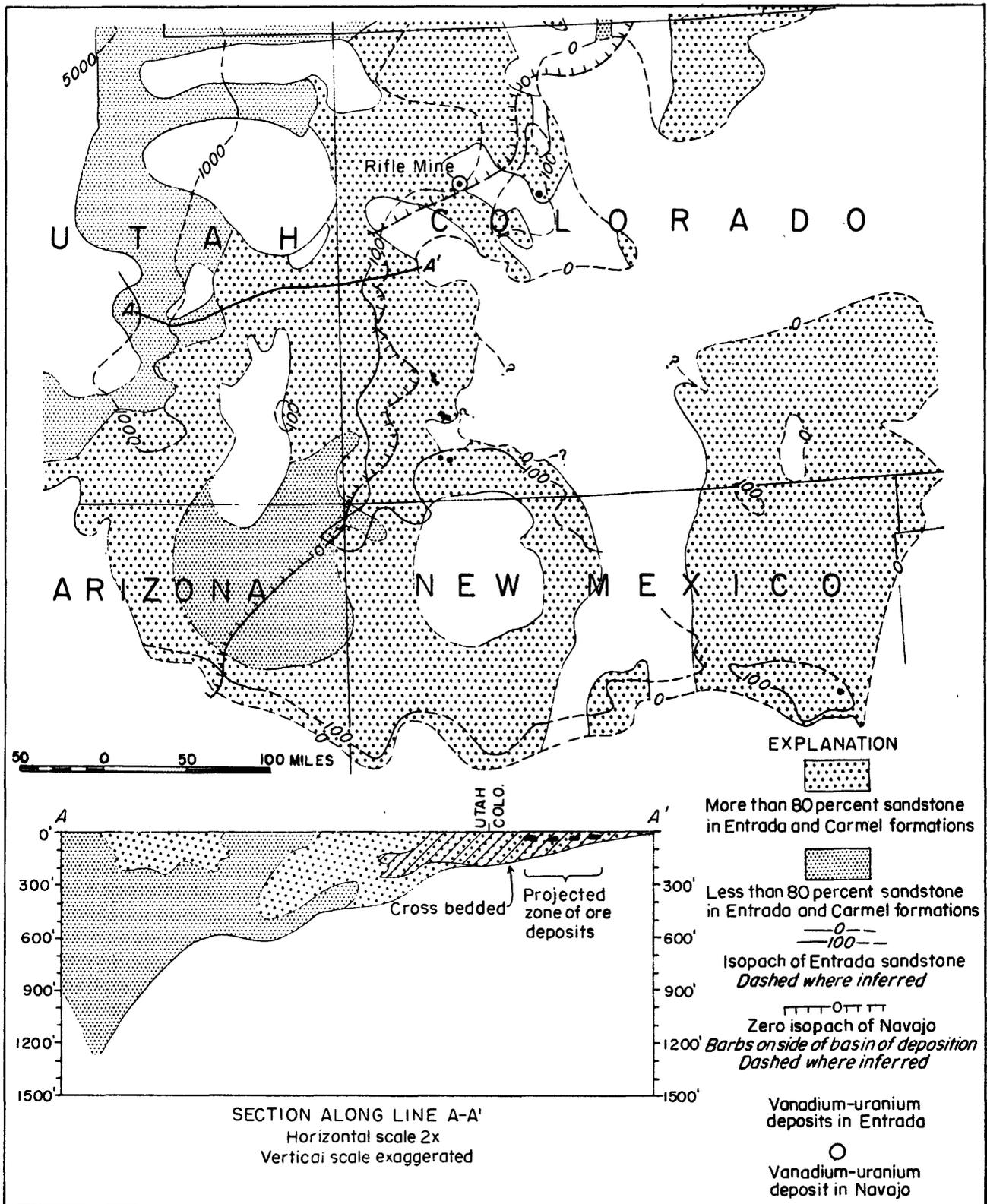


FIGURE 50 MAP OF COLORADO AND ADJACENT AREAS SHOWING THE RELATION OF THE VANADIUM URANIUM DEPOSITS IN THE NAVAJO AND ENTRADA FORMATIONS TO THEIR EASTERN LIMITS OF DEPOSITION. (Modified from McKee and others, 1956).

Finch, W. I., Uranium in terrestrial sedimentary deposits in the United States exclusive of the Colorado Plateau: p. 321-328.

Neuerburg, G. J., Uranium in igneous rocks of the United States: p. 55-64.

Osterwald, F. W., Relation of tectonic elements in Precambrian rocks to uranium deposits in the Cordilleran foreland of western United States: p. 329-336.

Stead, F. W., Instruments and techniques for measuring radioactivity in the field: p. 705-714.

Swanson, V. E., Uranium in marine black shales of the United States: p. 451-456.

Twenhofel, W. S., and Buck, K. L., Geology of thorium deposits of the United States: p. 559-566.

Vine, J. D., Geology of uranium in basins of Tertiary age in Wyoming and the northern Great Plains: p. 337-344.

\_\_\_\_\_, Uranium-bearing coal in the United States: p. 405-412.

Walker, G. W., and Osterwald, F. W., Relation of secondary uranium minerals to pitchblende-bearing veins at Marysvale, Piute County, Utah: p. 123-130.

The following additional reports were published during the period:

Neuerburg, G. J., Antweiler, J. C., and Bieler, B. H., 1956, Uranium content and leachability of some igneous rocks and their geochemical significance: 20th Internat. Geol. Conf., Mexico City.

Stead, F. W., 1956, Airborne radioactivity surveying, USA: Jour. Air Pollution Control Assoc., v. 6, p. 147-150.

## Relation of fossil wood to uranium concentration

By

R. A. Scott

A general survey was made during the report period of the Mesozoic woody flora of the Colorado Plateau to determine the variety of plants which might have been effective in the concentration of uranium. Preliminary examination of the collections taken during the summer of 1956 indicates that only one type of wood is represented. If this proves to be the case, the prospects are not good for determining, except negatively, the influence of varied botanical affinities upon the selective concentration of uranium by woody remains.

The material already collected provides an adequate sample to evaluate, and perhaps solve, the problem, and work will be continued during the next report period.

## GEOPHYSICAL INVESTIGATIONS

Colorado Plateau region

Regional geophysical studies

By

H. R. Joesting, P. E. Byerly and D. Plouff

Compilation of aeromagnetic data covering about 20,000 square miles of the central and eastern parts of the Colorado Plateau (fig. 51) is about 80 percent completed. Additional magnetic surveys of comparatively small areas were flown during the past summer over the Abajo and La Sal Mountains in Utah and over the northwestern extension of the Uncompahgre uplift in Colorado and Utah. These surveys, together with evidence supplied by gravimetric and geologic data, should yield additional information on the shapes and structural control of the laccolithic mountains of the Colorado Plateau, and on the configuration of the basement and overlying Paleozoic rocks where the Uncompahgre uplift plunges under Cretaceous rocks in Grand Valley.

Regional gravity surveys have been wholly or partly completed in various areas totalling about 9,000 square miles, as shown in figure 51. During the past six months gravity surveys were completed in the La Sal Mountains area, Utah. Preliminary surveys were made in the Sage Plain area, Utah and in the Carlisle quadrangles east of the Colorado River. Additional stations were also established in the Inter-River and La Sal areas, Utah and in the Carrizo Mountain area, Arizona.

A total of 1,170 gravity stations was established during the past six months. The present status of regional gravity surveys on the Colorado Plateau is shown in table 3.

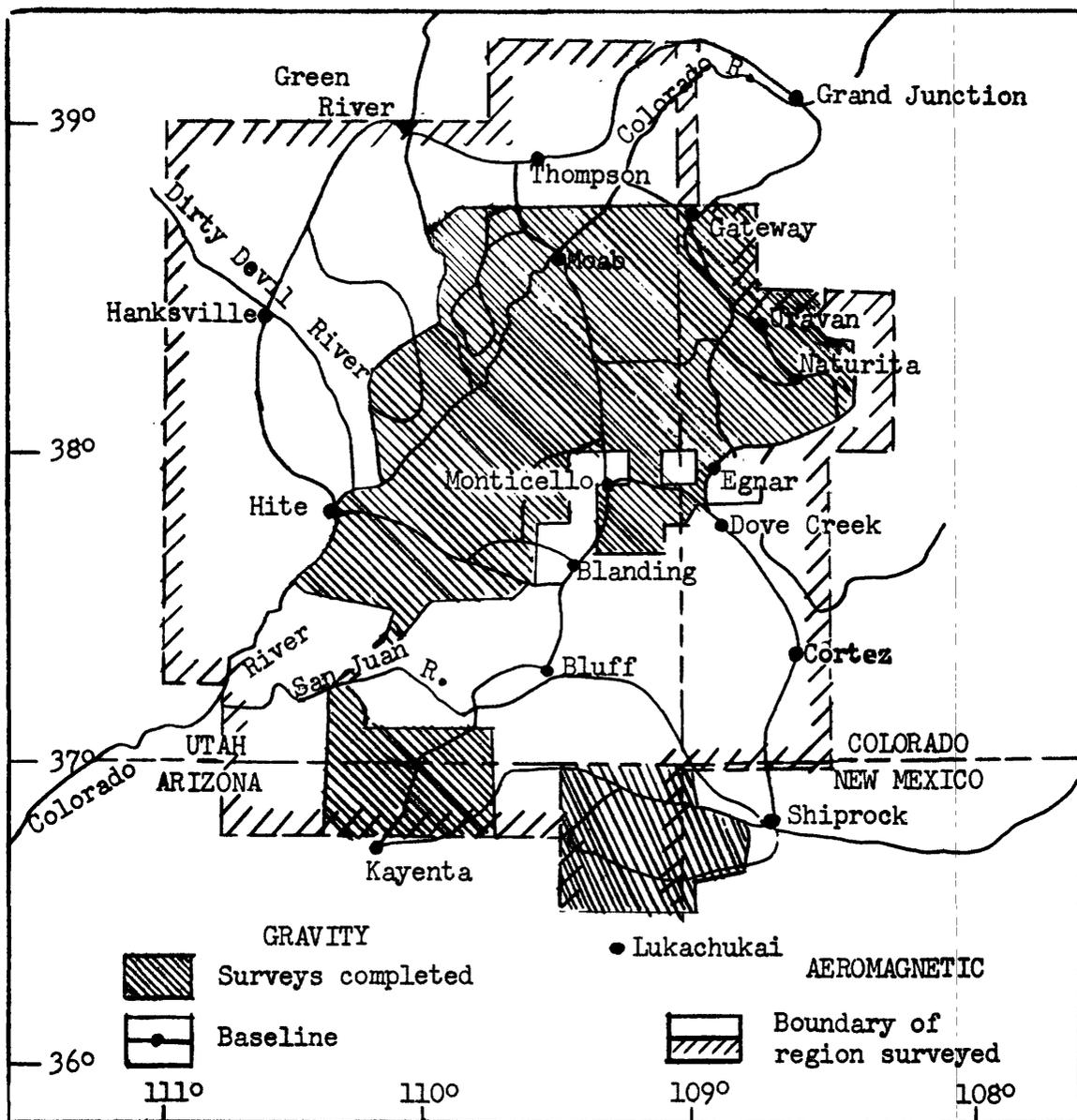


Figure 51. Regional geophysical surveys in the Colorado Plateau.

Table 3.—Regional gravity field work completed through November 1956

| Area              | No. of<br>7½ minute<br>quadrangles | Approximate<br>area, square<br>miles. | Stations |       | Station density        |                            |
|-------------------|------------------------------------|---------------------------------------|----------|-------|------------------------|----------------------------|
|                   |                                    |                                       | Base     | Total | Station<br>square/mile | Square<br>mile/<br>station |
| Uravan            | 23                                 | 1,380                                 | 21       | 680   | .49                    | 2.0                        |
| Inter-River       | 12                                 | 640                                   | 48       | 343   | .53                    | 1.9                        |
| Carlisle 1/       | 10                                 | 580                                   | 2        | 149   | .25                    | 4.0                        |
| Orange Cliffs 1/  | 20                                 | 1,200                                 | 10       | 70    | .05                    | 17.0                       |
| Lisbon Valley     | 10                                 | 580                                   | 47       | 431   | .74                    | 1.3                        |
| La Sal Mountains  | 15                                 | 860                                   | 43       | 651   | .75                    | 1.3                        |
| Sage Plain 1/     | 5                                  | 250                                   | 6        | 160   | .64                    | 1.6                        |
| Elk Ridge 1/      | 26                                 | 1,530                                 | 27       | 387   | .25                    | 4.0                        |
| White Canyon      | —                                  | —                                     | —        | —     | —                      | —                          |
| Clay Hills 1/     | 1                                  | 40                                    | —        | 32    | .80                    | 1.3                        |
| Monument Valley   | 19                                 | 1,000                                 | 62       | 492   | .49                    | 2.0                        |
| Carrizo Mountains | 20                                 | 990                                   | 43       | 583   | .58                    | 1.7                        |
| Other stations 2/ | —                                  | —                                     | 60       | 60    | —                      | —                          |
| Totals            | 161                                | 9,050                                 | 369      | 4,035 |                        |                            |

1/ Field work incomplete

2/ Includes stations in main base net as follows:

|  |    |
|--|----|
| Crescent Junction - Hite, Utah                   | 14 |
| Inter-River - White Canyon, Utah                 | 11 |
| Dove Creek, Colorado - Shiprock,<br>New Mexico   | 10 |
| Carrizo Mountains area - Monument<br>Valley area | 1  |
| Blanding - Mexican Hat, Utah                     | 9  |
| Grand Junction - Gateway, Colorado               | 8  |
| Others   | 7  |
|  | 60 |

During the course of field work, additional specimens of igneous rocks were collected from the Carrizo and La Sal Mountains. Others from the Abajo Mountains were supplied by Irving Witkind of the Geological Survey. Densities and magnetic properties of these specimens will be determined, to aid in the interpretation of the geophysical data.

A generalized study of the stratigraphy and structure of the Paleozoic rocks of the Colorado Plateau will continue through the next half-year. This study, based mainly on drill logs, is required because of the need for reliable geologic guidance in the interpretation of the geophysical data.

From available evidence the major geophysical trends on the Plateau are alined with the major structural trends. Thus the great monoclinical upwarps are characterized by prominent anomalies, and the uplifted areas show magnetic and gravity patterns distinct from these over the intervening basins. This contrasting pattern is due not only to the shallower depth of burial of the Paleozoic and Precambrian rocks in the uplifted areas, but also to their greater diversity of composition and structure. The evidence also shows that at least some of the major structures intensify downward; that is, the older more deeply buried rocks are more deformed than the younger rocks. This indicates deformation prior to and in some instances during deposition of the overlying Mesozoic rocks.

The most striking examples of comparatively great Paleozoic deformation found thus far are along the Moab fault and salt anticline, and along the northwestern extension of the Uncompahgre uplift, under the Cretaceous rocks in Grand Valley. Along the Moab fault, the maximum vertical displacement is about 2,500 feet at the surface, whereas displacement of the basement and older Paleozoic rocks is on the order of 5,000 feet, according to gravitational evidence. Surface evidence of this deformation is largely absent because the Pennsylvanian and Permian rocks are much thicker on the downthrown side. The deposition and thickness of the Triassic rocks were also affected by the deformation. Along the northwestern extension of the Uncompahgre uplift the surface rocks are gently

folded, evidently because of basement deformation during Cenozoic time. Geophysical and subsurface evidence, however, indicate a much greater displacement of the Paleozoic rocks and of the basement—on the order of 10,000 feet in some places.

In still other places, analysis of regional geophysical data indicates the presence of major structures with no surface expression. Chief among these buried structures are a prominent basement ridge and upwarp under the Disappointment syncline in Colorado, a prominent northwest-trending platform southwest of the Lisbon salt anticline in Utah, a ridge of basement or igneous rock extending from Grays Pasture and Upheaval Dome in the Inter-River area to the San Rafael Swell in Utah, and a salt anticline in the La Sal Creek Valley in Utah. These structures are parallel to the Uncompahgre front and to the great salt valleys of the Paradox Basin. They were probably formed during Pennsylvanian, Permian, and early Triassic times and were not reactivated during later periods. The flanks of the monoclines on which data are available are also characterized by zones of rock with magnetization about that of basalt. These may be pre-Permian intrusions that do not rise above the present top of basement, or they may be differentiates within the Precambrian basement.

Magnetic evidence indicates that there may be a relationship between regional structure and the emplacement of the laccolithic mountains of the Plateau. The La Sal and Abajo Mountains occur in or near the deepest parts of structural basins, according to preliminary analysis of magnetic data. The Henry Mountains are also in a structural basin, according to both geologic and magnetic evidence. Data are not yet available on the other laccolithic mountains.

In addition to evidence on the depth, configuration, and structural trends of the basement rocks, the regional geophysical surveys are affording information on variations in thickness of the Pennsylvanian salt beds in the Paradox basin, and thus indirectly on variations in thickness and facies of the overlying rocks and on conditions controlling deposition of the late Paleozoic and Triassic beds. For example, the thickness of salt in the Moab anticline near Moab, Utah, is indicated to be about 10,000 feet, on the basis of gravity measurements. Computations to determine the approximate form and thickness of the salt in the faulted Lisbon Valley anticline are in progress.

Temperature measurements were continued in deep diamond drill holes in Disappointment Valley, Colorado, and in the Big Indian and Temple Mountain areas, Utah. Specimens of cores from these holes have been prepared for thermal conductivity measurements, so that heat flow from several places can be determined.

Detailed temperature measurements were also made in boreholes cutting large uranium deposits in the Ambrosia Lake and Cebolleta areas in New Mexico. Thermal effects of uranium decay were found to be extremely small; the effects of structure and of non-uniform lithology and ground water were in fact greater than the thermal effects of the ore. These experimental results are in agreement with theory.

#### Reference

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Central region

Southeast Texas geophysical and geologic studies

By

R. M. Moxham, D. H. Eargle, and J. A. MacKallor

The geophysical and geologic studies in the Coastal Plain region of southeast Texas are directed toward the correlation of airborne radioactivity and magnetic measurements with surface and subsurface radioactivity, stratigraphy, geologic structure, and ore deposits.

An airborne radioactivity and magnetic survey of an area of about 15,000 square miles, shown in figure 52, has been completed. Airborne radioactivity measurements have been completed in an area of about 500 square miles in the mineralized and peripheral areas of Karnes, Wilson and Gonzales Counties. This survey has covered a 10-mile wide strike section of the Jackson (Eocene) formation and a 30-mile wide dip section extending from the Cook Mountain (Eocene) formation to the middle of the Catahoula (Miocene (?)) tuff. The airborne work during the report period was concerned primarily with the collection of field data; in general, however both airborne and surface radioactivity measurements seem to be related to the stratigraphy, lithology, texture, and perhaps to some extent to structure, though no definite information on the latter is available as yet. At some places the intrinsic radiation intensity increases directly with the ratio of surficial clay to sand but this relation is probably oversimplified and may not hold generally; there are undoubtedly additional factors involved.

Geologic mapping at a scale of 1:20,000 is being undertaken in the area of interest with respect to potential uranium production, extending from southern Gonzales County to Atascosa and Live Oak Counties (fig. 52). Mapping was begun in the Tordilla Hill area in southwestern Karnes

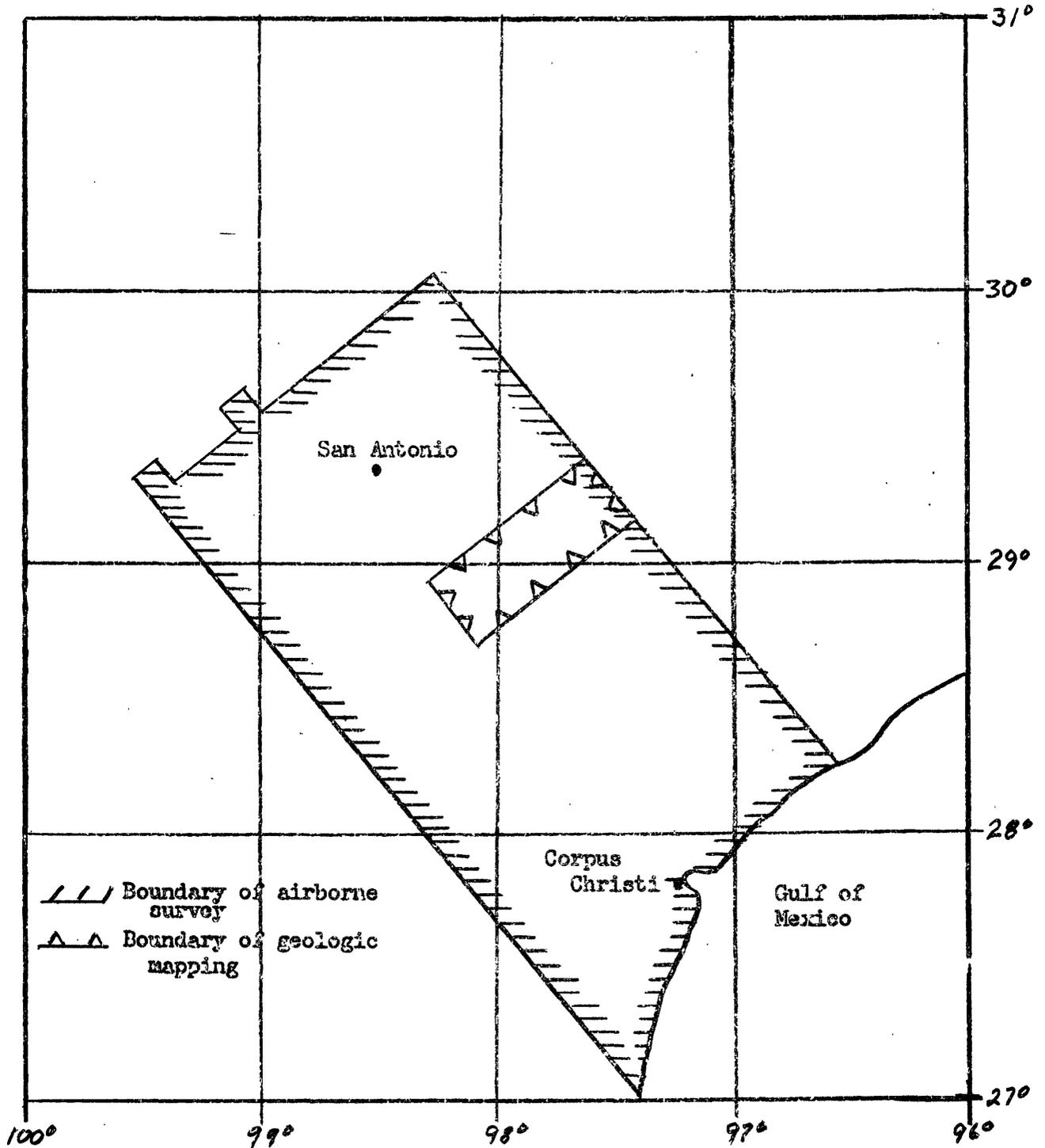


Figure 52 - Texas Coastal Plain geophysical and geologic studies.

County, and will delineate the lithology of all units to be correlated with the radiation measurements, geochemical and mineralogical character and ore-deposit geology.

Detailed geologic and radiometric studies of the principal ore deposits are being undertaken. An isoradioactivity survey on a 100-foot grid has been completed at the Boso prospect at Tordilla Hill and a similar survey is nearly completed at the Korzekwa and C. Lyssy tracts, 1-1/2 miles to the northeast. Geologic mapping on a scale of 1:4,800 is in progress at both places. Ore bodies on the Boso and Korzekwa tracts are being auger-drilled and probed with a gamma-ray logger in order to make a three-dimensional study of the gamma radioactivity in an effort to relate surface and subsurface radiometry to the mineralized area.

In connection with a study of the general problem of the physical properties of uranium-bearing rocks a bore hole was drilled with oil-base mud on the P. Lyssy tract, 1-1/2 miles northeast of Tordilla Hill. The work is described under "Physical properties of ore and host rocks" in this volume.

Samples of ground water from the Jackson and underlying Yegua formations have been collected and radon analyses are in progress.

The principal uranium minerals in the area being mapped occur in the Stones Switch member (the member designations used are those of Ellisor, Am. Assoc. Petroleum Geologists Bull., v. 17, 1933) of the Jackson (Eocene) formation. The deposits are for the most part within a few feet to a few tens of feet from the surface and are composed of carnotite and autunite.

Preliminary observations show that both the uranium-bearing rocks and the rocks overlying them are tuffaceous. Some of the sandstone strata in the Jackson formation have been silicified to different degrees. There is generally a close spatial relationship between the uranium minerals in the Stones Switch member and silicification; the uranium minerals are emplaced in the softer, unsilicified part of the member and some of the deposits are overlain by silicified sands. The isoradioactivity surveys indicate that the silicified rocks are only moderately radioactive; a persistent sharp increase in activity is recorded over the underlying, unsilicified strata. The silicification, at least in part, seems to be a surficial phenomenon related to a surface of erosion antedating the deposition of the Catahoula sediments, although definite evidence to this effect has not been obtained. The close spatial relation of silicification to the occurrence of uranium minerals also indicates that the silica is related to the ore solutions.

Erosion in recent geologic times has removed the Catahoula sediments that had overlapped the Jackson formation in the vicinity of the deposits. The silicified zones are resistant to erosion and generally stand up as mesas and cuestas of higher topographic relief than the less silicified zones. Sandstone beds that are indurated with siliceous cement and that support the higher cuestas are composed, in down-dip positions, of a high percentage of volcanic glass shards that are extremely soft and friable. These beds are soft not only in the subsurface but also in down-dip positions on the surface where overlying beds have been stripped in recent geologic times. It is presumed that because of climatic conditions in the region, the volcanic glass was altered to siliceous cement which impregnated the rocks and indurated them.

Desilicification of some of the surficial rocks has gone on in recent geologic times by leaching of the silica from the rocks exposed to weathering.

Three types or degrees of silicification have been observed: induration with moderate silicification to depths of only a few feet from the modern surface, where hard beds grade down within about 10 feet to soft friable beds of the same texture and composition as the hard rocks above; intense silicification, which has changed sandstone to quartzite and tuffaceous beds to "porcelainite" (these zones also grade into softer rocks, and in some places the intense silicification is near areas where uranium minerals occur); and irregular masses of nearly pure siliceous or opaline material.

Induration by calcareous cement is rare. In the immediate vicinity of the deposits near Tordilla Hill, none of the sands contain calcareous cement, although carbonate nodules as much as three feet in diameter are fairly abundant in the Falls City shale member of the Jackson formation underlying the ore-bearing sand. A few thin calcareous beds are known to exist in the upper part of the Jackson formation a few miles to the south and southwest of the deposits. Fibrous or prismatic calcite bands and septarian concretions are common in marine beds in the uppermost part of the formation. The Catahoula tuff is slightly calcareous in the subsurface, and soils derived from this formation are strongly calichified. Soils from the marine clays of the Jackson show moderate caliche development but those from the sands are only slightly calcareous or are non-calcareous.

The relationship of silicate and carbonate deposition to the emplacement of ore and to structure is being investigated. Several areas

of known faults contain silicified sandstone, but many intensely silicified areas are not associated with obvious faulting or with the occurrence of uranium minerals.

Mineralogical investigations, by A. D. Weeks

Two new uranium molybdenum minerals from Tordilla Hill, Karnes County, Texas, are being studied. One, a purple mineral containing uranium and molybdenum, is found associated with pyrite in a black highly silicified sandstone; fine-grained aggregates of this purple mineral replace sand grains. About 50 milligrams of the mineral were purified and the X-ray pattern differs from that of any known uranium-molybdenum mineral. The other new mineral is pale yellow and may be an oxidized product of the purple mineral. The X-ray pattern matches that of a synthetic yellow mineral grown in the USGS laboratories. The synthetic mineral has the composition  $H_2(UO_2)(MoO_4)_2 \cdot nH_2O$  and may be related to the new mineral, preguinite, reported by Russians at the United Nations Geneva conference in 1955.

Samples were collected for further mineralogic and petrographic study of the Texas Coastal Plain uranium deposits.

The close association of the uranium deposits of the Texas Coastal Plain with altered volcanic ash and with caliche deposits and silicification strongly suggests a ground water rather than a hydrothermal origin. A study of ground water in south-central Texas by Lonsdale (1935), Sayre (1937), and Winslow and Kister (1956) indicates that highly mineralized water containing sodium carbonate and other salts is common in the Eocene and Miocene formations that contain volcanic ash and uranium deposits. For many years the possible genetic relation of the silicified rocks with the carbonate ground water has been recognized. Inasmuch as

sodium carbonate in the ground water would be effective in leaching uranium and other trace elements from the volcanic ash, a ground water origin of the uranium deposits seems to be the best working hypothesis at present.

### References

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- Sayre, A. N., 1937, Geology and ground-water resources of Duval County, Texas: U. S. Geol. Survey Water Supply Paper 776, 116 p.
- Winslow, A. G., and Kister, L. R., 1956, Saline-water resources of Texas: U. S. Geol. Survey Water Supply Paper 1365, 105 p.

### General investigations

Physical properties of ore and host rock

By

G. E. Manger

Experimental core drilling of one borehole in the Karnes County, Texas, uranium terrain has been completed and drilling of three others is in progress. In the completed hole there is a fine-grained sandstone containing minor amounts of clay between depths of 139 and 163.5 feet; the uraniferous zone is from 152 to 163.5 feet. Below this sandstone the section becomes more argillaceous. An induction log borehole survey in oil-base mud gave the most accurate true formation resistivities. The gamma-ray log indicates the most strongly mineralized part of the uraniferous zone is the interval between 157.6 and 158.8 feet where  $U_3O_8$  content is 0.11 percent. The highest resistivity between the depths of 30 feet and 280 feet is 15 ohm-meters in the upper part of the sandstone between 139 and 150 feet. These resistivity relations in and above the

mineralized zone are similar to those found on the Colorado Plateau (TEI-620, p. 160-163) and may correspond to differences in the amount and salinity of pore water associated with mineralized rock and adjacent barren ground, as they do in the Colorado Plateau, but the porosity and the amounts and salinity of pore water in the cores have not yet been determined.

### Geophysical studies in uranium geology

By

R. A. Black

The regional gravity survey in the Crooks Gap area, Wyoming, has been completed, and final Bouguer and residual gravity maps have been prepared. There is good correlation between the Bouguer and residual gravity maps and the known geology. A previously unknown buried thrust mass extending into the Crooks Gap area from the northwest was inferred from gravity measurements and later verified by seismic measurements and by data from an oil well drilled nearby. A normal, east-trending fault that bisects the Crooks Gap area is well defined by the gravity data, and the trace can be extended considerably beyond its surface expression. The maximum gravity gradient across this fault trace is 72 gravity units. The vertical displacement indicated by this gradient ranges from approximately 800 feet for a density contrast of 0.7 gm per cm<sup>3</sup> to approximately 1,900 feet for a density contrast of 0.3 gm per cm<sup>3</sup>. These density contrasts are considered extremes and reflect minimum and maximum displacements. A density contrast of 0.5 gm per cm<sup>3</sup> is more reasonable for unconsolidated sediments and granite and indicates an approximate displacement of 1,150 feet. Geologic estimates of the displacement on this fault range from 2,500 feet (Bauer, 1934) to 1,310 feet (J. G. Stephens, written communication).

Only one of the four known anticlinal structures under the Green Mountain belt is definitely indicated by the gravity data. Older, more dense formations and the basement are closer to the surface in the anticlinal structure indicated by the gravity data; the increased depth of burial of the other three anticlinal structures may account for their lack of gravity expression.

A seismic refraction survey was carried out in an area near Maybelle, Colorado, to delineate fault patterns in the Tertiary Browns Park formation that blankets the area. The uranium deposits in this area seem to be associated with faulting in the Browns Park. The interpretation of the seismic data has not been completed, but preliminary inspection indicates that the measurements were successful. An attempt to map the thickness of the Browns Park formation by the reflection method was unsuccessful.

A seismic refraction survey was made in Elk Ridge, Utah, in August-September 1956, to determine if channels or scours cut into the Moenkopi formation and filled with sediments of the Mossback member of the Chinle formation could be traced. Rigorous interpretation of the data is still in progress, but field examination indicated that the refraction method can detect the channels or scours.

Geophysical studies in the southern Black Hills, South Dakota, are described on pages 112-114 of this report. Investigations in the Gas Hills, Wyoming, are described on pages 116-119.

The following report was published during the period:

Black, R. A., 1956, Geophysical exploration for uranium 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. 721-728.

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Development and maintenance of radiation equipment

By

W. W. Vaughn

A new model of the Time Interval Differentiator Equipment (dubbed TIDE) has been designed and built to incorporate changes suggested by use of the first model. These included: a higher input sensitivity, acceptance of either a positive or a negative input pulse, stable built-in trigger circuit at the input, and a short time channel (actinon) output as well as a long time channel (thoron) output.

The name DIPARR (Differential-Integral Pulse Analyser Recording Ratemeter) has been given to the versatile instrument built on specifications for the Radiation laboratory. Four commercial models of this instrument were delivered to the laboratory in early October and have undergone severe testing. Only minor troubles in sub-assemblies were detected. In general the unit is operating very well and should be used effectively in conjunction with spectral studies.

A probe for an alpha-gamma bore hole logger was designed. The probe uses a modified "O" ring in a captive gland arrangement to seal the windows. The windows are pyrex for greater strength.

## Gamma-ray logging studies

By

C. M. Bunker

Simulated drill holes containing an assortment of grades and thicknesses of uranium ore in secular equilibrium were assembled at the Denver Federal Center for the purpose of calibrating gamma-ray logging equipment. The ore grades range from 0.009 to 4.25 percent  $^{238}\text{U}$ . Each hole contains from 1 to 3 layers of radioactive material sandwiched between layers of essentially nonradioactive sand. The ore thicknesses range from 0.2 to 2.0 feet.

Preliminary drilling and gamma-ray logging was begun on the Texas Coastal Plain in Karnes County, Texas, in connection with the project "Physical properties of ore and host rock" (p. 240-241, this report). Results indicate a large halo of low-grade radioactive material surrounding the presently known deposits. Work on the project was temporarily recessed until repairs are made on malfunctioning drilling equipment.

Two cobalt-60 sources with a total intensity of 976 millicuries were obtained. They will be used for subsurface density measurements by the gamma-gamma method and for irradiating samples of materials to study radiation damage. Several rock samples were irradiated and thermoluminescence curves were compared with nonirradiated samples. The majority of the samples showed intense damage a few degrees above room temperature. These tests are described in more detail in the report on development and maintenance of radiation detection equipment.

Gamma-ray logging for a U. S. Geological Survey exploration project near Edgemont, South Dakota, was continued from the last report period. A total of 118 drill holes with an aggregate footage of 16,471 feet were logged. A report on the geology and subsurface radioactivity is in progress.

Scintillation ratemeter equipment designed to specifications of the Geological Survey has been delivered by the manufacturer and is currently under test. Gamma-spectra measurements with small Cs<sup>137</sup> sources are being made to calibrate the equipment. Preliminary results indicate that the equipment is suitable for making valid spectral measurements of radioisotopes in small samples. Tests will be expanded to include large samples and ultimately to subsurface spectral measurements of naturally occurring radioisotopes.

Maintenance services for hand counters and logging equipment, and the design and construction of accessory equipment, were continued in the instrument shop in Grand Junction.

Correlation of airborne radioactivity  
data and areal geology

By

Robert Bates and Robert Guillou

During the past six months approximately 2,500 traverse miles of airborne radioactivity surveying have been completed. About 1,000 traverse miles were flown in the drift-free area of Wisconsin in the vicinity of Wausau. Results of these surveys have been compiled as profiles; a striking linearity of radioactivity anomalies is apparent. In conjunction with magnetic surveys in the vicinity of Florence, Wisconsin, approximately 1,500 traverse miles of airborne radioactivity data were also obtained. About a dozen significant apparent anomalies were detected. A calibration method, using a caesium source, is being used with considerable success to decrease the drift of the equipment. However, flights across a broad source have indicated that the equipment may now be counting at a rate 20 percent lower than when flights were made

across the broad source approximately four months ago.

Analysis of data obtained in surveys made in 1954 of the Pine Ridge Escarpment, Niobrara County, and Pine Mountain area, Natrona County, Wyoming, shows that in the East Pine Ridge Escarpment area most of the radioactive deposits are found in the arkosic conglomerative sandstones of the White River formation of Oligocene age. In the Pine Mountain area, the radioactive deposits are in sandstones of the Wind River formation of Eocene age. Both areas contain sedimentary rocks ranging in age from Upper Jurassic to Tertiary which are representative of marine and non-marine depositional environments. Shale comprises the greater part of the stratigraphic column in both areas.

It has not been possible to differentiate among the various shales on the basis of radioactivity; however, sandstones and to some extent limestone, can be differentiated from the enclosing shale by their generally lower level of radioactivity.

A high level of radioactivity is associated with the Wind River formation and quite accurately outlines the outcrop pattern of the formation in the Pine Mountain area. In the East Pine Ridge Escarpment area, the White River formation is easily distinguished by a higher radioactivity level especially where remnants of the White River formation cap mesas of the Pierre shale.

During the summer of 1955 a survey was made of parts of Baraga, Marquette, and Dickinson Counties in the north-central part of the Michigan peninsula. The area had been surveyed in 1951 with Geiger-Müller equipment, and was resurveyed in 1955 to provide a comparison of the old data and that obtained by scintillation detection equipment and to obtain information on the relationship of radioactivity data to

the geology in a complex area of igneous and metamorphic rocks. An evaluation of the correlation of radioactivity data and areal geology is being made.

"Radioactivity units" on the nested, rectified profiles can be identified by the character of the radiation or by the level of the radiation, either a uniform level or the level of peak heights. There is no consistent correlation between radioactivity features and topographic features. Some cases of excellent correlation exist but major topographic changes are not consistently expressed. Minor changes (100 feet or less) in detector-ground distance do not cause noticeable variations in the radiation record. Except in the rugged Huron Mountains, the lack of altitude-compensated data does not seriously affect the interpretation of the data.

The "Republic granite" and the Cambrian sedimentary rocks are the most characteristic radioactivity units in the area. Other features on the radiation record are interpreted as representing Huronian metamorphic rocks and Laurentian granite, and lithologic variations within these two broad groups. Evidence for Lake Superior shore deposits is also found. Only the "Republic granite" and the Cambrian sedimentary rocks are consistently expressed by the radiation records, the other rock types showing up on some flight lines but not on all. Many smaller features can be delineated on only a few flight lines.

This preliminary evaluation indicates that only a complete and detailed investigation of the correlation of the radiation data and areal geology will produce definitive results. However, this study reinforces two general ideas concerning the concept of mapping by radioactivity:

(1) The ratio between the cone of response of the radiation equipment and the size of the radioactivity units (rocks) is an important consideration. It is believed that a smaller cone of response would be more effective in areas such as this.

(2) Except for a few rugged areas, the lack of compensation for changes in detector-ground distance is not a serious problem although radioactivity units are sharper and more clearly seen on compensated records.

## GEOCHEMICAL INVESTIGATIONS

Colorado Plateau region

## Distribution of elements

By

E. M. Shoemaker, W. L. Newman, and A. T. Miesch

Detailed reports on the distribution of elements in the Colorado Plateau have been given in previous Semiannual Reports (TEI-490, p. 58-78; TEI-540, p. 76-89; TEI-590, p. 127-131; TEI-620, p. 128-146). General conclusions drawn from the work done to date are summarized below:

Sandstone-type uranium deposits of the Colorado Plateau may be considered as composed of two fundamental parts: an indigenous or intrinsic part, and an extrinsic part which was added to the intrinsic part to form the deposit. The principal extrinsic components, in their approximate order of abundance, are vanadium, iron, magnesium, uranium, sulfur, arsenic, copper, lead, molybdenum, selenium, cobalt, and nickel.

At least six possible sources for the extrinsic components of the uranium deposits may be considered reasonably likely, depending upon the hypothesis adopted for the origin of the ores: (1) the sandstone beds enclosing the uranium deposits, (2) the marine Mancos shale of Cretaceous age, (3) bentonitic shales of Jurassic and Triassic age, (4) petroliferous rocks of Pennsylvanian age, (5) Precambrian crystalline rocks forming the basement complex of the Colorado Plateau, and (6) magmatic reservoirs of latest Cretaceous or Tertiary age. If the major source of some of the elements is external to the sandstone beds enclosing the deposits, it is likely that several sources have contributed to some if not most of the

extrinsic components and that the importance of the various sources differs from one element to the next. Precambrian crystalline rocks are considered by the authors to be the most likely major source of the uranium in the deposits.

### General investigations

Botanical research

By

H. L. Cannon

The experimental plot studies carried on for the past four seasons in Santa Fe, New Mexico, were terminated in September. The perennial plant material collected was used as slide material for stripping film experiments. Alpha tracks are beginning to show up on the slides. Analyses received of plants grown in plots salted with strontium-rich ore show an unusual content of strontium in the ash. The plants contained from 3,000 to 15,000 ppm Sr in the ash compared to 50 to 100 ppm Sr normal in vegetation. The reasons for this extraordinary absorption of Sr are being studied and comparative Sr analyses for plants rooted in other types of radioactive ores are being made.

During the report period a paper was delivered at the International Geologic Congress at Mexico City on "Advances in botanical methods of prospecting for uranium." A paper published during the period was:

Cannon, H. L., and Kleinhampl, F. J., 1956, Botanical methods of prospecting for uranium, 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. 681-686.

## Geochemistry of uranium-bearing shales

By  
Maurice Deul

Most of the laboratory work during the report period has been concerned with the Chattanooga shale because that formation has been of greatest interest as a possible future low-grade source of raw material for uranium extraction. It has been necessary, however, to examine in some detail the association of uranium and other elements with organic and mineral concentrates from other fine-grained sedimentary rocks.

Detailed reports of geochemical studies of carbonaceous sediments are scarce and in most instances investigators are forced to compile generalized data and to deal with averages, maxima and minima, and to use as standards of reference crustal abundances of the elements. This has been done by Krauskopf (1955), who mentions the provisional nature of the data available. Most analyses for minor elements in carbonaceous materials are reported as percent present in the ash of the rock. However, the enrichment of any particular element in the ash of carbonaceous material is often a spurious clue and, especially for low ash material, the importance of elemental concentrations may be greatly overemphasized unless the percentage of ash is kept in mind. A carbon content of more than one percent in a non-carbonate rock represents significant geochemical concentration of organic carbon, a fundamental fact that is frequently unrecognized.

In this investigation carbonaceous material, even in low percentages, has been separated from the rocks by mechanical means (Deul, 1956). Each of the samples--original rock as well as the carbonaceous and mineral

concentrates obtained from them--was ashed and the ashes were analyzed by the semiquantitative spectrographic method. Carbon was determined on unashed samples by microcombustion methods and uranium was fluorimetrically determined. With a known ash content and a known carbon content the spectrographic analyses could be converted to original basis, that is, to the state before ashing, and the percentage range of the elements detected could be compared for each separate and for the original rock. The standard of reference for each element in each series of samples is the percentage-range of the element present in the mineral concentrate; the percentage-range of the element in the carbonaceous concentrate is compared to this; both analyses are compared to the original sample analysis as a mass balance check.

The elements found to be concentrated in organic fractions separated from six sedimentary rocks are shown in table 4.

The enrichment factors are computed according to the equation:

$$\text{Approximate enrichment factor} = \frac{\text{Percent in organic concentrate}}{\text{Percent in mineral concentrate}}$$

These data are not absolute because the mineral concentrates always contain some carbonaceous matter and vice versa, but the data are useful and realistic in evaluation of the significance of these enrichment factors when the enrichment factor for carbon is used as a basis of comparison.

Of the six rocks studied in this investigation the shale from the Dakota formation is the only one which showed enrichment of uranium in the organic matter as compared to the mineral matter; this can be attributed directly to the coaly nature of the organic matter in this shale.

Table 4.—Enrichment factors for elements found concentrated in carbonaceous fractions as compared to mineral fractions separated from sedimentary rocks

|  | C    | B  | P | V  | Fe | Co | Ni   | Cu  | Zn  | As | Mo | Ag  | Sn   | Pb  | U   | La | Ce |
|--|------|----|---|----|----|----|------|-----|-----|----|----|-----|------|-----|-----|----|----|
| Sharon Springs shale—<br>Late Cretaceous                 | 6    | 2  |   |    |    |    |      |     |     | >5 |    |     |      |     |     |    |    |
| Shale from Dakota forma-<br>tion - Cretaceous            | 60   |    |   |    |    |    | 10   |     |     |    |    |     | 2    | 10  | 100 | >2 | 2  |
| Argillite from Lockatong<br>formation - Late<br>Triassic | 27†  | 10 | 5 |    |    |    | 100† |     |     |    | 72 | 20† | 7100 | >10 |     |    |    |
| Shale from Phosphoria<br>formation - Permian             | 18   | 2  |   | 10 | 20 | 2  | 10   | 20† | >10 |    | 2† | 50† |      | 10  |     | 2  |    |
| Chattanooga shale—<br>Devonian                           | 5-10 | 2  |   | 2  | 2  |    |      |     |     |    |    |     |      |     |     |    |    |
| Dripping Spring<br>quartzite -<br>Precambrian            | 62   | 2  |   |    |    |    | 10   |     |     |    | 10 | 2†  | 10   | 10  |     |    |    |

Except for uranium--which here is a special case--and for the rare earth elements lanthanum and cerium, none of the other elements concentrated in the organic matter is dominantly lithophile. Vanadium, iron, cobalt, nickel, copper, zinc, molybdenum, silver, lead, and tin characteristically form complex compounds which might be fixed with the organic material. Some of the possible processes for fixation of some of these elements have been discussed by Krauskopf (1956).

The mineral concentrates show concentrations of barium, strontium, titanium, and zirconium, in addition to silicon, aluminum, calcium, magnesium, sodium, and potassium.

Elements not significantly concentrated in either fraction are beryllium, scandium, chromium, gallium, manganese, yttrium, and ytterbium. Neither Bi (limit of detection 50 ppm) nor Ge (limit of detection 10 ppm) was found in either fraction.

The following paper was published during the period:

Breger, I. A., and Deul, Maurice, 1956, The organic geochemistry of uranium, 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. 505-510.

### References

- Deul, Maurice, 1956, Colloidal method for concentration of carbonaceous matter from rocks: Am. Assoc. Petroleum Geologists Bull., v. 40, p. 909-917.
- Krauskopf, K. B., 1955, Sedimentary deposits of rare metals, in Economic Geology, Fiftieth Ann. Volume, Part 1, p. 411-463.
- \_\_\_\_\_, 1956, Factors controlling the concentrations of thirteen rare metals in sea-water: Geochimica et Cosmochimica Acta, v. 9, p. 1-32b.

## Uranium in asphaltite and petroleum

By

A. T. Myers

The major effort during the report period was on the ashing of a large number of crude oil samples preparatory to chemical and spectrographic analyses. This work is now 75 percent completed. The samples were collected by N. Wood Bass of the U. S. Geological Survey from the Denver Basin as part of a study to establish the nature of the association of uranium and minor elements in crude oil with the nitrogen and sulfur content of these oils, and the geochemical relations with reservoir rocks.

Preliminary results on four crude oil samples used to study the leaching of uranium and other metals from uraniferous ores by petroleum show a large increase in the uranium content in the ash of the oils. The oils were filtered through a fine porosity filter (Seitz-bacteriological) prior to ashing in an attempt to remove fine ore particles. Because the ash content as well as the uranium content increased, contamination by finely divided material was suspected. Treatment of the filtered oil with 3 times its volume of carbon disulfide and centrifugation removed some material on the order of 1 micron in size. Re-ashing and chemical analysis gave results of the same order of magnitude but slightly lower. The evidence so far is inconclusive as to whether the increase in the uranium content is due to mechanical or to chemical causes.

Studies are being made on the distribution of uranium and minor elements in aliphatic, aromatic, nitrogenous, and oxygenated fractions of crude oil obtained from chromatographic separations of crude oil. These studies will be extended to the oils used in the leaching experiments in order to further separate and identify the organic compound or compounds that pick up uranium should such be the case.

The following papers on uranium in asphaltite and petroleum were published 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:

Hyden, H. J., 1956, Uranium and other trace metals in crude oils of the western United States: p. 511-520.

Hail, W. J., Jr., Myers, A. T., and Horr, C. A., 1956, Uranium in asphalt-bearing rocks of western United States: p. 521-526.

## MINERALOGIC STUDIES

Colorado Plateau region

Ore mineralogy  
By  
Theodore Botinelly

Most of the period covered by this report was spent on mapping selected parts of various uranium mines in Lisbon Valley area, San Juan County, Utah (see p. 51-57, this report), and collecting samples for mineralogic study.

Long wall mine sections were made at a scale of 1:60. These sections were selected to show the edges of ore, and the high grade parts of the ore deposit. Lithologic sections were made and an overlay contour map of the relative radioactivity was constructed for each lithologic section. The contours show the shape of the ore bodies and the relation of the ore to the lithologic units. The ore and mineralized rock form tabular bodies roughly parallel to the Chinle-Cutler contact. Minor irregularities of the contact are not reflected by the ore and irregularities in the shape of the ore do not coincide with any irregularity of the contact.

The ore is usually in the basal part of the Chinle formation but in some mines extends a foot or two into the Cutler formation. In other mines sharp ore boundaries coincide with the contact.

Ore rarely occurs in rocks other than sandstone; only a few thin mudstone layers in sandstone are highly mineralized. However, the ore does not occupy the entire sandstone in many mines. In others the ore terminates where the basal sandstones of the Chinle formation are cut

out by thick mudstones.

Minor variations in lithology, either small changes in grain size, or the intercalation of small units with large changes in grain size, seem to have little effect on the position or grade of ore. Where sandstone containing ore is in contact with thick mudstone the edge of ore is commonly at the contact between the sandstone and the mudstone. No correlations between grade of ore and grain size of the host sandstones were found.

The minerals of the uranium ores are mostly low valence minerals; secondary uranium minerals are scarce and for the most part occur on mine walls as a result of moist air oxidation after the opening of the mines.

Uraninite is the major uranium mineral and occurs as disseminations in sandstone. Montroseite and vanadium clays are the primary vanadium minerals. Sulfides are scarce; pyrite is the most abundant and occurs with the ore and in the barren mudstones and sandstones. Sphalerite, galena, and chalcopyrite are present in trace amounts in or close to ore. Chalcocite and native copper as well as malachite are present in the Big Buck mine. Vanadium in trace amounts is present with the native copper. Chalcocite, malachite and azurite are present in the copper prospects and mines along the Lisbon Valley fault. Secondary copper carbonates and sulfates occur sparsely in the uranium mines where they have apparently formed by oxidation of chalcopyrite.

Secondary minerals such as hewettite, "corvusite", liebigite(?), and andersonite(?), carnotite, ilsemannite, and other secondary minerals occur sparsely throughout the district.

Except for the granular detrital minerals, calcite is the most abundant gangue mineral; it occurs as cement in the sandstone, as detrital grains and as minor veins. Barite is the next most abundant gangue mineral; it occurs as veins and small irregular masses associated with coalified wood and rarely as cement in sandstone.

Molybdenum-bearing secondary minerals are present in Big Buck, Mi Vida, and Continental No. 1 mines; the primary molybdenum mineral has not yet been identified. Unoxidized molybdenum-bearing material closely simulates the appearance of vanadium ore, and molybdenum may be more abundant and widespread in the uranium-vanadium ores than has been previously thought.

The following reports were published during the report period:

Thompson, M. E., Roach, C. H., and Meyrowitz, Robert, 1956, Simplotite, a new calcium tetrovanadite from the Colorado Plateau: *Science*, v. 123, p. 1078.

\_\_\_\_\_, 1956, Duttonite, a new vanadium mineral from the Peanut mine, Montrose County, Colorado: *Science*, v. 123, p. 990.

#### Studies of clays in Triassic rocks

By  
L. G. Schultz

The rocks of the Chinle formation in Arizona and New Mexico are more montmorillonitic than their previously investigated equivalents to the north (TEI-620, p. 119). In Arizona, even the Owl Rock and Church Rock members contain considerably high montmorillonite clay. Kaolinite is a characteristic minor constituent of the Chinle in the western part of the Colorado Plateau and chlorite is a characteristic minor constituent in the eastern part. Chloritic and kaolinitic phases are separated by an area of erratic clay mineral distribution which

probably represents confluence of montmorillonite-kaolinite bearing sediments from a volcanic terrain to the south with illite-chlorite bearing sediments from the east. Such an interpretation agrees with source areas deduced from sedimentary structures (TEI-620, p. 94).

Two types of color changes can be distinguished at the Chinle-Moenkopi contact: (1) a pale green bleaching of the normally red Moenkopi rock with a sharp contact between the two colors, and (2) a greenish purple-red mottling of rock occurring between green Chinle and red Moenkopi rocks. The first type occurs below basal Chinle sandstones, is apparently caused by circulating ground-water, and does not result in appreciable argillic alteration. The second type is probably caused by weathering of pre-existing rocks during the Moenkopi-Chinle hiatus and is accompanied by the alteration of clays to either poorly crystallized kaolinite or a mixed-layer clay in which illite is more abundant than montmorillonite. Similarity in mineralogy between these altered mottled zones and the rocks of the Monitor Butte member of the Chinle formation in the San Rafael Swell and White Canyon suggests that part of the Monitor Butte sediments may be transported soil materials derived from altered zones developed on Moenkopi and older rocks.

#### Studies of clays in Jurassic rocks

By  
W. D. Keller

Glauconitic mica, similar in general appearance to glauconite, but intermediate in mineralogical properties between muscovite and glauconite (Foster, 1956), occurs in a layer of fine-grained sandstone in the upper part of the Brushy Basin member of the Morrison formation of Late Jurassic age on Blue (and Lone Tree) Mesa about 11 miles

northwest of Uravan, Montrose County, Colorado. This glauconitic mica is of interest for three reasons: it is intermediate in composition between muscovite and glauconite, which may be regarded as selected end-member types of dioctahedral potassium micas; it appears to represent an intermediate mineral stage in the alteration of montmorillonite to glauconite; and it occurs in the Morrison formation which is considered essentially without dispute to be nonmarine in origin (Craig and others, 1955), whereas glauconite has generally been described as being formed in a marine environment (Cloud, 1955; Hendricks and Ross, 1941).

The glauconitic sandstone is underlain by variegated mudstones about 500 feet thick, which contain montmorillonite (with very sparse relicts of shards), illite, quartz, and also, in several layers, scanty analcime. The Burro Canyon formation of Early Cretaceous age overlies the glauconitic sandstone.

The identifying properties of the glauconitic mica are: strong 001  $d$  spacing, 9.97A; very weak 002, 5.01 A; strong 003, 3.34 A; 060, 1.51 A; green color, pleochroic; X and Z indices, approximately 1.578 and 1.600; SiO<sub>2</sub> 49 percent, Al<sub>2</sub>O<sub>3</sub> 18 percent, Fe<sub>2</sub>O<sub>3</sub> 13 percent, FeO 1.3 percent, MgO 2.8 percent, K<sub>2</sub>O 7.8 percent, TiO<sub>2</sub> 1.1 percent, ignition loss 6 percent, others approximately 1 percent.

It is thought that the glauconitic mica originated in the following manner: (1) Devitrification, hydrolysis and other weathering processes converted in varying degree the volcanic material deposited in the Brushy Basin member to montmorillonite and other three-layer clay minerals. It is postulated that this alteration had not occurred completely by the close of Brushy Basin sedimentation, and that the permeability of

ash-containing rocks of the member was still relatively high. Evidence for this is the preservation of relict shard structures and the relatively continuous blue color throughout the Brushy Basin rocks at Blue Mesa.

(2) Toward the end of Brushy Basin time specialized conditions prevailed which gave rise to the development of blue and green minerals in the mudstone. This color alteration was later than the deposition of the Brushy Basin member, and older than deposition of the Burro Canyon formation. This is indicated by the lack, in the Burro Canyon, of the color effects associated with the Brushy Basin. (3) The green color at the top of the Brushy Basin and the fading of the blue color downward, indicates that the most intense chemical and mineral alteration which produced the color and mineral changes occurred near the top of the Brushy Basin. This suggests that the alteration was supergene. (4) It is therefore inferred that near the close of deposition of the Brushy Basin member downward moving solutions percolated through partly montmorillonized and still permeable ash deposits of the Brushy Basin, converting the montmorillonite in part to hydrous mica, and at shallower depths and locally, to glauconitic mica. The cause and origin of the downward moving solutions are not known and the exact geologic and topographic expression of the Blue Mesa area during the alteration cannot be described in detail. (5) During the alteration of the clay minerals, part of the magnesium was leached from the montmorillonite and significantly large amounts of potassium added. Potassium may have been furnished in abundance by saline brines from nearby salt anticlines or may have been released by hydrolysis of potassium-containing volcanic materials. Ferric iron was added in relatively large amounts to montmorillonite when the latter was converted to glauconitic mica. A specific source of the iron is not clearly evident,

but removal of a small amount of red iron oxide from only part of the rocks of the Brushy Basin elsewhere would suffice. Accompanying these chemical changes, the original montmorillonite structure was converted to mica structure. The exact chemical energy and process by which this change occurs is not well understood.\*

### General investigations

#### Mineralogy of uranium deposits

By

A. D. Weeks

The mineralogy and petrography of the Uravan mining district, Montrose County, Colorado, are being studied in cooperation with the field party working in this area. Preliminary examination of 150 thin sections of ore and of 50 thin sections of barren drill core indicates that pressure solution and movement of silica are much more prevalent in the ores than in barren rock.

Compaction due to interlocking of quartz grains and the filling of interstices with ore minerals has reduced the permeability of the ore sandstones. It is difficult to distinguish between effects of diagenetic processes and mineralization in the ores even after comparison with barren rocks. The various relations between minerals that appear in thin sections have alternative interpretations. Ore minerals may simply fill interstices between sand grains that have some silica overgrowth. Quartz grains and their overgrowths may be embayed by the ore minerals. Where ore minerals are between the quartz grains and the silica overgrowths, the ore may have replaced silica along the boundary or the overgrowths may be later than the ore. Carbonate cement may be

\* See p. 195.

diagenetic or associated with mineralization or with recent oxidation of the ores. Attempts to correlate study of clays in the thin sections with the X-ray identifications have not been very satisfactory as yet.

Some of the unoxidized ore at the Virgin No. 3 mine is bordered by thin bands of ferroselite ( $\text{FeSe}_2$ ) as other ores are commonly bounded by thin zones of pyrite, galena-clausthalite, or chalcocite. An interesting sample from the Shattuck Denn mine has an unoxidized core of coffinite, paramontroseite, pyrite, and sphalerite. Autunite is present close to the core where uranium has oxidized but vanadium has not reached the five-valent state. The outer rim of the sample has carnotite. The sphalerite has been purified for determination of temperature of formation.

Several samples of radioactive barite were prepared for study of the uranium daughter products.

Deposits in the lower part of the Salt Wash sandstone contain several unusual copper and vanadium minerals including volborthite, conichalcite, and the new barium copper vanadate, vesignieite.

Several examples have been found where the growth of secondary vanadium minerals around the border of vanadium-rich nodules has produced parallel fractures in the quartz grains within the border. The results of the mineralogic studies will be combined with the geologic studies in a major report on the Uravan district.

In a study of the mineralogy of the vanadiferous zones of the Phosphoria formation of the Paris-Bloomington area in Idaho, several sulfides and low-valent vanadium oxides were found, as well as sincosite, pascoite, and the more common hewettite.

Unoxidized ore from sec. 25, T. 13 N., R. 10 W. near Grants, New Mexico, contains uraninite with microscopic cubes of galena, and a primary vanadium mineral.

In the study of the minerals at the AEC No. 8 mine, Temple Mountain, Utah, the rare cobalt selenite, cobaltomenite was found.

Study of the new mineral, boltwoodite, from the Delta mine, San Rafael Swell, Utah, was completed. The formula is  $K_2(UO_2)_2(SiO_3)_2(OH)_2 \cdot 5H_2O$ .

Chemical analyses of a new purplish red fibrous vanadium mineral from three mines in the Paradox Valley area of Colorado was completed. The mineral has a tentative formula  $K_2O \cdot 2V_2O_4 \cdot 2(Fe_2O_3, V_2O_5) \cdot 8H_2O$ . The chemical analysis of a new yellow, acicular uranium mineral from the Lucky Mc mine, Fremont County, Wyoming, indicates the formula to be  $Ca(UO_2)(CO_3)_2 \cdot 3-4H_2O$ .

Three samples of a new yellow, acicular uranium mineral from Posey mine, San Juan County, Utah; Korzekwa pit, Karnes County, Texas; and from Austin, Nevada, were analyzed; the tentative formula of the mineral is  $Ca_2(UO_2)_3(PO_4)_2(OH)_4 \cdot 8H_2O$ . The chemical analysis of a new pale greenish yellow vanadium mineral from the Hummer mine, Montrose County, Colorado, indicates the formula  $Sr Ca V_2O_7 \cdot 3H_2O$ .

The mineralogy of the uranium deposits in Karnes County, Texas, is discussed on pages 239-240 of this report.

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

Fron del, Clifford, 1956, Mineralogy of thorium: p. 567-579.

Weeks, A. D., 1956, Mineralogy and oxidation of the Colorado Plateau uranium ores: p. 187-193.

Crystallography of uranium and  
associated minerals

By

H. T. Evans, Jr.

The most significant development during this report period is a new determination of the crystal structure of carnotite, which has cleared up the anomalies in the geochemistry of this mineral.

Crystal structure of carnotite

The crystal structure of carnotite reported by Sundberg and Sillen (1949) has been suspected of being in error for three reasons: (1) the structure incorporates regular tetrahedral orthovanadate groups ( $\text{VO}_4^{-3}$ ), whereas the mineral is known to form readily in neutral or slightly acid environments, in which the concentration of  $\text{VO}_4^{-3}$  ions is  $10^{-12}$  molar or less; (2) the coordination of oxygen around the linear uranyl ion ( $\text{UO}_2^{+2}$ ) is extremely unsymmetrical and considered to be very unlikely; and (3) there is an abnormally close approach of vanadium and uranium atoms (2.6 Å). Therefore, the structure was redetermined (Appleman, Evans and Clark) by X-ray diffraction studies on the anhydrous analogs  $\text{KUO}_2\text{VO}_4$  and  $\text{CsUO}_2\text{VO}_4$ . The crystals were prepared from  $\text{KVO}_3$  melts. Although the uranium atom positions in the crystal structure were found to be approximately correct as determined by Sundberg and Sillen, a completely different arrangement was found for the vanadium and oxygen atoms. Clear images of all atoms were obtained in electron density maps of both analogs. It was found that the sheet arrangement consists of a linkage of uranyl groups with divanadate groups ( $\text{V}_2\text{O}_8^{-6}$ ), in which oxygen

is in a nearly regular pentagon around the equator of the  $UO_2^{+2}$  group. Vanadium is in five-fold coordination, and the  $U_2O_8^{-6}$  group is nearly identical with two links taken from the chain configuration found in potassium metavanadate monohydrate ( $KVO_3 \cdot H_2O$ ). Therefore, it is concluded that carnotite is essentially a metavanadate.

The metavanadate nature of carnotite has been conclusively confirmed by precipitation experiments in which solutions containing potassium vanadate and uranyl ions at various pH values were mixed and the time required for a precipitate to appear was measured. It was found that precipitation was instantaneous in the pH range 6.5 to 9.5, but the time of precipitation increased markedly above these values. The pH range corresponds exactly to that within which the metavanadate ion or ions are stable, according to titration and diffusion studies. Above pH 11 a new insoluble phase of unknown constitution appears, which is different from carnotite.

#### Other uranium and vanadium mineral studies

Further work was carried on to refine the structures of billietite, duttonite, doloresite and other mixed vanadium oxide phases. The details of the structure of three types of duttonite were established: (1) duttonite,  $VO(OH)_2$ , which is monoclinic, space group  $12/c$ , and contains ordered hydrogen bond chains; (2) synthetic duttonite,  $VO(OH)_2$  (Pommer), which is orthorhombic with space group  $Imcm$ , and contains disordered hydrogen bond chains; and (3) "oxy" duttonite,  $VO_2(OH)$ , which is monoclinic, space group  $Ic$ , and contains isolated hydrogen bonds.

#### Reference

- Sundberg, Ingrid, and Sillen, L. G., 1949, On the crystal structure of  $KUO_2VO_4$  (synthetic anhydrous carnotite): *Aktiv för Kemi*, Band 1, Nr. 42, p. 337-351.

## ANALYTICAL SERVICE AND RESEARCH ON METHODS

Sample control and processingBy  
J. J. Rowe

The number of samples received at the laboratories was approximately the same as that in the preceding report period. The number of samples submitted by the AEC decreased from about 2,500 to about 1,700; those sent in by the public totalled about 1,300, approximately the same as in the preceding period. A summary of analytical services and sample inventory for the six-months' period is given in table 5.

Radioactivity

Lead content of granite sample G-1

By  
F. J. Flanagan

The project has recently assisted in a study of the lead content of granite sample, G-1. Fairbairn (1951) reported 27, 24 and 25 ppm of lead oxide and Ahrens (1954) has since recommended the use of G-1 with a lead value of 27 ppm as a standard for use in the spectrochemical analysis of silicates. Table 3-2 (A) of Ahrens (1954) contains a result of 50 ppm reported by Nockolds and recently (TEI-620, p. 303) some 14 chemical values averaging slightly less than 50 ppm were reported.

The lead content of the granite may be due to the decay of radioactive series in minerals such as zircon and sphene, and the distribution of these minerals in the ground samples may affect the lead values. Even if these samples are not homogeneous, it is difficult to explain the apparent bimodal distribution of lead values report to date. To check

Table 5.--Analytical services and sample inventory, June 1, 1956 - December 1, 1956

| Project or source               | Analytical services completed |        |                          |                 | Sample inventory |                |                       |                      |       |
|---------------------------------|-------------------------------|--------|--------------------------|-----------------|------------------|----------------|-----------------------|----------------------|-------|
|                                 | Chem. Detns.                  |        | Radio-activity (samples) | Spec. (samples) | X-ray (samples)  | On hand 6/1/56 | Rec'd. June-Dec. 1956 | On hand Dec. 1, 1956 |       |
|                                 | U                             | Others |                          |                 |                  |                |                       |                      |       |
| <u>Washington laboratory</u>    |                               |        |                          |                 |                  |                |                       |                      |       |
| AEC                             | 257                           | 20     | 181                      | 28              | 43               | 13             | 292                   | 198                  | 107   |
| Colorado Plateau sandstones     | 12                            | 605    | ---                      | ---             | ---              | 511            | 75                    | 127                  | 459   |
| Sandstones - Other than Plateau | 9                             | 156    | 9                        | 13              | 6                | 36             | 280                   | 144                  | 172   |
| Veins                           | 9                             | 17     | 9                        | 17              | 7                | ---            | 105                   | 57                   | 76    |
| Carbonaceous rocks              | 359                           | 260    | 234                      | 257             | 1                | 316            | 399                   | 543                  | 172   |
| Phosphates                      | 374                           | 1,872  | 196                      | 123             | ---              | 194            | 273                   | 106                  | 361   |
| Alaskan                         | 46                            | ---    | 78                       | 38              | 2                | 17             | 111                   | 60                   | 68    |
| Public samples                  | 175                           | ---    | 228                      | 20              | 55               | 179            | 1,244                 | 1,145                | 278   |
| Mineralogical projects          | 156                           | 715    | 66                       | 378             | 276              | 495            | 860                   | 850                  | 505   |
| Geochemistry of U               | 729                           | 472    | ---                      | 80              | 335              | 561            | 960                   | 1,061                | 460   |
| Miscellaneous                   | 146                           | 244    | 76                       | 250             | 30               | 92             | 500                   | 361                  | 204   |
| Total                           | 1,272                         | 4,361  | 1,077                    | 1,204           | 755              | 2,415          | 5,099                 | 4,652                | 2,862 |
| <u>Denver laboratory</u>        |                               |        |                          |                 |                  |                |                       |                      |       |
| AEC                             | 655                           | 501    | 975                      | 292             | 138              | 664            | 1,392                 | 1,632                | 424   |
| Plants and soils                | 113                           | 171    | 29                       | ---             | ---              | 186            | 154                   | 249                  | 91    |
| Colorado Plateau sandstones     | 333                           | 1,268  | 682                      | 547             | 27               | 1,738          | 2,662                 | 1,848                | 2,552 |
| Sandstones - Other than Plateau | 95                            | 401    | 278                      | 77              | 50               | 617            | 910                   | 683                  | 844   |
| Veins                           | 67                            | 268    | 39                       | 39              | 19               | 153            | 451                   | 381                  | 239   |
| Carbonaceous rocks              | 27                            | 40     | 90                       | 103             | 1                | 202            | 290                   | 303                  | 189   |
| Phosphates                      | ---                           | 5      | ---                      | ---             | ---              | 17             | ---                   | 17                   | ---   |
| Waters                          | 295                           | 454    | ---                      | ---             | ---              | 37             | 195                   | 170                  | 62    |
| Public samples                  | 75                            | 27     | 40                       | ---             | ---              | 27             | 62                    | 62                   | 27    |
| Geochemistry of U               | ---                           | 5      | ---                      | 12              | 6                | 71             | 41                    | 1                    | 95    |
| Miscellaneous                   | 302                           | 541    | 419                      | 276             | 70               | 781            | 2,097                 | 2,000                | 878   |
| Total                           | 1,962                         | 3,681  | 2,552                    | 2,346           | 311              | 4,493          | 8,254                 | 7,346                | 5,401 |
| Grand Total                     | 4,234                         | 8,042  | 3,629                    | 2,550           | 1,066            | 6,908          | 13,353                | 11,998               | 8,263 |

the homogeneity, 17 bottles were randomly selected from the remaining stock and  $\beta$ - $\gamma$  counts as described by Smith and Flanagan (1956) were made on both the upper and lower halves of the contents of each bottle and these counts for five-minute periods are shown in table 6.

Table 6.--Duplicate counts for 5 minutes of G-1 samples

| Sample | Counts |     | Sample | Counts |     | Sample | Counts |     |
|--------|--------|-----|--------|--------|-----|--------|--------|-----|
| 1      | 847    | 826 | 7      | 786    | 857 | 13     |        |     |
| 2      | 881    | 776 | 8      | 808    | 815 | 14     | 822    | 787 |
| 3      | 867    | 822 | 9      | 786    | 853 | 15     | 804    | 891 |
| 4      | 787    | 819 | 10     | 771    | 821 | 16     | 789    | 777 |
| 5      | 749    | 785 | 11     | 851    | 877 | 17     | 808    | 720 |
| 6      | 864    | 823 | 12     | 777    | 838 |        |        |     |

Six bottles (numbers 6, 7, 10, 11, 12, and 16) were then chosen randomly for lead determinations. The contents of these bottles were halved and these halves numbered so that samples 1 and 7, 2 and 8, etc. were duplicate portions of the same bottles. Six laboratories, five of the U. S. Geological Survey and the spectrographic laboratory of the California Institute of Technology each determined lead in a randomly selected order and each laboratory sampled one pair of duplicates in each of six sampling positions. The results are shown in table 7.

The grand mean of the data is 48.9 ppm and the results range from 38 to 60 ppm. Because of the randomness in sample selection, it may be inferred that the remaining stock of G-1 has an average lead content of 48.9 ppm. Hence this test confirms but does not solve the 27 to 50 dilemma. Further tests whose results might explain the difference are being undertaken.

Routine radioactivity determinations reported during the previous six months period totalled 820.

Table 7.---Analytical data (by pairs) in the sampling order sequence

| Original samples | 1   | 2   | 3   | 4   | 5   | 6       |
|------------------|-----|-----|-----|-----|-----|---------|
| Your sample      | 1   | 2   | 3   | 4   | 5   | 12      |
| I                | A   | B   | C   | D   | E   | F*      |
|                  | 57  | 60  | 47  | 51  | 49  | 46      |
| Totals           |     |     |     |     |     | 47      |
|                  |     |     |     |     |     | 594     |
| II               | B   | C   | D   | E   | F   | A       |
|                  | 50  | 43  | 49  | 48  | 48  | 47      |
|                  |     |     |     |     |     | 50      |
|                  |     |     |     |     |     | 45      |
|                  |     |     |     |     |     | 47      |
|                  |     |     |     |     |     | 56      |
|                  |     |     |     |     |     | 48      |
|                  |     |     |     |     |     | 46      |
|                  |     |     |     |     |     | 571     |
| III              | C   | D   | E   | F   | A   | B       |
|                  | 49  | 47  | 46  | 56  | 47  | 47      |
|                  |     |     |     |     |     | 47      |
|                  |     |     |     |     |     | 56      |
|                  |     |     |     |     |     | 52      |
|                  |     |     |     |     |     | 50      |
|                  |     |     |     |     |     | 599     |
| IV               | D   | E   | F   | A   | B   | C       |
|                  | 46  | 51  | 47  | 48  | 48  | 48      |
|                  |     |     |     |     |     | 53      |
|                  |     |     |     |     |     | 58      |
|                  |     |     |     |     |     | 48      |
|                  |     |     |     |     |     | 38      |
|                  |     |     |     |     |     | 599     |
| V                | E   | F   | A   | B   | C   | D       |
|                  | 49  | 43  | 47  | 48  | 48  | 44      |
|                  |     |     |     |     |     | 46      |
|                  |     |     |     |     |     | 43      |
|                  |     |     |     |     |     | 44      |
|                  |     |     |     |     |     | 46      |
|                  |     |     |     |     |     | 561     |
| VI               | F   | A   | B   | C   | D   | E       |
|                  | 47  | 48  | 55  | 60  | 47  | 49      |
|                  |     |     |     |     |     | 48      |
|                  |     |     |     |     |     | 50      |
|                  |     |     |     |     |     | 49      |
|                  |     |     |     |     |     | 46      |
|                  |     |     |     |     |     | 599     |
| Totals           |     |     |     |     |     |         |
| Analyzed sample  | 298 | 292 | 294 | 308 | 285 | 296     |
|                  |     |     |     |     |     | 289     |
|                  |     |     |     |     |     | 298     |
|                  |     |     |     |     |     | 299     |
|                  |     |     |     |     |     | 295     |
|                  |     |     |     |     |     | 273     |
| Original sample  | 590 | 602 | 581 | 585 | 597 | 568     |
|                  |     |     |     |     |     | GT=3523 |

\*Letters A through F represent six laboratories.

The following reports were published during the period:

Kellagher, R. C., and Flanagan, F. J., 1956, The multiple cone sample splitter: Jour. Sed. Pet., v. 26, p. 213-221.

\_\_\_\_\_, 1956, A comparison of two methods for converting grain counts to weight percent composition: Jour. Sed. Pet., v. 26, p. 222-227.

### References

Ahrens, L. H., 1954, Quantitative spectrochemical analysis of silicates: Pergamon Press, London, 122 p.

Fairbairn, H. W., and others, 1951, A cooperative investigation of precision and accuracy in chemical, spectrochemical and modal analysis of silicate rocks: U. S. Geol. Survey Bull. 980, 71 p.

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

Analysis and research, Denver laboratory

By

J. N. Rosholt

During the period, 2,758 routine equivalent uranium determinations were made in the radiometric laboratory. In addition a total of 297 radiochemical determinations were made which included analyses for Pa<sup>231</sup>, Th<sup>232</sup>, Th<sup>230</sup>, Th<sup>228</sup>, Ac<sup>227</sup>, Ra<sup>226</sup>, Ra<sup>224</sup>, Ra<sup>223</sup>, Rn<sup>222</sup>, and Pb<sup>210</sup>.

Radioactivity studies were directed to the investigation of low-level radiochemical analyses using alpha counting and a possible age determination method utilizing the relative abundances of the long-lived daughter products compared to uranium. The feasibility of determining the required daughter product abundances in the ash of wood and charcoal samples which contain only small amounts of uranium (10 to 30 ppm) is being investigated to evaluate their potential for age study. This type of sample is selected because of the availability of results of C<sup>14</sup> dating and the availability of abundant samples which may be desirable

for future work. This low-level radioactivity study is also designed to demonstrate whether disequilibrium investigations are feasible on many different rock types which previously were considered too low in radioactivity for satisfactory analysis.

All of these samples on which the radiochemical separations and measurements were made contain significant amounts of  $\text{Th}^{232}$  or daughter products of  $\text{Th}^{232}$ . The presence of this additional radioactivity makes the analysis considerably more complicated; but the results show that, even with these complications, detailed analyses for the daughter products of the three radioactive series should prove to be entirely feasible, provided that a digital computer be used to perform the calculations when the daughter products of all three radioactive series are present, as manual calculation is too laborious to be performed on more than a token number of samples. This will complement the automatic measurement of the samples which is now being done in the laboratory.

#### Disequilibrium studies

By

F. E. Sentfle

The conventional method of determining the uranium content of rocks by radioactivity measurements yields a value of the equivalent uranium, i.e. the amount of uranium corresponding to the radioactivity if perfect equilibrium conditions existed. As many ores and minerals are out of equilibrium, this method is not satisfactory if one wishes to determine the actual amount of uranium present. An attempt has therefore been made to devise a non-destructive radioactivity method for uranium analysis which would be virtually independent of the state of equilibrium of the sample. The following methods are being tried.

### Measurement of Th<sup>234</sup>

Th<sup>234</sup>, the first daughter of U<sup>238</sup>, emits a 93 kev gamma ray. A thin crystal, single channel gamma ray spectrometer was constructed to measure this particular gamma. Considerable difficulty was experienced in resolving this peak from the 68 kev peak of Th<sup>230</sup>. Also backscatter peaks from several high energy gamma rays in the uranium series interfere with the 93 kev peak. Special electronic circuits are currently being constructed to cope with this problem.

### The beta absorber method

The two highest beta particle energies in the uranium series are 2.32 Mev (Pa<sup>234</sup>) and 3.17 Mev (Bi<sup>214</sup>). As Pa<sup>234</sup> is essentially in equilibrium with uranium at all times, and also as any disequilibrium in the series will be reflected in the Bi<sup>214</sup> content, a possible correction can be devised and applied to give the true uranium value. This method has been the most successful of those tried, and work is continuing to improve it.

### Beta-gamma coincidence method

Th<sup>234</sup> decays by a beta emission followed almost simultaneously by the 0.093 Mev gamma ray. In order to overcome some of the interference from other gamma rays an electronic coincidence method was devised to count only beta particles followed by 0.093 Mev gamma rays. The method is necessarily complicated and only preliminary measurements have been made so far. Work is continuing on this approach.

## Alpha absorption coefficient measurements

By  
F. E. Sentfle

Experimental alpha absorption coefficients were determined for monazite, sphene and zircon for different Th/U ratios. Monazite does not follow the experimental curve while zircon is close to the theoretical value. Thirty determinations have been made to date.

SpectrographyBy  
A. T. Myers and C. L. Waring

A total of 2,044 samples were analyzed by means of spectrographic methods during the report period. In addition, earlier spectrographic results on more than 1,000 samples were restudied and in some cases re-analyzed in order to aid in their evaluation. This work is related to the study on the distribution of elements in Colorado Plateau ores and sandstones.

The service testing included many pure pyrite samples from the Colorado Plateau deposits. These analysis were carried out to establish the minor and trace elements partition in the sulfides as related to the uranium deposits. The nickel-cobalt ratios are being used to establish the period of sulfide deposition. The other trace elements are being used to indicate which of these sulfides have been introduced by the ore forming fluids. Many requests to determine the purity of the samples prior to chemical or more detailed spectrographic analysis were received. A large number of analyses were made to help establish geochemical relationships.

An attempt is being made to develop a combined chemical and spectrographic method for the determination of thorium in rock samples. The thorium content of rock is probably 1 to 5 ppm and no method is available for this determination. Experiments have been conducted with the thorium introduced into zirconium. The work so far has indicated that thorium can be detected down to 3 ppm, as based on a chemically concentrated one-gram sample. Recent chemical tests demonstrated that the presence of aluminum in the rock samples interferes with the precipitation of thorium and therefore the spectrographic final tests were discontinued until the chemical problem has been solved.

The results of the controlled atmosphere studies described in TEI-590, p. 299, suggest the application of this technique to the determination of thorium in rock samples. One of the most sensitive thorium lines (4019.1A) falls in the heavily cyanogen banded portion of the spectrum. The carbon dioxide atmosphere greatly minimizes this banding and therefore it should be possible to detect thorium in low concentrations.

Selenium development tests this report period consisted of attempts to increase the sensitivity of this element below 0.0015 percent. Transferring the work to the eagle-type Baird spectrograph produced encouraging results. Tests are in progress now to increase the signal to noise ratio so that lower percentages of selenium can be detected without the presence of background.

## Infrared Spectroscopy

By

R. G. Milkey

During the past six-months period, data was obtained which nearly concludes the experimental work for three papers on (1) the potassium bromide method of infrared sampling, (2) the infrared spectra of approximately 60 tectosilicates, and (3) the infrared spectra of 50 vanadates. This work is related to and facilitates the service requirements and contributes to basic infrared data. For some tectosilicates, such as orthoclase and microcline, the infrared spectra are sufficiently distinctive to distinguish between two similar species; for others, such as the plagioclase series, spectra are not distinctive enough to reflect progressive changes in structures. The major absorption peaks of the tectosilicates all occur within a narrow band of the infrared spectrum, between wavelengths of approximately 9.0 and 10.2 microns. The work on the vanadates includes, for example, carnotite and its alkali analogs, and polyvanadates of potassium, calcium, sodium, zinc, magnesium, and barium. Correlations of the absorption peaks of these materials give indications of those which show similarities in structure.

Service work included the analysis of a variety of different samples. The spectra of such typical materials as a marine humus from Alaska; grahamite, gilsonite, and wurtzilite; stevensite, ghassoulite, and talc; oil extracts from sandstones and shales; and coal-type materials scraped from well cores, were studied. Their infrared absorptions were variously used to obtain such information as the purity of material, the unit structures contained in organic materials, the crystalline structure of inorganic materials, and possible identifications of unknown compounds.

Suites of materials, such as nine samples of coalified logs were compared, by means of their spectra, for differences in structure and content; and elution fractions obtained from the chromatographic fractionation of an oil were studied to evaluate the efficiency of the separation in the chromatographic column, as well as for further identification of the substituents of the oil.

### Chemistry

By

Irving May and L. F. Rader, Jr.

### Services

During the period, 10,458 chemical determinations were made on 5,148 samples. A breakdown of the analyses by type is presented in table 8.

Eleven chemists from various laboratories including three from foreign laboratories received from one-day to two-weeks training in analytical methodology under supervision of chemists of the U. S. Geological Survey laboratories.

### Research on analytical methods

A relatively rapid method for the determination of carbonate carbon and total carbon was adapted to the analysis of Colorado Plateau samples. Carbonate carbon and total carbon are determined separately by conversion to carbon dioxide under controlled conditions. The determination is made by measuring the volume of the gas and correcting to standard conditions rather than by absorbing and weighing the gas as is done in classical methods. Organic carbon is obtained by difference between total carbon and carbonate carbon.

Table 8.--Completed chemical determinations  
June 1, 1956 - November 30, 1956

| <u>Determination</u> | <u>Completed the<br/>past six months</u> | <u>Determination</u> | <u>Completed the<br/>past six months</u> |
|----------------------|--|----------------------|--|
| Uranium              | 3,526                                    | Nickel               | 45                                       |
| Thorium              | 47                                       | Strontium            | 77                                       |
| Quartz               | 13                                       | Arsenic              | 459                                      |
| Aluminum             | 29                                       | Gold                 | 89                                       |
| Iron                 | 274                                      | Silver               | 37                                       |
| Magnesium            | 130                                      | Silver + gold        | 40                                       |
| Calcium              | 163                                      | Boron                | 45                                       |
| Calcium carbonate    | 79                                       | Cobalt               | 45                                       |
| Sodium               | 153                                      | Copper               | 200                                      |
| Potassium            | 126                                      | Zinc                 | 479                                      |
| Lithium              | 32                                       | Molybdenum           | 82                                       |
| Water                | 438                                      | Lead                 | 48                                       |
| Titanium             | 109                                      | Rare earths          | 7  |
| Carbon dioxide       | 324                                      | Carbon               | 129                                      |
| Bicarbonate          | 181                                      | Hydrogen             | 52                                       |
| Phosphorus           | 228                                      | Organic matter       | 180                                      |
| Sulfur               | 202                                      | Oil                  | 206                                      |
| Selenium             | 504                                      | pH                   | 322                                      |
| Fluorine             | 267                                      | Ash                  | 477                                      |
| Chlorine             | 45                                       | Specific gravity     | 65                                       |
| Iodine               | 17                                       | Miscellaneous        | <u>161</u>                               |
| Vanadium             | 326                                      | Total*               | 10,458                                   |

\*Totals given in this table will not necessarily agree with those of table 5, Analytical service and sample inventory, because of time lag between laboratory completion and summary compilations in Sample control audits.

Preliminary work has been completed on colorimetric extraction methods for the determination of cobalt, nickel, and molybdenum in highly mineralized samples with particular attention to samples containing appreciable uranium. Separation procedures are being studied through the use of radioactive isotopes. This work should be completed during the next report period.

## Analytical chemistry of thorium

During this period increased emphasis was placed on the development of methods for the determination of thorium with special effort on the determination of less than 1 ppm  $\text{ThO}_2$  in basic rocks. Several approaches are under study. In one, increased specificity is sought in the mesityl oxide extraction and separation of thorium nitrate by conducting the extraction in the presence of tartaric acid. This allows thorium to extract quantitatively and prevents the extraction of Zr, Ti, Nb, and Ta. Of the 17 elements tested so far from tartaric acid medium, mercury and bismuth are the only elements that are extracted in significant amounts.

Another approach under investigation involves the chemical separation of small amounts of thorium for final determination by X-ray fluorescence. The tentative procedure developed consists of an acid decomposition of five grams of rock, extraction of thorium with mesityl oxide, precipitation by ammonia with aluminum to act as a carrier and thallium to act as an internal standard, evaporation of an acid solution of the precipitate on a mylar film, and then measurement by X-ray fluorescence. Excellent results have been obtained with pure solutions for 5 to 250 micrograms of thorium, and tests are underway with spiked gabbro samples.

The third approach is to adapt the recently developed method involving iodate separation of thorium from tartaric acid medium and spectrophotometric determination of thorium with thoron from mesotartaric acid medium to the determination of less than 1 ppm of  $\text{ThO}_2$  in basic rocks. To take care of the large samples that must be processed two additional separations were found necessary--a preliminary concentration of thorium by precipitation as the phosphate from acid medium using zirconium as a carrier and a

hydrofluoric acid separation of thorium using yttrium as a carrier. The phosphate separation is a modification of a published procedure and designed for greater specificity for thorium. It was found possible to precipitate microgram amounts of thorium phosphate quantitatively from acidities as high as 10 percent by volume of hydrochloric acid when 10 or more milligrams of zirconium are used as carriers. Under these conditions, the rare earths are not coprecipitated to a significant extent.

The proposed method consists of solution of the sample; phosphate, fluoride, and iodate separations; and spectrophotometric determination of thorium. With pure solutions better than 98 percent recovery of microgram amounts of thorium were obtained in each step and better than 97 percent recoveries were obtained on an overall basis. With five gram portions of a basic rock spiked with known amounts of thorium, very low recoveries of thorium were obtained. The difficulties were traced to the phosphate step, thorium phosphate failing to precipitate in the presence of large amounts of iron and aluminum. Because of the high specificity of the phosphate step at high acidities, it is thought desirable to make additional studies to try to overcome its defects.

The following papers on methods of chemical analyses were published during the period:

Feinstein, H. I., 1956, The determination of uranium in ores: Separation by ethyl acetate extraction and spectrophotometric determination by the thiocyanate method in acetone-water medium: U. S. Geol. Survey TEI-555, issued by U. S. Atomic Energy Comm. Tech. Inf. Service Extension, Oak Ridge, Tenn.

\_\_\_\_\_, 1956, The spectrophotometric determination of vanadium as thiocyanate in acetone-water medium: *Analytica Chimica Acta*, v. 15, p. 141.

\_\_\_\_\_, 1956, The spectrophotometric determination of uranium by means of the azide ion: *Analytica Chimica Acta*, v. 15, p. 288.

Fletcher, M. H., and Milkey, R. G., 1956, Spectrophotometric study of the thorium-morin mixed-color system: Anal. Chemistry, v. 28, p. 1402.

Grimaldi, F. S., 1956, The analytical chemistry of uranium and thorium, 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. 605-620.

May, Irving, and Smith, Roberta, 1956, Separation of aluminum phosphate minerals from kaolinite by selective solution: Jour. of the Assoc. of Off. Agr. Chem., v. 39, p. 766.

### Mineralogy

By

L. B. Riley and J. P. Owens

A total of 2,318 samples were processed for mineralogical identification and service studies during the report period. Of these 570 were handled in Denver and the remainder in Washington. Of the latter, 877 packages were received representing 1,456 samples.

Nuclear emulsions have been used to estimate uranium content of minerals and aggregates seen in thin sections. With the technique used, the track density expressed as about 0.10  $\alpha$ -tracks per square micron, per 100-hour exposure, has been found to be a reasonably reproducible result from grains of uraninite (containing about 85 percent U); other uranium minerals, after allowing for their lower uranium content, show good agreement with this factor if their daughter products are present in approximately equilibrium amounts. Use of this technique has allowed estimations of uranium content where the mineral grains concerned were too small or too few to separate for analysis.

Use of ultrasonic cavitation to separate mineral components without crushing and a scaler designed to obtain the equivalent uranium of minute

fractions have greatly aided in fulfilling special requests. An ultrasonic separator is being procured for the Washington laboratory to make studies in the utilization of this instrument for mineral separations and other mineralogic applications. The study on sampling techniques was temporarily suspended during this period, but this phase of the work will be reactivated later this year.

X-ray and electron microscopy services

By  
George Ashby

In this report period 1,354 identifications and/or determinations were made on 856 samples representing about a 10 percent increase in volume of service work over the previous six-months period.

A series of tests is being conducted to determine the reliability and accuracy of the Fourier computer described in a previous report. The accuracies of the various components have exceeded expectations in most cases but shifts in the phase of the 400 cycle wave with phase angle have caused some difficulty. Changes designed to minimize this effect are now being made. The construction of the automatic controls and the control console for the computer have been completed.

The study of the application of electron diffraction methods to mineralogy was continued. A large number of diffraction patterns were added to the laboratory file and are now being organized for publication. The relationship between cleavage and the selected-area diffraction pattern was studied for several cubic minerals and will be extended to other lattice types in the future.

The electron micrographs and the diffraction patterns of fervernite ( $\text{Fe}_4\text{V}_4\text{O}_{16} \cdot 5\text{H}_2\text{O}$ ) revealed a monoclinic cell with perfect (010) cleavage

for this mineral. Similarly, the patterns of sepiolite ( $4\text{MgO}\cdot 2\text{H}_2\text{O}$ ) indicate a monoclinic cell.

The study of metamict minerals by electron diffraction techniques was continued.

A paper entitled "A two dimensional Fourier synthesizer for crystal structure calculations" was read at the Annual X-ray analysis symposium at the Denver Research Institute.

The following paper was published during the report period:

Fron del, Clifford, Riska, Daphne, and Fron del, J. W., 1956, X-ray powder data for uranium and thorium minerals: U. S. Geol. Survey Bull. 1036-G.

## RESEARCH PROGRAMS

Physical behavior of radon

By

A. B. Tanner

The concentrations of radon in natural water-gas systems have been determined for samples from several places and compared with the equilibrium partition ratios determined by laboratory experiment. In samples from natural springs near Cuba, New Mexico, and in Douglas County, Colorado, the concentration of radon in the water phases relative to that in the gas phases was less than the experimentally determined equilibrium concentration at the same temperature; apparently the gas which exists as a separate phase from the subsurface source of the radon to the surface, did not mix sufficiently with the water to permit adjustment to equilibrium concentrations. In samples from a 1,200-foot artesian well at Owens Lake, California, the radon concentration in the water phase, relative to that in the gas phase, was greater than the experimentally determined equilibrium concentration at the same temperature; at least some of the gas must have been in solution until the water reached the discharge point where the samples were taken. By making measurements of radon concentrations in the water phase and the gaseous phase of a natural water-gas system, the existence of separate phases as the fluid makes its way from the radon source to the surface can be inferred if the radon concentration in the water is less than that at equilibrium and if the water temperature is not decreasing rapidly.

The reflux condenser, an item of laboratory glassware used for boiling radon from solutions into a vacuum system, was improved by adapting various standard glassware components to serve the same purpose. The resulting

apparatus, costing two-thirds as much as the one-piece special item, was tested and found to be efficient and easy to clean under field conditions.

Absorption and scattering of gamma-radiation

By

A. Y. Sakakura

The primary aim of the experimental studies in the absorption and scattering of gamma radiation is to determine the deviation of one-medium theoretical computations of gamma-ray intensity from two-media cylindrical geometry experimental results. The measurements with a two-inch diameter void have been completed, and results indicate that the build-up factor is not a function of penetration distance alone. Measurements in the four-inch pipe are now in progress, and the directional response of the spherical sodium-iodide crystal must be checked before the precise deviation from one-medium solutions can be established. It is anticipated that most of the experimental work will be completed by December 1956.

The following paper was published during the period:

Sakakura, A. Y., 1956, Air scattering of gamma rays from thick uranium sources, 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. 715-720.

Radon and helium studies

By

A. P. Pierce

Work during the past half-year has been largely devoted to revision of a final report summarizing studies on the occurrence and distribution of uranium and its decay products in the Texas Panhandle Field. The results of these studies show that the abnormal radon concentrations and a part of the helium in the Panhandle Field are derived from uraniumiferous asphaltite mineralization (TEI-540, p. 234-237 and TEI-620, p. 305-309).

Additional investigations during the past six months have involved studies of the distribution and origin of uraniumiferous asphaltite in oil- and gas-bearing rocks; and a study of the migration and accumulation of helium- and nitrogen-bearing gases in the Panhandle-Hugoton Field and adjacent areas.

Uranium in natural waters

By

P. F. Fix

Field work was terminated on June 30 of surface-water samples from tuffaceous terrain in the Black Hills-northern Great Plains region and of water from Lake Marie in the Medicine Bow Range west of Laramie, Wyoming. Water from Lake Marie, collected during melting of snow heavily contaminated by dustfalls from the Colorado Plateau region during the spring months, contained only 0.1 ppb U, or regional background, and indicates that contamination of Front Range streams by such dustfalls is unimportant.

Further checking was done on effects of organic matter dissolved from peat bogs and mountain meadows on pH and other factors involved in leaching, transportation, and precipitation of uranium by natural waters, particularly those waters strongly acid from post-mine oxidation.

Several additional water samples from the Ouray Peak (Marshall Pass) area near Salida and the Idledale area near Denver, Colorado, increased the data base for standardization of hydrogeochemical methods for finding pitchblende deposits in Precambrian rocks.

The uranium content of the Weber River in its canyon near Ogden, Utah, was found to increase systematically downstream as the result of uraniumiferous ground-water issuing from fractured Precambrian rocks in the bed. Results are comparable with increases previously found in streams of the Colorado Front Range passing through the Morrison and Dakota formations, and agree closely with increase in radon content of the Weber River found by Rogers and Tanner.

The following papers on uranium in natural waters were published during the period 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:

Denson, N. M., Zeller, H. D., and Stephens, J. G., 1956, Water sampling as a guide in the search for uranium deposits and its use in evaluating widespread volcanic units as potential source beds for uranium: p. 673-680.

Fix, P. F., 1956, Hydrochemical exploration for uranium: p. 667-672.

Organic geochemistry of uranium

By

I. A. Breger

Approximately 30 large specimens of coalified logs, both uraniferous and non-uraniferous, from various parts of the Colorado Plateau area are being analyzed in studies of the geochemical relationship of plant debris to uranium on the Colorado Plateau. Silicified cores of some of the coalified logs are also being examined by other members of the U. S. Geological Survey to determine the species of the log and the relationship of species to uranium mineralization.

A sample of conglomeratic sandstone from the Dirty Devil No. 4 mine, San Rafael Swell, Emery County, Utah, was found to contain approximately 1.3 percent by weight of very small carbonaceous pellets. Analysis of the sandstone shows it to contain 0.1 to 0.5 percent tungsten and 0.05 and 0.1 percent each of arsenic and molybdenum. This is apparently the first time that tungsten has been detected in any appreciable concentration in Colorado Plateau sediments. This particular sediment also contains 0.12 percent uranium; the concentration of uranium in the carbonaceous pellets is essentially the same as that in the enclosing sandstone.

Analysis of ten carbonaceous pellets ringing the impregnated sandstone collected in the old adit, northwest corner of Temple Mountain, Utah. (TEI-620, table 34, p. 336), shows them to be nearly identical in composition to the impregnation. The reasons for the variations in modes of occurrence of such material, i.e. pellets or impregnations, are not yet understood.

Three oils isolated from sediments of the Temple Mountain region, were found to contain 0.5, 32, and 73 ppm uranium. As previously reported (TEI-490, p. 172), it is thought that this wide variation in uranium content

reflects the migration of an oil through uraniferous and non-uraniferous zones. Oils from areas outside the limits of the Colorado Plateau generally contain a maximum of 0.1 ppm uranium. Studies are being carried out to establish the distribution of the uranium in several gross fractions of these oils. This work should lead to additional information on the mode of retention of uranium by the oil. All analyses were based on wet-ashing techniques developed during the course of the study.

Cooperative experiments are being carried out with other members of the U. S. Geological Survey working on weathering and transportation of uranium to determine the conditions under which coalified wood from the Colorado Plateau will reduce the uranyl ion to uraninite. Experimental work is being conducted over a pH range of 3.4 to 11.0 and a temperature range of 20° to 155° C.

Initial studies of the effects of pile radiation on coals (TEI-590, p. 274) have been extended by exposures up to 120 days in duration. Exposures of up to 90 days indicate that lignite, subbituminous coal, and three bituminous coals of high, medium and low volatile content are all very stable showing practically no change in hydrogen content and increases of only about 2.5 percent in carbon content. Analysis of the data indicates that elimination of methane is probably a major reaction. When humic acid isolated from peat is similarly exposed, however, the analytical data suggest a totally different behavior. The humic acid apparently loses carbon dioxide and water with an attendant enrichment of the residue by about 10 percent in carbon. Changes in the humic acid indicate that it is being converted into a medium rank lignite, and that longer irradiation periods may extend the trend and result in the conversion of the humic acid into a substance having the composition and

properties of a bituminous coal. Such changes, if experimentally confirmed, may indicate the possible use of low-temperature pile radiation as a substitute for geologic time in bringing about certain geochemical reactions.

Study of carbonaceous substances from the Uinta Basin, Utah, is continuing with the analysis of wurtzilites, gilsonites, and related substances leading to the accumulation of data concerning their origin and interrelationships. Employing a paraffinic crude oil collected in the Uinta Basin, the pigment responsible for the fluorescence of the oil has been isolated, purified, and tentatively identified by infrared analysis as a phthalic acid derivative.

Carbon isotope ratios for a series of gilsonites are remarkably similar and seem to indicate that the various veins were derived from a single reservoir of material.

The following papers were published during this period:

Breger, I. A., and Brittin, E. B., 1956, Effects of radiation on coal: National Colloid Symposium, Madison, Wisconsin, Preprint.

Breger, I. A., and Deul, Maurice, 1956, The organic geochemistry of uranium, 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. 505-510.

Breger, I. A., and Schopf, J. M., 1956, Geochemical studies of coalified wood from the Colorado Plateau: Geol. Soc. Am., Abstracts of papers for Minneapolis meeting.

Deul, Maurice, and Ansell, 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.

Distribution of uranium in igneous complexes

By  
David Gottfried

Precambrian granites of the Front Range of Colorado

During the 1956 field season, sampling of most of the major batholiths in the Front Range of Colorado was completed. The Pikes Peak and Log Cabin batholiths were extensively sampled so that comparisons of the uranium content of these alkalic rocks may be made with those of the calc-alkalic Boulder Creek batholith. Reconnaissance sampling was carried out in the Precambrian batholiths of the Wind River, Big Horn and Beartooth ranges in order to determine if regional variations in their uranium content exist.

Boulder Creek batholith

Leaching experiments.—The distribution of uranium in rocks of the Boulder Creek batholith has been discussed in previous reports (TEI-590, p. 310-312; TEI-620, p. 312-317). Splits of the samples previously analyzed for uranium were leached with 2.5 N hydrochloric acid for 24 hours on a steam bath. The tests were made on rocks ranging in composition from quartz diorite to granite and containing widely different amounts of uranium. The data are given in table 9. They indicate that the amount and also the percentage of uranium leached, increases in a general way with the uranium content of the rock.

Sphene.—Sphene is present in nearly all the rocks of the batholith in variable amounts. In the course of separating the sphene on the Frantz isodynamic separator, it was noticed that the magnetic susceptibility varies over a wide range. Holding the longitudinal and cross slope constant and varying the current from 0.6 to 1.4 amperes,

Table 9.—Leachable uranium from rocks of  
the Boulder Creek batholith

| <u>Sample no.</u>         | <u>Uranium content</u> | <u>Leached uranium (ppm)</u> | <u>Percent total uranium leached</u> |
|---------------------------|------------------------|------------------------------|--------------------------------------|
| <u>Quartz diorites</u>    |                        |                              |                                      |
| GP 42                     | 1.1                    | 0.81                         | 73.5                                 |
| GP 206                    | 0.91                   | 0.09                         | 9.9                                  |
| GP 194                    | 1.3                    | 0.15                         | 13.0                                 |
| GP 222                    | 0.59                   | 0.01                         | 2.0                                  |
| GP 40                     | 0.95                   | 0.34                         | 35.8                                 |
| Average percent U leached |                        |                              | 27                                   |
| <u>Granodiorites</u>      |                        |                              |                                      |
| GP 49                     | 0.72                   | 0.31                         | 43                                   |
| GP 99                     | 1.0                    | 0.35                         | 35                                   |
| GP 21                     | 1.1                    | 0.44                         | 40                                   |
| GP 166                    | 1.40                   | 0.62                         | 44.2                                 |
| Average percent U leached |                        |                              | 40                                   |
| <u>Quartz monzonites</u>  |                        |                              |                                      |
| GP 15                     | 1.0                    | 0.25                         | 25                                   |
| GP 245                    | 2.4                    | 1.4                          | 58.5                                 |
| GP 50                     | 1.5                    | 0.94                         | 62.6                                 |
| GP 70                     | 1.4                    | 0.3                          | 21.4                                 |
| GP 51                     | 1.9                    | 1.15                         | 65.0                                 |
| GP 1                      | 2.2                    | 1.43                         | 65.0                                 |
| GP 19                     | 1.70                   | 1.04                         | 61.0                                 |
| GP 53                     | 1.90                   | 0.80                         | 41.1                                 |
| GP 95                     | 2.8                    | 1.84                         | 65.5                                 |
| GP 84                     | 2.3                    | 1.74                         | 75.6                                 |
| GP 5                      | 3.1                    | 1.9                          | 61.2                                 |
| GP 81                     | 3.9                    | 3.2                          | 82.0                                 |
| GP 98                     | 3.6                    | 2.5                          | 69.5                                 |
| GP 80                     | 4.3                    | 3.73                         | 86.9                                 |
| GP 18                     | 2.4                    | 1.44                         | 60.0                                 |
| GP 55                     | 7.9                    | 7.26                         | 92.0                                 |
| GP 229                    | 1.3                    | 0.67                         | 51.5                                 |
| GP 167                    | 3.8                    | 2.83                         | 74.5                                 |
| Average percent U leached |                        |                              | 61                                   |
| <u>Granites</u>           |                        |                              |                                      |
| GP 34                     | 2.4                    | 1.92                         | 80.0                                 |
| GP 52                     | 2.7                    | 1.81                         | 67.0                                 |
| GP 75                     | 3.3                    | 2.39                         | 72.5                                 |
| GP 37                     | 1.80                   | 1.28                         | 71.0                                 |
| Average percent U leached |                        |                              | 73                                   |

different splits of sphene are obtained from the bulk concentrate. The sphene from the more siliceous rocks shows the greatest variation in magnetic susceptibility with most of the sample becoming magnetic at about 1.0 amperes. The sphene from the quartz diorites is less magnetic and is concentrated at 1.5 amperes. This variation suggests these are also differences in the chemical composition of the sphenes, hence the different magnetic splits were analyzed separately. Uranium and thorium analyses on sphenes from the Boulder Creek batholith are given in table 10. The variability of the uranium and thorium content

Table 10.--Uranium and thorium content of sphenes from the Boulder Creek batholith

| <u>Sample no.</u>        | <u>Magnetic susceptibility</u> | <u>ThO<sub>2</sub> (ppm)</u> | <u>U (ppm)</u> |
|--------------------------|--------------------------------|------------------------------|----------------|
| <u>Quartz diorites</u>   |                                |                              |                |
| GP 40                    | 1.5                            | 25                           | 29             |
| <u>Granodiorites</u>     |                                |                              |                |
| GP 2                     | 1.5                            | 30                           | 59             |
| GP 17                    | 1.5                            | 35                           | 75             |
| GP 21                    | 1.0                            | 105                          | 60             |
| GP 21                    | 1.2                            | 40                           | 29             |
| GP 1                     | 1.5                            | 15                           | 28             |
| GP 129                   | 1.0                            | 145                          | 170            |
| <u>Quartz monzonites</u> |                                |                              |                |
| GP 50                    | 1.0                            | 590                          | 230            |
| GP 98                    | 1.0                            | 865                          | 310            |
| GP 19                    | 1.0                            | 125                          | 170            |
| GP 5                     | 1.0                            | 65                           | 240            |
| GP 245                   | 1.0                            | 965                          | 365            |
| GP 245                   | 1.5                            | 95                           | 155            |
| GP 84                    | 1.0                            | 135                          | 98             |
| GP 81                    | 1.2                            | 435                          | 330            |
| GP 15                    | 1.5                            | 20                           | 60             |
| GP 95                    | 1.0                            | 340                          | 245            |

in different magnetic fractions from the same rock is evident. The sphene from sample GP 245 shows nearly a 10 fold difference in the thorium content over the less magnetic fraction. It should be emphasized that any given analysis on a particular fraction is not necessarily representative of all the sphene in the rock. In general the sphene from the more siliceous rocks contain greater amounts of uranium. The thorium appears to increase relative to uranium with an increase in the uranium content of the sphene.

Uranium content of apatite.---Apatite is a fairly abundant accessory mineral in the Boulder Creek batholith. It is present in greatest amount in the intermediate rocks. The average uranium content of the apatite from quartz diorites is low ( $<20$  ppm) increases in the granodiorites (27 ppm) and quartz monzonites (56 ppm), and then appears to decrease in the more siliceous rocks (11 ppm). The results are given in table 11.

Zircon.---Zircon is present in all rocks of the Boulder Creek batholith in varying amounts. The intermediate rocks contain from 50 to 120 ppm of zircon. The most siliceous rocks contain smaller amounts averaging about 10 ppm. Alpha activity measurements and lead-alpha ages were reported previously (TEI-620, table 28, p. 314). Preliminary petrographic studies on these zircons show that the more strongly zoned zircons are highest in uranium content. The color of nearly all the concentrates is purple and gradually passes to brownish purple and a brown color with increasing radioactivity. No purple zircon has been noted to date in the younger Precambrian batholiths of Colorado. The uranium content of the zircon from the different rock types is given in table 12.

Table 11.--Uranium content of apatite from rocks of the Boulder Creek batholith

| <u>Sample no.</u>        | <u>Uranium (ppm)</u> |
|--------------------------|----------------------|
| <u>Quartz diorites</u>   |                      |
| GP 40                    | 19.0                 |
| GP 61                    | <u>5.4</u>           |
| Average                  | 12.0                 |
| <u>Granodiorites</u>     |                      |
| GP 1                     | 22.5                 |
| GP 2                     | 16.0                 |
| GP 17                    | 60.0                 |
| GP 21                    | 20.0                 |
| GP 99                    | <u>15.0</u>          |
| Average                  | 27.0                 |
| <u>Quartz monzonites</u> |                      |
| GP 5                     | 61.5                 |
| GP 15                    | 23.0                 |
| GP 19                    | 44.0                 |
| GP 70                    | 40.0                 |
| GP 81                    | 45.0                 |
| GP 84                    | 65.0                 |
| GP 245                   | 40.7                 |
| GP 80                    | 88.5                 |
| GP 98                    | 76.0                 |
| GP 95                    | <u>80.0</u>          |
| Average                  | 56.0                 |
| <u>Granites</u>          |                      |
| GP 63                    | 12.0                 |
| GP 75                    | <u>10.0</u>          |
| Average                  | 11.0                 |

Table 12.--Uranium content of zircon

| <u>Sample no.</u>        | <u>Uranium (ppm)</u> |
|--------------------------|----------------------|
| <u>Quartz diorites</u>   |                      |
| GP 61                    | 220                  |
| GP 40                    | 550                  |
| Average uranium content  | 385 ppm              |
| <u>Granodiorites</u>     |                      |
| GP 49                    | 590                  |
| GP 2                     | 420                  |
| GP 21                    | 770                  |
| Average uranium content  | 593 ppm              |
| <u>Quartz monzonites</u> |                      |
| GP 84                    | 600                  |
| GP 5                     | 600                  |
| GP 15                    | 510                  |
| GP 81                    | 720                  |
| GP 245                   | 620                  |
| GP 50                    | 780                  |
| GP 51                    | 750                  |
| GP 98                    | 660                  |
| GP 95                    | 900                  |
| GP 53                    | 600                  |
| GP 70                    | 720                  |
| GP 80                    | 1,100                |
| GP 62                    | 720                  |
| Average uranium content  | 721 ppm              |

White Mountain plutonic series,  
New Hampshire

By  
A. P. Butler, Jr.

Examination of some thin sections of geologic samples of granite from the main batholithic mass of the White Mountain plutonic series in central New Hampshire and further analysis of data pertaining to uranium content of the samples suggest some refinements in the way the samples should be grouped, but also pose some as yet unresolved questions about the meaning of some of the data. As previously reported (TEI-620,

p. 317-318) the predominance of biotite over amphibole, other than riebeckite, remains the only compositional feature so far discerned that characterizes granite richer in uranium from granite leaner in uranium. Mean uranium contents of samples arranged according to the relative amounts of biotite and amphibole and the kind of granite, or phase, distinguished and mapped by other geologists are given in table 13.

Table 13.--Mean uranium contents (revised) of granite (Conway and Mt. Osceola phases) main batholith, White Mountain plutonic series, New Hampshire

| Type of granite                       | No. of sample localities <sup>1/</sup> | Uranium range ppm | mean ppm | Standard deviation of the mean ppm |
|---------------------------------------|--|-------------------|----------|------------------------------------|
| Conway biotite granite                | 27                                     | 6.0-26.3          | 12.5     | 0.8                                |
| Mt. Osceola biotite-amphibole granite | 4                                      | 12.8-16.8         | 15.0     | 1.5                                |
| amphibole-biotite granite             | 6                                      | 4.0-9.0           | 7.2      | 0.7                                |

<sup>1/</sup> At some localities such as one quarry or outcrop from 2 to 5 individual samples of Conway granite and Mt. Osceola amphibole-biotite granite have been averaged to give one mean value for that locality. Thus the 27 localities listed opposite Conway granite take into account analyses of 36 samples, and 6 localities listed opposite Mt. Osceola take into account 14 analyses of 14 samples.

The range of uranium content of samples of the Conway biotite granite overlap the range of uranium content of the Mt. Osceola amphibole-biotite granite, but the uranium content of 21 of the 27 Conway samples exceeds the uranium content of the amphibole-biotite granite. The mean uranium content of the two kinds of granite is distinctly different and their standard deviations suggests that the chance is less than 1 in 100 that they represent samples drawn from the same population.

The uranium content of samples of Mt. Osceola granite in which biotite predominates appear, however, to resemble more closely the uranium content of the samples of Conway biotite granite, notwithstanding that the Mt. Osceola phase is generally a mappable unit distinct from the Conway phase, in which amphibole is lacking or distinctly subordinate. Thus, the amount of uranium in the samples appears to reflect more clearly the predominance of amphibole or biotite in the rock than it does the sum of all characteristics whereby Conway and Mt. Osceola are distinguished as separate units.

The mean contents of uranium in separates of zircon, allanite, biotite, and amphibole from Conway granite (mean uranium content of rock 12.5 ppm and in which biotite greatly predominates over amphibole) are greater, as might be expected, than the mean content of uranium in corresponding separates from Mt. Osceola granite in which amphibole predominates over biotite (mean uranium content in rock 7.2 ppm). In any individual rock sample there is, however, no obvious direct relation between uranium content of the rock and the uranium content of the separates of these four minerals from that sample.

The following paper was published during the period:

Gottfried, David, Waring, C. L., Worthing, Helen, 1956, Hafnium content, hafnium to zirconium ratio and radioactivity of zircon from igneous rocks (abstract): Geol. Soc. America Bull., v. 67, No. 12, pt. 2.

The following papers were also published, 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. Prof. Paper 300:

Coats, R. R., 1956, Uranium and certain other trace elements in felsic volcanic rocks in western United States: p. 75-78.

Larsen, E. S., Jr., Phair, George, Gottfried, David, and Smith, W. L., 1956, Uranium in magmatic differentiation: p. 65-74.

Synthesis and solution chemistry of  
uranium-bearing minerals

Field studies on the origin of primary uranium  
ores in the western United States

By

R. M. Garrels and C. L. Christ

The picture derived on the Colorado Plateau of a primary unoxidized ore modified by exposure to oxygen incident to the dropping of the water table in the Recent erosional cycle is generally applicable to the deposits inspected in the Wyoming-South Dakota area. However, the low vanadium content of the ores in this region permits the oxidized uranium to move much more freely than it does in the vanadiferous Plateau deposits. As a result, not only is oxidation migration an important factor in the control of commercial values, but secondary enrichment of uraninite at or near perched water tables may also be extremely important in producing ore.

Carbonaceous materials are effective localizers of reduced uranium minerals. It appears that most materials derived from wood are effective precipitants of uranium from migrant solutions, and that the presence of "hot wood" with "cold wood" nearby reflects high uranium concentrations in the solutions encountering what is now "hot wood". This implies that ore is formed by relatively restricted bodies of "concentrated" solutions migrating through the rocks. Inspection of numerous pre- and post-ore faults did not disclose any evidence that these faults may have functioned

as sources from which ore fluids might have emanated, or as barriers controlling the lateral extent of the ore. Ore fluid is more likely to move through permeable sands than to migrate along secondary openings.

Construction of a portion of the pH-potential  
diagram of the vanadium system

By

A. M. Pommer, R. M. Garrels, and H. T. Evans, Jr.

Experimental studies with a multiple pH-potential recorder yielded a pH-potential diagram resembling the one previously constructed by Evans (1955) from thermodynamic and crystal chemical data. The method used involved potentiometric titrations of reduced vanadium solutions at different pH values. The Eh and pH of the solutions were recorded throughout the titration. It then was possible to correct the potential at any given point for pH changes, giving in effect the potentiometric titration that would have been obtained at constant pH. A change in the oxidation potential-oxidant curve signified a phase change and could be plotted in the pH-Eh field.

Reference

- Evans, H. T., Jr., 1955, Vanadium mineral alteration sequence in relation to crystal chemistry and thermodynamics (abstract): Econ. Geol., v. 50, no. 7, p. 774.

Synthesis and the environment of deposition of  
uranium and vanadium minerals

By

A. M. Pommer and J. C. Chandler

In the light of existing indications (TEI-620, p. 319) that uranium minerals may have been deposited from uranyl carbonate solutions, the preparation of primary uranium minerals from uranyl carbonate complexes by reduction with carbonaceous material was studied. It was shown that a subbituminous coal was capable of reducing such solutions and that part of the uranium precipitated with the coal as a separate solid, while another part was absorbed by the coal. The presence of uraninite could be established in coal treated with a uranyl chloride solution at 150° C at a pH of 3.4. The reduction of a uranyl carbonate solution of pH 8 at 170° C with fresh wood resulted in the formation of a solid having an X-ray pattern close to uraninite.

Mineral synthesis studies indicate that tyuyamunite may be preferentially formed at a pH of 4 - 5, while carnotite may form over a wide pH range. There may be some relation between these findings and the observation that in weathered uranium-vanadium ores the ratio of carnotite to tyuyamunite is higher than might be expected from a consideration of the K: Ca abundance ratio in the environment of these ores. Solids having an X-ray pattern close to that of uvanite and rauvite could be prepared at a pH of 3 or less; attempts to prepare these solids at higher pH values did not succeed. Hydrous uranium oxides having X-ray patterns somewhat resembling that of schoepite could be formed over a wide pH range (4 - 11). Duttonite was prepared from V(IV) solutions at about 125° C at a pH of 4.5. In the presence of carbonate the pH range could be extended to 3.5 - 5; wood also extended the pH range similarly. This indicates that wood in a V(IV)

solution may act as a buffering agent without exerting a reducing action. A solid having an X-ray pattern close to doloresite could be formed under similar conditions at a pH of 5 only in the presence of wood and carbonate ion; in the presence of wood alone a mixture of duttonite and this solid was formed. It is possible that the formation of doloresite requires a strongly buffered system; however, the solid formed may be mineral "B" (Evans and Mrose, 1956) which probably has an X-ray pattern closely resembling doloresite, indicating some reduction to V(III). Vanadium(IV) solutions of similar composition heated to 150° C for six days yielded a mixture of minerals "A" and "B" (Evans and Mrose, 1956). In this case the presence of V(III) was definitely indicated. A solid having an X-ray pattern identical with that of a mineral found in the San Rafael Swell of the Temple Mountain area was prepared by adjusting a solution containing vanadyl sulfate and uranyl nitrate to a pH of 5 with potassium hydroxide and potassium carbonate. Similar solutions at lower pH values yielded corvusite-like material, while higher pH values resulted in non-crystalline material or solids having diffuse X-ray patterns.

#### Reference

Evans, H. T., and Mrose, M. E., 1956, Geol. Soc. America, Program 1956 Annual Meetings, Minneapolis, Minn., p. 47.

#### Studies on vanadium(IV) solutions

By  
R. F. Marvin

An investigation of the solubility of vanadium(IV) as a function of pH, temperature, and concentration was completed. Vanadium(IV) is soluble in strongly acid or basic solutions. In moderately acid or

basic solutions an amorphous or very fine-grained hydrate of  $V_2O_4$  of varying water content is precipitated. The maximum concentration of vanadium(IV) in a solution which will not yield a precipitate over the entire pH range is  $1 \times 10^{-4}M$  at  $30^\circ$  and  $1 \times 10^{-3}M$  at  $90^\circ C$ . Experiments with  $VO(ClO_4)_2$  solutions (0.1M, 0.01M, etc.) at  $30^\circ$ ,  $50^\circ$ ,  $70^\circ$  and  $90^\circ C$  show that the solubility of  $V_2O_4$  hydrate in acid solutions varies with pH, concentration, and temperature. The more concentrated the solution, the lower the pH at which precipitation begins. The pH at the point of precipitation also decreases approximately 0.1 pH unit per  $10^\circ C$  increase in temperature. The precipitation boundary was determined for acid solutions but could not be determined for basic solutions. The presence of  $SO_4^{2-}$  ions tends to delay precipitation.

#### Synthesis of complex minerals

By

G. J. Jansen and G. B. Magin, Jr.

A number of runs were made in an attempt to synthesize rare-earth fluocarbonates. Theoretical amounts of the rare-earth carbonates were dispersed in hot distilled water in a  $CO_2$  atmosphere and the theoretical amount of very dilute HF was then slowly added. The reaction product was kept in the  $CO_2$  atmosphere and digested on the steam bath for five days. Bastnaesite,  $CeFCO_3$ , and  $(Ce, La)FCO_3$  with Ce and La in a 1:1 ratio were prepared.

A number of syntheses of uranyl molybdates were attempted. One uranyl molybdate identical to a new mineral from Karnes County, Texas, was synthesized by mixing stoichiometric amounts of calcium molybdate and uranyl nitrate to which was added concentrated  $HNO_3$  until the pH reached 2.5. The reaction product was digested on the steam bath for

ten days and the resulting yellow precipitate was found to yield an X-ray diffraction pattern identical to the new mineral.

The following papers were published during the period:

Pommer, A. M., 1956, Oxidation potential and state of some vanadium ores and the relation of woody material to their deposition: U. S. Geol. Survey Open File Report.

Pommer, A. M., Garrels, R. M., and Evans, H. T., Jr., 1956, The construction of a portion of the pH-potential diagram of the vanadium system from potentiometric titrations at constant pH (abstract): Abstracts of papers, 130th National Meeting of the American Chemical Society, Atlantic City, N. J., Sept. 1956.

#### Synthesis of pitchblende

By  
R. C. Vickers

Hard botryoidal microscopically crystalline pitchblende has been produced at room temperature and pressures. Pyrite ground to  $-70\pm 100$  mesh was used to reduce a 1 percent uranyl sulfate solution. The pyrite was placed in a 20 cm length of glass tubing of 2 cm internal dimensions. The pyrite filled the tube for about 10 cm and the remainder of the tube was filled with a 1 percent uranyl sulfate solution and sealed. At the end of two months a layer of black material about 2 mm thick and the same diameter as the tube had formed about 2 mm down from the top of the pyrite. X-ray patterns of this material showed strong but slightly broadened lines of pitchblende. Polished sections showed that the pitchblende has a typical colloform texture, rims pyrite fragments, and also forms hollow spherulites. It is suggested that in nature pyrite, regardless of its origin, could form the locus of deposition for a pitchblende deposit provided that channelways were available to provide access of uranium-bearing solutions to the reducing environment caused by pyrite.

Stable isotope analysis

By

Irving Friedman

The deuterium analysis of borate samples from California was completed. The interpretation of the data awaits laboratory studies of the fractionation of deuterium during the crystallization of the various borate minerals. During the natural dehydration of borax to tincalconite a small but variable fractionation of deuterium occurs. In general in the suite of 18 samples analyzed, the six samples of borax and kernite tincalconite derived from the borax all have a deuterium concentration in the range of sea water. The calcium containing borates (eight samples) ulexite and colemanite are depleted in deuterium. One sample of probertite (calcium sodium borate) is in the same range as borax. It is planned to study synthetic systems in order to evaluate results.

Isotope geology of lead

By

R. S. Cannon, Jr.

New isotope analyses include four additional analyses of lead from lead minerals of the Coeur d'Alene district, Idaho, which add a new facet to present knowledge of the lead-isotope geology of this district. Two new analyses of galena from lead veins conform with the consistent pattern for Coeur d'Alene lead reported here earlier (TEI-620, p. 326-331), but the two other new analyses, of lead from traces of galena in the uranium vein of the Sunshine mine, do not.

The two analyses of galena-lead from the uranium vein in the Sunshine mine exhibit a gross excess of uranogenic lead, as compared with our other Coeur d'Alene analyses. Among four analyses of galena-lead from

Table 14.—Analyses of galena from lead veins

| Lab. no. | Sample and locality   | 204          | 206            | 207            | 208            | Sum             |
|----------|---|--------------|----------------|----------------|----------------|-----------------|
| GS/485   | Galena from fine-grained Pb-Zn ore, 1400-level, Highland Surprise mine; in Prichard formation, Belt series; west end of Coeur d'Alene district.   | 1.00<br>1.45 | 16.30<br>23.69 | 15.49<br>22.50 | 36.04<br>52.36 | 68.83<br>100.00 |
| GS/408   | Galena, from Chester vein (Pb-Ag), 3250-level, Sunshine mine No. 2, Rotbart area; in St. Regis quartzite, Belt series; silver belt of Coeur d'Alene.  | 1.00<br>1.49 | 16.01<br>23.87 | 15.12<br>22.55 | 34.93<br>52.09 | 67.06<br>100.00 |
| GS/405   | Galena, in weakly radioactive vein matter (Sb, U), Sunshine mine, 3700-level west vein; 98 feet west from crosscut; in St. Regis quartzite, Belt series; silver belt of Coeur d'Alene.                        | 1.00<br>1.42 | 18.03<br>25.61 | 15.49<br>22.02 | 35.86<br>50.95 | 70.38<br>100.00 |
| GS/404   | Galena, in radioactive vein matter with uraninite, Sunshine mine, from uranium exploration stope 60 feet above 3700-level in footwall of Sunshine vein; in St. Regis quartzite, Belt series of Coeur d'Alene. | 1.00<br>1.10 | 36.95<br>40.72 | 17.17<br>18.92 | 35.62<br>39.26 | 90.74<br>100.00 |
|          | Average of four analyses of galena-lead from Coeur d'Alene lead veins.  | 1.00<br>1.47 | 16.14<br>23.74 | 15.31<br>22.52 | 35.54<br>52.27 | 67.99<br>100.00 |

Coeur d'Alene lead veins, expressed in atom percent, variations from the mean for each of the lead isotopes are extremely small, ranging from a minimum variation of  $\pm$  0.35 percent for Pb<sup>208</sup> to a maximum of  $\pm$  1.4 percent for Pb<sup>204</sup>. This suggests that ore-lead of the lead veins is essentially uniform, isotopically, throughout the district or even, as suggested here earlier, throughout Belt terrane. By contrast, for the two new analyses of galena-lead from the Sunshine uranium vein variations from these values range from a minimum of 16 percent for Pb<sup>207</sup> to a maximum 71 percent for

Pb<sup>206</sup>. These latter figures are a measure of contrast between galena-lead from lead ore (GS/408) and galena-lead from uranium ore (GS/404) within a single mine. Nevertheless only one kind of "ore-lead" may be involved, for the two anomalous compositions can be derived simply by adding 3.5 percent and 34 percent of uranogenic lead, respectively, to the composition of the widespread Coeur d'Alene ore-lead.

The Pb<sup>207</sup>/Pb<sup>206</sup> ratio of this excess radiogenic lead in the anomalous galenas also needs to be examined and interpreted. The ratio is about 0.09 for the excess uranogenic lead in the two galenas, as compared with 0.07 for the radiogenic lead in uraninite ore of the same vein, according to the one analysis so far published (Kerr and Kulp, 1952). The ratios correspond to a lead/lead apparent age of about 950 million years for the uraninite and, in such terms, about 1,450 million years for the galenas. These data thus add one more to the growing number of uranium deposits now known to contain anomalously radiogenic sulfide-lead, commonly "older" in apparent age than radiogenic lead in associated uraninite.

The correct interpretation of this isotopic record of geologic history is still uncertain. Obviously the excess radiogenic lead in galena was not generated in situ and therefore is not a direct measure of the date at which the sulfide crystallized. Uranogenic lead of ratio 0.09 is the kind that was being generated 825 million years ago, or during periods of time spanning that date, as from 1,100 to about 500 million years ago. Two alternative models offer comparatively simple interpretations of these data. One would involve old radiogenic lead generated prior to the uranium deposition; the other would require a mild recrystallization long after deposition of the uranium ore. Under

the first model, the uranium rested in some reservoir, from about 1,000 million years ago until about 600 million years ago, when uranium and some of its radiogenic lead were transported and deposited in the Sunshine mine. Under the second model, Sunshine uraninite must be older than this, perhaps 1,100 million years old. In this case, some radiogenic lead was leached from Sunshine uraninite at a much later date, perhaps 500 million years ago, and crystallized nearby within the vein as anomalous galena. Under either model the uranium mineralization appears to be of Precambrian age, a tentative conclusion that will soon be tested by additional age analyses of Sunshine uraninite.

Other activity during the report period included field collection of sample materials to test our hypothesis that the Precambrian of southwest Wyoming may include some exceptionally old rocks. This hypothesis grew from our lead-isotope analysis of a galena from the Atlantic City district, Wyoming, which proved exceptionally primitive in composition. As reported here in 1953 (TEI-390, p. 252), this was the most primitive sample of earth-lead so far discovered outside the African Shield. Preliminary analytical results on our suite of rocks and minerals collected to test this hypothesis should be available to summarize for the next semiannual report.

#### Reference

Kerr, P. F., and Kulp, J. L., 1952, Precambrian uraninite, Sunshine mine, Idaho: *Science*, v. 115, p. 86-88.

Nuclear geology

By

F. E. Senftle

Measurements of the  $\text{Cu}^{63}/\text{Cu}^{65}$  ratios are continuing and a preliminary report on the work done so far is in preparation. A specimen of native copper from a fissure in the White Pine mine, Michigan, showed an enrichment of the heavy isotope of copper while samples of chalcocite from fissures in the same area are slightly enriched in the light isotope of copper. Additional experimental work is in progress to confirm these results.

Considerable time was spent during the summer months in realigning the mass spectrometer and in improving the resolution of the copper peaks. In anticipation of further work on small samples, microgram quantities of copper were precipitated with lead as a carrier. The lead chloride was run in the mass spectrometer at several concentrations of copper but in all cases the lead appeared to suppress the copper peaks. As an alternative method, the copper was precipitated as  $\text{CuS}$  and converted to the iodide in the mass spectrometer source by addition of a small amount of  $\text{HI}_4$ . This method proved satisfactory, and reasonably large copper peaks were obtained. Using this method, samples of the order of 50-100 micrograms can be analyzed.

A neutron activation technique has been studied for  $\text{Cu}^{63}/\text{Cu}^{65}$  analysis and preliminary experiments performed. Two single channel analyzers were constructed in a manner permitting them to be started simultaneously. The activity of a standard and an unknown sample is compared under identical geometries. Three trial runs on copper were made at Brookhaven National Laboratory, and some of the problems involved,

such as sample preparation, electronic stability, etc. were partially solved. Work continued on efforts to improve the precision and accuracy of the method. It is hoped that results approaching those of the mass spectrometer can be obtained.

The magnetic susceptibility balance was completed but due to excessive vibrations in the building no reliable measurements were successfully taken. To remove some of the vibration a spring mounted table was constructed. After realignment some preliminary measurements were taken, but these have not yet been calculated.

A very pure sample of zircon was irradiated in the Brookhaven National Laboratory reactor for 60, 90 and 120 days. It is hoped that the radiation damage due to neutrons could be followed by X-ray analysis similar to natural alpha radiation damage. For the total flux used no significant change was noticed in the lattice constants (table 15).

Table 15.—Lattice constants for neutron irradiated zircon

| Irradiation<br>time | 20(200) | 20(112) | a     | c     |
|---------------------|---------|---------|-------|-------|
| Fresh               | 26.963  | 35.601  | 6.608 | 5.984 |
| 60 days             | 26.964  | 35.596  | 6.607 | 5.985 |
| 90 days             | 26.964  | 35.602  | 6.607 | 5.984 |
| 120 days            | 26.963  | 35.599  | 6.605 | 5.985 |

## Neutron irradiation

By

Henry Faul

Preliminary literature surveys began in November 1956. Conferences with workers on projects of a similar nature outside the Geological Survey are planned as the next step to establish the general plan of research. Extensive work seems to have been done in this field by some oil companies, and although virtually none of it has been published, it is hoped to gain access to much of the data.

Geochronology research

By

L. R. Stieff

As part of a long range program to establish reliable isotopic ages at key points in the geologic column, a suite of Silurian and Devonian igneous rocks was collected from Somerset County, Maine. An additional suite of igneous rocks from the laccolithic mountains of the Colorado Plateau was collected to study the anomalously high zircon ages obtained earlier from the La Sal Mountains. These two suites of igneous rocks along with the samples of igneous rock obtained last year from Massachusetts and New Hampshire were crushed, sieved and preliminary heavy mineral concentrates made.

Twenty-four samples of uranium, thorium and lead ores were prepared for chemical and isotopic analysis. Approximately 25 isotopic analyses were made and analytical chemical work was completed on approximately 50 samples.

The 12-inch radius, solid sample, mass spectrometer was placed in operation. Preliminary tests indicate that ion beam intensity and

stability are very good and that resolution of even  $PbI^+$  ions is excellent. Tests of the spectrometer are continuing in order to compare its performance with that of the 6-inch radius instrument.

The following papers were published during the report period:

Stern, T. W., Stieff, L. R., Gerhard, M. W., and Meyrowitz, Robert, 1956, The occurrence and properties of meta-tyuyamunite,  $Ca(UO_2)_2(UO_4)_2 \cdot 3-5H_2O$ : *Amer. Mineralogist*, v. 41, p. 187-201.

Stieff, L. R., and Stern, T. W., 1956, Interpretation of the discordant age sequence of uranium ores, 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. 549-558.

Stieff, L. R., Stern, T. W., and Sherwood, A. N., 1956, Coffinite, a uranous silicate with hydroxyl substitution: a new mineral: *Amer. Mineralogist*, v. 41, p. 675-688.

#### Natural radioactivity of the atmosphere

By

H. B. Evans

The project was initiated July 1, 1956 to investigate near-surface and subsurface contributions to natural atmospheric radioactivity. Radon daughter products, adhering to dust particles, constitute the major source of natural radioactivity at near-surface levels. Thus, a study of the diffusion of radon through rocks and into the atmosphere was begun as the first phase of the project. Necessarily, the primary effort to date has been assembling and testing of instruments and equipment. The basic equipment consists of two vibrating reed electrometers, two strip chart recorders, and ionization chambers. Barren sections of drill core were obtained from DMEA and cores of various sandstones, shales, and conglomerates were cut to convenient lengths and sealed in

plastic cylinders with an open plastic tube at each end. Several types of cylinders were constructed and tested. Although a satisfactory plastic core mount has been selected for use, testing of other types continues. A unit is also being constructed that will couple a solenoid valve to the sealed cores.

The diffusion rate system is shown in figure 53. The method of operation now in use is somewhat limited because much of the accessory equipment is not yet in operation. An insulated heating and cooling jacket, when completed, will provide a temperature gradient across the sealed core cut. This jacket will allow diffusion rate measurements under various controlled temperature conditions.

Measurements of diffusion rates are conducted as follows:

Ionization chamber A (see fig. 53) is evacuated and filled to atmospheric pressure with a known concentration of radon. Chamber B is evacuated to provide the desired pressure gradient across the sealed core. The sealed core is connected to an ionization chamber at each end and the radon flows into the core when the solenoid valve is opened. At the same time, the solenoid valve energizes a marking pen, and the event is recorded on the strip chart of recorder B. The radon, responding to the initial pressure gradient, flows through the core, enters ionization chamber B, and is marked by a sudden increase of the recorder reading. The travel time through the core is read from the strip chart and the diffusion rate is easily computed. However, ionization in chamber B depends on the initial vacuum maintained so that errors are introduced using this method. It may be necessary to use an alpha phosphor-phototube detector to insure accuracy.

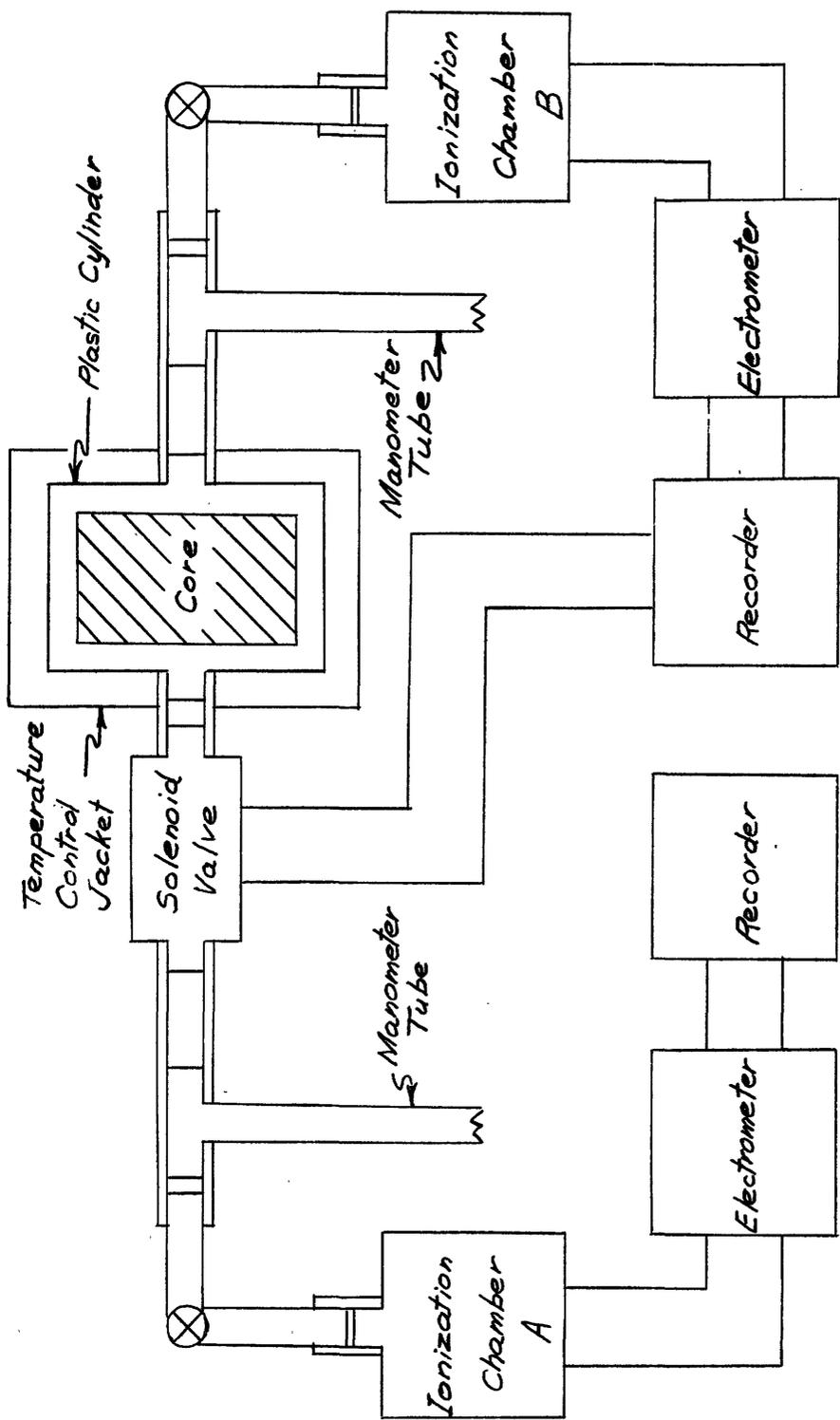


Figure 53.--Diagrammatic sketch of diffusion rate system.

Several diffusion rate determinations have been made holding the initial pressure constant, but varying the overall temperature of the system. The same core was used in each run. Under the present operating conditions, no clear correlation between temperature and travel time through the core has been noted. Travel time through a 50 mm sandstone core averages between three and four minutes.

Diffusion rates for each core will be determined under various combinations of pressure, temperature, radon concentration, and water saturation. The radon concentration on both sides of the core is continuously available from the separate strip charts.

A continuous filter air monitor unit was obtained from the Oak Ridge National Laboratory for use in the determination of any variation of natural radioactivity over rock outcrops of different types and at different heights above the ground surface. The monitor consists of a roll of filter paper that unwinds, passes over a vacuum pump where dust particles are collected, and finally reaches the alpha counting unit. The monitor will be operated over various rock types for one to two weeks at a time. A barograph, a thermograph, and a recording anemometer provide records of meteorological conditions.

To investigate the variations of radioactivity with altitude, or gradients, air is pumped through plastic pipes from heights up to 200 feet. The operation of the monitor unit is essentially the same as described above.

Thermoluminescence of radioactive minerals

By  
C. L. Christ

An apparatus has been designed for thermoluminescence studies. It consists of a photomultiplier and sample stage mounted inside a light and gas tight chamber. The walls of the chamber have a removable port into which either a beryllium or quartz plate can be inserted. The sample can be "activated" by either X-rays through the beryllium plate or by ultra-violet light through the quartz plate. A spectrograph can also be positioned at the quartz plate for spectral analysis of the thermoluminescence.

The sample stage consists of a silver foil of low thermal mass insulated from the body of the apparatus. It can be cooled or heated by a stream of dry nitrogen gas which is directed at the center of the stage. The temperature of gas can be controlled in the range  $-190^{\circ}$  to  $+150^{\circ}$  C.

A nichrome V heating element, of low thermal mass, is positioned below the silver stage. The heat from this element is transferred to the stage across an electrically insulating gap by radiation. The temperature of the stage, in the range of  $30^{\circ}$  to  $500^{\circ}$  C is controlled by the temperature of the surface of the nichrome wire. The photomultiplier is shielded from the light of the heating element by the stage.

An RCA 5819 photomultiplier is mounted above the sample stage. A shutter, opaque to X-rays and visible light, can be interposed between the stage and the photomultiplier.

Voltage is supplied to the nodes of the tube by a series of 45 volt batteries and is stabilized by a Morton-type circuit modified for the 5819 tube. The anode current of the tube is amplified and made the "X" input to an "X-Y" recorder. If a chart is desired showing thermoluminescent yield as a function of temperature (the "glow curve") then the voltage generated by a thermocouple at the sample is used for the "Y" input. If a chart is desired showing thermoluminescent yield as a function of time (the "decay curve") a voltage generated as a linear function of time is used as the "Y" input. All charts are obtained in the form of Keysort type cards.

Negotiations have begun to establish a source of quartz crystals with carefully controlled composition. Several possible sources of supply for Mexican Iceland spar are being canvassed as sources of "thermoluminescent pure" calcite.

#### Nuclear magnetic resonance studies

By  
Henry Faul

A literature survey began in November 1956, in an effort to appraise the potential value of nuclear magnetic resonance methods to the earth sciences.

Gutowsky and Henderson at the University of Illinois have applied the method to structure analysis of crystals. In particular they have determined the position of the hydrogen atom in portlandite ( $\text{Ca}(\text{OH})_2$ ). Such determinations are difficult with X-rays because of the small scattering cross section of hydrogen. However, the same determination has been made using neutron diffraction with a comparable precision.

From the fragmentary data thus far obtained, it is concluded that the nuclear magnetic resonance has its greatest possibility of usefulness in mineral structure studies, but only as a subsidiary technique.

### Geochemistry and geology of thorium

Geochemistry

By

E. S. Larsen, 3rd

The most immediate need in investigating the geochemical distribution of thorium is rapid and reliable analytical procedure for the quantitative determination of thorium in amounts at least as low as 1 ppm. The principal emphasis of the work was on the development of such analytical methods, and two have been developed to the point where they are being tested on rock samples.

One method is a spectrophotometric determination, a further development of the method reported by Grimaldi and Fletcher (TEI-620, p. 303). The other is an X-ray fluorescence spectrometric determination of thorium in a sample chemically concentrated from the rock. The procedure as developed at this time follows.

#### Combined chemical and X-ray fluorimetric method for determination of thorium in rocks

The X-ray procedure is simple and consists of evaporating a concentrate of the sample on a thin mylar film (0.00025 inches) in a special sample holder. The detector is a scintillation counter used in conjunction with a pulse height discriminator. Thallium is used as a reference element to serve as a control on both the chemical and X-ray procedures. The

procedure has given reproducible results in residues ranging from 5 to 30 milligrams of  $\text{AlCl}_3$  with 5 micrograms of  $\text{ThO}_2$  as the lower limit of detection. For an initial sample size of 5 grams this would represent 1 ppm.

At present experimental work is being performed on a gabbro sample spiked with known amounts of thorium. The procedure for the rock sample involves decomposition of a 5 gram sample with  $\text{HNO}_3$  and  $\text{HF}$  in platinum. The fluorides obtained are then removed by repeated evaporations with  $\text{HNO}_3$ . Boric acid is added to expedite the removal of the fluorides. After the fluorides have been converted to the nitrate, the sample is then transferred to glass, made 15 percent  $\text{HNO}_3$  to 25 ml and aluminum nitrate added to make solution 9.5 gram  $\text{Al}(\text{NO}_3)_3$  per 5 ml of 15 percent  $\text{HNO}_3$ . The solution is warmed to dissolve salts and cooled to room temperature; it is then extracted with mesityl oxide. After discarding the aqueous layer, the organic layer is then washed three times with a solution of  $\text{LiNO}_3$  (4 gram per 5 ml 1N  $\text{HNO}_3$ ), discarding the aqueous layer each time. The organic layer is then stripped twice with  $\text{H}_2\text{O}$  catching the water layer in a 150 ml beaker. It is then taken to dryness on a steam bath. The salts in the beaker are then treated with  $\text{HNO}_3$  and  $\text{HClO}_4$  and brought to fumes of perchloric to remove last traces of organic matter. After fuming for several minutes, the residue is then cooled, water is added and digested on steam bath to dissolve salts.

A known amount of thallium (as an internal standard) and aluminum (as a carrier) is added and the thorium, thallium, and aluminum are co-precipitated with  $\text{NH}_4\text{OH}$ . The precipitate is centrifuged, the supernatant liquid decanted off, and the precipitate dissolved with concentrated  $\text{HCl}$ .

The liquid in the centrifuge tube is evaporated down to about 1 ml., and is transferred to a nylon film and evaporated to dryness. The sample is now ready for X-ray fluorescent measurement. Whether the procedure will work on most rocks is not yet known, but it appears promising.

Thorium determinations upon Laramide intrusions from the Front Range, Colorado

Twenty samples of Laramide intrusives from the middle and northern parts of the Front Range mineral belt, Colorado, were analyzed by a recently developed chemical method. This method involves the spectrophotometric determination of thorium using thoron as the reagent and meso-tartaric acid as a masking agent for zirconium, after an iodate separation in a tartaric acid-hydrogen peroxide medium. These 20 samples were chosen for the following reasons:

(1) As igneous rocks go they are in the slightly to highly enriched thorium range in which the errors of the method are minimal.

(2) Many of the 20 samples have previously been analyzed for thorium by as many as four different methods. They will serve therefore, as useful standards for the calibration of the gamma-ray spectrometer now under construction.

(3) They provide needed data on the path of thorium enrichment in a single well studied igneous rock series.

The data are as follows:

Laramide intrusives, mainly radioactive, arranged by groups in inferred order of intrusion:

|   | <u>Th (ppm)</u> |
|---|-----------------|
| (1) Deep stocks (very high CaO, very high MgO)                        |                 |
| P914 Hb-Px monzonite, Empire  | 39, 37          |
| P915 Hb-Px monzonite, Empire  | 60, 60          |
| P640 Hb granodiorite, Jamestown                                       | 17, 17          |
| (2) Shallow stocks (high CaO, low MgO)                                |                 |
| P400 Quartz syenite, Central City                                     | 43, 39          |
| P 42 Syenite Idaho Springs  | 38, 36          |
| (3) Shallow dikes   |                 |
| (a) Calc. alkali (CaO, 0.6-1.5 percent,<br>MgO very low)              |                 |
| P370 rhyolite, Central City   | 33, 36          |
| (b) CaO-poor, <u>sodic</u> (CaO, 0.3-0.6<br>percent, MgO very low)    |                 |
| P399 sodic trachyte, Central City                                     | 62, 65          |
| P629 sodic rhyolite, Jamestown  | 50, 51          |
| P633 sodic rhyolite, Jamestown  | 75, 84          |
| (c) CaO-poor, <u>potassic</u> (CaO, 0.0-0.3<br>percent, MgO very low) |                 |
| P108 potassic rhyolite, Central City                                  | 310, 278        |
| P559 potassic rhyolite, Jamestown                                     | 55, 50          |
| P548 potassic rhyolite, Rowena  | 49, 50          |
| P581 potassic rhyolite, Idaho Springs                                 | 213, 218        |
| P465 potassic rhyolite, Freeland                                      | 196, 227, 235   |
| P107 potassic rhyolite, Central City                                  | 408, 392        |
| P 17 potassic rhyolite, Central City                                  | 343, 351        |
| P 8 potassic rhyolite, Central City                                   | 206, 240, 241   |
| P 36 potassic rhyolite, Idaho Springs                                 | 31, 33, 33      |
| P825 potassic rhyolite, Central City                                  | 157, 118, 148   |
| P118 potassic rhyolite, Central City                                  | 100, 107        |

These results generally confirm the magnitude of the thorium estimates obtained by earlier, less precise methods. They show the expected parallelism with the path of uranium enrichment in the same rocks, except that in the youngest and most extreme differentiates the Th/U ratio changes rather abruptly from its normal average of about 3.5 to approximately 6.0. These are also the rocks which show the greatest enrichment in both uranium and thorium. The abrupt change in Th/U ratio noted is consistent with the

view that in the final stages of "shallow" differentiation a part of the uranium originally present in the magma moved into the nearby veins.

The monzonites of the Empire stock which are unusually radioactive for such mafic compositions are enriched in both uranium and thorium. Comparable stock rocks in the northern part of the intrusive belt show more "normal" contents of both these elements. There the younger differentiates are less radioactive dikes and the number of radioactive dikes is distinctly fewer than in the central part of the belt where, closely following intrusion, the major deposition of vein pitchblende took place.

#### Thorium complexes

In connection with the transport and deposition and association of thorium, a study of the composition of the basic salts of thorium was begun. It is expected that these studies will furnish information in regard to the association of thorium with the lighter rare earth elements and in regard to the stability and composition of the thorium component complexes. Starting with soluble thorium nitrate, precipitation studies at pH's of 3.5, 4.0, 6.8, and 7.5 have been made, and the composition of the precipitates has been determined to vary from  $\text{Th(OH)}_4 \cdot \text{Th(NO}_3)_4$  at the lowest pH to  $7\text{Th(OH)}_4 \cdot \text{Th(NO}_3)_4$  at the pH of 7.5.

Field investigations, Gunnison County, Colorado

By

J. C. Olson and D. C. Hedlund

The study of the distribution and geologic relations of thorium deposits in the Powderhorn district, Gunnison County, Colorado, was begun July 1, 1956. Objectives of the investigation are to determine the relation of thorium and other rare elements to the various rock types and

mineral deposits, particularly the alkalic igneous rocks, and to interpret the origin of the thorium deposits.

In the field season July-September 1956, the northwest quarter of the Gateview 7-1/2-minute quadrangle was mapped geologically, and thorium deposits in that area were examined in detail. In an area of about 20 square miles, which includes part of Sapinero Mesa and the Lake Fork of the Gunnison River, about 50 previously unknown thorium-bearing veins were found. Inasmuch as thorium deposits are known to occur over an area of at least 120 square miles it is likely that several hundred thorium-bearing veins are present in the entire district.

The thorium-bearing veins are composed chiefly of quartz, dolomite-ankerite or calcite, barite, and iron oxides. The extremely fine-grained thorium-bearing mineral has not been identified in most veins, but it is probably thorogummite or thorite. The veins have been found in a wide variety of rocks, mostly if not all of Precambrian age, including granite, chloritic and hornblendic schists and gneisses, biotite schist, quartzite, metarhyolite, and syenitic rocks. Of the thorium-bearing veins studied in the northwest quarter of the Gateview quadrangle, about 90 percent are in fractures which strike northwest and are discordant with the foliation of the metamorphic rocks, which commonly strikes northeast. Only 10 percent of the thorium-bearing veins studied strike northeast, although numerous quartz-carbonate-chlorite veins, showing negligible radioactivity, have a northeasterly trend.

The following publications of thorium geology and geochemistry were published during the period, 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

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Geologic thermometry of radioactive minerals

By

R. G. Coleman

Sulfide systems, where the extent of solid solution is sensitive to temperature were examined in order to evaluate the limitations and possible application of these systems to ascertain the temperature of formation of sulfide-bearing uranium deposits. Most of the unoxidized deposits in the Colorado Plateau contain minor amounts of sulfides that formed contemporaneously with the uranium oxides and a study of associated sulfides as related to known systems may give some clue as to the temperature of formation. Paragenetic studies of many polished sections reveal that pyrite and marcasite are the most common sulfides introduced during mineralization with minor amounts of copper, lead, and zinc sulfides.

The system  $\text{FeS}_2\text{-FeSe}_2$  may be temperature sensitive, however, the system has not been completely worked out. Analyses of purified pyrites from the Colorado Plateau deposits reveals that Se substitutes for S in the pyrite structure. The maximum solid solution found is about 4 mol. percent  $\text{FeSe}_2$  in pyrite. Recent work by Gunnar Kullerud (personal communication) has shown that synthetic  $\text{FeSe}_2$  has a structure similar to marcasite and on the basis of crystal chemistry it would seem that a

complete solid solution between  $\text{FeS}_2$  (pyrite) and  $\text{FeSe}_2$  (ferroselite) is not likely at low temperatures; however, the amount of  $\text{FeSe}_2$  in pyrite may increase with temperature. Ferroselite has been found in the deposits from the Colorado Plateau associated with pyrite and further experimental work in the  $\text{FeS}_2$ - $\text{FeSe}_2$  system may prove to be useful as an indicator of temperature of deposition particularly where selenian pyrite is associated with ferroselite.

The system  $\text{PbS}$ - $\text{PbSe}$  as shown by Early (1950) forms a continuous solid solution between galena and clausthalite, but this system has not been worked out in detail and it is not certain if it can be used as a temperature sensitive system. The roscoelite-type deposits contain thin bands of galena-clausthalite in juxtaposition with the vanadium ore and strong variations in the amount of  $\text{PbSe}$  in galena have been found in analyzed specimens from these bands. Exsolution of intergrown galena was not found in the galena-clausthalite from these bands and it would seem that this system would not be useful as a possible indicator of temperature.

The presence of sphalerite in a few scattered deposits from the Colorado Plateau has allowed its use as a temperature sensitive mineral where it has formed with iron sulfides. As shown by Kullerud (1953) the  $\text{Fe}$ - $\text{Zn}$ s system may be used as a geologic thermometer. Sphalerite from the Plateau deposits is generally a trace sulfide and up to the present time only seven localities have produced sphalerite, among them the Happy Jack mine, San Juan County, Utah; the Hidden Splendor mine, Emery County, Utah; and the Cushin Copper mine, Wayne County, Utah. Three of the sphalerites were purified and analyzed; all show less than 0.5 mol. percent  $\text{FeS}$  in the sphalerite. As the amount of  $\text{FeS}$  in solid solution

with ZnS is a function of temperature as shown by Kullerud, the equilibrium diagram is not complete in this region where iron is so low, and an accurate estimate of temperature cannot be given. However, by projecting the known curve downward, these sphalerites probably formed at temperatures less than 138° C. Further analyses on sphalerites are being completed and evaluation of the results will be made in order to establish the reliability of this method in low-iron sphalerites.

The system Cu<sub>2</sub>-CuS was studied in some detail although its use as a temperature sensitive system is confused by conflicting data in the literature. Several chalcocites and digenites were purified and will be analyzed in hopes that the present work carried on in the Geophysical laboratory will clarify this system.

A study of uraninites from the Colorado Plateau deposits has shown that the unit cell size of these uraninites is similar to those reported for uraninites from hydrothermal deposits. No systematic variation with unit cell size and UO<sub>2</sub>/UO<sub>3</sub> ratio could be established. Further work on uraninites from various types of deposits will be carried out to establish what variations, if any, temperature has on the cell size and the UO<sub>2</sub>/UO<sub>3</sub> ratio.

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