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Subject Category: GEOLOGY AND MINERALOGY

DEPARTMENT OF THE INTERIOR

GEOLOGIC INVESTIGATIONS OF RADIOACTIVE DEPOSITS

Semiannual Progress Report—December 1, 1954 to May 31, 1955

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

June 1955

United States Geological Survey
Washington, D. C.

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

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Since nontechnical and nonessential prefatory material has been deleted, the first page of the report is page 7.

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGIC INVESTIGATIONS OF RADIOACTIVE DEPOSITS

SEMIANNUAL PROGRESS REPORT

December 1, 1954 to May 31, 1955

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Trace Elements Investigations Report 540

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

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INTRODUCTION

This report is a statement of progress during the six-months period from December 1, 1954 to May 31, 1955 on investigations of radioactive materials in the United States and Alaska, undertaken by the U. S. Geological Survey under the sponsorship of the U. S. Atomic Energy Commission.

The principal investigations during the period were in the Colorado Plateau region of Colorado, Utah, Arizona, and New Mexico, and in Wyoming, and the western Dakotas. The drilling program on the Plateau was continued, but no exploration was undertaken elsewhere during the period.

Many of the investigations of the USGS have progressed to the point where final reports are in preparation for future publication with the permission of the AEC. Other studies are incomplete and final reports cannot be expected for several years. Formal Survey publications (as distinguished from administrative Trace Elements reports) during this period, resulting from work done previously, consisted of two Professional Papers, one Bulletin, eight Bulletin chapters, and five Circulars. Other publications included 20 abstracts and 20 papers in scientific journals; six Trace Elements Reports sent to the Technical Information Service of the AEC for wider distribution; 54 papers presented before scientific societies; 25 Trace Elements Reports released on open file; and 61 papers prepared for the Proceedings of the International Conference on the Peaceful Uses of Atomic Energy to be held at Geneva, Switzerland, August 8-20, 1955.

The highlights of the main field and laboratory projects now underway are contained in the summary on pages 17 to 25.

SUMMARY

Uranium in sandstone-type deposits

Colorado Plateau Exploration

Within the past year the objectives of the Colorado Plateau Exploration Program have changed from the discovery and outlining of minable ore deposits to the discovery and delineation of ground favorable for the occurrence of uranium ore, and study of the geologic environment of ore deposits. Geologic investigations conducted in conjunction with physical exploration during the report period include studies of (1) criteria useful in the search for ore in the Beaver Mesa area, Gateway district; (2) the relation of intersecting "festoon" surfaces to some ore bodies, discovery of four previously undescribed vanadium minerals, and discovery of molybdenite and digenite with uranium ore in the Bull Canyon district; (3) the possible relation of channels and uranium deposits to monoclines and structural terraces in the Deer Flat area, White Canyon district; (4) geologic criteria for favorable ground in the La Sal Creek area, Paradox district; (5) preliminary results of heavy mineral separation and calcium carbonate studies in the Slick Rock district; (6) analysis of the relation of sedimentary features to ore deposition in the Uravan district; and (7) geologic criteria for favorable ground in the Gypsum Valley and Thompson districts.

Colorado Plateau Geologic Studies

Geologic mapping

Geologic mapping and office work was continued in connection with the following mapping projects: Elk Ridge, Utah; San Rafael Swell, Utah; Moab-Inter-river area, Utah; Lisbon Valley, Utah and Colorado; Circle Cliffs, Utah; Abajo Mountains, Utah; Sage Plain, Utah and Colorado; and Western San Juan Mountains, Colorado. Compilation and report writing, prior to final publication, continued on the southwestern Colorado area; Carrizo Mountains area, Arizona and New Mexico; Monument Valley area, Arizona; Red House Cliffs area, Utah; White Canyon area, Utah; Capitol Reef area, Utah; and the Comb Ridge area, Utah.

In the San Rafael Swell the Moss Back member of the Chinle formation northward from Temple Mountain is relatively thick, massive and is barren. Although relatively thick at Temple Mountain, the Moss Back thins to the south and becomes interbedded with mudstones; this facies change may account, in part, for the accumulation of uranium at Temple Mountain. Significant uranium deposits in Lisbon Valley are found in the Cutler, Chinle, and Morrison formations, and all show a degree of lithologic control. In Monument Valley some scour channels filled with Shinarump conglomerate mark the axes of broad swales 3 to 4 miles wide with about 50 feet of relief and of considerable length. Recognition of these swales may help future drilling or geophysical work in the search for concealed channels. Fluorescent silica is associated with many uranium deposits and is thought to be a useful ore guide in the Monument Valley area. Most of the Shinarump channels in the White Canyon area are contained in a northeast-trending belt of relatively continuous Shinarump conglomerate. All of the known significant uranium deposits are contained in channels that occur within the margins of this belt.

During the period photogeologic maps of 22 quadrangles were completed, bringing the total number of such maps since the program was started to 263. To date, 115 photogeologic maps have been submitted for publication, and 50 maps have been published.

Stratigraphic studies

Upper Triassic formations may be grouped, on the basis of lithology and genesis, into four major units; a basal claystone containing interbedded sandstones and conglomerates, a reddish siltstone unit containing thin interbedded limestone beds, a reddish structureless siltstone containing minor sandstones, and an upper eolian sandstone.

Pebble studies of Triassic formations show significant differences in the distribution of quartz, quartzite, chert, and limestone between the Moss Back member of the Chinle formation and the Shinarump conglomerate. Fossils contained in pebbles indicate the pebbles were derived from rocks of late Paleozoic age.

Compilation of regional permeability and transmissivity data indicates that Permian and Mesozoic rocks can be divided into three major groups: (1) units that are nontransmissive because of vanishingly low permeability, (2) units with uniform regional gradients of permeability and transmissivity, and (3) units with highly variable regional gradients of permeability and transmissivity. The distribution of uranium between these units contrasts sharply, but no apparent correlation of location of ore deposits with mean permeability or transmissive range has been detected within any particular unit.

Botanical studies

A study of analyses from experimental garden materials suggests that selenium becomes more available to indicator plants in the presence of carnotite. Solubility studies indicate that the presence of selenium and sulfur causes uranium in carnotite to be more soluble at pH 8.0 or higher and that selenite and sulfite ions tend to oxidize to higher states.

Statistical analysis of uranium assays of branch tips collected on Elk Ridge, Utah, indicates that uranium contents greater than 1.0 ppm for pinyons and 0.8 ppm for junipers constitute botanical anomalies. In the Circle Cliffs area pinyon and juniper may be useful for absorber plant prospecting under restricted conditions; indicator plants are unreliable. In the San Rafael Swell neither indicator nor absorber plants appear widely useful as prospecting aids.

Mineralogic studies

Studies of oxidation zoning in the JJ and Peanut mines show that thin, discontinuous transition zones exist between oxidized and unoxidized ores. These zones appear to be related to the configuration of the water table. Marcasite, which inverts to pyrite at a temperature of 450° C., and molybdenite, which in typical hydrothermal ores is deposited at a temperature of 500° C., have been found associated with unoxidized ores.

X-ray analyses indicate that Triassic clays are composed predominantly of illite with lesser amounts of kaolinite, chlorite, and mixed-layer clays.

Study of replicate semiquantitative spectrographic analyses shows that the correction for precision of analysis in the statistics of element distribution is small. Calculation of correlation coefficients between detectable elements in barren and mineralized Morrison sandstones shows all significate correlations to be positive.

Most of the elements detected in uranium ores have a high correlation with aluminum.

Olivine basalts of the Colorado Plateau contain more barium than basalts from widely speareated parts of the world. Alkaline basalts from the Plateau contain more uranium, thorium, niobium, lanthanum, and other cerium group rare earths than Plateau olivine basalts.

Geophysical investigations

The Oljeto Wash and other Monument Valley seismic refraction studies indicate that buried Shinarump channels can be located with the refraction seismograph in areas where there is no Chinle overburden. The problem of mapping the contact of the Shinrump and Moenkopi formations through Chinle overburden has not yet been resolved, but in one Chinle-covered area the seismic refraction data have proved successful in delineating the presence of a buried Shinarump channel.

Regional gravity surveys were made in the White Canyon, Carrizo Mountains, and Monument Valley areas. To date about 2,040 gravity stations have been established in several areas totalling about 4,500 square miles.

The magnetic anomalies are related predominantly to structural and compositional features in the basement rocks and to younger igneous intrusions. Regional gravity anomalies in the Paradox Salt Basin are controlled principally by salt structures and other irregularities in thickness of the salt. In areas where salt is thin or absent their controls are generally similar to those of the magnetic anomalies.

Original-state core studies

Over a 4-mile distance between the carnotite ore terrane of Long Park and the blue-black ore terrane of Bitter Creek in Montrose County, Colorado, gamma-ray and electrical bore hole logs bear a consistant relation to each other. Overall resistivity in the poorly mineralized drill holes is less than in the ore drill holes, particularly below the correlated position of the ore zone, because of the presence of low-resistive claystone beds. Although radioactive zones, including ore zones show diminished resistivity, the overall resistivity of the ore drill holes is greater. Below the ore where permeable sandstone contains appreciable water, maximum resistivity is reached.

South Dakota and Wyoming

Thermoluminescence studies at the Gould mine and Long Mountain in the Southern Black Hills, South Dakota indicate that high thermoluminescence anomalies correlate with high radioactivity anomalies both on the surface and in core holes. It is planned to sample systematically for thermoluminescence in areas distant from known uranium deposits in the hope of finding trends of anomalous thermoluminescence that might lead to the discovery of blind ore bodies at depth.

In the Gas Hills area, Wyoming, waters from springs, wells, streams and reservoirs were collected for uranium analysis. It was found that the uranium content of water draining from mineralized areas averaged 98 parts per billion in contrast to 6 parts per billion in water from unmineralized areas.

Sandstone containing as much as 3 percent uranium has been found in the Browns Park formation of Miocene age in Poison Basin, near Baggs, Wyoming. Uranophane, schroeckingerite, and tyuyamunite have been identified from the area.

Arizona

Uranium deposits in the Dripping Spring quartzite, Gila County, Arizona, have been found in two types of host rock; siltstone and feldspathized rock. In general, the deposits in the siltstone are more numerous and cover larger areas than those in the feldspathized rock. All the known deposits are limited by some as yet undefined stratigraphic control. Primary minerals of the deposits suggest an early stage of high-temperature deposition.

Texas

The uranium deposits in Karnes County, southern Texas, were examined and a preliminary stratigraphic section prepared. The deposits occur in the Jackson formation of Eocene age and the overlying Catahoula and Oakville sandstones of Oligocene age, largely in unconsolidated beds of tuff, sand, and sandy clay. The yellow and green uranium minerals are associated with large amounts of molybdenum and arsenic. The deposits range from very small occurrences to bodies several hundred feet across that contain thousands of tons of ore.

Uranium in veins, igneous rocks, and related deposits

Uranium occurs in several beds, over an area of several square miles, in a thick sequence of bentonite-bearing tuffaceous Oligocene sedimentary rocks northeast of Winston, Broadwater County, Montana. Secondary uranium minerals have been found at two localities in beds ranging in thickness from 1 inch to 2.5 feet. Reconnaissance of an area of similar tuffaceous sediments south of Radersburg, Broadwater County, disclosed anomalous radioactivity in beds of carbonaceous shale and in a 4-foot bed of lapilli tuff.

In rhyolitic and dacitic rocks from six western states the uranium content shows a significantly high positive correlation with the contents of niobium, beryllium, and fluorine; a less significant correlation with the content of lithium and tin; and a significant negative correlation with the content of boron and lanthanum; and no significant correlation with the content of zirconium and lead. Significant variations with the geographic provenance have been shown for all elements except tin and lanthanum.

Studies of the adsorption of uranium onto zeolites was begun with the idea that the amounts of uranium adsorbed may serve to locate volumes of rock through which uraniferous solutions may have passed. Chemical age determinations of uranothorite and allanite from a pegmatite provide evidence that may give a measure of the amount of magmatic lead absorbed by these minerals during their crystallization.

Uranium in carbonaceous rocks

Lignite, carbonaceous shale, and sandstone containing more than 0.10 percent uranium occur in rocks of Late Cretaceous to Miocene age at several widely separated localities in eastern Montana and the eastern Dakotas. In the Riley Pass area, Harding County, South Dakota about 440 acres is underlain by a lignite bed 1.3 feet thick and containing 0.76 percent uranium. Some samples from the area contain as much as 0.5 percent molybdenum and 0.9 percent arsenic. Deposits similar to but smaller than those at Riley Pass are known at Slim Buttes, South Dakota, and the Killdeer

Mountains, North Dakota.

Uranium was found in asphalt-bearing rocks from 45 areas in the western states, the average concentrations ranging from 0.001 to 0.376 percent in the ash of the extracted oil. Studies of asphaltite pellets and oil extracted from the same rock show some interesting inter-relationships, indicating that the pellets may have been derived from the oil. It was also found that the uranium is concentrated in the organic fractions of the samples and not in the host rock.

Analysis of stripping film exposures prepared from thin sections of ore-grade uraniferous sandstone impregnated with carbonaceous material from the Temple Mountain area shows that the uranium is not present in the ore as a coating of the mineral grains, that there is a dispersion of alpha-particle tracks throughout the carbonaceous material, and that the pyrite and quartz grains are practically devoid of tracks.

Detailed studies of four carbonaceous shales indicate that in the Chattanooga shale and in shale from the Phosphoria formation, uranium is present as a separate colloidal phase. In shale from the Dakota sandstone, there is a marked association of uranium with the organic fraction; and in the Sharon Springs member of the Pierre shale the uranium may be associated with a mineral fraction.

Uranium in phosphates

Field investigations in the hardrock phosphate district of Florida indicate that the secondary phosphate deposits in that area may have been derived by complex weathering processes from the phosphatic Miocene sediments which formerly covered the area. Auger drilling of anomalies discovered by airborne radioactivity surveys in the area show that the high radioactivity is associated with phosphatic materials.

Uraniferous slag from an elemental phosphorus furnace was found to be almost entirely α'-pseudowollastonite. Its composition, X-ray pattern, specific gravity and uranium content change during crystallization and it is possible to beneficiate uranium somewhat by heavy liquid fractionation.

It was found in field study that some ground water podzols are now being destroyed in the Land Pebble Field. Thus, their importance as agents in the leaching and weathering that produced the aluminum phosphate zone may be greater than evident from their present distribution.

Reconnaissance for uranium in the United States

Airborne radioactivity surveys totalling 3,490 miles were completed during the period. Of these, 1,910 miles were flown to evaluate the relationship of radioactivity measurements in the air to oil and gas accumulation, and 1,580 traverse miles were completed in southeastern Tennessee as part of a study of the relationship and distribution of radioactivity in crystalline rock areas.

A considerable number of uranium occurrences in the Pisgah National Forest in western North Carolina were examined. The number of such occurrences, and the fact that many samples of rock from this area contain 0.1 percent uranium or more, may be significant.

The Loon Lake batholith, which underlies a large area in northeastern Washington and northern Idaho, contains abnormally radioactive rocks over a considerable area and a number of samples which contain 0.10 percent or more uranium have been taken.

Carnotite mineralization was found in an erosion remnant of the North Park (?) formation along the northeast margin of the Hanna Basin, Carbon County, Wyoming. A sample from the north end of the 1/2-mile long exposure contains 0.051 percent U and 0.16 percent V_2O_5.

Analytical service and research on methods

The redetermination of the half-life of thorium is being approached by the use of alpha spectrometry. Measurements of Cu^{63}/Cu^{65} ratio were made by neutron activation analysis, with a reproducibility of about 1 percent. Methods for the chemical determination of Ti, Mo, Zr, Sb, and Cu in the presence of interfering elements were investigated in detail, and experimental work on the thiocyanate method for the determination of uranium was completed. It was observed during the course of this work that under similar conditions vanadium gives a blue color with thiocyanate in acetone-water solution. A method of vanadium determination, based on this reaction, was developed.

Laboratory work is essentially complete on methods for the determination of lead in monazites, and a direct colorimetric procedure involving no spearations was found applicable to the determination of thorium in monazite concentrates. Highly purified potassium salts were prepared from fresh and weathered granite as a contribution toward an isotopic fractionation study.

Geochemical and petrological research on basic principles

A study of the distribution of helium in the United States shows that in natural gas fields the proportions of helium, argon, and nitrogen vary within limits and that their concentrations increase with geologic age.

It is thought that the principal sources of helium, argon and nitrogen are: radioactive decay of uranium (helium source); potassium-40 (argon source); degradation of nitrogenous compounds in rocks (nitrogen source), possibly as a result of associated radioactivity; and occluded atmospheric air with rocks (nitrogen and argon source).

Tests of precision and accuracy of several methods of thorium analysis of igneous rocks were made. For the very low range represented by most igneous rocks the gamma-ray spectrometer seems to be the most suitable but the X-ray fluorescence and radiochemical methods offer much premise. The chemical wet methods as applied to these materials seems least satisfactory but further studies are needed. Native iron not due to contamination was found in the green phases of the Conway Granite of New Hampshire; only one other such occurrence in felsic rocks is reported in the literature.

Channel samples from several mines studied during the report period all are consistent with the concept of original low valence ore minerals oxidized in situ. Methods were developed for identification of vanadium silicates. Roscoelite does not appear to be affected by an oxidizing environment, but such an environment does affect vanadium chlorites and hydrous micas. Reducing capacities of woody material in vanadium solutions at 150° C. were determined; fresh spruce has a capacity of 1000 milliequivalents per 100 grams. Lignite is roughly half as effective. Most of the theoretical boundaries of the Eh-pH diagram of uranium, vanadium, and water have been checked experimentally.

The study of the solubility of carnotite was continued and work was started on the system $CaO.UO_3.V_2O_5.H_2O$. Study and synthesis of various non-uraniferous vanadates were continued.

Geologic studies of lead isotopes in three galena samples from the Sudbury district, Ontario confirmed two previously known types and added information that identified the geologic associations. Additional isotope analyses were made of galena from sedimentary formations around the perimeter of the Colorado Plateau. Fluorimetric determinations were made in 100 selected rocks, both igneous and sedimentary. A trend toward higher uranium values in samples of younger geologic ages seems to be indicated.

Copper isotope analyses are now well under way. Isotopic uranium analyses of seven selected samples indicate a constancy in the ratio of at least one percent. Preliminary tests are being made to measure the variation of K^{40} in geologic processes and also nuclear reactions taking place in lithium minerals.

Mineralogic and petrographic service and research

X-ray diffraction services were improved by the development of a method of unit cell determination for fine-grained minerals, and a high temperature sample mount for the diffractometer. Significant advances in crystal chemical studies include: (1) the elucidation of the numerous natural uranium oxide hydrates (becquerelite, schoepite, etc.), and determination of their structural principles; (2) the solution of the crystal structure and constitution of the new mineral duttonite, $VO(OH)_2$; (3) the evolution of the pH-oxidation potential phase diagram for vanadium in solution, showing relations and alteration sequences among vanadium mineral species on the Colorado Plateaus.

The study of vanadium minerals was continued and by a new method of electron diffraction analysis the a and b unit-cell constants of calcium hewettite, navajoite, and corvusite were tentatively assigned. Electron diffraction patterns and micrographs of uranium and vanadium minerals were obtained.

Geophysical service and research on methods and principles

Laboratory and field studies have been made on (1) the relation of ratio of phototube cathode area to phosphor area (2) spectral energy apparatus for drill hole loggers (3) water pressure strength of scintillation drill hole probe housings, (4) a comparison of plastic and sodium iodide phosphors for carborne counters, (5) the effect of vehicle speed and related parameters on "detectability" with carborne equipment and (6) temperature drift of carborne scintillation loggers.

URANIUM IN SANDSTONE-TYPE DEPOSITS

Colorado Plateau Exploration

Exploration and geologic studies on the Colorado Plateau by the USGS are directed toward assessing the uranium potential of the area. Since November 1947 physical exploration by drilling has had as its objective the discovering and outlining of ore deposits. Because private industry is assuming a major role in this effort the Survey has, in the past year, placed greater emphasis on the discovery and delineation of ground favorable for the occurrence of uranium ore and on the study of the geologic environment of the ore deposits. The amount of drilling on any particular ore body is limited to that necessary to determine its geologic configuration and habits, and wherever possible, drilling is done on public land rather than on privately held land.

In each of the areas where physical exploration is planned, in progress, or completed, a comprehensive geologic study is made by integrating the geologic information obtained from Government and private drilling, appraising all mines in the district and mapping in detail those exhibiting significant geologic relations, mapping in detail the surface geology where necessary, and making petrographic and mineralogic studies. The results of these investigations guide the drilling in progress and provide recommendations for future exploration. The geologic guides to ore and significant geologic information obtained from these studies are published in regular Survey, Trace Elements, or outside publications.

Exploration and related geologic investigations and report preparation were conducted during the report period in seven areas in the

Uravan mineral belt of southwestern Colorado and eastern Utah. These activities are directed mainly toward the evaluation of the uranium potential of the Salt Wash member of the Morrison formation (Jurassic age). Similar investigations were in progress in two areas known to contain uranium deposits in the Shinarump conglomerate (Triassic age) in Utah and Arizona (fig. 1). Geologic field work and diamond drilling were in progress in the Uravan, Bull Canyon, and Slick Rock districts of western Colorado, and in the Deer Flat area, White Canyon district of Utah, and in the Monument Valley district, Navajo County, Arizona. Field and office work necessary for preparation of reports continued on projects where drilling was recessed or completed in the Thompson, Gateway, Paradox, and Gypsum Valley districts in eastern Utah and southwestern Colorado.

Beaver Mesa area, Gateway district, Mesa County, Colorado and Grand County, Utah

by

L. J. Eicher

The Beaver Mesa area is on the northeast flank of the La Sal Mountains about 6 miles southwest of Gateway, Colorado.

All of the known significant uranium-bearing deposits in the Beaver Mesa area are in the uppermost sandstone lens of the Salt Wash member of the Jurassic Morrison formation. This lens, commonly referred to as the "ore-bearing sandstone", ranges from 15 to 80 feet in thickness. The ore-bearing sandstone is commonly lenticular and irregularly bedded.

Surface and subsurface geologic data indicate that the following geologic features are normally associated with known uranium-vanadium deposits in the Beaver Mesa area: (1) The mudstone in contact with the

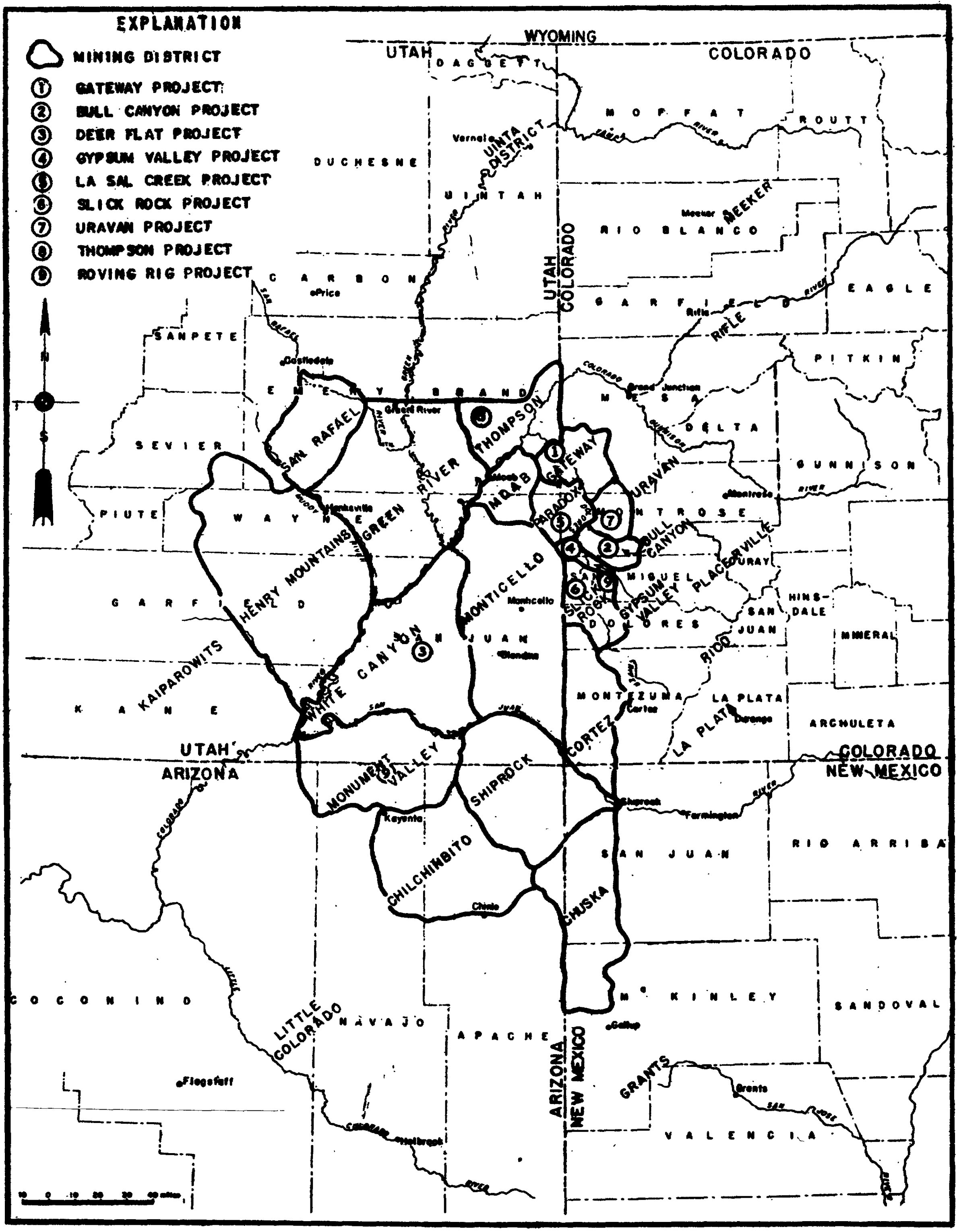


Figure 1. MAP SHOWING THE LOCATION OF PROJECTS OF THE COLORADO PLATEAU EXPLORATION PROGRAM, DECEMBER 1, 1954 - MAY 31, 1955

ore-bearing sandstone is a gray-green color; (2) the ore-bearing sandstone contains thin, discontinuous green mudstone lenses, thin zones of green mudstone pebble-conglomerate, and abundant fragments and masses of carbonaceous material; (3) the ore-bearing sandstone is a light-gray or light-brown color.

Application of the above criteria to the Beaver Mesa area indicates that several localities are underlain by sandstone considered favorable for the occurrence of uranium-vanadium deposits. These favorable areas coincide roughly with projected trends of the elongate sandstone lenses in the upper part of the Salt Wash member. One of the larger favorable areas is about 12,000 feet long, 5,000 feet wide, and is elongate in a northeast direction. Five significant deposits are known in this area.

The significant uranium-vanadium deposits in the Beaver Mesa area are the unoxidized (or only partially oxidized) uranium-vanadium type, commonly called "black ores". The principal ore minerals are the uranium-bearing minerals uraninite and coffinite and the vanadium-bearing minerals montroseite, lumsdenite, and doloresite.

Areal geologic mapping has been completed for about 40 percent of the Beaver Mesa area.

Bull Canyon project, Bull Canyon district, Montrose and San Miguel Counties, Colorado

by

A. E. Flint

The Bull Canyon mining district is between the Paradox Valley and Gypsum Valley salt anticlines about 70 miles south of Grand Junction, Colorado.

Known uranium and vanadium deposits in this district occur in the Morrison formation, mostly in the Salt Wash member. The ore is localized in lenticular strata of sandstone that are bounded by thin to thick mudstone layers. The most favorable host rock for ore seems to be a thick permeable sandstone containing a moderate amount of green mudstone as pebbles, seams, films, and as interstitial filling. Both oxidized and unoxidized deposits are being mined in the Bull Canyon mining district. The uranium minerals in the deposits usually occur as oxides and the vanadium minerals occur either as oxides or in vanadiferous clays as silicates. Copper is sparse to absent in the deposits.

Mine and outcrop mapping and exploratory drilling was in progress during the period. Mine mapping on plan and sectional views at a scale of 1 inch equals 20 feet was correlated with detailed sampling for study of trace element distribution, petrogenesis and oxidation states of the ore minerals. Elements of sedimentary structural control of the ore were mapped. To date these studies support the following tentative conclusions: (1) Relatively impermeable surfaces of crossbedding features called "festoons" slowed the migration of ore solutions through the ore-bearing sandstone and ore bodies formed in the traps beneath the surfaces of intersecting festoons; (2) ore bodies not occupying the entire trapping structure tend to lie near the roof of the structure.

Four previously undescribed vanadium minerals have been reported from this study in one of the mines, and trace element studies have shown the occurrence of molybdenite and digenite with the ore. Both minerals may be indicators of ore solution temperatures. Petrogenesis studies are incomplete. All phases of these studies are continuing. Mapping of five mines was in progress during the report period.

More than 16 miles of rim exposure was mapped during the period. The mapped strata are chiefly in the Morrison formation, which includes the important ore-bearing zones in the district.

Deer Flat area, White Canyon district, San Juan County, Utah

by
T. L. Finnell

Field work, except for spot checking, and the first exploratory drilling contract were completed in October 1954. Geologic mapping and drilling show that uranium deposits are localized in the Shinarump conglomerate where it fills scour channels in the top of the Moenkopi formation. Shinarump-filled channels are confined to a belt of dominantly continuous Shinarump that trends northeasterly across the area (fig. 2). Mineralized sandstones filling channels north of this belt are thought to be stratigraphic equivalents of Chinle sandstones above the Shinarump. This suggests that the Shinarump and Chinle sediments lap progressively northward onto a Triassic positive area.

Diamond drilling and mine mapping indicate that the uranium ore is localized in medium- to coarse-grained carbonaceous sandstone beneath gray Shinarump siltstone near the channel floors. The ore deposits contain relatively unoxidized uraninite, chalcopyrite, chalcocite, bornite, and covellite. The ore occurs as replacements of fossil wood and disseminations in sandstone. Some associated minerals are quartz, calcite, dolomite, manganosiderite(?), galena, sphalerite, barite, gypsum, and kaolinite(?). The ore is thickest and highest in grade near local scours in the channel floors.

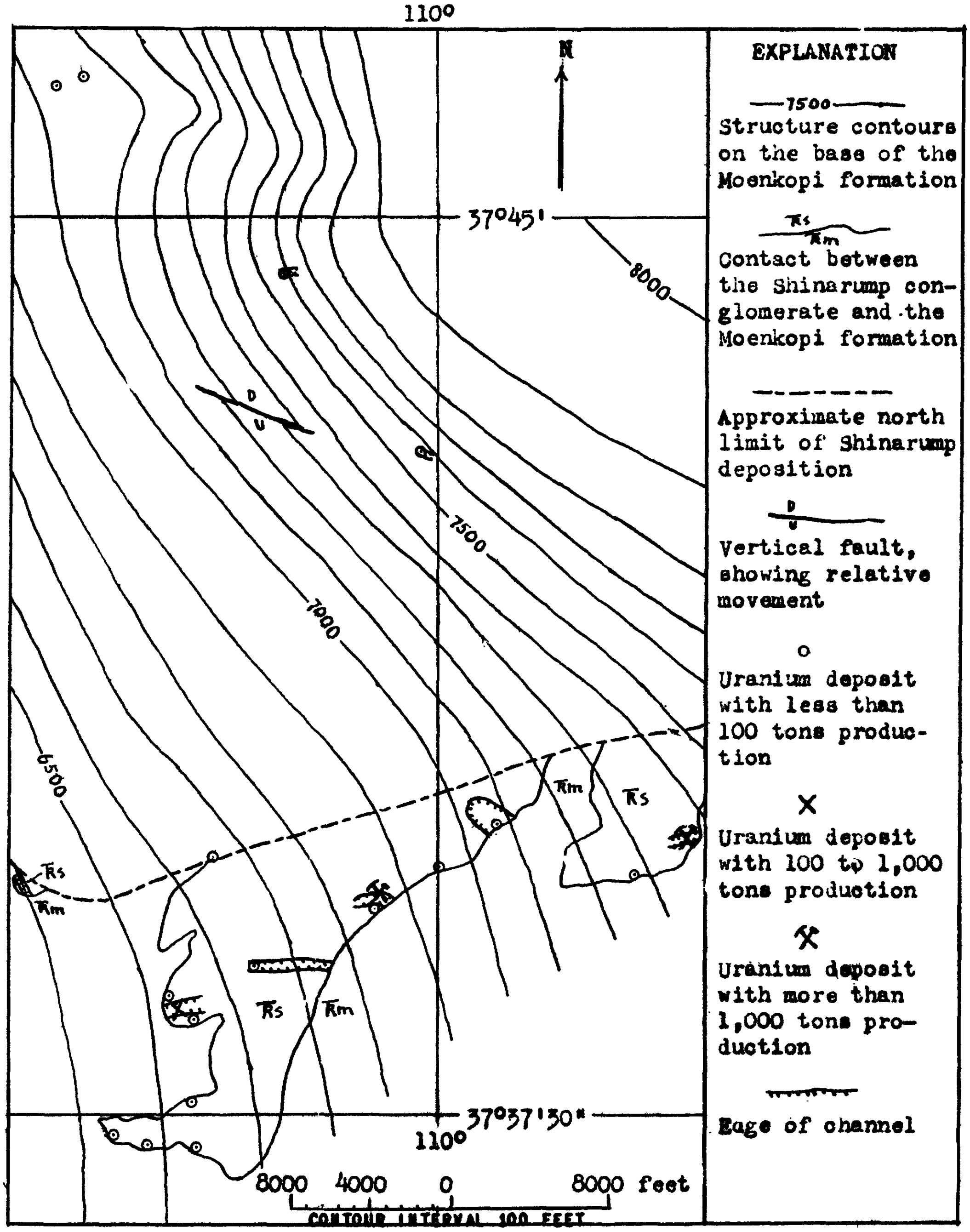


Figure 2. SKETCH MAP OF PART OF THE DEER FLAT AREA SHOWING STRUCTURE CONTOURS, CHANNELS, ORE DEPOSITS, AND APPROXIMATE NORTH LIMIT OF SHINARUMP CONGLOMERATE

Large known uranium deposits are in sediments of the Shinarump conglomerate that fill channels scoured into the Moenkopi formation. A comparison of the configuration of the base and the top of the Moenkopi suggest that the unit was folded locally before the Shinarump was deposited (cross-section, fig. 3). Further, structure contours drawn on the base of the Moenkopi tentatively suggest that those channels cut across a monoclinal steepening in areas of low dip are more favorable. For example, the largest known deposit is in a channel on a local monocline. This channel trends across the monocline and turns to parallel the dip (fig. 3). It is not cut as deeply, however, where the dip lessens west of the monocline. Possibly the channel was cut by a westward flowing stream across a local monocline resulting from the pre-Shinarump folding. The relation of this Triassic channel to the monocline is markedly similar to the relation of present day stream channels to the monoclines of the Colorado Plateau. Many of the modern channels are shallow on the low dip slopes on either side of the monoclines, but are relatively deep where they cross the monoclines. Contours on the eroded top of the Moenkopi (fig. 3) suggest that the upper surface of the fold was eroded before the Shinarump was deposited (cross-section, fig. 3).

Drilling resumed in May 1955 to test the value of uranium absorber plant anomalies in locating concealed uranium deposits, to test the relation of uranium deposits and channels to monoclines and structural terraces, and to determine diagnostic lithologic features of the Shinarump pinchout.

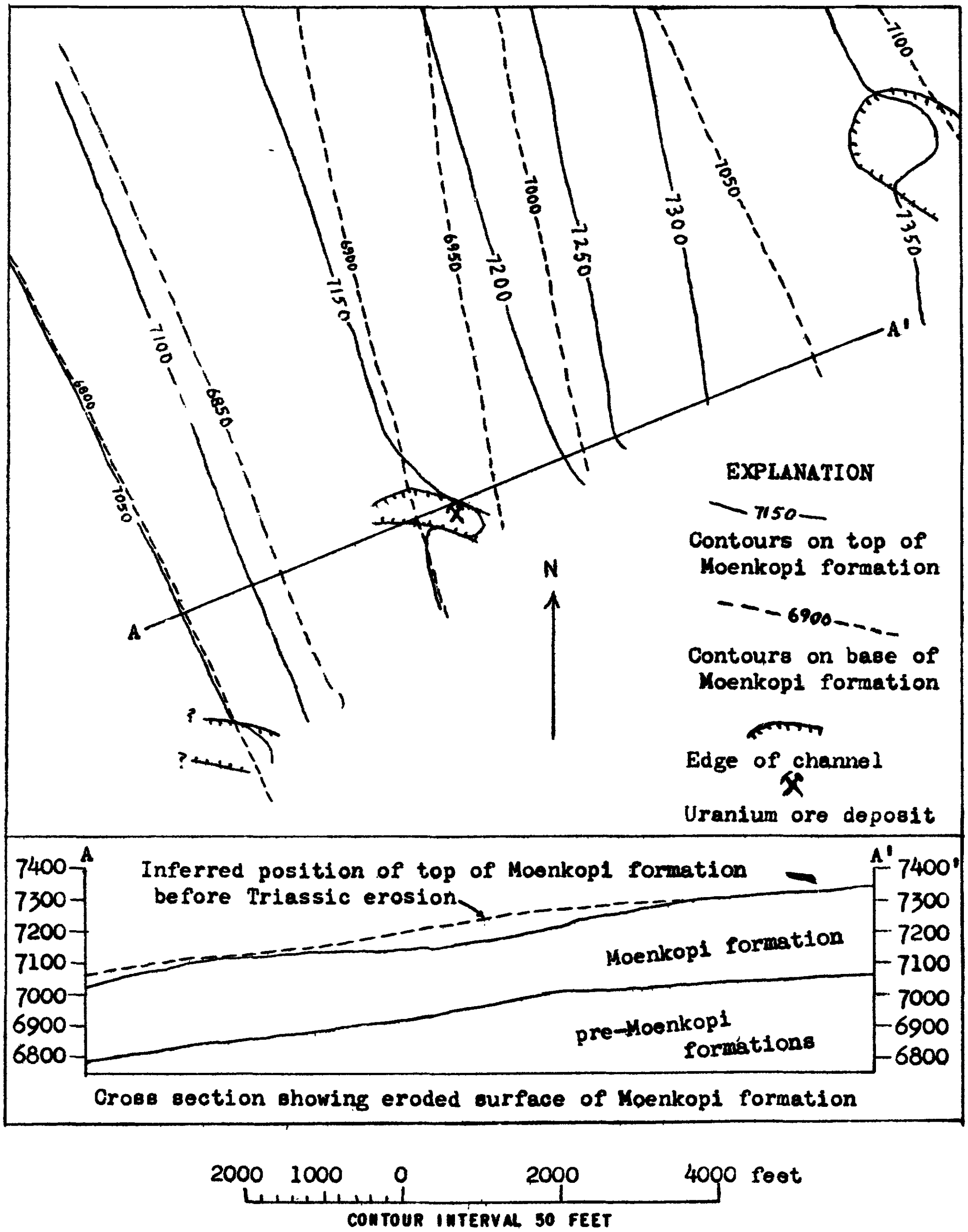


Figure 3. MAP OF PART OF THE DEER FLAT AREA SHOWING CONTOURS ON THE TOP AND BASE OF THE MOENKOPI FORMATION, AND A CROSS-SECTION SHOWING THE ERODED SURFACE OF THE MOENKOPI FORMATION

Gypsum Valley area, Gypsum Valley district, Montrose and San Miguel Counties, Colorado

by

C. F. Withington

Mining activity in the Gypsum Valley district is concentrated on the floor and along the inner walls of a collapsed salt anticline called Gypsum Valley. Economic deposits of uranium and vanadium occur in the Pennsylvanian Hermosa formation, the Jurassic Wingate formation, the Jurassic Carmel-Entrada formation (undivided), and the Salt Wash and Brushy Basin members of the Jurassic Morrison formation. Most of the production and known reserve is in the Salt Wash member of the Morrison formation.

A study of diamond-drill core and outcrops of the Salt Wash member indicates that the ore deposits are localized: (1) in narrow, lenticular sandstone strata that trend northwest, (2) near the contact of salt with the overlying Salt Wash member, or (3) in places where the Salt Wash member thins over the salt anticline.

The sandstone beds containing deposits in the Salt Wash member are usually light colored, contain gray or green pebbles, films, and seams, and are underlain by green mudstone. Organic remains are also present with ore.

Carnotite and a vanadium mica are the common ore minerals; limonite, calcite, and silica occurring as overgrowths on quartz grains are common accessory minerals, and secondary copper minerals are present locally.

La Sal Creek area, Paradox district,
Montrose County, Colorado, and San Juan County, Utah

by

W. D. Carter

The La Sal Creek area is in the western half of the Paradox Mining district in Montrose County, Colorado, and San Juan County, Utah. The area includes the eastern flank of the La Sal Mountains from Deep Creek on the north, to Coyote Wash and the Dolores River on the south, and to Paradox Valley on the east. Areal geologic mapping of the La Sal Creek area, covering about 280 square miles, commenced in May 1954 in conjunction with resource appraisal studies and diamond-drill exploration by the USGS. Approximately 20 percent of the area has been mapped in detail and 80 percent has been studied by reconnaissance methods.

The rocks exposed in the area are composed of sedimentary strata ranging in age from Pennsylvanian to Recent. A large portion of the area consists of mesas capped by the Cretaceous Dakota and/or Burro Canyon formations. The mesas are separated by deeply incised stream valleys which usually expose the Brushy Basin member of the Jurassic Morrison formation. Outcrops of the Salt Wash member of the Morrison and older formations are exposed along La Sal Creek, Coyote Wash to the south, the northwest end of Paradox Valley, and isolated spots near igneous rocks at the base of the La Sal Mountains.

All of the known uranium-vanadium deposits in the La Sal Creek area are in the Jurassic Morrison formation and the major deposits are in the uppermost continuous sandstone layer of the Salt Wash member.

Small, scattered deposits are found in cherty, conglomeratic sandstone lenses of the Brushy Basin member. A recent discovery of mineralized material in an arkosic sandstone and conglomerate in the Triassic Moenkopi formation that crops out in Paradox Valley has renewed interest in the older beds exposed in the area.

Exploration drilling along La Sal Creek by the USGS has discovered numerous uranium deposits in a large favorable area, trending east-northeast, that is approximately six miles long and varies in width from 500 to 3,000 feet. The deposits range from a few tons to many thousand tons and offer drilling targets that range from 12,000 to 180,000 square feet. Drilling, along with detailed mapping of about 10 mines in the area, indicates that in general the deposits consist of thin (average 3 feet), essentially tabular ore bodies oriented roughly east-west or slightly south of east in en echelon arrangement within the favorable area.

Favorable ground in the La Sal Creek area is determined by the following criteria: (1) The sandstone beds of the ore-bearing horizon should show lenticularity and reach a total thickness of 30 feet or more; (2) the sandstone should be light-brown, white or light gray in color; (3) green or gray mudstone should be present above or below the sandstone or within the sandstone as seams, pellets, or filling the interstices between sand grains; and (4) carbonaceous material should be present as scattered flakes and/or in trash pockets. On the outcrop and in the mines current lineation, ancient stream scours, ripple marks, festoon-type cross-bedding, and imbrication of mudstone pebbles or fragments aid in determining the trend of favorable ground.

The number and frequency of such favorable belts in the La Sal Creek area are unknown due to sedimentary cover and the sparse number of exposures across sedimentary trends. One deposit discovered north of the favorable area along La Sal Creek suggests the possibility of a second favorable belt. Its trend and dimensions are as yet unknown and must be determined by extensive drilling. Rim studies along 20 miles of the ore-bearing horizon have discovered a few places in the La Sal Creek area that have been tentatively classed as favorable.

Slick Rock district, San Miguel and Dolores Counties, Colorado

by

D. R. Shawe

The Slick Rock district is in the western part of San Miguel and Dolores Counties, Colorado, and comprises an area of about 500 square miles. The salient structural features of the district are the northwest-trending Disappointment syncline and adjacent Dolores anticline. Principal uranium-vanadium production is from a thick, continuous sandstone layer near the top of the Salt Wash member of the Jurassic Morrison formation. Sandstone considered favorable for ore is light gray or light brown, contains abundant carbonaceous material, and is underlain by gray-green mudstone lenses. Light reddish brown, and reddish brown, are the colors respectively of the normal or unaltered Salt Wash sandstone and mudstone. Salt Wash ore deposits range from a few tons to many thousands of tons in size and are found in areas of favorable ground as much as a mile wide and 5 miles long, trending generally easterly.

Mine mapping at a scale of 1 inch to 40 feet continued and is now about half completed in two mines in the district, and mapping was started in two mines. Details of the ore bodies, as revealed by mine mapping and in part by analyses of trace elements, suggest that mineralization took place along an interface between solutions of different composition and density, possibly connate water and a moving warm water solution. Roll ore bodies are abundant where the ore-bearing sandstone contains numerous thin mudstone layers and tabular bodies are abundant where mudstone layers are sparse or absent, suggesting that tabular bodies formed below a moving sheet of warm water and roll bodies formed where numerous mudstone layers directed the moving solution into sedimentary traps.

Surface mapping of the Morrison formation at a scale of 1:12,000 was continued throughout this period.

Special studies included investigations of the distribution of calcium carbonate in the Salt Wash member of the Morrison formation, of heavy minerals in the Salt Wash member, of fractures in the Slick Rock district, and of the stratigraphy of the Mancos shale. Tentative conclusions based on the calcium-carbonate study show that calcium carbonate in the altered mineralized sandstone has a spatial distribution related to the position and form of ore bodies.

Investigation of the heavy minerals in the Salt Wash member of the Morrison formation indicates that hematite, though abundant in unaltered sandstone, is almost completely absent in altered sandstone and barite has been recrystallized in altered sandstone. Spatial relationships of the alteration features to ore deposits suggest that they are a result of activity of the mineralizing solutions.

Uravan project, Uravan district, Montrose County, Colorado

by
R. L. Boardman

The USGS has conducted a program of exploration and related geologic studies in the western part of the Uravan district, Montrose County, Colorado, since 1948. The principal objectives of this work are: (1) to appraise the uranium-vanadium resources of this important producing part of the district, (2) to make a comprehensive study of geologic factors affecting the control and localization of ore deposits, and (3) to search for new deposits.

Since December 1, 1954, the exploration phase of the program has been devoted largely to testing unexplored ground east and southeast of the Long Park area in the southern part of the district. This drilling, which is being done to provide a basis for evaluating the uranium-vanadium potential of this ground, should be completed during the summer of 1955. Some drilling is being done to complete outlining of ore deposits previously discovered on public land that is withdrawn from mineral entry in the southeastern Long Park area.

A detailed rim study was completed late in 1954 of the upper sandstone lenses of the Salt Wash member of the Morrison formation in the western part of the Uravan district. The horizontal extent and geologic character of the sandstone lenses were recorded as were the sedimentary trends determined from festoon cross laminations, ripple and current lineations, and cross bedding. These lenses contain all of the principal uranium-vanadium deposits in the district. The data acquired during this study have been integrated with information derived from detailed mine mapping, from cursory mine examinations, and from partial compilation of data from the more than 3,000 USGS drill holes in the district. Together, these data give a general picture of the deposition, extent, and structure of the upper sandstone lenses of the Salt Wash, and provide a basis for relating sedimentary features to ore features throughout the area studied.

The tentative conclusions drawn thus far from this study are: (1) the sedimentary trends in the Uravan district are, in general, east, and the strike of the sedimentary features closely parallels the long axes of the ore bodies and the boundaries of favorable ground; (2) an en echelon arrangement of ore deposits in parts of the areas studied is believed to be directly related to an en echelon arrangement of sedimentary structures; (3) the individual sandstone lenses of the upper part of the Salt Wash may not be extensive regional aquifers; (4) the concept of the Uravan mineral belt striking north through the western part of the Uravan district cannot be seriously questioned on the basis of present knowledge; and (5) sedimentary data, together with known fracture relationships, make it unlikely that the genesis, localization, and concentration of ore in the Uravan district are controlled by faults or fractures.

Yellow Cat area, Thompson district, Grand County, Utah

by
E. S. Santos

In the Yellow Cat area uranium-vanadium deposits are within certain elongate lenticular sandstone strata throughout the Salt Wash sandstone member of the Jurassic Morrison formation. The USGS explored by diamond drilling a sandstone stratum near the base of the Salt Wash member that is 14,000 feet long, and locally exceeds 1,000 feet in width. The area explored contains at least six separate ore deposits along its length. Other favorable sandstone strata near the middle and the top of the Salt Wash member contain one or more uranium-vanadium deposits. As the ore deposits in the Yellow Cat area are not confined to a single sandstone layer in the Salt Wash, it is believed that in this district the lithology of permeable sandstone strata is more complex than it is in areas where the deposits are largely confined to a single layer.

Rock exposures in outcrop and in the mines and diamond-drill cores show that where the sandstone strata are favorable to ore they contain organic material, are light brown, light gray, or white in color, and are between 15 and 70 feet thick. The uranium-vanadium deposits are commonly localized in the thicker sandstone strata. Pebbles and seams of gray mudstone occur where sandstone strata are mineralized and in these places gray or green mudstone lies immediately above or below the ore-bearing stratum.

Deposits at depths greater than 100 feet below the land surface usually contain dark-colored uranium and vanadium minerals and the rocks are usually saturated with underground water. Near the land surface the ore minerals are usually yellow carnotite and gray vanadium mica, and the sandstone is stained with yellow-brown limonite; underground water is usually absent near these ores.

Colorado Plateau Geologic Studies

Regional geologic mapping

Prior to this report period field work was completed for the following quadrangle mapping projects: Southwestern Colorado area; Carrizo Mountains area, Ariz. and N. Mex.; Monument Valley area, Ariz.; Red House Cliffs area, Utah; White Canyon area, Utah; and Capitol Reef area, Utah. The strip mapping project in the Monument Valley area, Utah, was also completed (fig. 4). Some office work leading to final publications was continued by each of these projects.

During this report period field and office work was continued on the following quadrangle mapping projects: Elk Ridge area, Utah; Lisbon Valley area, Utah and Colo.; Circle Cliffs area, Utah; Abajo Mountains area, Utah; Sage Plain area, Utah and Colo.; and Western San Juan Mountains,

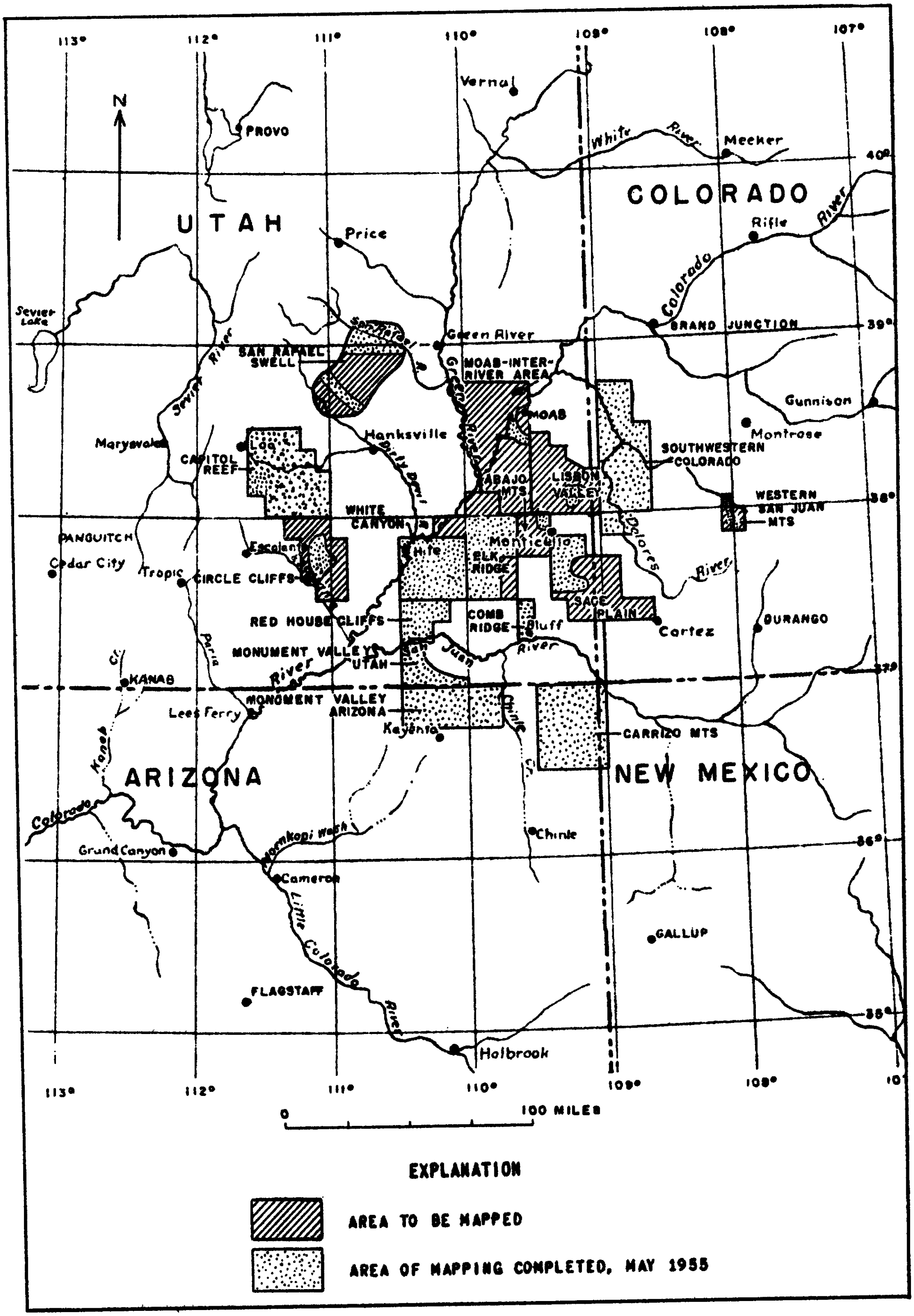


Figure 4. INDEX MAP OF PART OF THE COLORADO PLATEAU SHOWING LOCATION OF MAPPING PROJECTS

Colo. Work was continued on the following strip mapping projects: San Rafael Swell area, Utah and the Moab-Inter-river area, Utah. (See fig. 4.)

The regional mapping projects share five general objectives: (1) to construct a geologic map of the area, (2) to appraise the uranium and vanadium resources of the area, (3) to determine geologic guides to uranium deposits, (4) to obtain data on controls of ore deposition, and (5) to locate any areas favorable for concealed deposits. Strip mapping involves detailed study and mapping of only the major ore-bearing beds and adjacent strata; it is undertaken only in those regions where a complete and adequate geologic map already exists.

Southwestern Colorado quadrangle mapping, by F. W. Cater, Jr.

Field work on this project was completed in 1950 and geologic maps of eighteen 7-1/2 minute quadrangles are being published. The following black-and-white geologic maps were published in the Mineral Investigations Field Studies map series during this report period:

MF 17 "Preliminary geologic map of the Red Canyon quadrangle, Colo.," by E. J. McKay

MF 18 "Preliminary geologic map of the Atkinson Creek quadrangle, Colo.," by E. J. McKay

MF 19 "Preliminary geologic map of the Gypsum Gap quadrangle, Colo.," by F. W. Cater, Jr.

MF 20 "Preliminary geologic map of the Pine Mountain quadrangle, Mesa County, Colo.," by F. W. Cater, Jr.

MF 21 "Preliminary geologic map of the Hamm Canyon quadrangle, Colo.," by F. W. Cater, Jr.

MF 22 "Preliminary geologic map of the Paradox quadrangle, Colo.," by C. F. Withington

MF 26 "Preliminary geologic map of the Egnar quadrangle, Colo.," by F. W. Cater, Jr.

MF 27 "Preliminary geologic map of the Joe Davis Hill quadrangle, Colo.," by F. W. Cater, Jr.

MF 29 "Preliminary geologic map of the Horse Range Mesa quadrangle, Colo.," by F. W. Cater, Jr.

MF 30 "Preliminary geologic map of the Naturita NW quadrangle, Colo.," by F. W. Cater, Jr.

MF 31 "Preliminary geologic map of the Davis Mesa quadrangle, Colo.," by F. W. Cater, Jr., and E. J. McKay

MF 32 "Preliminary geologic map of the Calamity Mesa quadrangle, Colo.," by F. W. Cater, Jr.

Monument Valley area, Ariz., quadrangle mapping, by I. J. Witkind

Field work was completed in fiscal year 1953. Uraniferous deposits in the Monument Valley area are localized in scour channel fills in the Shinarump conglomerate of Triassic age, and much of the geologic work in the area has involved a study of the channels and their fills. Some scour channels at the base of the Shinarump conglomerate mark the axes of broad elongate erosional depressions, termed swales, cut in the underlying strata (fig. 5). The swales are 3-1/2 to 4 miles wide and generally have about 50 feet of relief. Locally, a swale can be traced beyond the limits of its included channel, and this fact suggests a possible method for the discovery of channels concealed beneath younger strata. If a swale can be detected on the outcrop, it may be possible to trace it beneath younger strata by geophysical or drilling methods. Swales cannot be easily perceived visually, because of their relatively great width and shallow depth, but they can be detected on isopachous maps of strata which underlie the Shinarump conglomerate. These maps are prepared most easily by photogeologic methods.

Monument Valley area, Utah, strip mapping, by R. Q. Lewis, Sr.

Field work was completed in fiscal year 1953. During this report

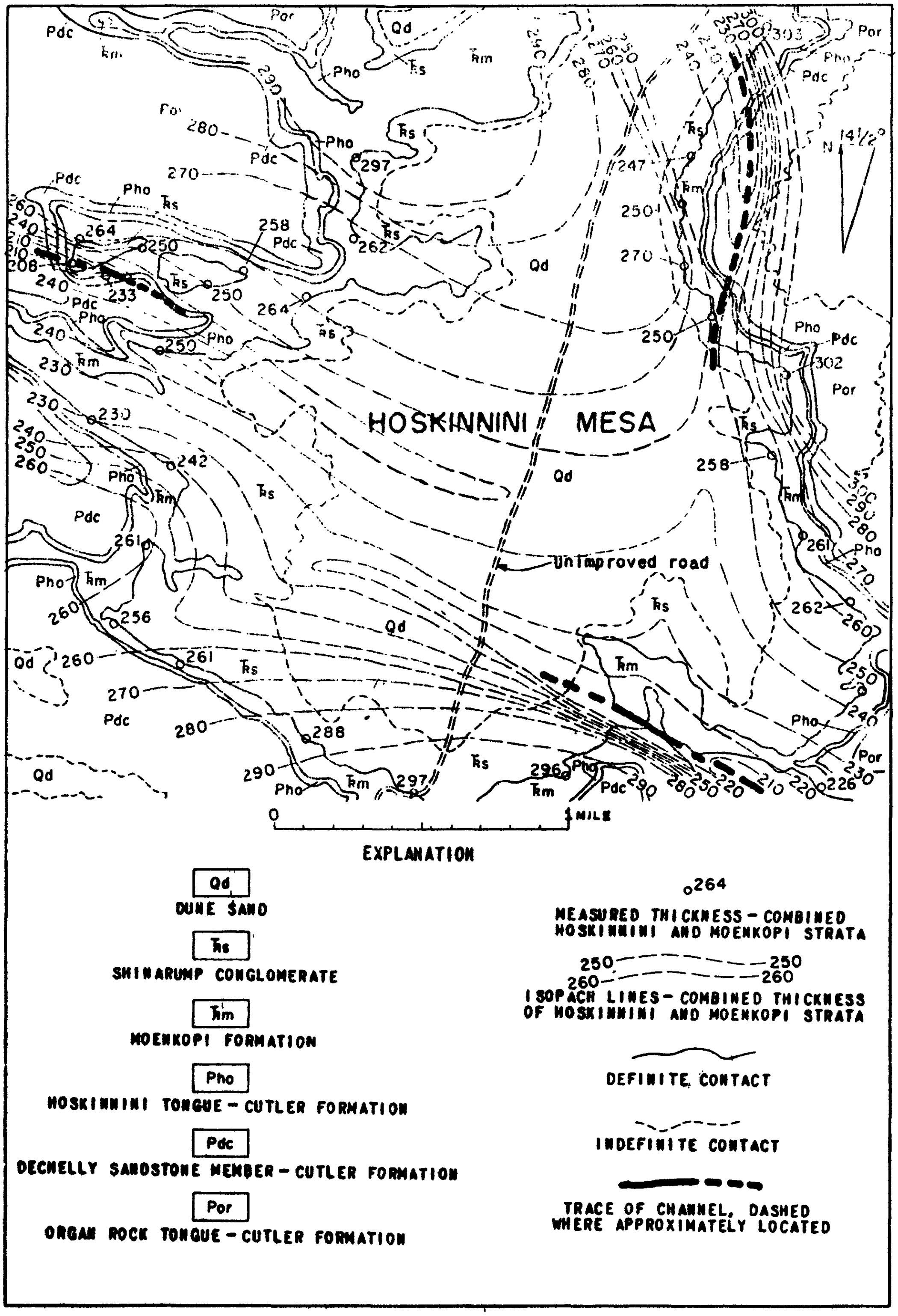


Figure 6 GEOLOGIC MAP SHOWING CHANNELS AND SWALES ON HOSKINNINI MESA, NAVAJO COUNTY, ARIZONA

period the significance of fluorescent silica (hyalite) as a guide to uranium ore in Monument Valley was recognized. A number of samples of Shinarump sandstones from and adjacent to ore deposits contain fluorescent secondary silica. The fluorescent color varies with increase in uranium content from a pale yellowish green to deep green. Quantitative analyses indicate a concentration of uranium in the silica about 10 times that found in the enclosing rock, and samples of silica taken near ore contain more uranium than samples more distant from ore. The occurrence of this fluorescent silica may prove useful as a guide to prospecting on rim exposures and talus slopes and in the examination of drill cores.

Red House Cliffs area, Utah, quadrangle mapping, by T. E. Mullens

Field work on the Red House Cliffs project was completed in fiscal year 1954. Preparation of the final report is nearing completion. As an interim measure the geologic map is being processed for publication in black and white by the USGS in the Mineral Investigations Field Studies map series.

White Canyon area, Utah, quadrangle mapping, by A. F. Trites, Jr.

Field work in the White Canyon area was completed in September 1954. A total of eight 7-1/2 minute quadrangles, or about 400 square miles, was mapped on a scale of 1:48,000. Detailed studies were made at the Blue Lizard, Happy Jack, Fry No. 4, and White Canyon No. 1 mines and at the Bell, Maybe, and Scotty claims.

Geologic studies show that the uranium deposits in the White Canyon area occur in channels cut into beds of the Moenkopi formation of Early Triassic age. Channels most favorable for uranium deposits appear to be those in which the sediments consist of 20 to 30 percent siltstone or claystone and 70 to 80 percent sandstone and conglomerate. The most highly mineralized rocks within these favorable channels are sandstone and conglomerate beds that intertongue with or overlie siltstone or claystone beds and contain a high percentage of clay cement, abundant claystone seams and pebbles, and concentrations of small pieces of carbonized wood. Fine-grained sediments and trashy material appear to have been concentrated at branches and bends in channels and in deep scours in channel floors.

Uraninite, the principal uranium mineral in the unoxidized deposits, is commonly associated with pyrite, chalcopyrite, bornite, sphalerite, and marcasite, and, in one deposit, with small amounts of galena. Nonmetallic gangue minerals most commonly associated with uraninite include the supergene sulfates, jarosite and gypsum, in addition to the quartz, microcline, hydromica, and kaolinite which are indigenous to the Shinarump conglomerate.

Copper has been secondarily enriched in most of the oxidized deposits; chalcocite, covellite, chalcanthite, brochantite, and malachite are the most common supergene copper minerals. Secondary uranium minerals include hydrous oxides; silicates, phosphates, and arsenates.

Elk Ridge area, Utah, quadrangle mapping, by R. Q. Lewis, Sr.

The Elk Ridge area is located near the center of San Juan County, Utah, on the north end of the Monument upwarp. Field work started in the summer of 1953 and continued during the 1954 field season. At the end of the 1954 field season 80 percent of the area was mapped.

A belt of relatively continuous Shinarump conglomerate crosses South Elk Ridge, trending in a northeasterly direction. This belt has been roughly outlined by careful plotting of all available rim exposures of Shinarump conglomerate, though much of the area is covered with soil and talus. Detailed studies during the coming field season will be directed chiefly to the Moss Back member of the Chinle formation, which is known to contain ore in the northern part of the Elk Ridge area.

San Rafael Swell area, Utah, strip mapping, by R. C. Robeck

Detailed field sketching of vertical sections along 20 miles of rim outcrop near Temple Mountain has helped to delineate the Moenkopi formation, the Shinarump conglomerate, and the Monitor Butte, Moss Back, and Church Rock members of the Chinle formation. The vertical sketches have also shown that minor sandstone channels of Shinarump cut into the underlying Moenkopi. These channels trend about N. 20° W.; none are radioactive, and they appear to be unfavorable sites for uranium deposits.

From Temple Mountain northward, Moss Back sandstone overlies the Shinarump, is relatively thick and massive, and is barren. At Temple Mountain, the Moss Back locally thickens. South of Temple Mountain, the Moss Back thins and is interbedded with mudstones. This facies change may be one of the main reasons for the accumulation of uranium at Temple Mountain. Deposits on Green Vein Mesa on the west side of the San Rafael Swell and at Flat Top Mesa may be in the same stratigraphic belt. The belt may project from Temple Mountain southeastward and may contain significant ore deposits along its course.

Southwest from a point about 2 miles southwest of Temple Mountain, the Moss Back becomes thin and ore of marginal commercial grade is found only in channels cut into the underlying Monitor Butte. The Shinarump is also present under the Monitor Butte at least as far southwest as Chute Canyon.

Mapping and vertical sketching of rim outcrops of the Shinarump and Chinle were started near the Hidden Splendor (Delta) mine and have extended northward along the west side of the Muddy River. Some of the numerous channels in the Moss Back in this area have recently yielded uranium ore. The Shinarump is absent throughout most of this area.

Lisbon Valley area, Utah-Colo., quadrangle mapping, by G. W. Weir

The Lisbon Valley quadrangle mapping project includes about 750 square miles in northeastern San Juan County, Utah, and adjacent counties in Colorado. Significant uranium deposits are known in the upper part of the Cutler formation of Permian age, in the Moss Back member of the Chinle formation of Upper Triassic age, and in the Salt Wash member of the Morrison formation of Upper Jurassic age. The Lisbon Valley area in general is thoroughly prospected, and small parts have been well explored by drilling. The Morrison, Chinle, and Cutler (?) formations, where they crop out around South Mountain, may offer opportunities for discoveries of uranium deposits by surface prospecting.

Compilation of drill-hole data in the Brown's Hole area, where ore occurs in the Salt Wash member of the Morrison formation, shows that the ore is associated with areas of thicker sandstone, but channels are not distinct and clear indications of structural control were not observed. The extension of known deposits suggests that other significant uranium deposits may be discovered in the Brown's Hole-West Coyote Creek area.

An anomalous concentration of uranium (0.01 percent) was noted in one sample collected from the Permian Cutler formation at the Woods copper mine, and similar anomalies have been reported previously from some other copper deposits in the area; in general, however, association of uranium with copper has not been demonstrated.

The northeast (downthrown) side of the Lisbon Valley fault is complicated structurally by many secondary hinge faults with displacements measuring several hundreds of feet. Sandstone and conglomerate of the Burro Canyon formation and the Dakota sandstone, both of Cretaceous age, are commonly highly silicified in the Lisbon Valley-West Coyote Wash area. This silicification appears to be related to the Lisbon Valley fault, but may also be related to the silicification noted in many coarse-grained formations near the igneous rocks of South Mountain. The silicified beds hamper drilling exploration of the more deeply buried formations and make it difficult to differentiate between the Burro Canyon formation and the Dakota sandstone.

Preliminary results of geochemical studies undertaken last summer in the project area indicate that anomalous concentrations of the ore metals in colluvium overlying high-grade ore are restricted to within a few inches of the contact and that background concentrations of some elements in the ore-bearing units vary with the clay (alumina) content. The geochemical studies are continuing.

Moab-Inter-river area, Utah, strip mapping, by E. N. Hinrichs

Project work during the report period consisted mainly of compiling field data and studying the mineralogy of the ore deposits in the lower Cane Creek region of the Inter-river area. The following minerals from mines of this region were identified: carnotite, metatyuyamunite, andersonite, schroeckingerite, bayleyite, beta-zippeite, uraninite, barite, and pyrolusite (?).

Circle Cliffs area, Utah, quadrangle mapping, by E. S. Davidson

Compilation of oil well data and library research shows that the so-called Coconino sandstone cropping out in Circle Cliffs may be the White Rim member of the Cutler formation, as indicated in a report by Robert H. Steed published in the 1954 annual guidebook of the Intermountain Association of Petroleum Geologists. Field work in the area was resumed May 20.

Abajo Mountains area, Utah, quadrangle mapping, by I. J. Witkind

During the report period thin sections representing the dominant igneous and sedimentary rock types were studied and compared. Much of the igneous rock is porphyritic in texture, and samples taken from widely separated localities are unusually uniform in composition. The principal igneous rock is a latite porphyry, which locally coarsens to become a diorite porphyry. The sedimentary rocks are principally sandstones and shales that have been metamorphosed into quartzites and slates near the igneous margins.

The known uranium and vanadium ore deposits are in the Salt Wash member of the Morrison formation (TEI-490, p. 38-39). Only a few economically significant deposits have been found. Dense foliage and a thick mantle of colluvium conceal large areas and hinder prospecting.

Sage Plain area, Utah-Colo., quadrangle mapping, by L. C. Huff

Near the Rim Rock mine (sec. 27, T. 24 S., R 24 E.) 50 samples were collected in duplicate so that reproducibility of sampling and analyses could be evaluated. Radiometric measurements by different operators furnished similar data in duplicate. The scintillometer measurements were found to have a high order of reproducibility (table 1). Measurements of total heavy metal content, vanadium content, and radioactivity determined with a field scaler have a similar high order of reproducibility. Uranium analyses were made using a field-type chromatographic method being perfected by the Survey's Geochemical Exploration Unit. The uranium measurements (table 2) and measurements of radioactivity with a geiger counter are less reproducible than the measurements of radioactivity with a scintillometer.

Table 1. Scatter diagram of duplicate measurements of radioactivity with a scintillometer at 50 sample sites

		Number of sample sites within the ranges of radioactivity (mr/hr) shown, measured by first operator					
		.01	.01 to .019	.02 to .039	.04 to .079	.08 to .159	>.16
Number of sample sites within the ranges of radioactivity (mr/hr) shown, measured by first operator	>.16	0	0	0	0	1	1
	.08 to .159	0	0	0	0	0	2
	.04 to .079	0	0	1	4	0	0
	.02 to .039	0	4	7	0	0	0
	.01 to .019	0	19	1	0	0	0
	<.01	9	1	0	0	0	0

Table 2. Scatter diagram of uranium analyses of 50 samples collected in duplicate

		Number of samples in ranges of uranium content in original samples (concentration expressed in PPM)				
		2	2	4	8	12
Number of samples in ranges of uranium content in duplicate samples (concentration expressed in PPM)	21	0	0	0	1	0
	8	1	1	0	0	0
	4	2	0	1	2	0
	2	1	0	0	0	0
	2	38	0	2	0	1

A series of samples was collected from all the formations exposed on the Sage Plain, ranging from the Navajo sandstone of Jurassic age to the Mancos shale of Cretaceous age, and also from several types of surface deposits. Fifty samples were collected from rocks within 50 feet of a uranium deposit and 50 samples were collected from rocks at least 500 feet or more away from the deposit. Seventeen samples taken near ore contained at least 2 ppm uranium, but all samples collected 500 feet or more from ore contained less than 2 ppm uranium. These data indicate that the uranium anomaly or "halo" in the vicinity of this deposit is irregular, probably too subtle to be defined by the present chromatographic method of uranium analysis.

Sixteen of the 50 samples collected near ore contained at least 4 ppm uranium. Seven of these 16 samples were taken from mudstone lenses underlying the ore body. These lenses contained only normal background radioactivity (about 0.01 mr/hr.) at the outcrop.

Nineteen of the 50 samples collected near ore were from sites that contained anomalous radioactivity of 0.04 mr/hr. or more at the outcrop. Of these 19 samples, 10 samples were taken from sandstone units overlying the ore; but these 10 samples contained less than 2 ppm uranium. Stated briefly, sandstones overlying the ore are relatively low in uranium but high in radioactivity, and mudstones underlying the ore are high in uranium but low in radioactivity. This lack of equilibrium between uranium content and radioactivity may be the result of recent leaching of uranium from the sandstones and reprecipitation in the mudstones below. Further investigation is planned to determine if uranium analysis of mudstones underlying the ore-bearing sandstone can reveal the presence of unexposed uranium deposits.

Western San Juan Mountains, Colo., quadrangle mapping, by A. L. Bush

During the preceding report period mapping in the Placerville quadrangle was essentially completed. During the present report period field maps of the Placerville quadrangle were compiled for eventual publication in the Mineral Investigations Field Studies series after some field checking; and library work and the petrographic study of the rocks in the quadrangle were largely completed. Areal and mine mapping was resumed early in May.

Photogeologic mapping

by

W. A. Fischer

The photogeologic mapping program is designed to provide regional geologic maps of specified areas in Utah and Arizona to serve until more detailed surveys can be made.

During the report period photogeologic maps of 22 quadrangles were completed, making a total of 263 produced since the program was started in 1951.

The practice of making photogeologic maps available to the public through open-filing has been discontinued. All new maps are now transmitted to AEC as Trace Elements reports and are later published by the USGS in the Miscellaneous Geologic Investigations Map series. Publication in this series was initiated to give wider distribution of photogeologic maps at lower cost than was possible under the open-file system. During the report period considerable effort has been devoted to processing not only current maps, but also maps previously released in open file, for publication. During the six-months period 57 maps were submitted for publication, bringing the total in that category to 115. Of these, 50 maps have actually been published.

Most of the quadrangles completed since November 30, 1954 have been prepared from high-altitude photography in conjunction with the Kelsh plotter. This change in procedure has resulted in increased accuracy in compilation.

The progress of the photogeologic mapping program is shown on the index map, figure 6.

Stratigraphic studies

by

G. A. Williams

Morrison formation

Field studies of the Morrison formation have been completed except for spot checking of critical areas. Brief visits in northeastern Utah and northwestern Colorado show that the Morrison formation can be differentiated only locally into two members. The Salt Wash member can be distinguished only for short distances along the outcrop where lenticular sandstone beds of Salt Wash aspect are present in the lower part of the Morrison. Based on lithologic characteristics, the upper part of the Morrison near Vernal, Utah, may contain beds equivalent to the Cedar Mountain formation of Stokes, a unit of Lower Cretaceous age in south-central Utah.

The first draft of the final report on the petrology of the Morrison formation is near completion. Two reports resulting from the study of the Morrison formation are in preparation. The first summarizes and analyzes the petrologic data collected by the laboratory and applies the results of this analysis to the interpretation of the geologic history of the Morrison formation. The second is a report on the sedimentary structures

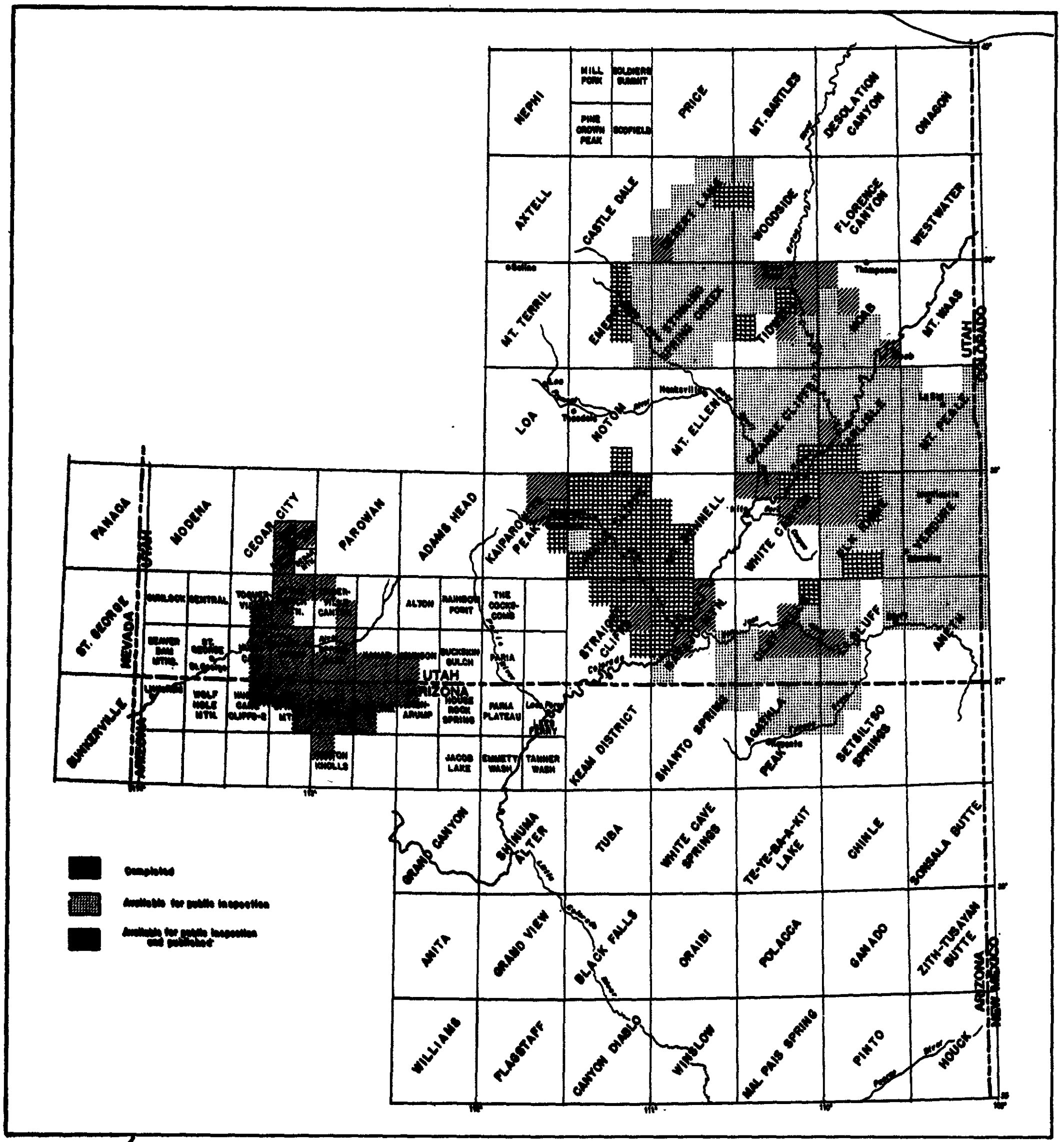


Figure 6 Index map of part of the Colorado Plateau area, showing location of photogeologic quadrangle maps completed, available for public inspection, and published as of June 1, 1955.

of the Morrison formation. These reports will be incorporated in the final comprehensive report.

Triassic and associated formations

Regional stratigraphic studies of Triassic rocks on the Colorado Plateau have reached a stage where some general conclusions can be made regarding the distribution, lithology, and origin of the rocks, and the paleogeology of Triassic time. An outline of these conclusions follows:

The Moenkopi formation of Early and Middle (?) Triassic age is present in outcrops in the western two-thirds of the Colorado Plateau province. The formation attains a maximum thickness of more than 2,100 feet near Cedar City, Iron County, Utah, but thins eastward to a wedge-edge along an irregular north-south line near the Utah-Colorado and Arizona-New Mexico borders.

The Moenkopi is dominantly a pale reddish brown, horizontally-laminated and ripple-marked siltstone. Limestone members are present near the western limit of the Plateau and include the Sinbad limestone member in central Utah and Virgin limestone and the Timpoweap members in northwestern Arizona and southwestern Utah. Cross-stratified conglomeratic sandstone beds are present in a belt about 30 miles wide near the eastern limit of the formation.

The Moenkopi formation probably is a tidal flat deposit formed adjacent to a sea that lay to the west of the Colorado Plateau. The limestones are marine deposits formed as the sea transgressed eastward onto the Colorado Plateau region. The sandstone beds near the eastern margin of the Moenkopi are interpreted to be stream deposits and the direction of dip of the cross-strata indicate that the streams flowed dominantly northwest. The source area for the sandstone beds and possibly for much of the Moenkopi, as indicated by the presence of conglomerates as well as by the trend of sedimentary structures, probably lay to the east of the eastern limit of the Moenkopi.

Upper Triassic formations, which unconformably overlie the Moenkopi formation, are the Shinarump conglomerate, Chinle formation, and Wingate sandstone. These formations appear to be conformable and commonly intertongue or intergrade with one another. Deposition was continuous throughout Upper Triassic time on much of the Colorado Plateau.

Present stratigraphic terminology of the Upper Triassic rocks is complex and hides some gross stratigraphic relations. In order to indicate major lithologic and genetic differences, the Upper Triassic rocks can be divided into four units, which here will be called, in ascending order, units 1, 2, 3, and 4. Distribution of these units is shown in figure 7. Locally the units can be subdivided, but the lithologic differences between these subdivisions are minor as compared with the differences between the four major units. The units are in stratigraphic sequence in any one area, but a large part of a unit in one area may have been deposited at the same time as a part of another unit in another area.

Most of the information on the distribution of these units in northeastern Arizona and adjoining parts of New Mexico is taken from work done by J. W. Harshbarger and his associates of the Ground Water Division of the Geological Survey.

Unit 1 is composed of the strata from the base of the Shinarump conglomerate to the top of the Petrified Forest member of the Chinle formation. It includes the Monitor Butte and Moss Back members of the Chinle formation and the lower member of the Chinle formation (a member in part

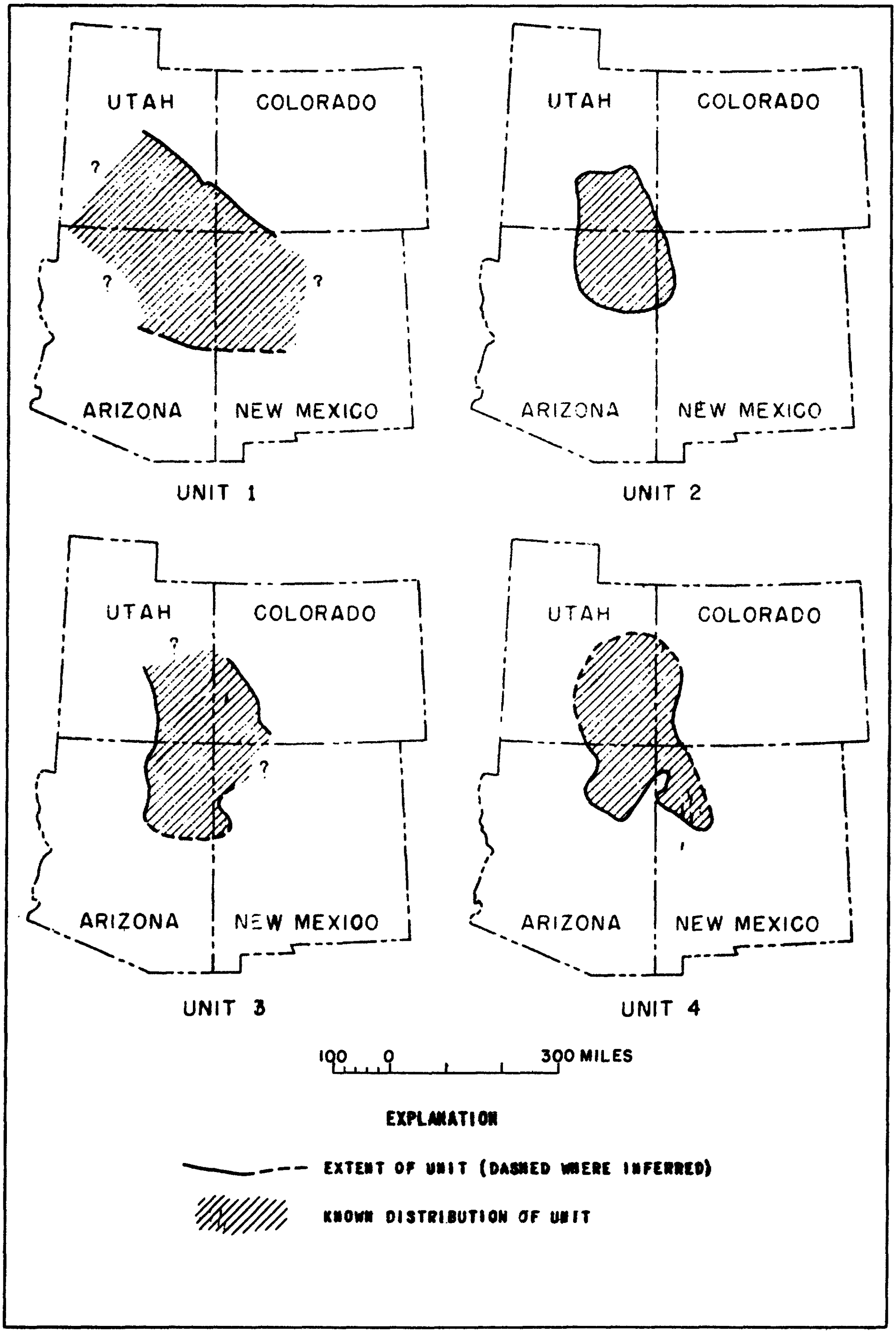


Figure 7. DISTRIBUTION OF UNITS 1, 2, 3 AND 4 OF UPPER TRIASSIC ROCKS OF THE COLORADO PLATEAU

of northeastern Arizona). The Petrified Forest member forms the main mass of unit 1 in most areas.

About 80 to 90 percent of unit 1 is banded red, green, gray, and purple bentonitic cross-stratified or structureless claystone or clayey sandstone that weathers as badlands. From 1 to 10 percent of the sandstone is orange chert (?), and a small percent is dark green mica (probably biotite). The rest of unit 1 is yellowish gray, very fine-grained to conglomeratic, cross-stratified sandstone that weathers to form ledges. These sandstones include the Shinarump conglomerate, the Moss Back member, and several sandstone beds in northeastern Arizona that lie a few hundred feet above the base of the Chinle formation. Unit 1 is more than 1,000 feet thick near its southern margin (a limit of the preservation of Upper Triassic rocks) and thins along any northeast oriented line to a wedge-edge at its northern limit (a limit of deposition).

Unit 1 was probably deposited in a stream and floodplain environment. Studies of the direction of dip of cross-strata indicate that the streams flowed north and northwest. Volcanic source rocks for most of the material are indicated by the presence of bentonitic clays throughout the unit and of pebbles of extrusive igneous rock in some of the sandstone beds in east-central Arizona. The direction of stream flow suggests a large source area extending across southern Arizona and New Mexico.

Unit 2 is the Owl Rock member of the Chinle formation or "division B" of the Chinle of Gregory. It is composed of reddish siltstone and about 5 to 10 percent greenish gray limestone beds which distinguish the unit from the underlying and overlying rocks. Intertonguing of this member with adjacent strata is prominent in many areas. The member is 300 to 400 feet thick in the central part of its area of deposition. The Owl Rock member is interpreted to be chiefly a fresh-water lake deposit and may have received sediment from several sources.

Unit 3 is composed of the Church Rock member of the Chinle formation in southeastern Utah and the Monument Valley area, Ariz.; undifferentiated Chinle formation in southwestern Colorado; the Dolores formation in the San Juan Mountains; and the Rock Point member of the Wingate sandstone in northeastern Arizona or "division A" of the Chinle of Gregory.

Unit 3 is composed of reddish horizontally-laminated and structureless siltstone and minor quantities of pale red, very fine-grained, cross-stratified sandstone. This unit intertongues and intergrades extensively with the overlying and underlying rocks. The thickness is generally about 200 to 300 feet, but the unit reaches a thickness of more than 800 feet in the southern part of the Navajo Indian Reservation and more than 600 feet in part of the San Juan Mountain region.

The siltstone of unit 3 was probably deposited in fresh-water lakes and the subordinate sandstone by streams. The Uncompahgre highland of southwestern Colorado may have been the major source of the sediment for this unit because the unit thins to the west away from the Uncompahgre highland.

Unit 4 is the Lukachukai member of the Wingate sandstone which forms the entire Wingate sandstone in southeastern Utah and in the Monument Valley area, Ariz. The Lukachukai member is composed of very pale orange and light brown, very fine- to fine-grained well-sorted sandstone, which is cross-stratified on a large scale. It averages about 300 feet thick.

The Lukachukai member is interpreted to be an eolian deposit. Studies of direction of dip of cross-strata indicate that the prevailing winds blew to the southeast. The source of the sediments is not known.

Results of a study of the directional tendencies of sedimentary structures in the rocks of the Colorado Plateau are summarized as follows: Sedimentary structure studies made in Permian rocks indicate that (1) the Coconino sandstone had a southerly direction of transport, (2) the Cedar Mesa sandstone member of the Cutler formation had a southeasterly direction of transport, and (3) the DeChelly sandstone member of the Cutler formation was transported southwesterly. The sandstones of the Moenkopi formation, Shinarump conglomerate, and Moss Back member of the Chinle formation, all of Triassic age, indicate a northwesterly direction of transport. The Wingate sandstone of Triassic age and Navajo sandstone of Jurassic and Jurassic (?) age were transported southeasterly.

Sedimentary structures are useful in determining depositional environments and are helpful in stratigraphic correlation; they can also be used in the exploration for uranium and vanadium ore deposits of the Colorado Plateau. Many ore bodies are localized in channel-filling sandstones and tend to be elongate in the direction of transport of the sandstone. Evaluation of sedimentary structures at the outcrop, combined with information gained from preliminary drilling, may reduce the number of holes required to locate or to outline an ore body.

Analyses of lithology, color, size, sphericity, and roundness of pebbles in the Shinarump conglomerate and the Moss Back member of the Chinle formation were made. The difference in ratio of quartz, quartzite, and chert pebbles; the distribution of limestone and siltstone pebbles; and, to a lesser degree, the difference in color serve to distinguish the Moss Back from the Shinarump. In areas where the Moss Back and Shinarump are both present the average ratios of quartz, quartzite, and chert are respectively about 12:37:51 for the Moss Back and 82:16:2 for the Shinarump.

Limestone and siltstone pebbles are commonly found in the Moss Back, whereas they are rarely found in the Shinarump. The Moss Back contains more gray to black pebbles and less light colored pebbles, such as red, orange, and white, than the Shinarump. Size, sphericity, and roundness of pebbles do not show a significant difference between the two units.

Fossils in selected pebbles from each unit have been identified and indicate that most of the fossiliferous pebbles in the Moss Back and Shinarump were derived from rock chiefly of late Paleozoic age and that the pebbles could have had a common source.

The sedimentary petrology laboratory completed a study on two samples of the Browns Park formation (late Miocene and early Pliocene) from northwestern Colorado as a service to the reconnaissance resource appraisal program. A brief summary of the results follows: One sample is from a low-grade uranium deposit 3 miles west of Lay, Moffat County, Colo.; the other sample, from a site several miles away, is not associated with mineralized rock. The sandstone of the Browns Park formation in this region, as represented by the two samples, is an arkose. Mineral composition includes orthoclase, albite, oligoclase, labradorite, quartz, noselite, biotite, and muscovite. Heavy minerals include clinozoisite, zoisite, hypersthene, hornblende, garnet, magnetite, and unidentified opaques. The two samples average 10 percent noselite, suggesting a highly alkaline composition for the source rock such as a soda-rich monzonite.

Comparison of the two samples revealed only a few differences. The mineralized sample has only one-seventh to one-fourteenth as much total heavy minerals by weight as the unmineralized sample. The suites of heavy minerals had similar mineral proportions except that the mineralized sample had only 8 percent as much hornblende and 60 percent as much magnetite as the unmineralized sample.

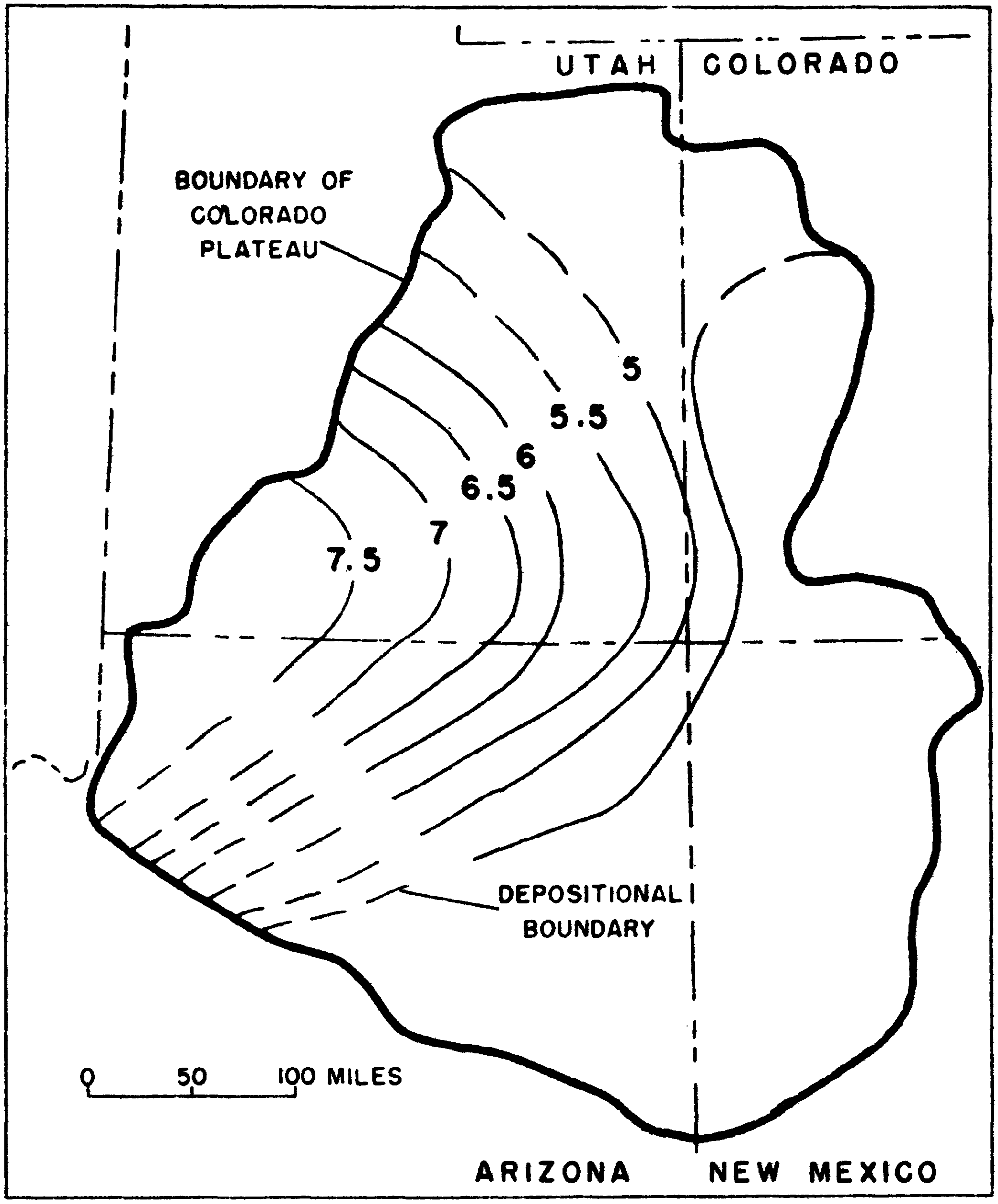
A comparison of the light mineral suites reveals twice as much noselite (13 percent) in the barren sandstone. Seven percent of the grains in the mineralized sandstone are coated with an unidentified brown opaque substance.

Ground-water studies

by

D. A. Jobin

Field work during the report period shows that the rocks of the Colorado Plateau with appreciable transmissive capacity may be grouped into two main categories: (1) eolian and marine sandstones and siltstones that have relatively uniform thicknesses and permeabilities over large areas, and (2) fluvial sandstones and conglomerates that locally are lenticular and exhibit relatively great ranges in thickness and permeability. The transmissivity of eolian and marine sediments is relatively high, and fluid movement through them would be relatively uniform. Generally, higher mean permeability, greater thickness, and a more uniform gradient in both permeability and thickness give the eolian (cf. Navajo sandstone, fig. 8) and marine sandstones a higher transmissive capacity than the fluvial sediments (cf. Shinarump conglomerate, fig. 9, and Morrison sandstones, fig. 10). Fluvial rocks consist of one or more strata of lenticular sandstone or conglomerate that have a large range in permeability and are separated by relatively impermeable mudstones. The permeability gradient within a fluvial stratum varies erratically both vertically and horizontally, but in general high mean permeabilities correspond with the thicker parts and low mean permeabilities correspond with the thinner parts.

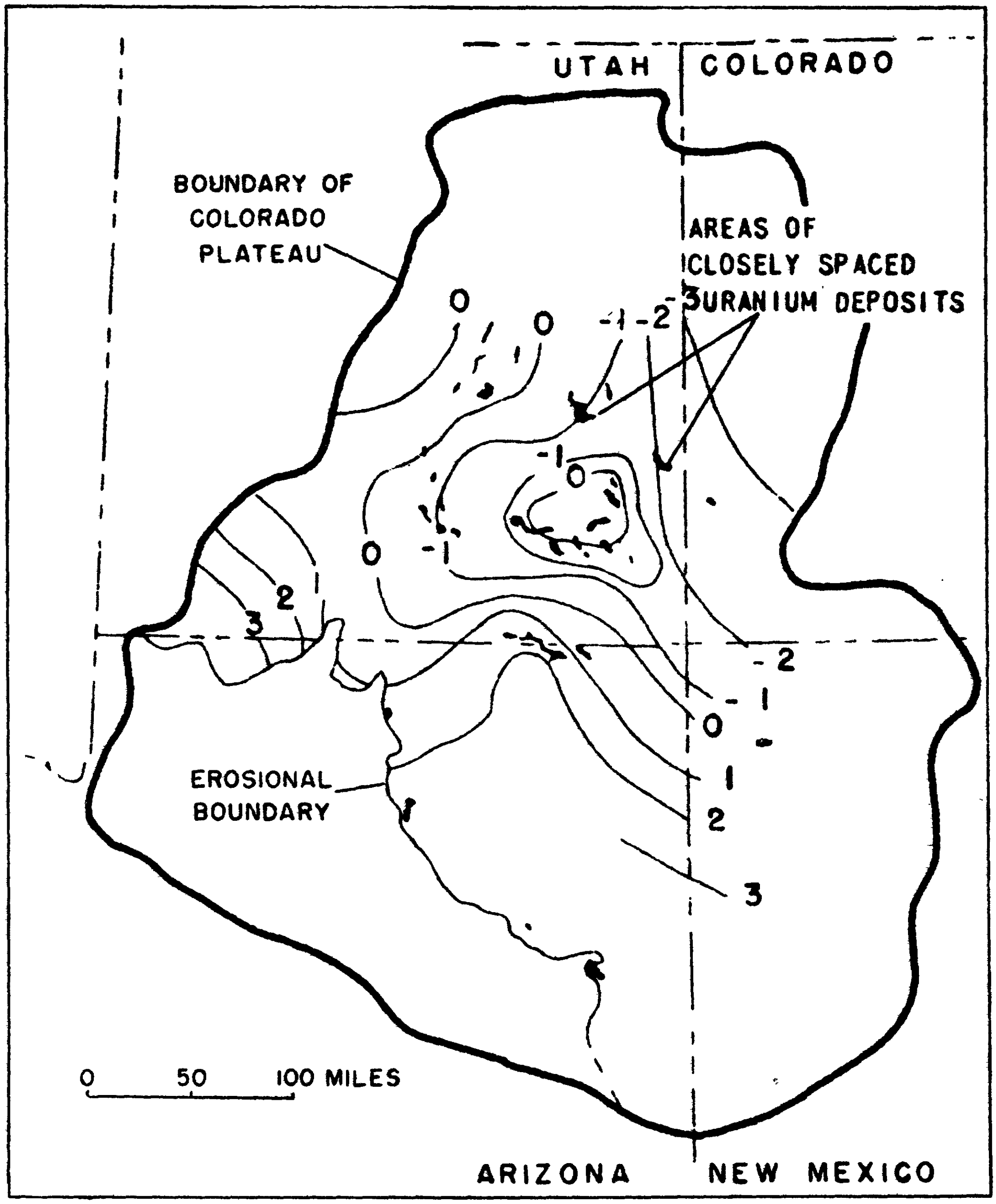


EXPLANATION

~7~

ISOPLETH OF TRANSMISSIVITY IN DARCY-FEET EXPRESSED IN NATURAL LOGARITHMS

Figure 8. ISOTRANSMISSIVITY MAP OF THE NAVAJO SANDSTONE



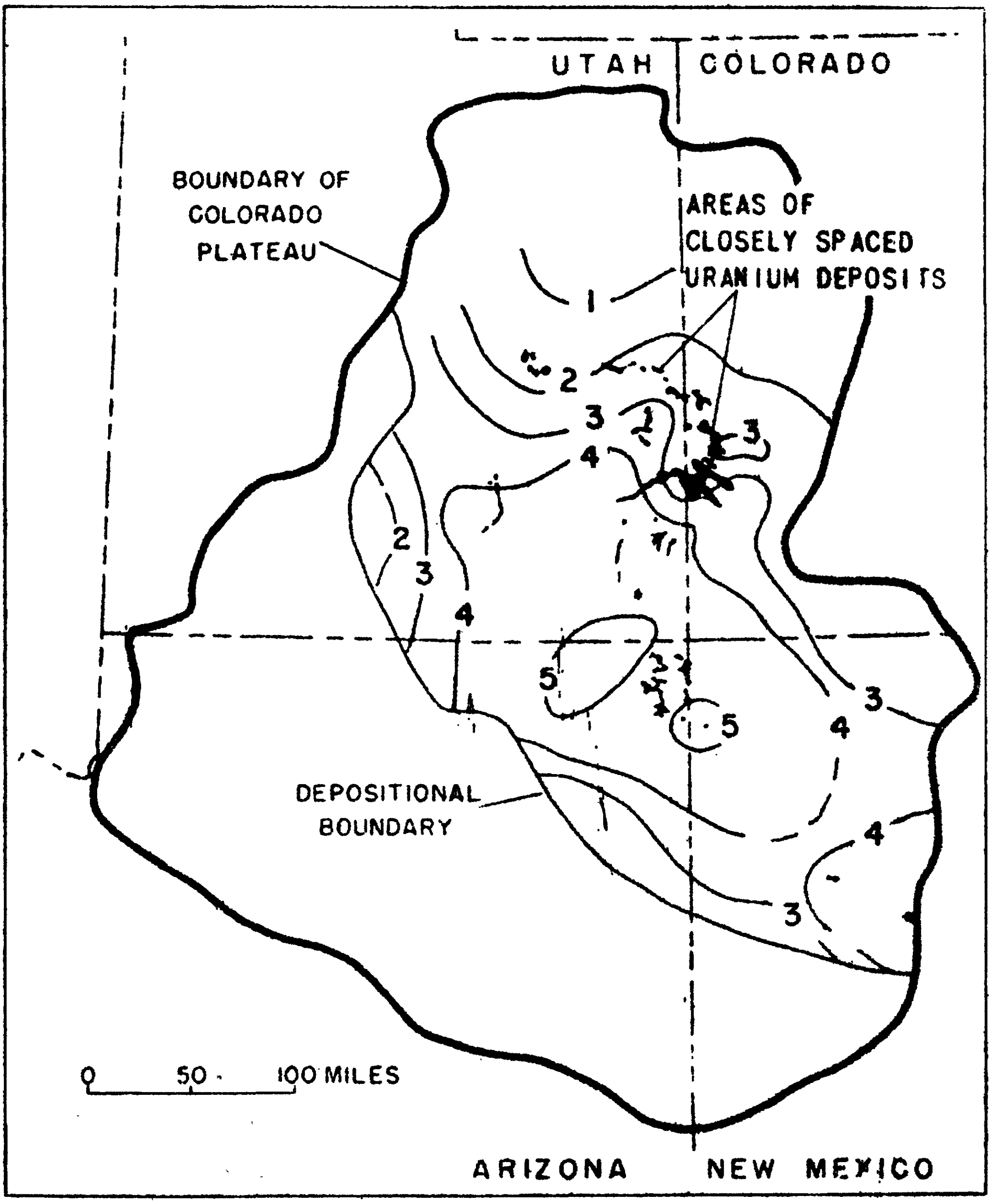
EXPLANATION

2

ISOPLETH OF TRANSMISSIVITY IN DARCY-FEET EXPRESSED IN NATURAL LOGARITHMS

AREAS UNDERLAIN BY CLOSELY SPACED URANIUM DEPOSITS

Figure 9. ISOTRANSMISSIVITY MAP OF THE SHINARUMP CONGLOMERATE AND LOWER CHINLE SANDSTONES SHOWING DISTRIBUTION OF URANIUM DEPOSITS



EXPLANATION

—3—

ISOPLETH OF TRANSMISSIVITY IN DARCY-FEET EXPRESSED IN NATURAL LOGARITHMS

AREAS UNDERLAIN BY CLOSELY SPACED URANIUM DEPOSITS

Figure 10. ISOTRANSMISSIVITY MAP OF THE MORRISON SANDSTONES SHOWING DISTRIBUTION OF URANIUM DEPOSITS

The gross lithologic sequence, transmissivity, and distribution of uranium in the exposed Permian and Mesozoic sedimentary rocks of the Colorado Plateau are shown in table 3. Although few strata are entirely devoid of uranium deposits, a large majority of the deposits are confined to essentially two groups of beds: the sandstones of the Morrison formation, and the Shinarump conglomerate and sandstones and conglomerates of the lower Chinle formation. The regional distribution of deposits in both groups of beds appears unrelated to any particular transmissivity range.

The differences in transmissive characteristics between the Morrison and Shinarump-Chinle strata, chiefly the high transmissivity and smaller range in local variation of transmissive capacity in the Morrison strata, seem to correlate with the greater frequency of occurrence and smaller range is size of uranium deposits in the Morrison strata. The bulk of the mined ore and known reserves in the Morrison strata are found in many widely scattered moderate-sized deposits. The bulk of the mined ore and known reserves of the Shinarump-Chinle strata are found in a few, widely scattered, large deposits.

Other lithologic assemblages which contain significant amounts of uranium are the Mesaverde, Dakota-Burro Canyon-Buckhorn, Cutler, Entrada, and Todilto-Pony Express units. The first three of these units are fluvial sandstones and conglomerates, have transmissive characteristics essentially similar to the Morrison and Shinarump-Chinle strata, and are also overlain by relatively nontransmissive units. Although uranium deposits are widely spaced in these strata they do not approach in either frequency or size the deposits in the Morrison or Shinarump strata.

Table 3. Summary of Lithologic Sequence, Transmissivity, and Uranium Distribution of the Colorado Plateau

System	Formations or lithologic assemblage treated as a unit a/	Intrinsic Transmissivity		Distribution of uranium deposits c/	
		Type	Mean b/	Relative Frequency	Mode
Cretaceous	Mesaverde	Moderately variable	5.5	Moderate	Small widely scattered
	Mancos	Uniform	0	Infrequent	One occurrence, small
	Dakota-Burro Canyon-Buckhorn Conglomerate	Highly variable	3.3	Moderate	Small, widely scattered
Jurassic	Morrison Mudstones	Uniform	0	Infrequent	Associated with sandstone deposits
	Morrison Sandstones	Highly Variable	3.8	Very high	Wide distribution, Large and small
	Bluff-Junction Creek	Uniform	4.0	Infrequent	One occurrence
	Cow Springs	Uniform	4.4	None	None
	Summerville	Uniform	0	Infrequent	Small, widely scattered
	Todilto-Pony Express	Uniform	0	Moderate	Medium to large, most in one District, Fracture control
	Curtis	Uniform	2.0	Infrequent	Two small deposits
	Entrada	Uniform	3.2	Moderate	Small, widely scattered, Large deposits in Three Districts
	Carmel	Uniform	0	Infrequent	Small, one District
Jurassic and Jurassic (?)	Navajo	Uniform	6.1	Infrequent	Two occurrences, Fracture control
Jurassic (?)	Kayenta	Moderately variable	2.1	Infrequent	Small, widely scattered
Triassic	Wingate	Uniform	3.6	Infrequent	Small, widely scattered one large deposit at Temple Mountain, Utah
	Chinle (excluding Basal sandstones)	Uniform	0	Infrequent	Small, two localities
	Shinarump conglomerate (including basal Chinle sandstones)	Highly variable	0	High	Small, wide distribution with few widely scattered very large
	Moenkopi	Uniform	0	Infrequent	Small, widely scattered
Permian	Kaibab	Uniform	0	Infrequent	Small, one district, Fracture control
	Cutler (Undivided)	Highly variable	1.0	Moderate	Small, one district
	Coconino-San Andreas (and sandstone members of Cutler)	Uniform	4.0	Infrequent	One occurrence in Coconino, fracture control
	Hermit Shale	Uniform	0	Infrequent	One occurrence
	Supai	Uniform	0	Infrequent	One occurrence, vein type

a/ Lithologic sequence is in chronological order except where equivalents are treated as individual units

b/ Natural logarithm of product of arithmetic mean thickness in feet and arithmetic mean permeability in Darcys

c/ 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. Geological Survey Mineral Investigations, Field Studies Map MF 16. Isachsen, Y. W. Mitcham, T. W., and Wood, H. B. 1955, Age and sedimentary environments of uranium host rocks, Colorado Plateau, Economic Geology, volume 50, pages 127-134.

The Entrada sandstone and Todilto limestone constitute opposite extremes in intrinsic transmissive capacity and the habit and distribution of uranium deposits seem to be controlled to some degree by these differences. The Entrada deposits are the only known sizable uranium deposits found in eolian or marine sandstones of the Colorado Plateau. Most of these deposits are in three districts and in each district the ore bodies represent locally thickened portions of an essentially continuous layer. Individual ore bodies are large relative to those in the Morrison and Shinarump strata, and exhibit most of the same habits, but on a larger scale and with less distinct boundaries. The Todilto-Pony Express strata, with no intrinsic transmissive capacity, is also unique in that it contains nearly all the sizable deposits of uranium found in limestone on the Colorado Plateau.

In summary, the contrast in total quantity of uranium, and in frequency and mode of distribution of uranium deposits between major intrinsic transmissivity types, is striking. Those strata that vary greatly in local transmissivity, have a moderate to low regional intrinsic transmissive capacity, and are overlain by a thick nontransmissive unit, contain a large majority of the mined ore and known reserves. Strata that fall into this category have a moderate to high frequency of uranium occurrence with the distribution of deposits showing no preferred transmissivity range. With the exception of the Entrada sandstone, units with a uniform intrinsic transmissive capacity, either high or low, contain only a few small uranium deposits.

The mode of uranium distribution correlates well with intrinsic transmissive capacity in all uranium-bearing units. Generally, as the transmissive capacity increases and the range in local transmissivity decreases, the range in size of deposits decreases.

Botanical studies

Botanical research, by H. L. Cannon

Laboratory studies.--Analyses of the experimental garden material were compiled and evaluated during the report period. It was found that selenium becomes more available to selenium indicator plants in the presence of carnotite. This obviously has a direct bearing on the presence of such plants in the vicinity of carnotite deposits.

Laboratory studies were started on the effect of selenium and sulfur on the solubility of uranium in carnotite and conversely, the effect of carnotite on the solubility of selenium and sulfur. Results of preliminary experiments indicate that: (1) the presence of selenium and sulfur causes the uranium in carnotite to be more soluble at pH 8.0 or more; (2) that in such a system the selenite and sulfite ions tend to be oxidized to the selenate and sulfate states.

By arrangement with the U. S. Department of Agriculture Nutrition Laboratory at Ithaca, New York, plans were made to have the Santa Fe plot experiments duplicated in the greenhouse. These will be check studies on the absorption of uranium, vanadium, selenium, sulfur, calcium, phosphorous, sodium, and potassium in plants.

Field studies.--Field studies were started on high altitude Astragalus species and their relation to selenium, uranium, and equivalent uranium in the soil. It is planned to study the absorption of radioactive daughter products from carnotite ore bodies by plants and to ascertain their effect on plant growth. An investigation also was started of the variation from one locality to another of the cell sap pH of each indicator plant and the pH of the soil in which it grows, in order to determine the relation, if any, between the cell sap pH and the pH of the soil.

Botanical prospecting, by F. J. Kleinhampl and P. F. Narten

The evaluation of botanical prospecting data obtained during the previous report period was continued for projects in the Elk Ridge area, San Juan County, Utah; the Circle Cliffs area, Garfield County, Utah; the San Rafael Swell area, Emery County, Utah; and in the Grants district, Valencia and McKinley Counties, N. Mex.

Absorber plant anomalies occur along the Shinarump conglomerate in the southwestern part of Elk Ridge. These anomalies are indicated by many abnormally high uranium assays from tree samples and are supported by favorable geologic criteria, such as the presence of thick sandstone, carbon, pyrite or limonite, and abnormally high radioactivity. Statistical study of analyses of 340 branch-tip samples collected on Elk Ridge indicates that 1.0 ppm or more uranium in pinyons and 0.8 ppm or more in junipers probably indicates anomalously large amounts of uranium in the rooting medium. These cutoff values differ only slightly from the cutoff values adopted in other sampled areas.

An evaluation of botanical prospecting methods in the Circle Cliffs area showed that sulfur and calcium indicator plants are not useful in defining uraniferous ground along the ore zone at the contact of the Moenkopi formation and Shinarump conglomerate. Stanleya pinnata, a weak selenium and sulfur indicator, and Astragalus pattersoni, a selenium indicator, however, can be used to define approximately the favorable area within which ore deposits may occur. Astragalus pattersoni is relatively rare in the area and consequently is not so useful as Stanleya pinnata. The absorber plant method appears to be useful in those parts of the Circle

Cliffs area where pinyons and junipers grow on Shinarump conglomerate from 1 to about 70 feet above uraniferous ground.

In the San Rafael Swell area neither the indicator nor the absorber plant method of prospecting appears to be widely useful. Evaluation of botanical prospecting methods in the Grants district is in progress.

Mineralogic studies

Ore mineralogy, by T. Botinelly

Mineralogic work during the report period was concentrated on a study of two mines in the Uravan mineral belt: the JJ mine at the north end of the Jo Dandy group and the Peanut mine in Bull Canyon.

Studies of oxidation zoning in these mines show that a thin and irregular intermediate zone exists between oxidized and unoxidized ore. The base of this zone is generally at the top of the water table, but it extends downward where fractures or fracture zones have acted as conduits for oxidizing ground waters. The top of the zone is irregular and shows no obvious relations to any geologic features except for a rough parallelism to the water table. Residual pockets of only partly oxidized ore are found in oxidized ore associated with carbonaceous material and impermeable clay lenses. Rare vanadium minerals have been found in the intermediate zone and probably represent transitory phases in the oxidation of vanadium.

Study of the textural relations between low-valent uranium and vanadium minerals in polished sections has continued, but no definite conclusions have been reached on the relative times of deposition of the two elements.

Sulfide minerals found associated with unoxidized ore are pyrite, marcasite, digenite, chalcocite, chalcopyrite, sphalerite, galena, bornite, clausthalite, and molybdenite. The presence of marcasite and molybdenite is especially interesting in that marcasite converts to pyrite at about 450° C. and molybdenite forms about 500° C. in hydrothermal deposits (Edwards, Textures of ore minerals: Australian Institute of Mining and Metallurgy, Melbourne, 185 p., 1947). The digenite-chalcocite relations are being studied to obtain information on temperature of deposition.

Clay mineralogy, by W. D. Keller and L. G. Schultz

X-ray spectrometer studies have been made of 144 samples of Triassic clays. Preliminary results indicate that the clays are predominantly illitic with lesser amounts of kaolinite, chlorite, and mixed-layer clays. The lower part of the Chinle is characterized by montmorillonite-rich mixed-layer clays. Kaolinite was found to be the dominant clay mineral in a few samples of claystone taken from below the Moss Back member of the Chinle formation.

The preliminary results indicate that the sample distribution is adequate to detect regional variations in clay minerals in the Triassic formations. X-ray studies will be continued on the remainder of the samples.

Analyses of paired samples of red and green clay indicate that both types of clay have the same gross mineralogy. The color change appears to be a result of an alteration process which bleached iron oxide contained in the clay but did not alter the clay minerals and the micas. Similar effects have been noted in paired samples of purple and white clays. The evidence suggests that solutions, possibly carrying the ore metals, were able to bleach the iron oxides in the clays but were unable to alter the clay minerals. Detailed work on lattice structures and substitutions in the clay minerals is now in progress.

Distribution of elements, by E. M. Shoemaker

Mathematical treatment of semiquantitative spectrographic analyses.--Ten replicate semiquantitative spectrographic analyses of each of three samples were made by R. G. Havens, of the Denver spectrographic laboratory, for the purpose of determining the precision of the spectrographic analyses used in the distribution of elements investigation. The following expression was derived to express the frequency of misses in placing an element in the modal class or subgroup in terms of the log standard deviation from the geometric mean where the analytical "error" or deviation from the geometric mean is log-normally distributed.

$$f = \frac{1}{\sigma\sqrt{2\pi}} \int_0^1 \int_x^\infty e^{\frac{-x^2}{2\sigma^2}} dx\,dx$$

f = frequency of misses

σ = log standard deviation

x = log of fraction of class interval or subgroup

By integration between the limits 0 to 1, f reduces to a function of σ. Graphical solution of this equation gives values for σ from the frequency of misses that are nearly identical with values for σ derived by conventional equations for the standard deviation. The distribution of deviation from the mean in 630 individual determinations of elements was found to be almost exactly log-normal. The average log standard deviation from the mean for 21 elements present in concentrations above the spectrographic limit of sensitivity was found to be 0.041. This is probably a minimum value, but it is much lower than the log standard deviations of the elements in Colorado Plateau sedimentary rocks and uranium ores which range from 0.28 to 0.8. The correction for the precision of analysis in the statistical parameters of element distribution will be small.

Spectrographic analyses for uranium, vanadium, and calcium were compared with chemical analyses to evaluate accuracy of the spectrographic analyses obtained for the distribution of elements investigation. The absolute precision of the spectrographic analyses is a linear function of the concentration between the lower and upper limits of sensitivity. The linear correlation coefficient (after log transformation) between spectrographic and chemical analyses for the samples studied was found to be +0.89 for uranium, +0.92 for vanadium, and +0.67 for calcium. The following regression equations of chemical results as a function of spectrographic results were obtained:

Regression equation	Log standard error
$U_{chem} = 0.88\, U_{spec}^{0.97}$	0.196
$V_{chem} = 1.50\, V_{spec}^{0.84}$	0.207
$Ca_{chem} = 0.79\, Ca_{spec}^{0.74}$	0.311

The agreement of spectrographic with chemical analyses for uranium is excellent. Wet chemical analyses for vanadium are systematically about 50 percent greater than the spectrographic results. Further research by A. T. Myers indicates that part of this difference is due to error of the spectrographic determinations. The comparatively poor correlation and high log standard error obtained for calcium are due mainly to two widely descrepant pairs of analyses.

Sedimentary rocks.--Compilation of published and unpublished stratigraphic sections on the Colorado Plateau and preparation of isopach maps has made it possible to estimate relative amounts of different rock types in formations of Paleozoic and Mesozoic age. Two averages of the chemical composition of sandstone on the Colorado Plateau have been calculated (table 4); one is a geometric mean of the geometric means for sandstone from each major formation from Cambrian through Cretaceous, and the other an arithmetic mean of the geometric means for sandstone from the Permian Cutler formation to the Cretaceous Dakota sandstone weighted according to the volume of sandstone. The first average is an estimate of the most probable composition of a sample collected randomly from a randomly selected formation. From the second average the estimated true weighted arithmetic mean composition of all sandstone from the Cutler formation to the Dakota sandstone can be obtained by multiplying the mean for each element by a factor derived from the log variance of each element, a factor which for most elements is close to two.

Ore deposits.--The correlation of elements, one with another, in the uranium deposits of the Morrison formation has been studied and compared with the correlations found for the elements in the unmineralized sandstones of the Salt Wash member of the Morrison formation. Linear correlation coefficients, calculated after log transformation, for all pairs of elements generally found in amounts above the spectrographic limit of sensitivity are given in chart form in figure 11. One of the most noteworthy features of the correlation of elements in both the ores and in the unmineralized sandstones is that all linear correlations that are significant at the 99 percent level of confidence are positive. The lack of significant negative correlations may prove to be a key factor in evaluating the geochemical environment of the ores and the sandstone host rocks.

The second most outstanding feature of the correlation of the elements is the comparatively high correlation with aluminum of most elements in the ores and the significant correlation with aluminum of most of the

CORRELATION OF ELEMENTS IN UNMINERALIZED SANDSTONES

CORRELATION OF ELEMENTS IN URANIUM DEPOSITS

	V	Ni	Cu	Pb	Mo	Cr	Y	Ti	Zr	B	Mn	Ba	Sr	K	Na	Ca	Mg	Fe	Al	U
V	V	+07	+.23	+.35	+.07	+.22	+.26	+.15	+.37	+.27	+.07	+.34	+.34	+.15	+.09	+.03	+.30	+.28	+.50	+.32
Ni		Ni	+.08	+.14	+.49	+.10	+.27	+.14	+.08	+.12	.00	+.02	+.08	+.03	+.05	−.04	−.06	+.37	+.11	+.10
Cu	+.06		Cu	+.56	+.16	+.30	+.04	+.27	+.29	+.23	+.26	+.15	+.31	+.27	+.26	+.32	+.36	+.07	+.36	−.04
Pb				Pb	+.14	+.33	+.07	+.21	+.25	+.15	+.26	+.14	+.23	+.29	+.21	+.23	+.39	+.25	+.49	+.11
Mo					Mo	+.25	+.24	+.04	+.22	−.09	.00	+.01	+.13	+.14	+.10	+.04	.00	+.34	−.13	+.06
Cr	+.38		.00			Cr	+.12	+.22	+.20	+.32	+.21	+.20	+.25	+.38	+.21	+.20	+.27	+.20	+.36	+.10
Y							Y	+.25	+.39	+.39	+.05	+.25	+.11	+.08	+.15	−.04	+.11	+.31	+.22	+.18
Ti	+.17		+.28			+.21		Ti	+.41	+.22	+.37	+.26	+.34	+.44	+.39	+.35	+ 25	+.17	+.50	+.19
Zr	+.28		+.01			+.42		+.50	Zr	+.26	+.35	+.25	+.14	+.19	+.43	+.39	+.38	+.31	+.46	+.15
B										B	+.10	+.21	+.17	+.28	+.21	+.13	+.23	+.16	+.35	+.11
Mn	+.16		+.22			+.24		+.02	−.05		Mn	+.19	+.28	+.37	+.56	+.75	+.30	+.20	+.47	−.09
Ba	+.11		−.08			+.20		+.08	+.16		−.03	Ba	+.37	+.27	+.19	+.11	+.15	+.15	+.28	+.05
Sr	−.04		+.39			+.15		+.31	+.05		+.34	+.34	Sr	+.42	+.26	+.36	+.19	+.10	+.40	+.10
K														K	+.34	+.45	+.22	+.02	+.45	+.06
Na	+.04		−22			+.26		+.35	+.14		+.47	−.09	+.31		Na	+.56	+.45	+.37	+.47	+.08
Ca	+08		+.26			+22		−.12	−.12		+.83	−.05	+ 41		+.39	Ca	+.48	+.12	+.46	−.14
Mg	+ 30		+.20			+.16		+.09	+.14		+.22	+.19	+.07		+.19	+.17	Mg	+ 34	+.58	+.11
Fe	+.20		+.32			+.29		+.30	+.20		+.21	+.19	+.16		+.27	+.05	+.44	Fe	+.30	+.23
Al	+.24		+.35			+.25		+.60	+.40		+.12	+.23	+.24		+.30	+.04	+.16	+.48	Al	+.14
U																				U

CORRELATION OF ELEMENTS IN URANIUM DEPOSITS

CORRELATION OF ELEMENTS IN UNMINERALIZED SANDSTONES

NUMBERS ARE LINEAR CORRELATION COEFFICIENTS CALCULATED AFTER LOG TRANSFORMATION

LOWEST SIGNIFICANT VALUE AT 99 PERCENT CONFIDENCE IS 0.19 FOR CORRELATION OF ELEMENTS IN URANIUM DEPOSITS AND 0.26 FOR CORRELATION OF ELEMENTS IN UNMINERALIZED SANDSTONES

Figure 11. CORRELATION OF ELEMENTS IN UNMINERALIZED SANDSTONES AND IN URANIUM ORE DEPOSITS FROM THE SALT WASH MEMBER OF THE MORRISON FORMATION

Table 4. Average content of spectrographically detectable elements in Paleozoic and Mesozoic sandstones of the Colorado Plateau

Element	Average 1/ sandstone (by formation)	Weighted 2/ average sandstone
	ppm	ppm
Si	>100,000	>100,000
Al	10,000	12,600
Fe	3,700	5,000
Mg	2,700	4,500
Ca	12,000	15,800
Na	690	2,200
K	4,300	8,500
Ti	580	690
Zr	88	110
Mn	140	230
Ba	280	370
Sr	45	83
B	16	21
V	11	15
Cr	7	11
Co	1	1
Ni	2	3
Cu	9	11
Y	4	5

1/ Geometric mean of geometric means for sandstones of the principal formations from Cambrian through Cretaceous.

2/ Arithmetic mean of geometric means for sandstones of the Permian Cutler formation through the Dakota sandstone weighted according to the volume of the sandstone.

elements in the unmineralized sandstones. Aluminum is probably contained chiefly in feldspar and interstitial clay in the unmineralized sandstones and in interstitial clay, clay pebbles, and clay seams in the ores. Probably many of the intrinsic elements in the sandstones and ores are largely contained in the clay minerals or in finely comminuted detrital minerals and soluble carbonate minerals associated with the clay.

The ratio of average concentration of elements in the uranium deposits of the Morrison formation to the average concentration in the unmineralized Salt Wash sandstones in given in table 5. It may be seen from the table that two elements which have a high correlation with aluminum in both ores and sandstones, titanium and zirconium, show about a two-fold increase in the ores over the sandstones, as does aluminum. Most other intrinsic elements that correlate with aluminum show comparable increases except potassium and the elements contained largely in carbonates: calcium, sodium, and manganese. This increase is believed to be due to a higher initial content of clay size components in the rocks that were mineralized with uranium.

The intercorrelation of elements shown in figure 11 also serves to differentiate the spectrographically detectable extrinsic accessory elements of the Morrison uranium deposits into two distinct groups; the copper-lead group, and the nickel-cobalt-molybdenum-yttrium group. The copper-lead group, which also includes zinc and silver where these elements are present as extrinsic components of the ores, correlates significantly with aluminum, whereas the nickel-cobalt-molybdenum-yttrium group correlates with iron. The copper-lead group has a regional pattern of distribution that includes an area of predominantly high values partially coincident with the region of salt structures (Distribution of elements, Shoemaker, E. M., in TEI-490),

Table 5. Ratio of concentration of elements in uranium deposits in the Morrison formation to average concentration in unmineralized sandstones of the Salt Wash member of the Morrison formation

	Element	Concentration ratio
DOMINANTLY INTRINSIC - ELEMENTS	Calcium	0.59
	Sodium	1.0
	Potassium	1.0
	Manganese	1.4
	Silver	1.8
	Boron	1.9
	Titanium	2.0
	Aluminum	2.1
	Zinc	2.2
	Zirconium	2.3
	Barium	2.4
	Strontium	2.5
	Chromium	2.6
	Magnesium	3.0
	Iron	3.7
DOMINANTLY EXTRINSIC - ELEMENTS	Copper	6.6
	Yttrium	8
	Selenium	>14
	Arsenic	>18
	Molybdenum	>19
	Nickel	40
	Cobalt	50
	Lead	>88
	Vanadium	493

and the nickel-cobalt-molybdenum-yttrium group generally tends to be higher in an area northwest of the Colorado River.

Igneous rocks.--The association of uranium deposits with alkaline basalts in diatremes in the south-central part of the Colorado Plateau makes the composition of all types of basaltic rocks on the Colorado Plateau of special interest. In table 6 the average minor-element content of Colorado Plateau olivine basalts is compared with published data on the content of minor elements in other basalts from widely separated parts of the world. Most of the spectrographically detectable minor elements in Colorado Plateau olivine basalts fall within or close to the range of concentration in these other basalts. Barium is the only element whose concentration may distinctly characterize the Colorado Plateau olivine basalts; barium content is distinctly high in those rocks.

The average content of spectrographically detectable elements in each of the three major types of alkaline basaltic rocks on the Colorado Plateau is given in table 7, together with the average content in olivine basalt from the Plateau for comparison. All three groups of alkaline basaltic rocks have distinctly high concentrations of niobium and lanthanum, and the probability is good that they are richer than olivine basalt in other cerium-group rare earths, in addition to lanthanum. The analcite diabases and minettes both contain higher concentrations of barium than the olivine basalts, and some monchiquites are characterized by higher concentrations of zirconium. Minette is also distinctively high in potassium, strontium, beryllium, lead, and boron. All three main groups of alkaline basaltic rocks are lower than average Colorado Plateau olivine basalt in vanadium, cobalt, and copper.

Table 6. Minor element content of basalts from the Colorado Plateau, Ontario, Ireland, Greenland, Hawaiian Islands, Union of South Africa, and Michigan

Element	Colorado Plateau olivine basalt geometric mean	Colorado Plateau olivine basalt arithmetic mean 1/	Ontario diabase arithmetic mean 2/	Northern Ireland olivine basalt arithmetic mean 3/	Skaergaard complex initial magma 4/ (Greenland)	Hawaiian basalt 5/ arithmetic mean	Karoo dolerite Kokstadt type 6/ (Union of South Africa)	Karoo dolerite Perdekloof type 6/ (Union of South Africa)	Kearsarge and Greenstone flows, Michigan 7/ weighted arithmetic mean
	%	%	%	%	%	%	%	%	%
Ti	.9	1.0	---	.70	---	---	.50	.55	---
Zr	.015	.015	.010	.018	.005	.010	---	---	---
Mn	.22	.24	---	.138	.08	---	.05	.17	---
Ba	.05	.07	.028	.031	.0043	.012	.018	.018	---
Sr	.08	.08	.03	.068	.035	.080	---	---	---
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Sc	30	30	37	19	12	10	10	26	---
V	200	220	220	630	140	300	300	270	---
Cr	280	310	220	1600	170	470	410	270	---
Co	50	50	39	140	53	33	28	28	42
Ni	260	300	110	900	170	80	80	70	175
Cu	220	270	72	400	130	170	160	80	105
Ga	15	15	17	33	17	23	22	26	---
Y	22	24	---	50	---	23	---	---	---
Ag	<1	<1	≈2	---	<1	---	---	---	---
La	<50	<50	15	---	---	---	---	---	---
Pb	<10	<10	8.7	<20	<10	---	---	---	≈6

1/ Estimated true arithmetic mean computed from Sichel's (1952) solution for the likelihood equation.

2/ Fairbairn, Arhens, and Gorfinkle (1953, p. 43-46).

3/ Patterson (1952, p. 291, table 4).

4/ Wager and Mitchell (1951, table 10).

5/ Wager and Mitchell (1953, p. 220, table 2).

6/ Walker and Poldervaart (1949, p. 644, table 14).

7/ Sandell and Goldich (1943, p. 103, table 2).

Table 7. Geometric mean composition of Colorado Plateau basaltic rocks calculated from spectrographic analyses

Element	Colorado Plateau olivine basalt 13 samples	San Rafael Swell analcite diabase 8 samples	Navajo-Hopi region monchiquite group 39 samples	Navajo-Hopi region minette group 213 samples
	percent	percent	percent	percent
Fe	9		7	3.9
Mg	14		9	4.8
Na	1.6		1.4	1.2
K	.9		.7	5.4
Ti	.9	.4	1.3	.61
Zr	.015	.015	.022	.015
Mn	.22	.10	.14	.069
Ba	.05	.15	.08	.15
Sr	.08	.07	.08	.15
	ppm	ppm	ppm	ppm
Be	< 1	< 1	< 1	2.1
B	<10	<10	<10	11
Sc	30	30	30	14
V	200	150	150	80
Cr	280	150	150	250
Co	50	30	34	25
Ni	260	150	160	220
Cu	220	80	140	62
Ga	15	15	12	6.4
Y	22	15	19	16
Nb	< 5	12	31	12
La	<50	70	80	140
Ce	<100	<70	120	310
Nd	<50	<70	140	97
Yb	2.6	1.5	1.7	1.6
Pb	<10	< 9	< 10	22
Percent radio-activity (arithmetic mean)	0.0005	0.0019	0.0012	0.0046

The Colorado Plateau alkaline basaltic rocks are all more radioactive than Colorado Plateau olivine basalts and probably than average Plateau basalts. The higher radioactivity is due principally to higher concentrations of both uranium and thorium (table 8).

Some of the intrusions containing alkaline basaltic rocks are composite: dikes or sills of alkaline basalt or diabase enclose pods, stringers, dikes, or sills of alkaline syenite. The fractionation of elements between the basaltic and syenitic facies of the composite intrusions is shown in figure 12 together with the fractionation between a Scottish tholeiite and its glassy groundmass for purposes of comparison. The relation of the differentiation in the composite intrusions of the Colorado Plateau and in the Scottish tholeiite to the liquid differentiation sequence of the Skaergaard intrusion, Greenland, is shown in figure 13. The ranges of differentiation in the Colorado Plateau intrusions and in the Scottish tholeiite are approximately equivalent to complementary parts of the Skaergaard liquid line of descent. Rare earths are much more concentrated in the alkaline rocks from the Colorado Plateau than in the Scottish tholeiite or Skaergaard liquid and tend to be enriched in the syenitic differentiates. The syenitic differentiates also tend to be more radioactive than the basaltic rocks enclosing them, and uranium and thorium are probably enriched in the syenites during magmatic fractionation.

Mineralogy of uranium in sandstone-type deposits, by Alice D. Weeks

Studies of roscoelite, chlorite, and other vanadium silicates in the Colorado Plateau ores were continued during this report period. New occurrences of native selenium were found at Slickrock, Colorado, Thompsons, Utah, and Wind River Basin, Wyoming. Chemical analyses of synthetic sodium vanadate and naturally occurring sodium analogue of hewettite gave the

Table 8. Uranium and thorium content of samples of alkaline basalts from the Colorado Plateau

	Analcite basalt, San Rafael Swell, Utah		Olivine monchiquite, Bidahochi Butte, Arizona		Nepheline monchiquite, Wildcat Peak, Arizona		Basic Minette, Outlet Neck, New Mexico		Minette, Bennett Peak, New Mexico		Feldspathic minette, Mitten Rock, New Mexico	
	U	Th	U	Th	U	Th	U	Th	U	Th	U	Th
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Total rock	2.7	12.7	2.2	6.4	4.6	17.5	11.9	28.4	12.3	31.5	10.6	50.1
Leached residue	2.9	12.8	2.2	6.3	5.0	17.7	10.7	29.3	13.0	33.3	10.9	52.0
Leachate	1.1	12.1	2.4	7.3	1.6	16.4	29.8	15.7	1.7	3.9	3.1	9.0
	Percent		Percent		Percent		Percent		Percent		Percent	
Percent rock leached	9.90		12.51		12.33		6.34		6.31		4.45	
Percent uranium leached 1/	4.0		13.5		4.4		15.9		0.9		1.3	
Percent thorium leached 1/	9.4		14.2		11.5		3.5		0.8		0.8	
	ratio		ratio		ratio		ratio		ratio		ratio	
Percent U leached/percent rock leached 2/	0.4		1.1		0.4		2.5		0.1		0.3	
Percent Th leached/percent rock leached 2/	0.95		1.1		0.9		0.6		0.1		0.2	
Th/U total rock	4.7		2.9		3.8		2.4		2.6		4.8	
Th/U leached residue 1/	4.4		2.9		3.5		2.7		2.6		4.8	
Th/U leachate 1/	10.9		3.0		10.1		0.5		2.3		2.9	

1/ Powdered rock leached in 0.05 molar HNO_3 in steam bath for 1/2 hour.

2/ If the ratio is less than 1.0 the element was depleted in the leachate, or dissolved rock, relative to the entire rock.

Analyst: J. C. Antweiler; calculations by G. J. Neuerburg: U. S. Geological Survey, Denver, Colo.

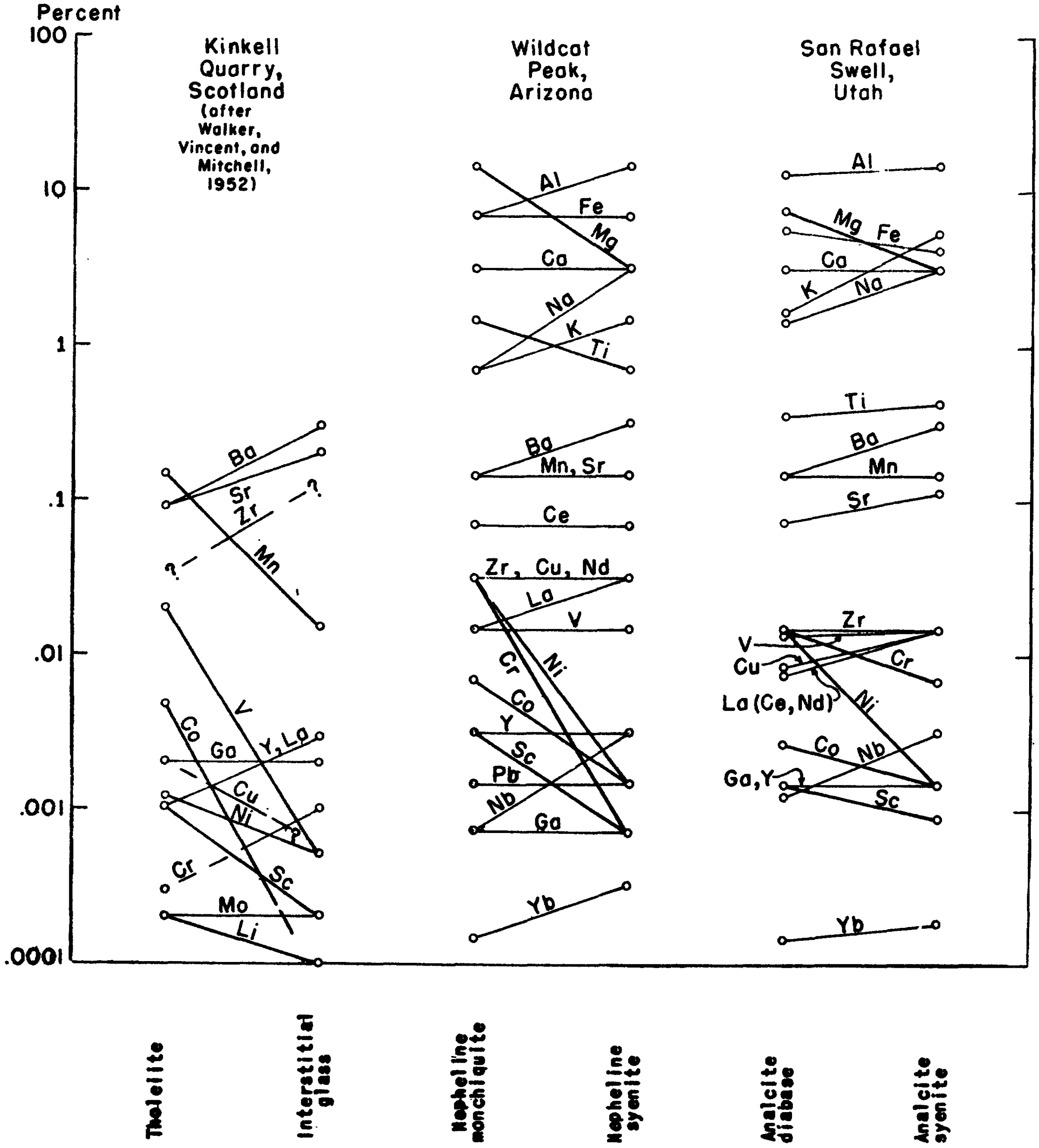
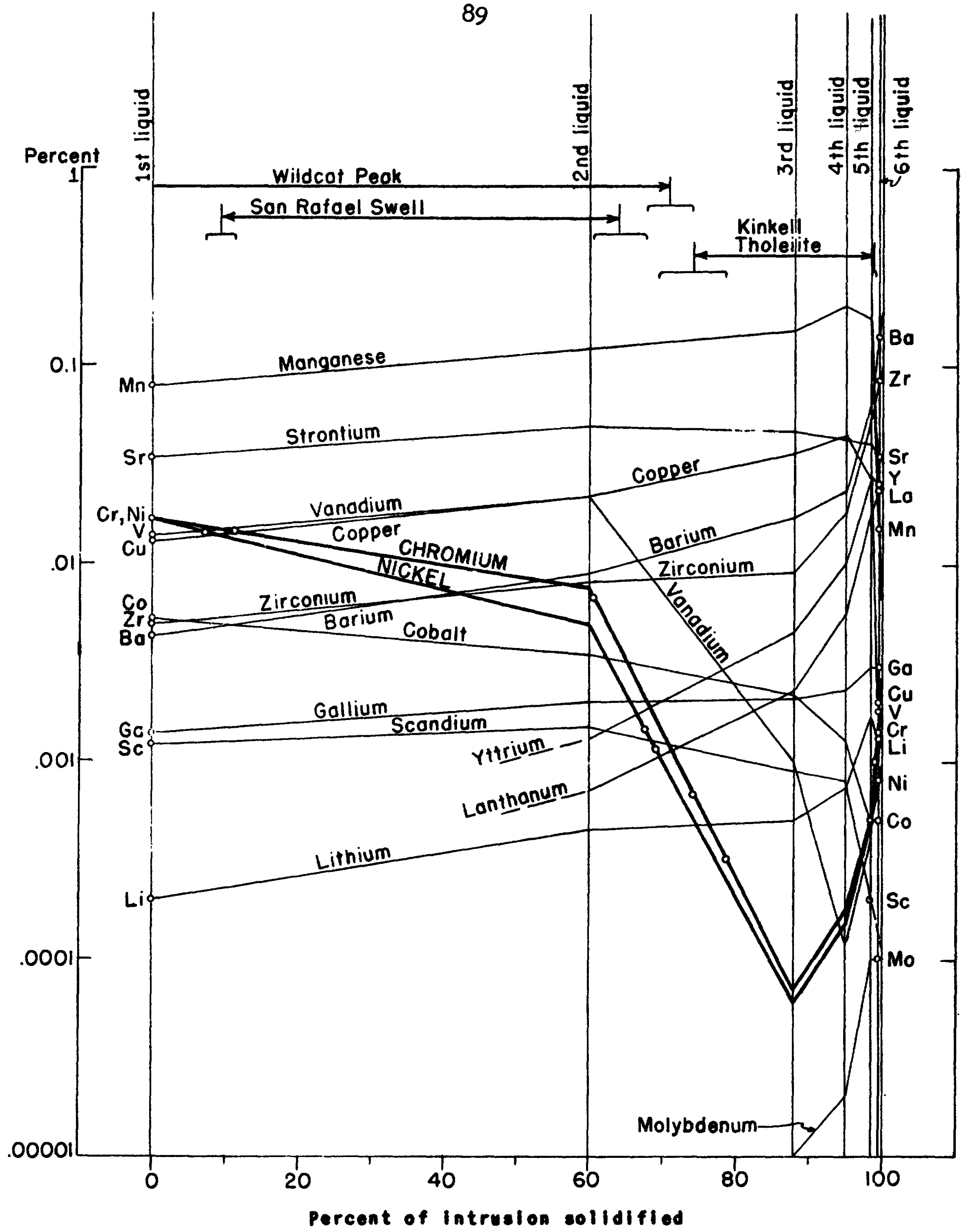


Figure 12. VARIATION DIAGRAMS FOR ELEMENTS DETERMINED SPECTROGRAPHICALLY IN THE THOLEIITE DIKE AT KINKELL QUARRY, SCOTLAND, IN THE COMPOSITE DIKE AT WILDCAT PEAK, ARIZONA AND IN THE COMPOSITE INTRUSIONS OF THE SAN RAFAEL SWELL, UTAH



(Data on minor element content of Skaergaard liquids from Wager and Mitchell, 1951, table 10)

Figure 13. VARIATION DIAGRAM FOR ELEMENTS IN THE COMPUTED SUCCESSIVE LIQUIDS OF THE SKAERGAARD INTRUSION, GREENLAND, SHOWING THE CORRESPONDING RANGES OF VARIATION FOR CHROMIUM AND NICKEL IN THE THOLEIITE AT KINKELL QUARRY, SCOTLAND, IN THE COMPOSITE DIKE AT WILDCAT PEAK, ARIZONA, AND IN THE COMPOSITE INTRUSIONS OF THE SAN RAFAEL SWELL, UTAH

formula $Na_2V_6O_{16}\cdot 3H_2O$. This new mineral is named Barnesite, after William H. Barnes, Ottawa, Canada.

Work was in progress on studies of five new minerals: (1) vanadium oxide $VO(OH)_2$, (2) calcium tetravanadite $CaV_4O_9\cdot 5H_2O$, (3) a tetragonal vanadium mineral not yet analyzed chemically, (4) an iron vanadyl vanadate, and (5) possible calcium selenate.

Seven pyrite samples from Wyoming were analyzed chemically for selenium and spectrographically for other elements. The Ni/Co ratios showed no variation in relationship to the association with uranium as they do on the Colorado Plateau. A pure pyrite from the Wind River Basin, Wyoming, shows 1.5 percent selenium; this is the highest selenium content yet recorded for pyrite in the sandstone-type uranium deposits.

Uranium mineral exhibits were prepared for the Annual meeting of American Association of Petroleum Geologists in New York, N. Y., and for a special exhibit in Glendive, Montana, in March 1955.

"Rabbittite, a new uranyl carbonate from Utah", by Thompson, Weeks, and Sherwood, and "Navajoite, a new vanadium oxide from Arizona", by Weeks, Thompson, and Sherwood were published in the March-April issue of American Mineralogist.

"Abernathyite, a new uranium mineral of the metatorbernite group", by Thompson, Ingram, and Gross, and "New occurrences of native selenium", by Thompson, Braddock, and Roach were accepted for publication in the American Mineralogist.

A compilation of types of ore in the major mines in each district of the Colorado Plateau was prepared and revised.

Geophysical investigations

District studies, by R. A. Black

The seismic refraction studies in Oljeto Wash, Monument Valley, Arizona were continued through this report period. These studies were made to further refine the seismic refraction methods previously used in the Monument Valley area, and to determine if the seismic refraction method could be successfully used to map the Shinarump-Moenkopi contact through Chinle overburden. Reconnaissance and detailed seismic refraction surveys were also made in the Oljeto Wash area to delineate buried channels for future exploration.

Reconnaissance seismic profiles were shot along parallel lines one mile apart. The detailed seismic measurements were made by continuous profiling with reversed shots on parallel traverses 500 feet apart. The shot points were commonly 500 feet apart along the traverse lines, and air shooting was extensively used. Detailed seismic work has been done in an area of approximately 10 square miles, and these data are presently being compiled and interpreted.

The results of the Oljeto Wash and other Monument Valley seismic refraction measurements clearly indicate that buried Shinarump channels can be located with the refraction seismograph in areas where there is no Chinle overburden. On small mesas, where channel cross sections are revealed in rim exposures, wagon drilling is probably the most economical means of tracing the channels and prospecting for uranium deposits. In the interior of large Shinarump capped mesas, and in the large areas in Monument Valley where the Shinarump is buried by sand, the refraction seismograph can be economically used to delineate channel trends and thus guide drilling for uranium deposits.

The standard textbook methods of interpreting seismic refraction data based on the critical distance and time intercept formulae have often been found to yield misleading results when the seismic profiles cross channel structures. A modification of a procedure of interpretation suggested by A. J. Barthelmes (Geophysics, v. 11, 1946, p. 24-42) for computing the depth times has proved to be the most reliable method of interpreting the Monument Valley seismic data. Delay time analysis will often detect channel structures that would not be revealed by conventional methods of interpretation.

The problem of mapping the contact of the Shinarump and Moenkopi formations through Chinle overburden has not as yet been resolved, but in one Chinle-covered area the delay time method of analysis has proved successful in delineating the presence of a buried Shinarump channel. Absolute depth determinations could not be made, but the relative topography of the Shinarump-Moenkopi contact was correctly determined. This single example, though not conclusive, is encouraging.

The electric logging program was recessed during the winter months and one of the multiple electrode logging units was returned to the Well Instrument Developing Company for repair and modification. The neoprene logging cable was replaced with an armored cable which is stronger, smaller in diameter, and has much lower leakage characteristics. The electric logging sonde was modified to permit field stripping in case of damage or leakage, as well as making it simpler to change logging configurations. Electric logging was resumed in May 1955 to continue the compilation of electric log data on the Colorado Plateau uranium-bearing formations.

In May 1955 shallow seismic reflection measurements were resumed at Deer Flat, Utah. More detailed experimental measurements are being made in this area with multiple geophones in an attempt to obtain higher quality reflections. The applicability of shallow seismic reflection techniques to uranium exploration is yet to be determined.

Regional studies, by H. R. Joesting, P. E. Byerly, D. F. Plouff

Regional geophysical studies of the Colorado Plateau, started in July 1953, involve the systematic collection of magnetic, gravimetric, geothermal, and subsurface geologic data, and analysis of these data in terms of regional structural trends, basement topography and composition of intrusive rocks. An attempt will be made subsequently to determine if the major geologic features thus defined are related to the occurrence and distribution of uranium and associated elements.

Aeromagnetic surveys and related investigation.--Aeromagnetic surveys of about 20,000 square miles of the Colorado Plateau were completed late in 1954. During the past six months preliminary aeromagnetic maps of the Upheaval Dome and Boundary Butte areas in Utah were prepared and maps of most of the southern part of the region were brought to various stages of completion.

Magnetic susceptibilities of about 270 specimens representative of Precambrian crystalline rocks and of younger intrusive and extrusive rocks of the Plateau were measured. Remanent magnetizations of about 55 oriented specimens of diorite porphyry and related intrusive rocks from the La Sal and Henry Mountains were determined. These measurements will aid in evaluating magnetic survey data.

Gravity surveys.--Preliminary regional surveys were made in the White Canyon area, Utah, and Carrizo Mountains area, Arizona; and a fill-in survey was completed in Monument Valley. A gravity base line was extended from a base station in Blanding, Utah, to Hite via White Canyon, thence to Hanksville and the San Rafael Swell and thence to a base station at Green River, Utah, Closing errors of all base lines have been well below the maximum permissible error.

About 2,040 gravity stations have been established to date, in an area totaling about 4,000 square miles. About 240 stations were established during the past winter. All stations are referred through base lines to the U. S. Coast and Geodetic pendulum station at Egnar, Colorado.

Bouguer anomaly gravity maps of the Uravan and Inter-river areas were completed, and a preliminary gravity map was completed of the Monument Valley area.

Geothermal measurements.--Through the cooperation of the AEC it was possible to measure detailed thermal profiles in three deep diamond drill holes in the Temple Mountain area, Utah. Cores for thermal conductivity measurements were also made available. Several months were required for the first hole to regain thermal equilibrium after drilling. The other two holes have not yet reached equilibrium.

Analysis of results.--Analysis of the magnetic, gravity and available subsurface information on the Uravan area, Colorado has been completed and a report for publication is in preparation.

The gravity map of the Inter-river area shows large negative anomalies along the Moab fault, and along the Moab and Cane Creek anticlines in the northern part of the area. These structures were formed by intrusion and thickening of salt in the underlying salt formation.

South of the Cane Creek anticline the salt thins considerably, according to gravity data, and reaches a minimum thickness along a zone which extends southeast from Upheaval Dome toward the Rustler Dome near the Colorado River. The positive gravity anomalies along this zone seem to be related predominantly to basement or intrusive igneous rocks rather than to salt.

On the basis of available geophysical evidence it is believed that Upheaval Dome, a small structural dome in the southern part of the Inter-river area, was formed by a small igneous plug. However, the area is apparently also underlain at greater depth by a much larger rock mass which is relatively dense and magnetic. This rock mass is much too broad to be directly related to the structure of Upheaval Dome; in fact, it is not related to any apparent structural features in the sedimentary rocks. The source of the large gravity and magnetic highs is therefore believed to be basin differentiates of the Precambrian rocks or younger igneous rocks that did not intrude the overlying sediments. More detailed analysis awaits completion of the aeromagnetic map of the Inter-river area.

In Monument Valley, the area covered to date by regional gravity surveys includes most of the eighteen 7-1/2 minute quadrangles along both sides of the Utah-Arizona border and between Garnet Ridge on the east and Nokai syncline on the west. Control of the gravity lies predominantly in the structure and composition of the basement rocks, which in turn seem to exert important control over the major structural features in the overlying sedimentary rocks. The Comb Ridge monocline, for example, is reflected in considerable detail by a gravity 'monocline'; and other folds are reflected in somewhat lesser detail by corresponding gravity anomalies. In addition, several broad non-linear anomalies are not related to structure; their source is probably in relatively dense facies of the basement rock.

The Tertiary igneous intrusive rocks in the area have no apparent effect on the regional gravity.

More complete analysis of the Monument Valley area will be made on completion of the aeromagnetic and gravity maps.

A preliminary gravity map of Beclabito Dome, on the east flank of the Carrizo Mountains, shows a gravity high about one-half mile east of the center of the Dome. A well had previously been drilled to Cambrian rocks to a depth of 6,000 feet without entering igneous rocks. The available gravity data suggest a relatively dense plug a short distance east of the well.

Original-state core studies

by

G. E. Manger

During the past half year further analysis was made of the data supplied by the U. S. Bureau of Mines and of bore hole gamma-ray and electric logs in relation to core properties.

Table 9 shows the relationships of average values of water content, permeability, soluble solids content, radioactivity, and uranium content in Long Park and Bitter Creek, Montrose County, Colorado. Figure 14 is a graphic presentation of the water content and permeability relationships in these areas. Most of the data of table 9 and figure 14 was supplied by the San Francisco office of the U. S. Bureau of Mines. The data are representative of the ore-bearing sandstone which lies at the top of the Salt Wash member of the Morrison formation, and apply to both carnotite terrane in Long Park and "blue-black" ore terrane in Bitter Creek. Drill hole LP-531 is 1,680 feet S 74° E from drill holes LP-530 and LP-530 A; drill hole BCX-2 is 160 feet N 70° W from drill hole BCX-1. On the basis of the permeability and amount of water in the pore space, the ore-bearing sandstone is divisible into several zones, A, B, C, and D, which are significantly related to the position of the ore zone, both in the higher permeable drill holes in carnotite terrane in Long Park, and in drill holes of very low permeability in "blue-black" ore terrane in Bitter Creek. The notable features of these relationships in Long Park and Bitter Creek are: (1) the occurrence of the "knee" (zone B) in the ore-bearing drill holes just above the ore zone, where both the average permeability and pore water content increase over the average permeability and pore water content of zone A, and the poor development or absence of zone B in the poorly mineralized drill holes; (2) the further increase in pore water content but decrease of permeability in ore zone C; (3) the appreciable pore water content and permeability in zone D underlying the ore in contrast to the low pore water content accompanying appreciable permeability in zone D underlying the essentially barren equivalent of the ore zone; (4) the presence of claystone beds indicated by intervals of much lower permeability in zone D in the essentially barren drill holes below the correlated level of the ore; (5) the overall similarity of the pore water-permeability patterns in the Long Park and Bitter Creek drill holes although the permeability in the Long Park drill holes is vastly greater.

Figures 15 and 16 show the relationships between bore hole radioactivity and bore hole resistivity for the same drill holes shown in figure 14, except that drill hole LP-530 is represented by a 10-foot offset drill hole LP-530 A. (Equal depths in LP-530 and LP-530 A are stratigraphically identical.) The notable features of these relationships

Table 9. Average values of water content, permeability, soluble solids content, radioactivity, and uranium content in cores from ore-bearing and poorly mineralized drill holes in the "ore-bearing" sandstone unit of the Salt Wash member of Morrison formation, Long Park and Bitter Creek areas, Uravan district, Montrose County, Colorado.

Zone[1]			Water	Permeability	Solubles	Radioactivity	U
Name	Drill hole interval, feet	Thickness, feet	amount in pore space, percent	dry air, millidarcies	assigned to pore water, mg/1	counts per minute above background	chemical, percent
	I Long Park area, carnotite terrane I - a Drill hole LP-530, ore-bearing						
A	246.27-273.00	26.73	7.83	266	794,000	sl.r. [2]	
B	273.00-275.56	2.56	18.47	452	96,000		
C	275.56-278.46	2.90	46.39	174	49,900	9814(0.93')	0.42(0.93')
D	278.46-312.73	34.27	29.13	479	83,100		
	I-b Drill hole LP-531, poorly mineralized						
A	205.49-222.64	17.15	3.64	199	3,580,000	[3]	
	222.64-235.81	13.17	46.28	0.054	269,000		
B	Absent						
C	235.81-237.37	1.56	13.25	0.080	350,000	(200 ?, 1') [4]	Not determined
D	237.37-257.79	20.42	4.42	292	1,550,000		
	257.79-267.51	9.72	27.98	0.055	327,000		
	269.00-291.49	22.49	7.94	137	1,470,000		

II Bitter Creek area, "blue-black ore" terrane

II - a Drill hole BCX-1, ore-bearing

A	193.45-213.84	20.39	37.60	0.027	736,000		
B	213.84-216.40	2.56	50.33	0.380	672,000		
C	216.40-220.00	3.60	55.67	0.179	701,000	4264(1.2')	Not determined
D	220.00-231.81	11.81	70.49	0.037	502,000		
	231.81-245.00	13.19	66.04	0.005	1,057,000	5/	

II - b Drill hole BCX-2, poorly mineralized

A	149.30-181.77	22.47	23.09	1.3	866,000		
B?	181.77-183.62	1.85	37.60	0.195	555,000		
C	183.62-189.22	5.60	40.47	0.120	692,000	63(4.70')	Not determined
D	189.22-199.75	10.53	50.54	0.0025	283,000		
	200.65-232.66	32.01	64.13	0.045	203,000		

1/ Zones beginning at the top of Salt Wash member (top of "ore-bearing" sandstone) are as follows:

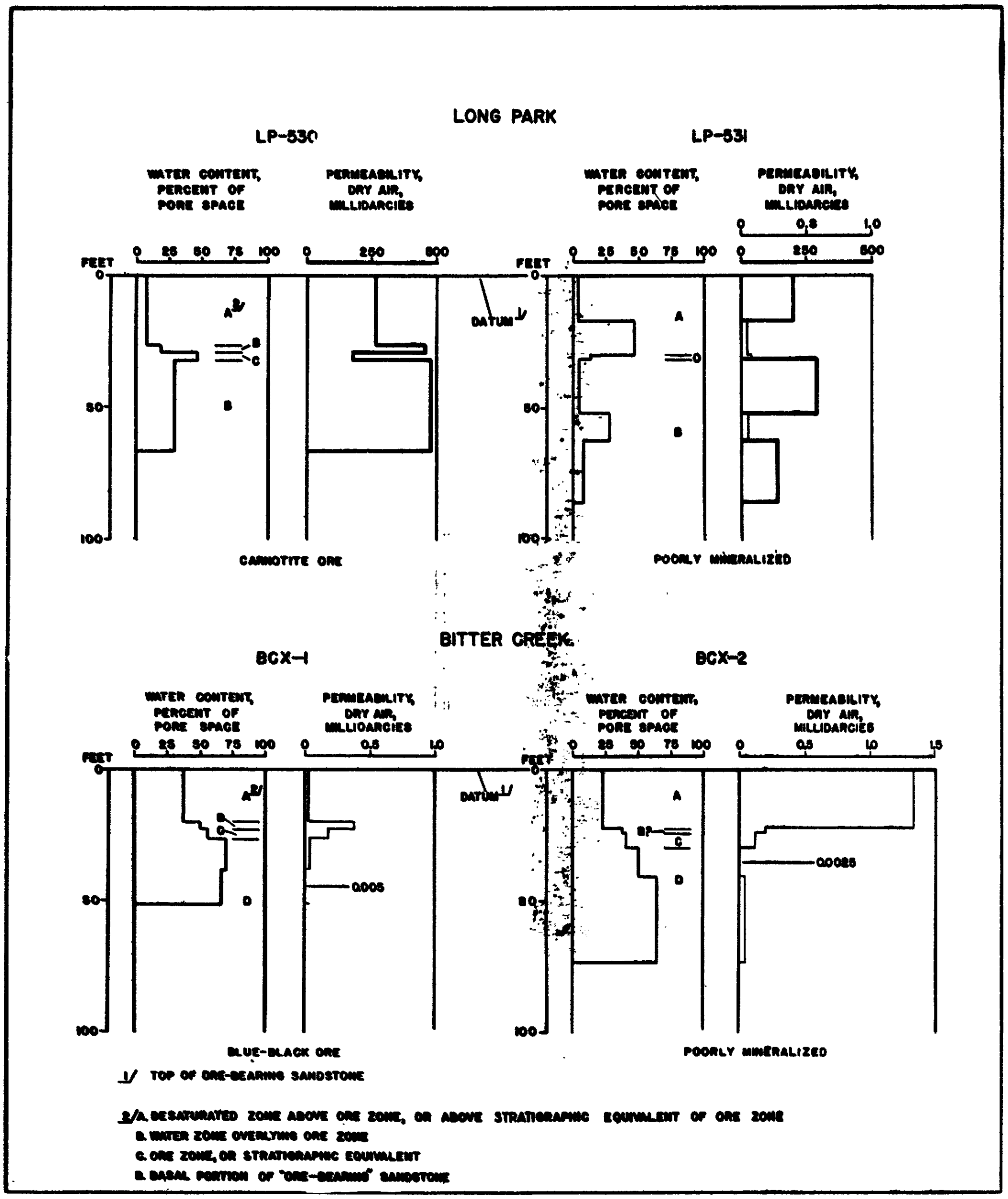
A. Desaturated zone above ore or above stratigraphic equivalent of ore.
B. Water zone immediately overlying ore.
C. Ore zone or stratigraphic equivalent.
D. Basal "ore-bearing" sandstone.

2/ Scattered intervals of slight radioactivity.

3/ Very infrequent weak radioactivity.

4/ Core counts not determined. From the gamma-ray log 0.013 percent eU_3O_8 is inferred. Within wide latitude, this value may correspond to about 200 counts per minute.

5/ Rare radioactivity, 40 to 60 counts per minute.



1/ TOP OF ORE-BEARING SANDSTONE

2/A. DESATURATED ZONE ABOVE ORE ZONE, OR ABOVE STRATIGRAPHIC EQUIVALENT OF ORE ZONE
B. WATER ZONE OVERLYING ORE ZONE
C. ORE ZONE, OR STRATIGRAPHIC EQUIVALENT
D. BASAL PORTION OF "ORE-BEARING" SANDSTONE

FIG. 14.—— WATER CONTENT AND PERMEABILITY OF CORES FROM ORE-BEARING AND POORLY MINERALIZED DRILL HOLES IN THE SALT WASH MEMBER, MORRISON FORMATION, LONG PARK AND BITTER CREEK AREAS, URAVAN DISTRICT, MONTROSE COUNTY, COLORADO

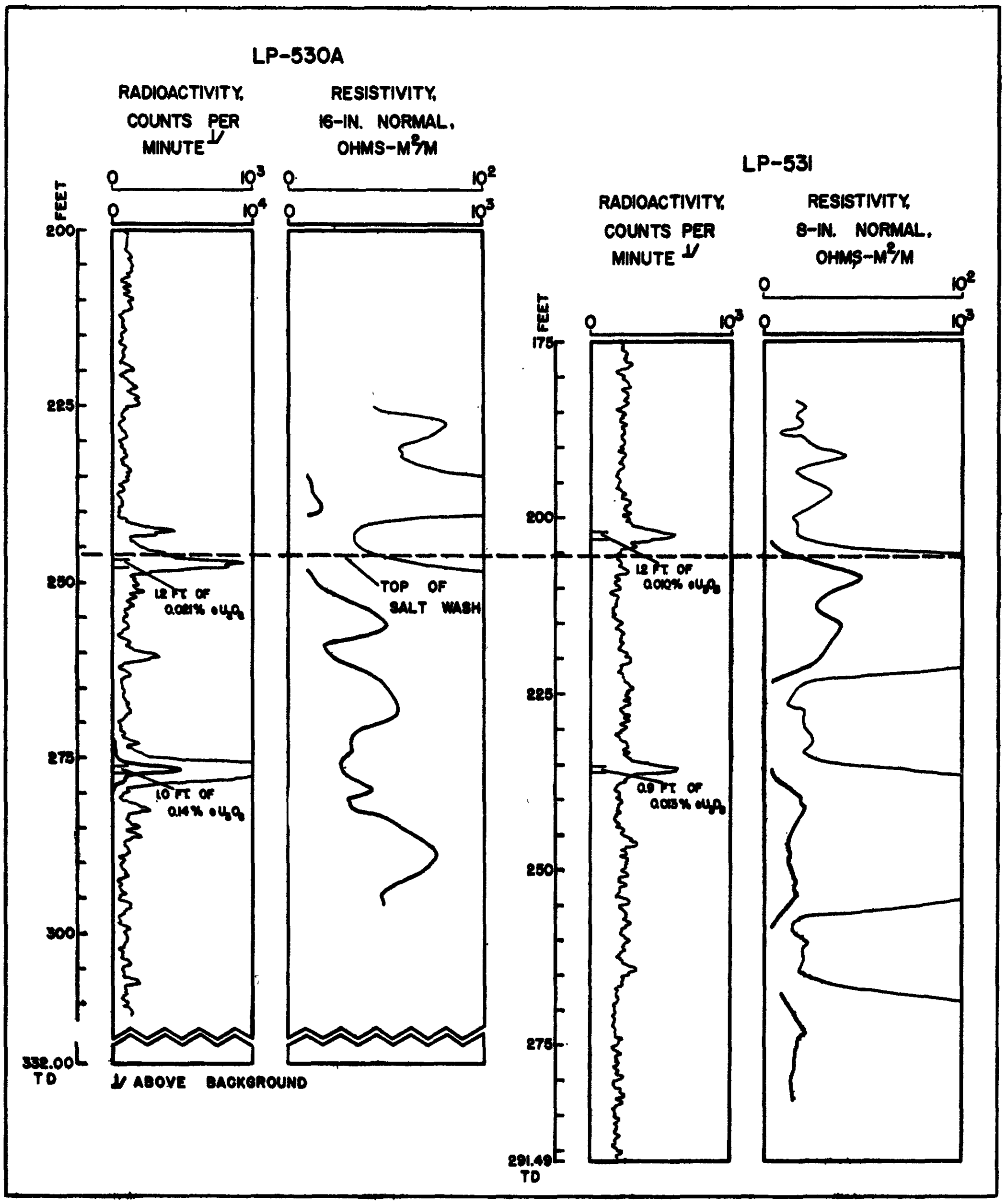


FIGURE 15.--DRILL HOLE PROPERTIES IN CARNOTITE TERRANE, LONG PARK AREA, URAVAN DISTRICT, MONTROSE COUNTY, COLORADO

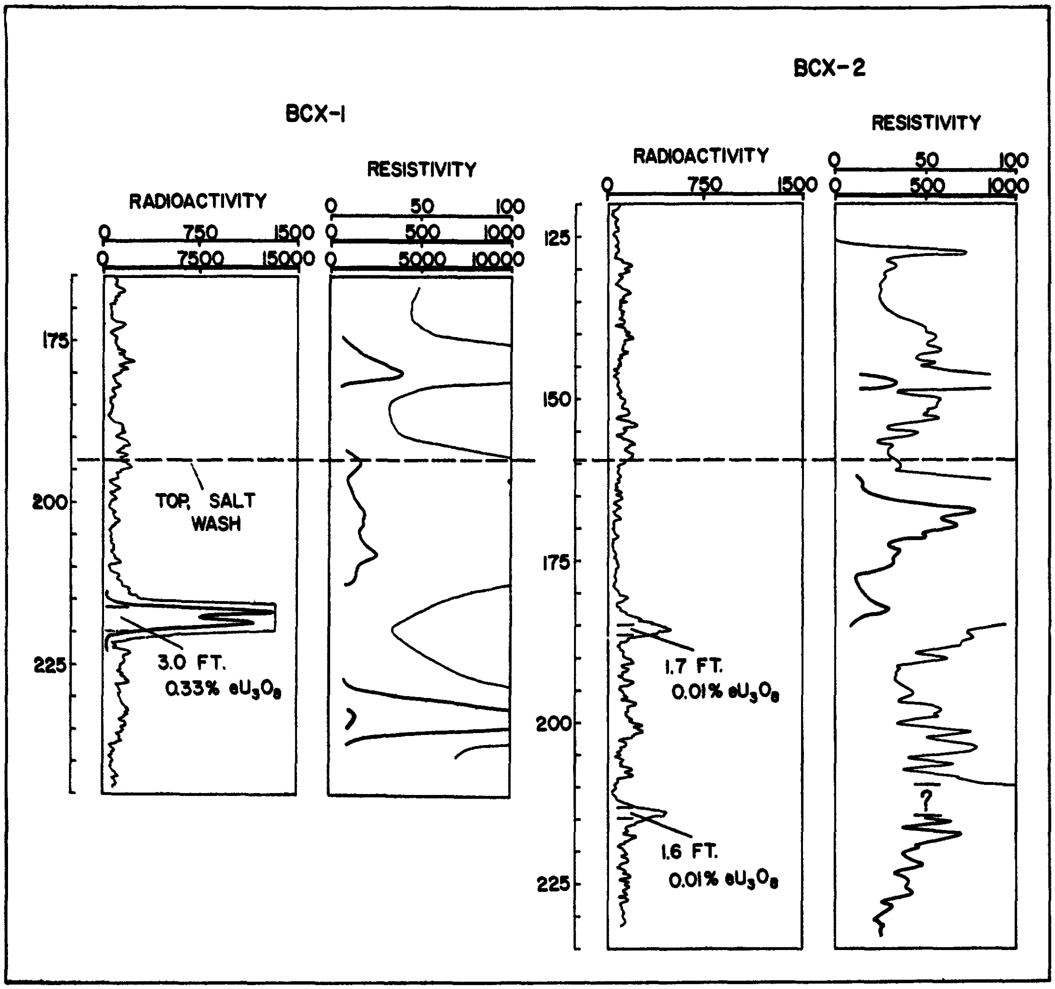


FIG. 16.-- DRILL HOLE PROPERTIES IN BLUE-BLACK ORE TERRANE, BITTER CREEK AREA, URAVAN DISTRICT, MONTROSE COUNTY, COLORADO

of the ore zone indicating claystone beds in the ore-bearing sandstone in these intervals; (5) the overall similarity of the gamma ray-resistivity patterns in the Long Park and Bitter Creek drill holes.

The Bitter Creek (BCX) drill holes are 4 miles southeast of the Long Park (LP) drill holes. Thus the relations between the permeability-pore water profiles and the gamma ray-resistivity logs in Long Park and Bitter Creek, showing similarity on the one hand between the ore-bearing drill holes in the two areas and between the essentially barren drill holes, indicate that: (1) the distribution of pore (ground) water bears a fundamental relation to ore occurrence at least over the four-mile distance involved; (2) there, in this area at least, electric bore hole logging independent of other methods should be capable of detecting ore by the appearance of maximum resistivity below both carnotite and "blue-black" ore; (3) and possibly some empirical methods, based on the ratios of resistivity above and below the correlated position of the ore, may serve to denote proximity to ore. Recently completed bore-hole electric logging of a number of drill holes midway between Long Park and Bitter Creek consistently shows maximum resistivity below the ore zone of the ore-bearing sandstone where mineralization is ore grade.

It has been previously stated (TEI-490) that the maximum resistivity below the ore probably is due to diminished salinity of the pore water. The accompanying figure 17, which compares the reciprocal of the square of the pore water saturation in cores with bore hole resistivity for drill hole LP-530, substantiates this conclusion. The reciprocal graph of pore water saturation emphasizes the low values. Increasingly low values of pore water saturation and increasingly high values of reciprocal

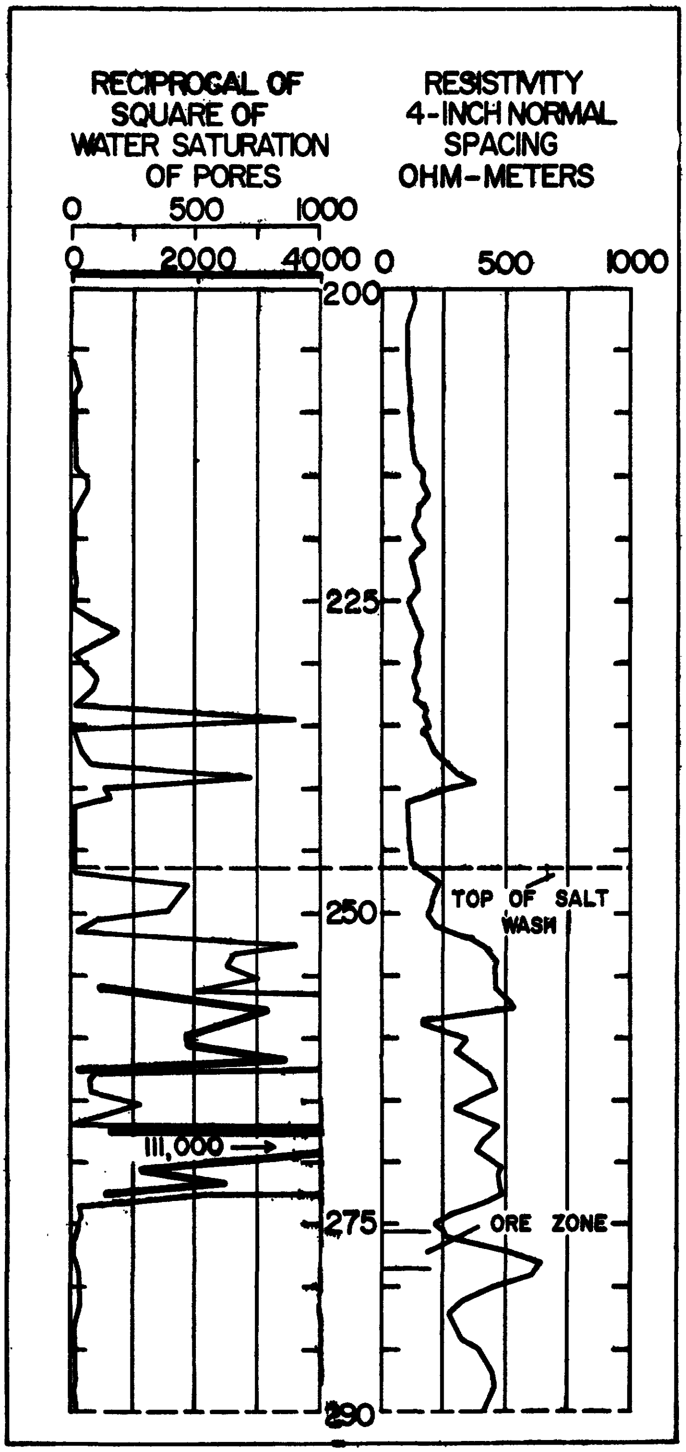


FIG. 17.--WATER SATURATION AND RESISTIVITY. DRILL HOLE LP-530, LONG PARK AREA, URAVAN DISTRICT, MONTROSE COUNTY, COLORADO

function are shown towards the right. Obviously, resistivity depends on pore water saturation, and small changes in the amounts of pore water at low saturations at the depth of 273 feet and shallower are closely related to changes to resistivity. Below 273 feet, although the pore water saturation is high (reciprocal function is very low), the resistivity reaches a maximum. Earlier resistivity work indicated that favorable ground generally is evidenced by ore-bearing sandstone of greater thickness and greater resistivity, and unfavorable ground by less thickness and lesser resistivity. The results of the present investigation substantially agree with the results of the earlier surface resistivity work and without regard to restrictions imposed by the depth of the overburden, offer a reasonable explanation that ore ground may often show high resistivity by surface resistivity methods. Drill holes cutting ore indicate high resistivity in the ore-bearing sandstone above the ore because of very low pore water saturation, even though the pore water is indicated to be salty. In the ore-bearing sandstone below the ore, although the pore saturation is much higher, the pore water evidently is much less salty and the resistivity reached a maximum for the section. The low resistive radioactive zones operate to decrease the resistivity, but the net overall tendency in ore ground in usually towards maximum resistivity. On the contrary in poorly mineralized ground, resistivity below the ore is no greater than above, and thick low resistive claystone beds intervene in the ore-bearing sandstone; hence the overall effect is reduced resistivity.

Resource appraisal

Reconnaissance resource appraisal

The objectives of the reconnaissance resource appraisal studies are to determine the order of magnitude of the uranium resources of each formation in each mining district of the Colorado Plateau, and to contribute to an understanding of the origin and controls of the deposits.

Map MF-16, "Preliminary geologic map showing the distribution of uranium deposits and principal ore-bearing formations of the Colorado Plateau region", by W. I. Finch was published during the report period. Printed on the map is a short text in which the history of production, the general geology, the major uranium-, vanadium-, and copper-bearing formations, and the ore deposits of the region are briefly described and discussed.

Northwestern New Mexico, by L. S. Hilpert.--The larger known uranium deposits in the Morrison formation in the Gallup-Laguna area of New Mexico are in two sandstone units in the Brushy Basin member. These two units are called the Poison Canyon and Jackpile sandstones of local usage.

The Poison Canyon sandstone crops out northwest of Grants and is exposed along the rim of Poison Canyon for a distance of more than 3 miles and extends northward from the rim for at least half a mile. It ranges from about 35 feet to 90 feet in thickness. The Jackpile sandstone is present north of Laguna throughout an area of at least 200 square miles. It ranges from a knife edge to about 175 feet in thickness.

Both the Poison Canyon and Jackpile sandstones range from white to moderate brown. The grains are mostly quartz, but locally pink feldspar grains and white specks of kaolin are common. The sandstones are relatively coarse and locally are conglomeratic. They generally are friable, and cross-bedding and scour-and-fill structures are characteristic. Carbonaceous debris is common locally, and claystone lenses and galls are fairly abundant. These characteristics make it possible to distinguish the Poison Canyon and Jackpile sandstone units from other Brushy Basin sandstones. The other sandstones are in relatively thin lenses, are green, and are composed mostly of quartz. They contain a large amount of interstitial clay and locally are highly calcareous. Characteristics of the Jackpile and Poison Canyon sandstone units make it possible to extend and define these units by drilling.

Areas outside the Colorado Plateau

Black Hills, South Dakota

by
G. B. Gott, E. V. Post, W. A. Braddock, Henry Bell III,
R. S. Jones, and R. W. Schnabel

Past investigations carried out under the Black Hills project have consisted of areal mapping at a scale of 1:7,200, mine mapping, and attempts to adapt geochemical techniques to prospecting for concealed deposits.

During the report period geologic maps at a scale of 1:7,200 were compiled of the Edgemont, Edgemont NE, 80 percent of the Flint Hill, and most of the Minnekahta quadrangles. Structure contour maps of the Inyan Kara rocks in these quadrangles also were prepared.

In January all geologic and structure maps completed during fiscal year 1954 were open-filed.

Petrographic studies

Limited petrographic studies indicate that locally there may be persistent differences between the Lakota and Fall River sandstones (see table 10). These sandstones contain both fragments of single quartz crystals and grains composed of several quartz crystals with sutured contacts. The latter type may have been derived from metamorphic quartzite. Chert grains make up from 1 to 40 percent of the sandstones and appear to be more abundant in the Lakota than in the Fall River sandstone. Potassium feldspars were observed in both the Lakota sandstone and Fuson formation but none were noted in any of the Fall River sandstone samples that were studied. Only a few grains of plagioclase were observed.

The angular white clay grains that are so conspicuous in many of the Lakota sandstones could not be identified in thin section, probably because they were lost during grinding. Their abundance was estimated from hand specimens. It may be significant that the clay grains are absent in the Fall River sandstone and seem to correlate with the feldspathic sandstones of the Lakota sandstone and Fuson formation.

Clay galls were represented in several of the thin sections that were studied. One of these specimens contains volcanic glass.

The cementing material in the samples studied is composed largely of oriented silica overgrowths with minor amounts of calcite, iron oxide, and manganese oxide. In general the paragenetic relationships indicate that the silica was followed by either the calcite or the oxides, but several of the thin sections from the extensively silicified

Table 10. Mineral constituents of Inyan Kara sandstone

Formation	Sample	Quartz percent	Chert percent	Microcline percent	Clay grains*	Clay galls	Cement	Approx. size range, mm
Lakota	BB- 48-53	82	3	15	?	0	Si	Very fine
	BB- 52-53	?		5	3	0	Si	0.03 - .14
	BB- 54-53	74-	26	?	A	0	Si	.05 - .45
	BB- 56-53	92-	7	?	?	0		.04 - .15
	BB- 59-53	93	4	3	?	0	Si	.05 - .20
	BB- 62-53	17	41	2	0	40		.07 -3.1
	BB- 65-53	95	5	0	B	0	Si	.04 - .10
	BB- 68-53	?	?	5	B	0	Si	.05 - .25
	BB- 71-53	?	?	3	A	0		.05 - .50
	BB- 74-53	96-	4	?	?	0		.03 - .10
	BB-271-53	?	Minor	Rare	?	0	Si-Fe	.04 - .15
	BB-272-53	90	3	7	C	0		.03 - .15
	MK - 24	91	4	5	?	0	Si	.05 - .20
	MK - 39	90+	5-	5-	?	0	Si-Fe	.03 - .20
	MK - 40	91-	8	1+	?	0	Si-Fe	.03 - .30
Fuson	MK - 4	93	4	3	D	0	Si	.05 - .20
	MK - 5	91	4	5	D	0	Si	.03 - .20
	MK - 13	91	4	5	D	0	Si	.03 - .20
	MK - 25	94	3	3	D	0	Si	.05 - .20
	MK - 26	96	1	3	D	0	Si-$CaCO_3$	.03 - .20
	MK - 33	98+	2-	0	0	0	Si-Fe-$CaCO_3$	.05 - .40
Fall River	MK - 15	99+	Trace	0	0	0	Si	.10 - .40
	MK - 16	97	2	0	0	1	Si	.05 - .38
	MK - 19	98+	2-	0	0	0	Si	.10 - .40
	MK - 27	98+	2-	0	0	0	Si-Mn	.06 - .33
	MK - 28	98+	2-	0	0	0	Si	.09 -1.05
	MK - 29	99+	1-	0	0	0	Fe-Si	.15 - .44
	MK - 30	98+	2-	0	0	0	Si	.10 - .44
	MK - 31	98+	2-	0	0	0	Si	.10 - .44
	MK - 32	98+	2-	0	0	0	Si-$CaCO_3$	.11 - .33
	MK - 35	98±	2-	0	0	0	Si	.05 - .40
	MK - 37	95+	5-	0	0	0	Fe-Si	.10 - .30
	MK - 38	97+	3-	0	0	0	Si	.10 - .33
	BB- 62-53	95±	5±	0	0	0	Si-$CaCO_3$	.05 - .30
	BB-307-53	93+	3-	1-	3	0	Si	.03 - .10
	BB-311-53	92+	3-	5	D	0	Si	.03 - .10

* A - Abundant
B - Moderate
C - Minor
D - Trace

sandstone in the Parker Peak area show that the secondary silica is later than the iron oxide.

Permeability analyses

Permeability analyses were made on 13 samples from the Gould and Holdup 15 mines. The samples were oriented and a horizontal and vertical core was taken from each sample. Results of these analyses indicate that there is no relationship between permeability and mineralization in the samples (see table 11).

Thermoluminescence investigations

During the winter of 1953-54, 53 samples of Inyan Kara sandstones originally collected for petrographic study were run for thermoluminescence. This study indicated in general that the uranium-bearing rocks produced glow-curve peaks at greater than 40 units, whereas the non-uranium-bearing rocks produced curves with peaks at less than 40 units. Some rocks apparently essentially barren of uranium from areas of no known uranium deposits produced curves with significant peaks. Because of the irregular distribution of the samples it could not be determined whether or not these high peaks indicated pathways along which radioactive materials had passed, or whether the high curves merely indicated the presence of a strongly thermoluminescent accessory mineral in the predominantly quartzose sandstone.

In order to better evaluate the use of thermoluminescence as an aid to uranium exploration in the southern Black Hills, additional samples of Inyan Kara sandstones were collected during the 1954 field season both at a detailed mapping project on Long Mountain in the Edgemont NE quadrangle and in the Gould Mine in the Flint Hill quadrangle.

Table 11. Permeability and uranium content of 13 samples from the Gould and Holdup 15 mines

Sample No.	Type of sample (vertical or horizontal)	Uranium in water passed through sample (ppb)	Uranium (percent)	Equivalent Uranium (percent)	Coefficient of Permeability (k) gal/day (Meinzer's units)	Permeability (millidarcies)
133	vert.	2	0.074	0.063	550	30,151
	horiz.		.019	.024	610	33,440
134	vert.	18	.46	.13	280	15,350
	horiz.		1.05	.25	180	9,868
136	vert.	1	.041	.026	190	10,416
	horiz.		.012	.007	440	24,121
137	vert.	9	.017	.007	350	19,187
	horiz.		.17	.13	230	12,609
138	vert.	<1	.012	.011	130	7,127
	horiz.		.056	.051	190	10,416
139	vert.	3	.72	.62	20	1,096
	horiz.		.18	.14	190	10,416
140	vert.	2	1.03	.7	30	1,645
	horiz.		.23	.18	140	7,675
149	vert.	10	.004	.004	6	329
	horiz.		.001	.001	4	219
150	vert.	26	.002	.003	1	55
	horiz.		.002	.004	.7	38
151	vert.	24	.003	0.004	.2	11
	horiz.		.001	<.001	.1	5
152	vert.	4	.001	.002	2	110
	horiz.		.001	.005	.2	11
153	vert.	6	.001	.002	.5	27
	horiz.		.003	<.001	.2	11
154	vert.	<1	.001	<.001	20	1,096
	horiz.		.001	.005	10	548

Long Mountain.--Of the 54 samples collected at Long Mountain, 16 were taken from the southeast wall of the Clarabelle adit as shown in figure 18. Some of these samples contain carnotite; others are apparently free of uranium minerals, yet some of the supposedly barren rocks give higher peaks than the mineralized rock. "Barren" sample LM-46-54, for example, has a thermoluminescence peak of 63 units, whereas LM-43-54, in carnotite, has a peak of 48; yet both samples assay .06 percent eU.

Eight other samples (LM-23 through 30-54) from the Long Mountain area were taken, as shown in figure 19, in a 2-foot fine-grained white sandstone bed underlain and overlain by mudstone. Although there is a variability of 14 percent in the peak values of the curves, all the samples give low peaks characteristic of rocks barren of uranium.

Figure 20 shows the distribution of the remainder of the samples collected for thermoluminescence on Long Mountain. Outcrop samples indicate a correlation of high thermoluminescence peaks with high radioactivity anomalies as outlined by the .02 mr/hr isorad. They also indicate the possible presence of a zone of high thermoluminescence between the group of significant peaks in the northwest part of the area and the group of high peaks in the southeast part of the area. Samples of the same unit studied in the outcrop were taken from diamond drill cores of ten holes in the center of the area. Significantly high thermoluminescence peaks were obtained from the drill core samples (FR-50, 51, and 54) located between the two anomalous areas on the surface. Incomplete gamma ray logs of the core holes show a positive correlation between the intensity of thermoluminescence and the intensity of gamma radiation.

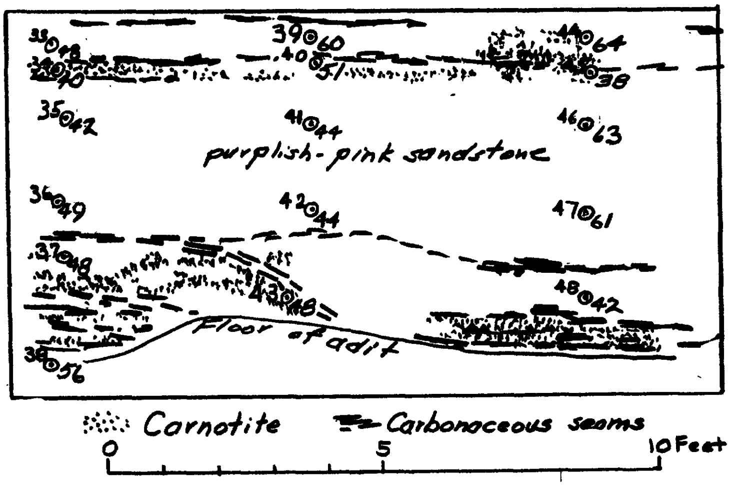


Figure 18.--Section of SE wall of Clarabelle Adit, showing location of samples, intensity of thermoluminescence, and distribution of uranium.

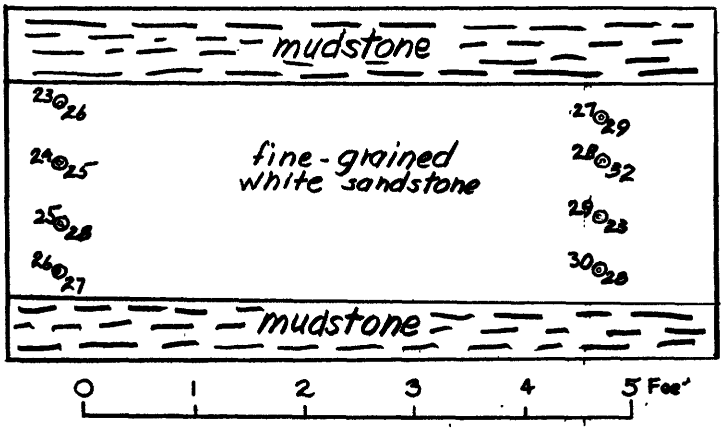
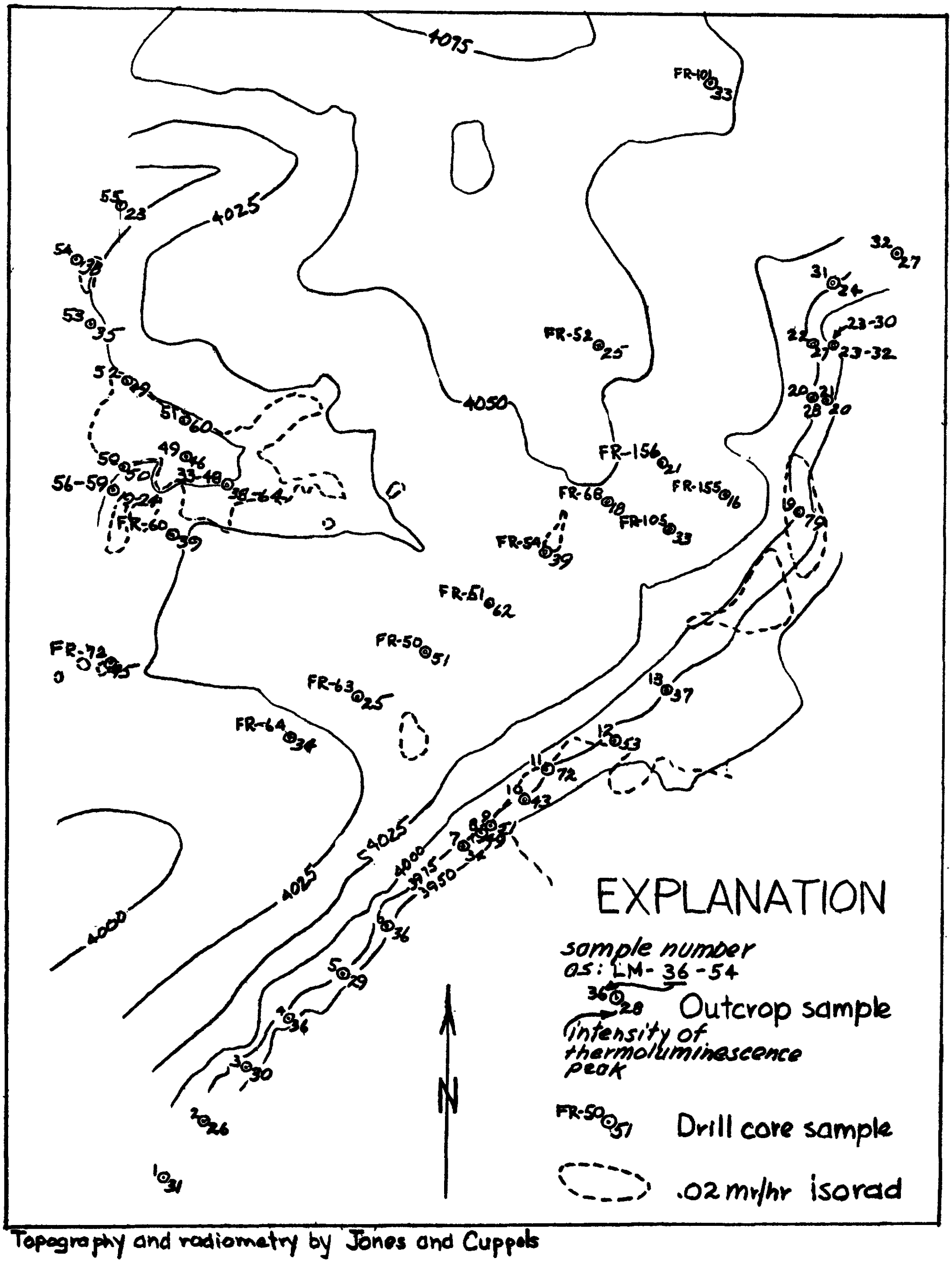


Figure 19 --Section of an isolated sandstone bed, showing location of samples and variability of thermoluminescence.

SAMPLE LOCATION



Topography and radiometry by Jones and Cuppels

Figure 20.--Topographic map of part of Long Mountain, showing location of samples, intensity of thermoluminescence, and .02 mr/hr isorad

0 300 Feet

Contour interval 25 feet

All of the above mentioned samples produce glow curves of essentially the same character - two peaks, one at 200° C and a second higher peak at 276° C, possibly indicating a similar source for the quartz grains of the sandstones and a similar depositional and diagenetic environment.

Gould mine.--Thirteen samples of sandstone and one of silty claystone from the underground working of the Gould mine were tested for thermoluminescence. All the samples except the claystone give significantly high peaks. The claystone may be low for either of two reasons: (1) It is so impermeable that solutions carrying radioactive materials are unable to penetrate it, or (2) the clay minerals are not highly thermoluminescent, even after considerable gamma-ray bombardment.

Table 12 shows the variation of glow curve peaks in 12 samples of ferruginous and non-ferruginous "ore" and "low-grade" rock.

Table 12. Thermoluminescence glow curve peaks of samples from the Gould mine 1/

"Ore"				"Low-grade"			
Fe		No Fe		Fe		No Fe	
Sample No.	Peak	Sample No.	Peak	Sample No.	Peak	Sample No.	Peak
EVP-16-54	77	EVP-12-54	86	EVP-11-54	75	EVP-13-54	70
EVP-17-54	69	EVP-19-54	81	EVP-15-54	45	EVP-14-54	73
EVP-18-54	69	EVP-22-54	76	EVP-20-54	61	EVP-21-54	73
						EVP-23-54	7 (clay)

1/ "Ore" was considered to be within the 1 mr/hr isorad as outlined on the mine walls. This compares favorably with the limits of ore-grade rock as outlined by the miners.

The Gould mine studies again indicate a correlation of thermoluminescence with radioactivity, and illustrate the dampening effect of iron stain on the intensity of thermoluminescence.

Conclusions.--The results of the limited thermoluminescence studies to date appear to indicate that high thermoluminescence anomalies correlate with high radioactivity anomalies both on the surface and in diamond core drill holes. The same anomalies might be detected more easily with a radioactivity survey of the surface or a gamma ray log of drill holes in areas of known deposits.

No attempt has been made, however, to sample systematically for thermoluminescence in areas distant from known uranium deposits and known radioactivity anomalies in the hopes of finding trends of anomalous thermoluminescence that might lead to the discovery of blind ore bodies at depth. It is planned to collect samples for this purpose during the forthcoming field season.

Geochemical investigations

During the past two field seasons geochemical prospecting techniques have been investigated to determine whether they might be of practical assistance in the search for concealed uranium deposits. The studies were based on the assumption that ion migration outward from ore deposits in porous sandstones is probable and that the detection of the resulting halos might give evidence of the location of the deposit. Several hundred analyses of soil and core samples, particularly from the Long Mountain area, are now partly evaluated. The data include quantitative and qualitative analyses of uranium, vanadium, and other metals. Evaluation of these data suggests that prospecting for uranium in the southern Black Hills by means of soil analyses has no advantages over radioactivity surveys and has the disadvantages of being more expensive and time-consuming.

Analyses of core samples likewise indicate that significant amounts of uranium and vanadium have not migrated vertically from ore deposits. Analytical data based on core analyses indicate, however, that the presence of detectable amounts of uranium is increasingly more probable in the coarser textured rocks. The correlation between uranium and texture of the rocks is illustrated in table 13 by the results of statistical studies based on uranium analyses of 306 core samples from the Long Mountain area.

Table 13. Analyses of log variance and log geometric mean of the uranium content, in parts per million, of sediments at Long Mountain, South Dakota*

Rock type	No. of samples	Log geometric mean	Log Variance	Percent of samples with detectable U (2 ppm and more)
Mudstone	24	0.29	0.23	38
Siltstone	130	.57	.61	48
Sandstone, very fine-grained	96	.65	.86	50
Sandstone, very fine- to fine-grained	5	.74	.32	80
Sandstone, fine-grained	41	1.15	1.53	80
Sandstone, fine- to medium-grained	10	9.76	1.19	90

* The rank correlation coefficient for the log of the geometric mean and log variance is +.77. For 5 degrees of freedom at the 5 percent level of significance the value is .75. The results are therefore concluded to be valid.

X-ray and paleontological studies

Incompleted X-ray diffraction studies of the clay-size fraction from 17 samples of mudstone suggest that kaolinite and illite are the most common clay minerals. Montmorillonite and chlorite are present in lesser amounts. Many of the samples show poorly crystalline minerals, with clays of mixed lattice structure common. Montmorillonite is present in many of the samples but has not been found as the dominant clay mineral; it occurs mostly as a minor constituent in some clay fractions. As yet studies have disclosed no systematic clay-mineralogy differences between highly calcareous mudstone and noncalcareous mudstone or between mudstones containing only plant remains and those containing ostracad and other invertebrate remains.

Fossil ostracods, gastropods, and fish all seem to indicate a freshwater environment and large bodies of quiet water. Additional detailed fossil evidence is being sought to indicate the depositional environment of the uranium-bearing sandstones. It is possible that a better understanding of the environment in which the sandstones were deposited will aid in prospecting and interpreting geochemical data.

Pumpkin Buttes area, Powder River Basin, Wyoming

by

W. N. Sharp

The report period was spent in compilation and correlation of data resulting from studies of the preceding summer's work in which geologic mapping of the Pumpkin Buttes area on 7-1/2 minute quadrangles was completed. The mapping of uranium deposits exposed by mining was concluded in April 1955.

All known deposits of uranium minerals are found in sandstone lenses within the dominantly claystone-siltstone sequence of the Wasatch formation of Eocene age and directly associated with red color in sandstone. The limit of red or partly red sandstones in the Pumpkin Buttes area is shown in figure 21. This gives a possible production area of uranium ore in the Buttes area of 350 square miles.

Secondary uranium minerals--principally carnotite, tyuyamunite, and uranophane--are disseminated in gray to buff sandstone at and near buff to red color changes in the sandstone. Uraninite associated with pyrite cements sandstone into nodular masses in red sandstone; the nodules commonly have a thick halo of secondary uranium vanadates around them. Manganese oxide nodules which enclose sandstone rich in secondary uranium minerals, principally uranophane, are also found in red sandstone. Unoxidized vanadium minerals, represented principally by paramontrosite, are found at one place, and in the vanadium group of minerals are analogous to uraninite in the uranium group of minerals.

Local and regional spatial association of uranium deposits with epigenetic red color in sandstone leads to the conclusion that the same process or processes are responsible for both features. Interpretation of field and laboratory data leads to the suggestion that uranium in the Pumpkin Buttes area is derived from components of the sandstone and redeposited under conditions of pH and Eh that varied locally within sandstone lenses to give the several habits of occurrence.

Devils Tower, Wyoming and Montana

by

C. S. Robinson

The Devils Tower area (fig. 22), on the western and northern flanks of the Black Hills uplift, includes an essentially concordant sequence of sedimentary rocks ranging in age from Permian (Opeche formation) to Eocene (Wasatch formation). These rocks have an aggregate thickness of about 8,500 feet. Their outcrop belt extends from the southern edges of

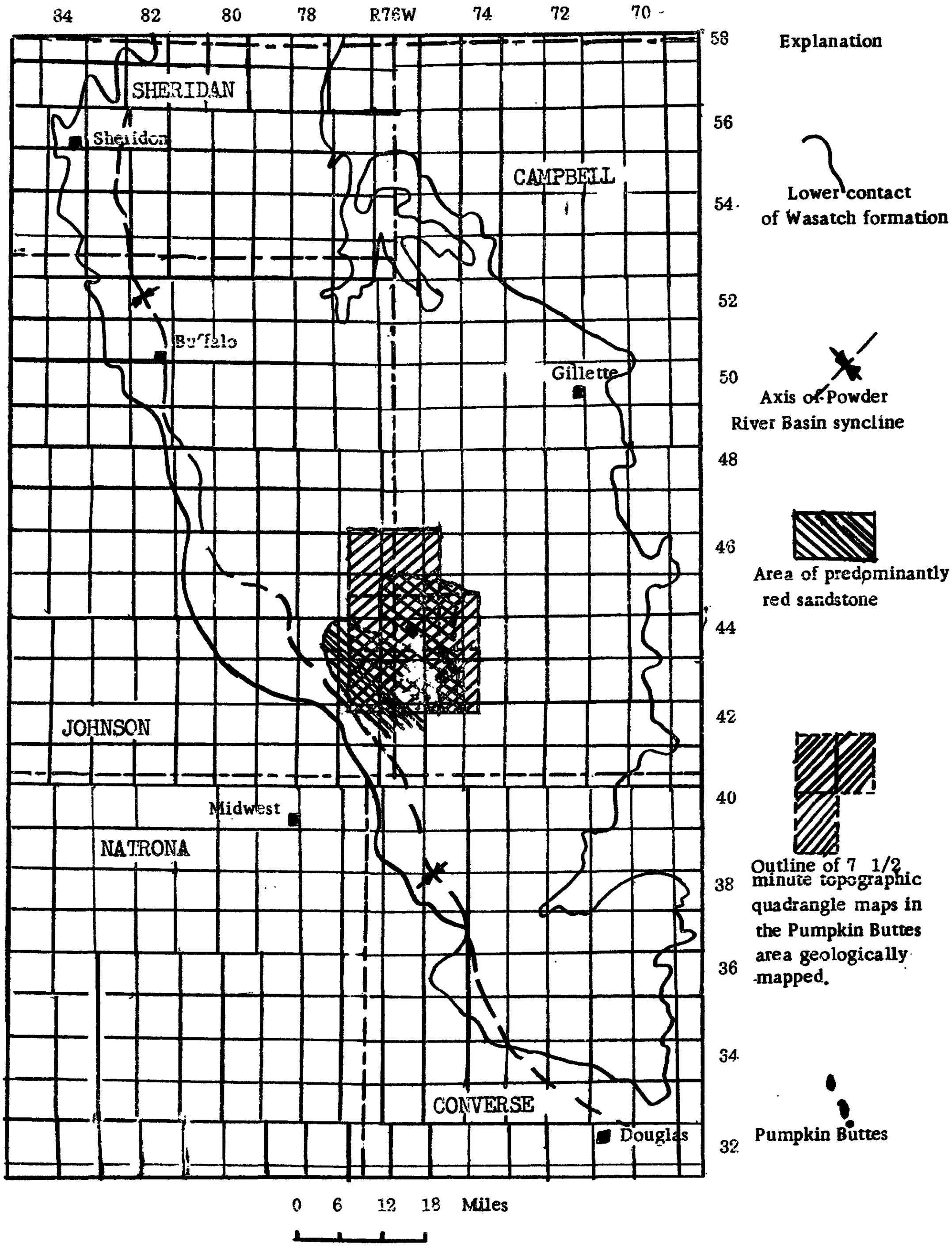


Figure 21. Map of the Powder River Basin, Wyoming, showing known extent of red sandstone and status of geologic mapping

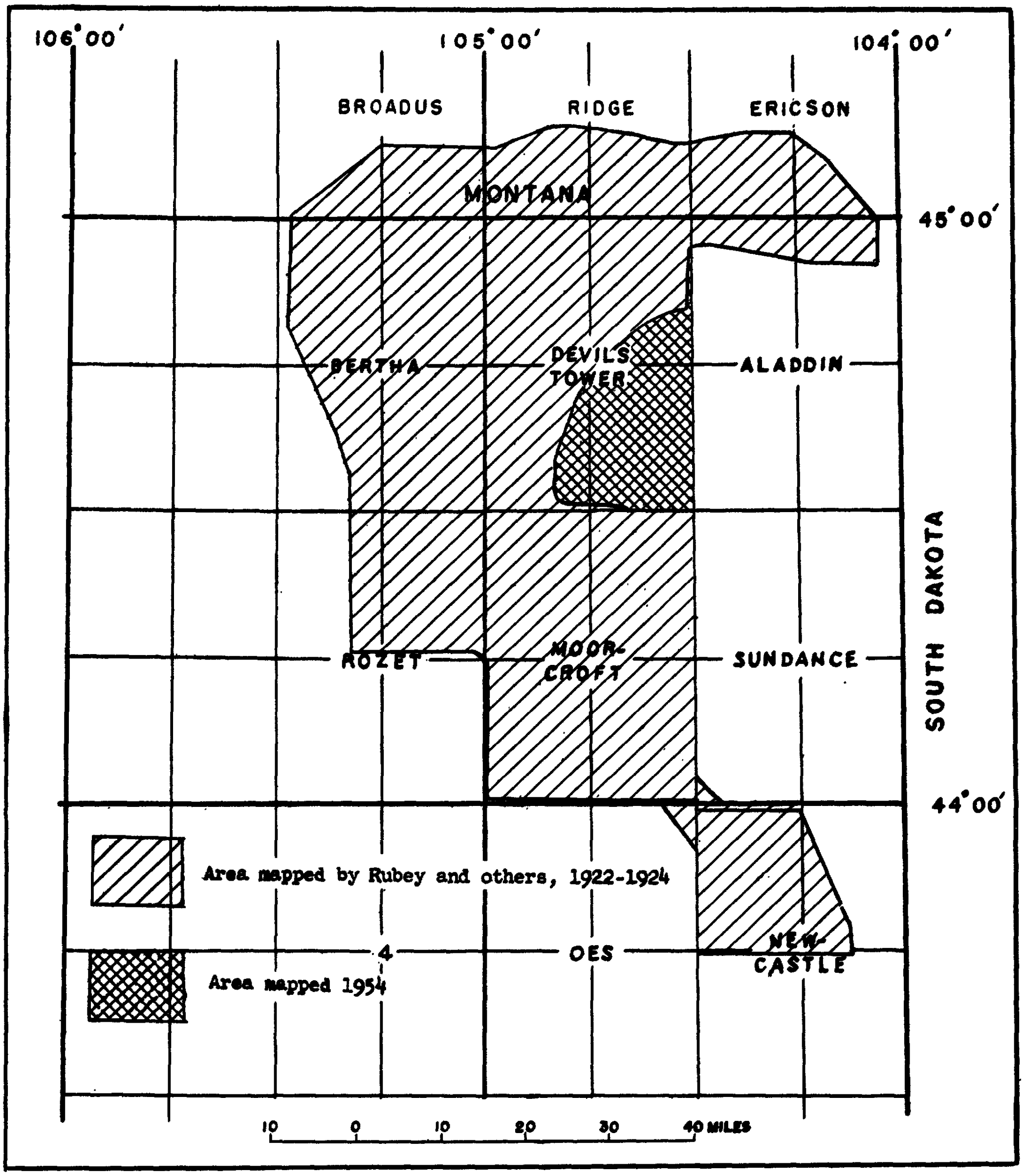


FIGURE 22--DEVILS TOWER PROJECT, WYOMING AND MONTANA

Newcastle and Rozet quadrangles in a broad arc across the Devils Tower area to the eastern edges of the Erickson and Aladdin quadrangles. The pre-Oligocene sediments are unconformably overlapped at some places by the White River formation of Oligocene age and are intruded locally by igneous sills, dikes, and stocks of Late Cretaceous or Early Tertiary age.

Commercial deposits of uranium and many radioactivity anomalies occur in the Devils Tower area in the non-marine Inyan Kara group of Early Cretaceous age, and radioactivity anomalies have also been reported in the Sundance and Morrison formations of Jurassic age, and in the Fox Hills sandstone of Late Cretaceous age.

A preliminary map of the Devils Tower area at a scale of 1:96,000, and a preliminary structure map of the Devils Tower 30-minute quadrangle at a scale of 1:63,360 showing contours at 100-foot intervals on the top of the Fall River sandstone of the Inyan Kara group, were compiled during the report period and are now being field checked before being transmitted for publication. A report on the Gypsum Spring formation of the northwestern Black Hills is being prepared.

Plans for the summer of 1955 include remapping and field-checking parts of the area and measuring stratigraphic sections in places where information is sparse or lacking.

Gas Hills area, Fremont County, Wyoming

by

H. D. Zeller, P. E. Soister, and H. J. Hyden

The Gas Hills area is in east-central Fremont County and west-central Natrona County, Wyoming near the south-central margin of the Wind River Basin. The Wind River formation, which dips gently to the south, rests with angular discordance on rocks ranging in age from Cambrian to late Cretaceous and is overlain by tuffaceous rocks ranging in age from middle Eocene to Miocene.

Uranium deposits occur in the upper coarse-grained part of the Wind River formation of lower Eocene age, with the exception of two minor occurrences in subjacent Mesozoic rocks. Meta-autunite and an unnamed yellow uranium phosphate are the most common ore minerals and generally occur as interstitial fillings in irregular blankets in brownish-red to gray coarse-grained arkosic sandstone of fluviatile origin. Other uranium minerals found in the area include uraniferous carbonate-fluorapatite, uraninite, liebigite, rutherfordine, uranospinite, becquerelite, metatorbernite, metazeunerite, uranophane, uranocircite, and an unnamed uranium silicate.

During the course of the field work in the Gas Hills area, waters from springs, wells, streams, and reservoirs were collected for uranium analysis. The generalized geologic map (fig. 23) shows the regional distribution of uranium in these waters and its greater concentration in the vicinity of known uranium deposits. The data on these waters (excluding reservoir samples) are summarized in the following table:

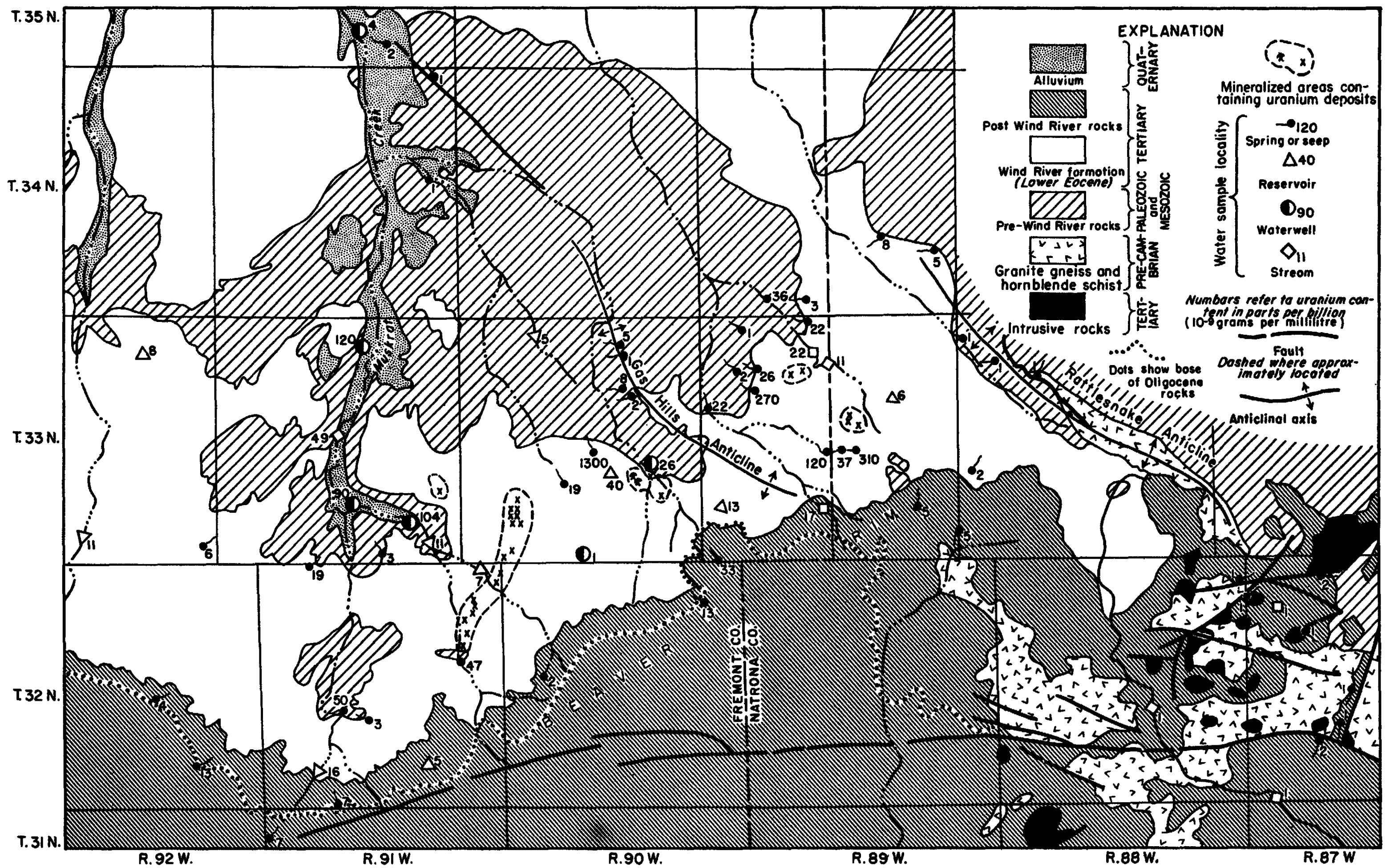


FIGURE 23. GENERALIZED GEOLOGIC MAP SHOWING REGIONAL DISTRIBUTION OF URANIUM IN WATER AND ITS GREATER CONCENTRATION IN THE VICINITY OF KNOWN URANIUM DEPOSITS, GAS HILLS AREA, WYOMING

0 1 2 3 Miles

1955

Table 14. Data on waters from Gas Hills area

Units from which water was sampled	No. of samples	Average U content of water (ppb)	Average pH
Oligocene and Miocene rocks	6	12	7.92
Eocene and older rocks	37	6	7.86
Precambrian and Tertiary intrusives	3	1	7.43
Mineralized areas	16	98	6.81
Total	62		

The uranium content of water draining from mineralized areas averages 98 parts per billion in contrast to 6 parts per billion uranium in waters from nonmineralized areas. A water sample from a seep in the mineralized area contains 1,300 parts per billion. This figure was not included in the average.

Poison Basin area, Carbon and Sweetwater Counties, Wyoming

by

G. E. Prichard and W. A. Chisholm

The Poison Basin area includes about 275 square miles in southern Carbon and Sweetwater Counties. Uranium deposits in the area occur in the Browns Park formation of Miocene age. Figure 24 is a structure contour map of the Browns Park formation in Poison Basin, where most of the known uranium deposits occur. The Browns Park formation covers much of the topographic basin that coincides generally with the asymmetric westward plunging Poison Basin syncline. Although the Browns Park formation is as much as 1,000 feet thick at other localities, the outlying remnant of the formation in Poison Basin is only about 300 feet thick.

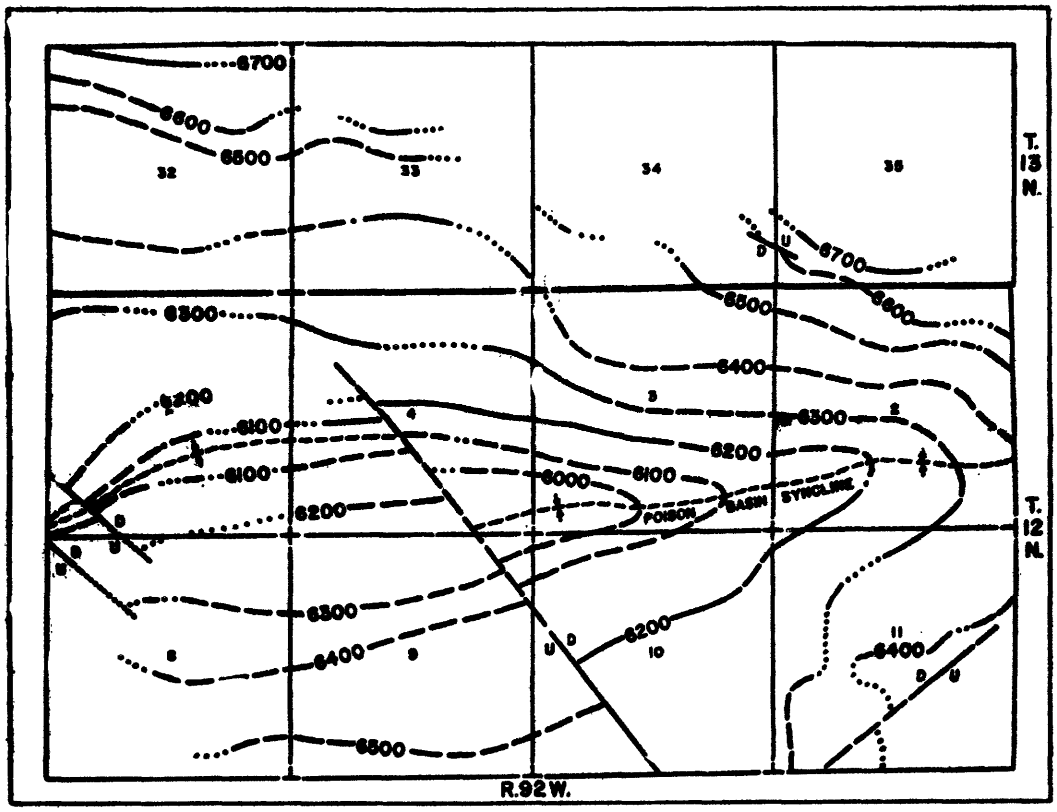


Fig. 24 STRUCTURE MAP OF POISON BASIN IN THE POISON BASIN AREA, CARBON AND SWEETWATER COUNTIES, WYOMING

Structure contours drawn on base of Browns Park formation; contours dashed where elevation is inferred; dotted where base is concealed or removed by erosion. Contour interval is 100 feet; datum is mean sea level.

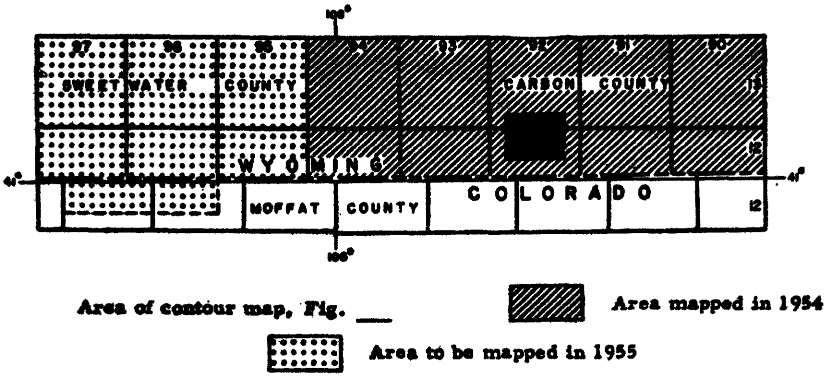


Fig. 25 INDEX MAP OF POISON BASIN AREA, CARBON AND SWEETWATER COUNTIES, WYOMING

The occurrence of uranium in the Poison Basin area is similar to occurrences in other areas in Wyoming where secondary uranium minerals are present near the surface in sandstone deposits of Tertiary age. Uranium is erratically distributed through the strongly cross-bedded sandstone overlying the basal conglomerate of the Browns Park formation. Locally, yellow secondary uranium minerals are visible, but commonly the uranium is finely disseminated in the sandstone with little or no visible mineralization even in strongly radioactive samples.

Sandstone containing as much as 3 percent uranium occurs in the Browns Park formation in Poison Basin. Uranophane and schroeckingerite have been identified as the principal uranium minerals in samples from outcropping sandstone beds. Tyuyamunite has been identified as the principal uranium mineral in a sample from an adit in Poison Basin. The tyuyamunite is compact to cryptocrystalline, and where visible, occurs in irregular greenish yellow bands as much as 3 mm wide. Replacement by tyuyamunite has occurred along the filled incipient fractures in quartz grains and along cleavage planes in feldspar grains. These secondary uranium minerals occur in surface deposits in Tertiary strata at other localities in Wyoming.

A pale to moderate blue argillaceous very fine- to fine-grained sandstone zone occurs at depths ranging from 20 to 70 feet below the surface. The floor of the adit on the Poison Basin claims is at the top of the "blue zone". Frequent testing of the "blue zone" in the adit and in auger holes for radioactivity gave negative results. A recent examination of a dry sample from the "blue zone", however, resulted in the discovery of two minerals tentatively identified as schroeckingerite and autunite.

Geologic investigations planned for the 1955 field season include (1) additional detailed geologic mapping of the Browns Park formation in an area of about 200 square miles (fig. 25) west of the Poison Basin area, (2) detailed studies of individual uranium occurrences and favorable areas, and (3) preparation of a structure contour map of the area.

Crooks Gap area, Fremont County, Wyoming

by

J. G. Stephens and M. J. Bergin

The Crooks Gap area, in the southeastern corner of Fremont County, is bounded on the north by the Sweetwater Arch and on the south by the Great Divide Basin. Miocene and Eocene rocks crop out over a large part of the area. Older rocks ranging in age from Precambrian to Paleocene are exposed in the vicinity of Crooks Gap. The pre-Tertiary rocks are characterized by asymmetric anticlines and thrust faults, and the Tertiary rocks by gentle folds and normal faults.

Preliminary investigations of the uranium deposits in the area reveal that the Wasatch formation of early Eocene age is the principal ore-bearing formation. Occurrences of uranium are present in overthrust Cambrian rocks in the northern part of the area, but are not of commercial importance.

The uranium deposits occur as impregnations in conglomeratic arkosic sandstone localized near thin carbonaceous, clayey siltstone beds. The most important uranium mineral is uranophane. Other minerals identified from the Wasatch deposits include phosphuranylite, uraninite, coffinite, and meta-tyuyamunite. Minerals identified from the Cambrian occurrences include uranophane, meta-autunite, autunite, and an unclassified uranium silicate.

Water samples were collected for uranium determinations in the vicinity of Crooks Gap in an endeavor to locate new ore bodies or to outline areas for intensive prospecting. The uranium content of well and spring water samples is plotted on figure 26. The results are summarized in table 15.

Table 15. Results of water sampling, Crooks Gap area

Unit from which water was sampled	No. of samples	Average uranium content of water (ppb)	Average pH
Miocene rocks	9	19	-
Eocene and older rocks	55	4	7.5
Mineralized areas	6	124	7.5

The sampling indicates an anomalously high uranium content in water from the northeast slope of Crooks Mountain on the west side of Crooks Gap, suggesting the possibility of a buried ore body in this area.

Dripping Spring quartzite, Arizona
by
H. C. Granger

All presently known uranium deposits in the Dripping Spring quartzite are in the middle and lower units of the upper member of the formation, which is distinguished from the lower arkosic quartzite member by its flaggy bedding and abundant siltstone. The known deposits are also confined to Gila County, although the formation is found in several other counties to the south.

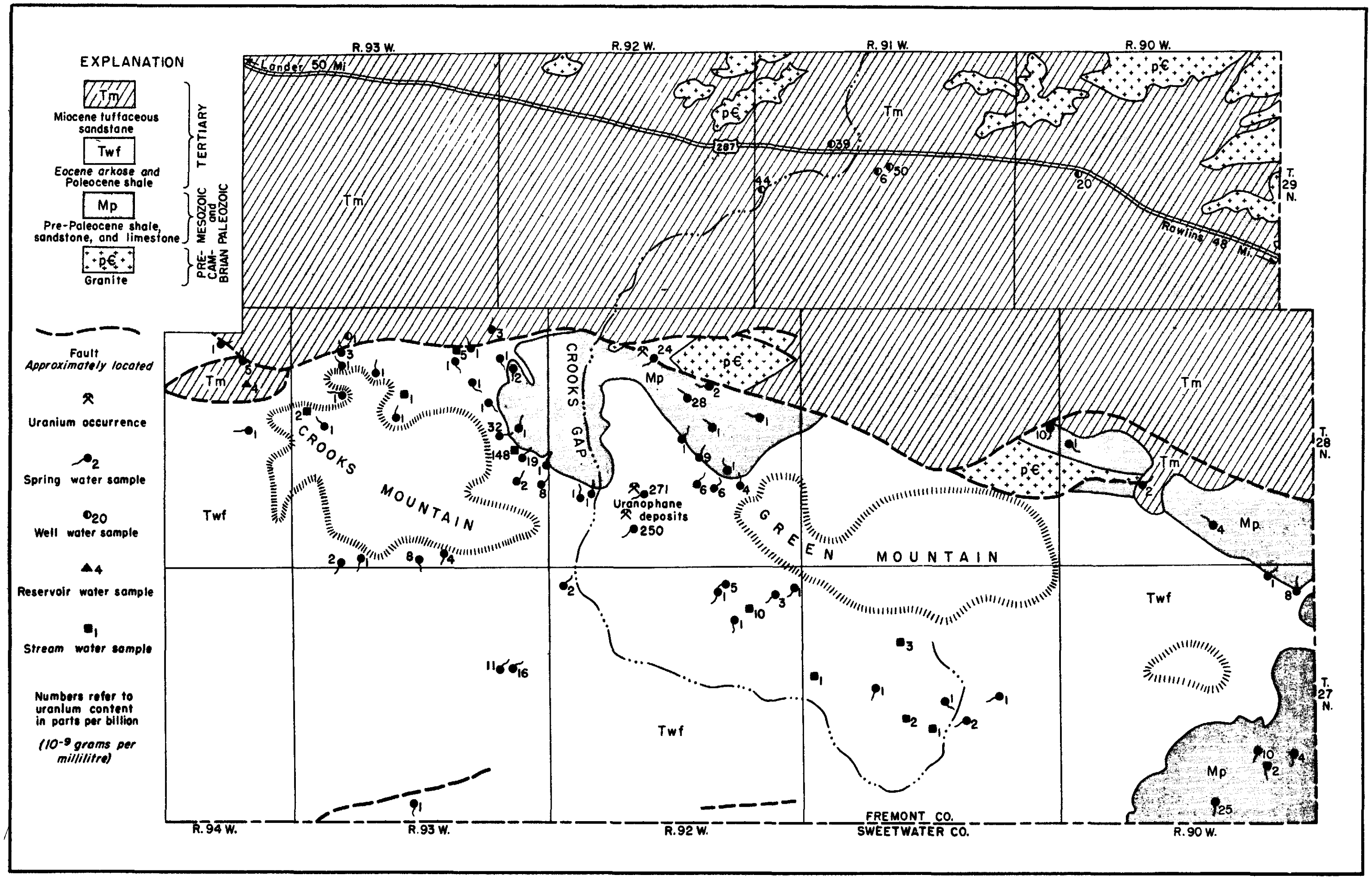


FIGURE 26—GENERALIZED GEOLOGIC MAP SHOWING THE URANIUM CONTENT OF WATER IN THE CROOKS GAP AREA, FREMONT COUNTY, WYOMING

Host rock

Uranium deposits have been found primarily in two types of host rock within the upper member. Most of the deposits are in the normal siltstones but some are in a metamorphosed equivalent of the siltstone.

Siltstone.--The siltstone host rock is commonly a laminated light- to dark-gray argillaceous and feldspathic siltstone. Thin beds of fine- to medium-grained quartzite and conglomerate lenses are interlaminated with the siltstones in some areas. Near the surface these rocks may be strongly bleached but a few feet below the surface are dark-colored owing to finely disseminated pyrite and carbon.

Feldspathized rock.--Near discordant intrusive diabase bodies the siltstones of the upper member are locally metamorphosed to an igneous-textured rock consisting primarily of potash feldspar with lesser amounts of albite, sphene, augite, biotite, quartz, and metallic sulfides. The grain size varies from coarse crystalline to aphanitic. Where aphanitic, the feldspathized rock may be megascopically indistinguishable from normal siltstone. Bedding is in part preserved. Locally, the feldspathized rock is brecciated and cemented either by similar material or by aplite.

Some rich uranium deposits in the Dripping Spring quartzite are in feldspathized rock but they are fewer and are restricted to a much smaller area than those localized in the normal siltstone. Several deposits in the siltstone are, however, spatially close to apparently barren feldspathized rock.

Structure

At outcrop many of the deposits in both host rocks are within a few hundred feet of a discordant diabase body. Near some other deposits erosion has removed sills of diabase that may have been locally discordant. Some of the most promising deposits are exposed within a few feet of diabase contacts.

The near-surface parts of the deposits commonly follow steep fractures that trend about N 20° E. or N 70° W. Whether these fractures control only the near-surface secondary deposits or also control the deeper primary deposits is not yet fully known.

All the known deposits are limited vertically by some as yet undefined stratigraphic control. The largest individual ore bodies are several hundred feet long and of stoping width with assay walls, but less than 20 feet thick vertically.

Alteration

Aside from weathering, no alteration of the feldspathized rock has been noted. The feldspathization in itself, however, may be considered to be an alteration and it may have been nearly contemporaneous with the uranium mineralization.

Except for feldspathization, alteration of the siltstone varies, although only one type seems to be unique to the uranium deposits. A green illite clay forms small pods and veinlets in the secondary parts of some deposits.

Mineralogy

Primary minerals of these deposits suggest an early stage of high-temperature deposition. The minerals are discussed below approximately in order of paragenesis.

Uraninite.--Occurs disseminated and in lenses and irregular bodies commonly conforming to the relict bedding planes in feldspathized rock. The lenses and other forms are composed of aggregates of discrete rounded to cubic uraninite grains less than 0.1 mm in diameter. In many specimens the texture of the feldspathized rock appears to be virtually undisturbed by the uraninite. That is, the uraninite grains form inclusions in the feldspar and, by their abundance, appear as lenses in the feldspathized rock.

Coffinite.--Identified, by X-ray powder pattern, in association with uraninite.

Pyrrhotite.--Commonly disseminated in the feldspathized host rock. It has been seen also in the quartzite lenses associated with siltstones. It locally occupies the spaces between uraninite grains but does not appear to replace them. X-ray powder patterns indicate that the pyrrhotite is of the variety troilite or nearly pure FeS.

Molybdenite.--Forms rare flakes in pyrrhotite and the adjacent host rock.

Chalcopyrite.--Found in both types of host rock. It may not all be of the same age. It is generally disseminated but locally fills fractures associated with pyrite. It replaces and occupies the same positions as pyrrhotite.

Pyrite.--Ubiquitous and evidently of several different ages. It is disseminated, forms veinlets associated with quartz or other gangue minerals, and fills stylolites in the siltstones.

Marcasite.--May be of two or more ages. A peculiar colloform-like occurrence in the feldspathized host rock may be earlier than the chalcopyrite. It also fills very late fractures in both host rocks.

Galena.--Some may be radiogenic and occurs as micron-sized grains between uraninite grains. Later galena occupies fractures and calcite veins in both types of host rock.

Sphalerite.--Rare, and associated with galena.

Secondary uranium minerals are prevalent in the near-surface parts of the deposits. They are disseminated in the host rock or, more commonly, coat joint and bedding-plane surfaces near N 20° E. and N 70° W. fractures. To date, uranophane, metatorbernite, bassetite, uranocircite, and uraniferous hyalite have been identified. Autunite probably is present. Limonite, gypsum, and malachite are common associates. Azurite, chalcocite, and covellite are present locally.

Spectrographic data

Spectrographic analyses suggest that there is a positive relationship between the concentration of uranium and the concentrations of copper, lead, nickel, cobalt, molybdenum, and silver. Arsenic, bismuth, and mercury generally are absent or below the threshold detection value. The vanadium content in every sample tested in below .05 percent.

Karnes County, Texas

by

W. I. Finch

The uranium deposits in Karnes County, southern Texas, occur in flat-lying beds of the Jackson formation of Eocene age and in the overlying Catahoula and Oakville sandstones of Oligocene age. The ore-bearing rocks consist of poorly bedded and mostly unconsolidated marine, brackish water, near-shore, and continental beds of light-colored tuff, sand, and sandy clay. The mineralogy of these deposits is still imperfectly known. Yellow and green uranium minerals, probably phosphates and silicates, occur along fractures and bedding planes, and disseminated in the rock. Large amounts of arsenic and molybdenum occur with the uranium. The best mineralized rock appears to be associated with hydrated iron oxides, bentonite, and rocks that are characterized by mixed and irregular bedding. Carbonaceous material is rare and commonly shows no spatial relation with the ore. The deposits range from bodies a few feet across that contain a few tons of ore to bodies several hundred feet across that contain thousands of tons. The deposits appear to have been concentrated by ground water from a disseminated volcanic source.

Stratigraphy, by D. H. Eargle

The generalized stratigraphy of the Karnes County uranium deposits and adjacent areas is shown on figure 27. A preliminary stratigraphic section, indicating the beds containing uranium deposits, is shown in figure 28.

The sandstone at the top of the Jackson formation (Eocene) in the area consists of sand and silt containing tuffaceous material and bentonitic, carbonaceous clay. Some of the beds of sand are cemented with secondary silica and are highly resistant to erosion. The sand contains abundant silicified wood and, rarely, leaf prints. Several sand beds are thin bedded, but most are cross-bedded, delta-type deposits 20 feet or more thick. Some of the sands have been traced many miles but others are lenses, probably bar deposits of local extent. The silts are chiefly bedded tuffs, white to gray, soft, friable, light in weight, and contain abundant stems and other plant matter. Impure lignite beds are characteristically found at several horizons. Several beds containing *Corbula*, *Ostrea*, and other mollusks can be traced for a number of miles.

The Frio clay, which is present on the surface in this area only in northern Live Oak County, overlies unconformably the Jackson rocks and is overlain unconformably by the Catahoula sandstone, which overlaps it

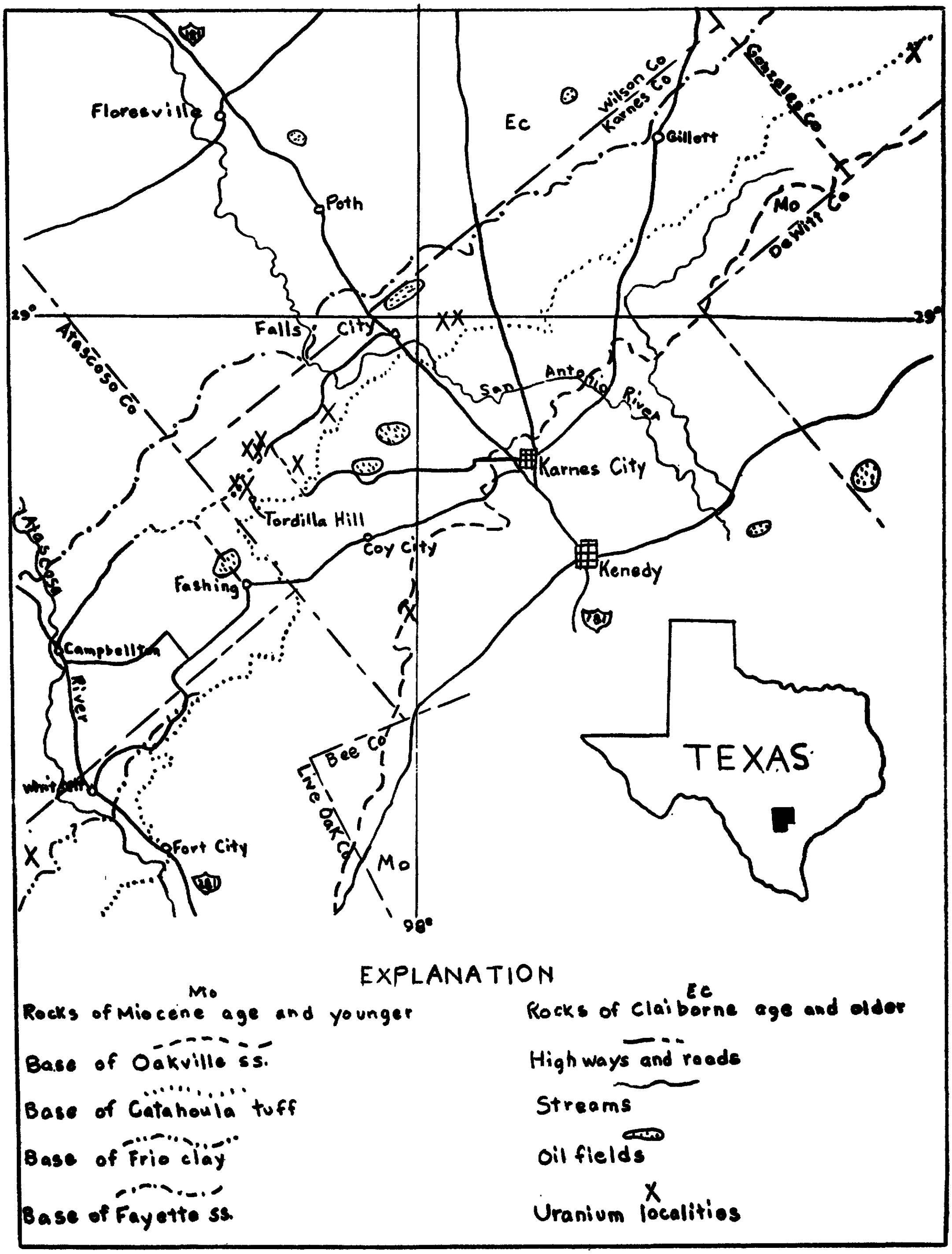


Figure 27.—Reconnaissance geologic map of the Karnes County area, southeast Texas, showing location of uranium prospects

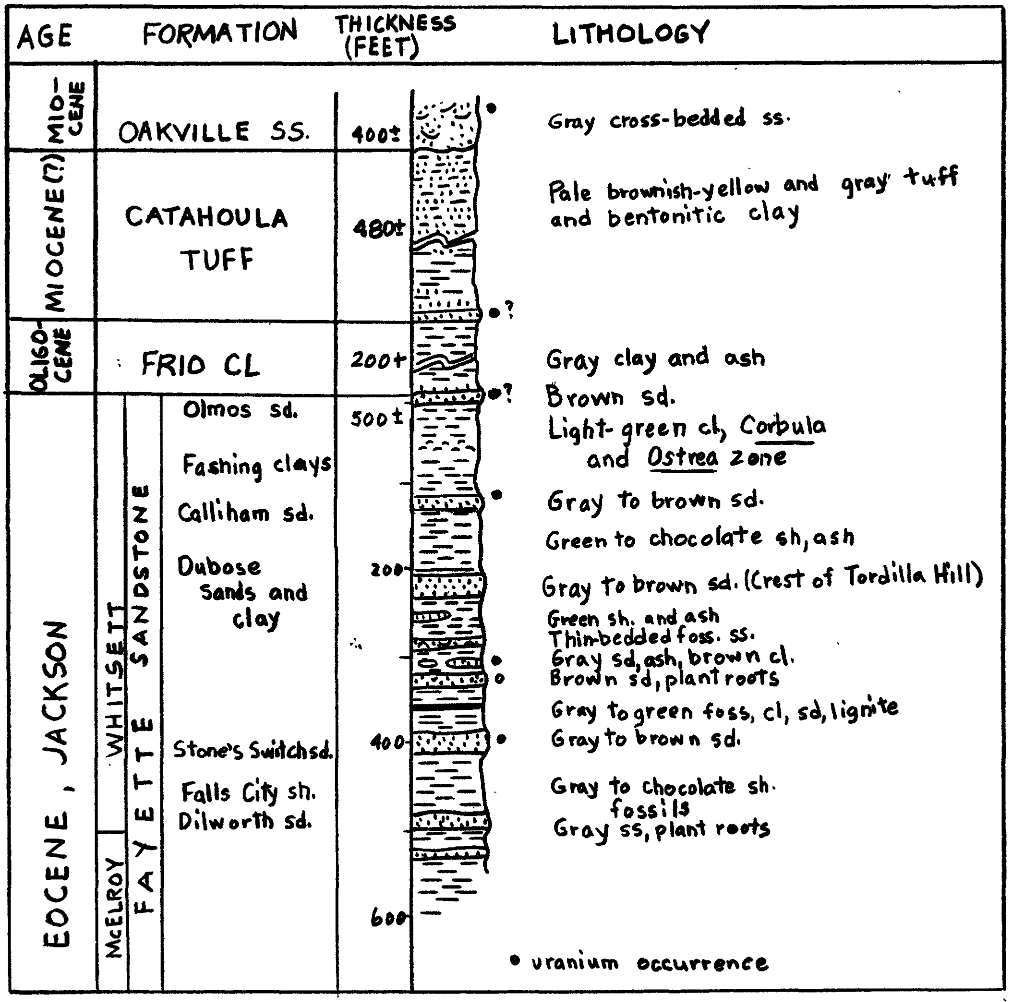


Figure 28.—Stratigraphic section, Karnes County area

(Fayette sandstone section modified from Ellisor, Bull. AAPC, v. 17, p. 1312.)

to the northeast. It is a gray to greenish-gray marine clay, contains few or no fossils, and is probably bentonitic in character.

The Catahoula sandstone (Oligocene?) consists chiefly of soft, friable, pale-yellowish-brown to gray, soft silt. It contains, especially toward its base, beds of brittle cream-colored clay and a few beds of sand. In the northeastern part of the area its basal bed of coarse sand is termed the "rice sands." The formation unconformably overlies and overlaps progressively all beds from the Frio to the middle Jackson from southwest to northeast in this area.

The Oakville sandstone (Oligocene), which overlies the Catahoula sandstone, consists of a basal bed of crossbedded, fine- to medium-grained sandstone, and of overlying beds of tuffaceous clay, silt, and sand. The basal sand consists, in part, of channel sands and laminated ashy clay.

Uranium minerals occur locally in at least six zones throughout a section of about 1,200 feet, extending downward from the basal Oakville sandstone to the base of the upper sandstone unit of the Jackson formation. Most of the uranium deposits now being prospected are in beds termed by Ellisor (Ellisor, A. U., American Association of Petroleum Geologists Bull., vol. 11, p. 1312) the "Dubose sands and clay" of her Whitsett formation, the upper unit of the beds of Jackson age which constitutes about half of her Fayette sandstone. These deposits are generally within 150 feet or less of the contact of the overlapping Catahoula sandstone and are generally progressively lower in the section to the northeast, as the Calahoula overlaps the upper part of the Jackson from southwest to northeast. Some of the uranium deposits are in the sandstone beds that appear to be of deltaic origin, but some of the richest deposits are in sandstone lenses in silty and clayey beds. The lenses, probably bar deposits, are oriented at a slight angle to the direction of the strike of the rocks. Some of the most conspicuous uranium minerals are in the sandstone associated with carbonaceous trash. Beds of lignite, however, seem to have been only slightly mineralized. Because some of the richer deposits closely adjoin faults, it is believed that the proximity of faulting may be an important factor in the accumulation of the uranium minerals in the sand and clay.

One uranium occurrence in Gonzales County is believed to be in the basal coarse sand of the Catahoula, near a line where the Catahoula is in fault contact with the upper Jackson. A prospect in southern Karnes County is in a channel deposit in the basal Oakville sandstone.

URANIUM IN VEINS, IGNEOUS ROCKS, AND RELATED DEPOSITS

District Studies

Colorado Front Range

A discussion of the general geology of the Central City district and adjoining areas, was given in TEI-390. A summary of the distribution, structure, mineralogy, paragenesis, and origin of the uranium deposits was presented in TEI-440, and an evaluation of the uranium potential of the region was given in TEI-490. Only current studies are described below.

Precambrian pegmatites, by P. K. Sims

Analyses of many uraninite-bearing Precambrian pegmatites, of the type mined at the Highlander claim, indicate that these pegmatites contain about .05 percent uranium. Some parts of the pegmatite bodies are higher in grade than others and a small volume of each pegmatite body is of ore grade. It is concluded, therefore, that although the potential tonnage of low-grade pegmatites is in the tens of thousands of tons, the pegmatites cannot be mined profitably at present ore prices.

Tertiary vein deposits, by P. K. Sims

More than 100 abnormally radioactive Tertiary veins are present in the 50-square-mile area studied by the Colorado Front Range project. Of these localities, about 40 percent contain selected material assaying 0.10 percent uranium or greater, and about 25 percent contain material of ore grade. Most of the localities are listed in TEI-440. Most of the significant vein deposits occur in the earliest Laramide fracture sets -- northwest-, west-northwest-, east-northeast-, and east-trending--

and but few are in the younger Laramide fracture sets. Therefore this early group of vein-filled fractures are considered most favorable for exploration. Further, the significant deposits occur in clusters which do not comprise more than a square mile in extent.

The uranium vein deposits show no relation to the geographic pattern of hypogene mineral zoning, contrary to some earlier views. It is tentatively concluded that the uranium-bearing fluids which deposited the pitchblende were derived from quartz bostonite magma; and that the precious- and base-metal ores were derived a different source--a deep-seated, differentiating early Tertiary magma. This conclusion also differs from that previously published by others.

Blackhawk district, Gilpin County, by R. U. King and P. K. Theobald

Radioactivity is associated with quartz-hematite breccia in the northwest-trending Blackhawk fault zone at the Priscilla claim, 1 1/2 miles southeast of Blackhawk. The discovery, made early in 1955, is 1-3/4 miles southeast of the Silver Hill uranium deposit (TEI-490, p. 224). A sample of the breccia from the discovery cut contains 0.17 percent uranium, and dump material from a nearby abandoned shaft in the fault zone contains 0.017 percent uranium.

The Silver Hill deposit, a vein-type deposit that contains disseminated secondary uranium minerals in weathered schist, is being explored by drifting along the vein. Additional ore-grade material is being found as the drift is advanced. A sample from the vein contains 0.43 percent uranium.

These two deposits extend the favorable area of the Central City district eastward in the direction of the known uranium deposits of the Ralston Creek-Golden Gate area, and suggest that further prospecting of breccia reefs and major faults may disclose additional uranium deposits.

Wall-rock alteration studies, by E. W. Tooker

Study of altered wall rocks in the Central City-Idaho Springs district and adjoining areas in Gilpin and Clear Creek Counties, Colorado has shown that there is a poor and irregularly defined zonation about veins, but that alteration is relatively weak and not a pervasive feature as elsewhere. Generally a quartz (silicified) sericite zone adjoins the veins and grades laterally into an argillic zone of varying thickness as yet not quantitatively subdivided and thence into fresh rock. Plagioclase was the first host-rock mineral to alter, changing to montmorillonite. Later biotite altered to the mixed-layer mineral montmorillonite-illite. This in turn, adjacent to the vein, was transformed into illite-sericite and sericite. Kaolinite and halloysite occurred as local variations in the argillic zone near the vein. Chlorite, a minor constituent, formed away from the vein zone and may be related to both plagioclase and biotite alteration.

Aside from the garnet-quartz gneiss in the Fall River area, no overall relationship between primary ore type and altered rock type has been observed. Near-neutral pH relations and favorable wall rock (with illite-montmorillonite type alteration) are necessary for the localization of secondary uranium minerals in the Central City area.

Ralston Buttes district, Colorado
by
D. M. Sheridan and C. H. Maxwell

The Ralston Buttes district is in the eastern foothills of the Colorado Front Range west of Denver. Significant occurrences of pitchblende in the district are associated with base-metal sulfides in or near carbonate-bearing fault breccias of probable Tertiary age. A general description of the geologic associations of the pitchblende occurrences was given in TEI-490 and more detailed descriptions were published in USGS Circular 320.

Field work on the project during the report period was limited to about one month. Approximately 3 square miles were mapped at a scale of 1:20,000 in the southeast corner of the Ralston Buttes quadrangle. Twelve old prospect pits were examined for radioactivity and mineralized areas and preliminary traverses totalling 5,000 feet in length were made in searching for radioactive anomalies.

During the past six months production of pitchblende-bearing ore has continued at the Ralston Creek (Schwartzwalder) mine in the northeastern part of the district. Other private parties are prospecting in the vicinity of the Nigger Shaft on Ralston Creek and in the Golden Gate Canyon area. The Ladwig No. 2 adit in the Golden Gate Canyon area has been rehabilitated and extended and the shaft has been cleared.

Plans for the next fiscal year include completion of field mapping and search for uraniferous deposits in the Ralston Buttes district and compilation of the results into a USGS Bulletin.

Boulder Batholith, Montana

by

G. E. Becraft

A brief examination was made in March 1955 of a thick sequence of uraniferous bentonite-bearing tuffaceous Oligocene sedimentary rocks northeast of Winston, Broadwater County, Montana. In an area of several square miles, uranium occurs in a number of beds of tuff and tuffaceous shale and particularly in tuffaceous shale rich in organic matter.

Secondary uranium minerals, tentatively identified as meta-autunite and carnotite or tyuyamunite, have been found at two locations. The uranium-bearing beds range in thickness from 1 inch to 2.5 feet. Selected samples contain as much as 0.36 percent eU.

Reconnaissance of an area of similar tuffaceous sediments south of Radersburg, Broadwater County, disclosed radioactivity anomalies in secs. 1, 2, and 3, T. 3 N., R. 1 W. The strongest radioactivity, about 10 times background, was in a 5-inch bed of light-pinkish gray carbonaceous shale. A 4-foot bed of lapilli tuff containing rounded fragments of pumice gave a reading of 3 to 4 times background. Radioactivity was also detected in a Tertiary carbonaceous shale about 10 inches thick in the northeast corner of sec. 12, T. 2 N., R. 1 W.

To appraise the uranium potential of the Winston area and determine whether detailed work by the Survey might be desirable, a study of the stratigraphy, structure, and distribution of uranium in the Tertiary sediments was started on May 9 and continued to the end of the fiscal year.

Petrologic studies of the rocks of the Boulder batholith and laboratory studies of the ore minerals from veins in the batholith were continued.

Thomas Range, Utah

by

M. H. Staatz

The main eastern part of the Thomas Range consists of a large silicic volcanic series with a small patch of Early Paleozoic sediments, 1 1/4 square miles in area, at the southern end. The western and northwestern parts of the Thomas Range and the Dugway Range are separate blocks of Paleozoic sediments, chiefly carbonates. .

During the report period about 50 square miles, covered chiefly by volcanics of two periods, was mapped. The older group of these volcanics consists of crystal tuff, brown to purple rhyolite, and latite. After rocks were eroded into rugged mountains a younger group of volcanics consisting of white to orange vitric and lithic tuff, an obsidian layer, and recurring layers of topaz-bearing rhyolite were emplaced upon them. The younger volcanics, however, consist chiefly of the topaz-bearing rhyolite; obsidian, where present, represents the first quickly cooled part of the rhyolite flow and acts as a marker bed at the bottom of the flow.

Uranium minerals are known in two places in the mapped area. On the east side of the range near its southern end shear zone contains uranium mineralization along several small fractures. The most abundant mineral is opal, with minor amounts of calcite, fluorite, and a yellow uranium mineral. This mineral, which has not previously been described, is a uranium silicate probably similar in composition to uranophane. The grade of the ore in four channel samples ranges from 0.009 to 0.026 percent U. A selected sample of high-grade ore from the dump, however, contains 0.20 percent U.

Uranium minerals occur also in the wide swale along the west side of the main volcanic mass, in a large lens of extremely friable tuff interbedded with a limestone-bearing agglomerate. A yellow uranium mineral resembling the unknown uranium mineral mentioned above occurs in the limestone boulders, and a greenish-yellow mineral resembling schroeckingerite is found in the tuff. All available pits were sampled. Abnormally high counter readings are obtained along strike in the tuff for over 600 feet. Considerable exploration will be required to uncover the size of the ore body and determine its average grade. As the ore occurs in a porous friable tuff it is quite possible that a moderate-sized ore body is present.

Both these uranium deposits occur in the group of older volcanics. The younger group of volcanics also may be favorable, as a bulk sample of the unaltered rhyolite from the northern part of the range contains 0.006 percent U; this suggests that these rocks may be of above average uranium content.

Jarbidge quadrangle, Nevada-Utah

by

R. R. Coats

Work on the Jarbidge project during the report period included office study of samples collected in 1954, and drafting of a geologic map of the Jarbidge quadrangle which is now about one-third complete. Up to the present time no systematic variations in the distribution of uranium in the rocks of the quadrangle have been observed.

Work planned for the next six months includes continuation of geologic mapping in the Jarbidge quadrangle at a scale of 1:48,000 or larger, and further laboratory study of the rhyolitic rocks from that vicinity.

Wet Mountains thorium district, Colorado

by

Q. D. Singewald

Previous work in the Wet Mountains thorium district, Custer and Fremont Counties, Colorado, was reported in TEI-440, pp. 163-165. During the past six months, under the sponsorship of the USGS, mapping

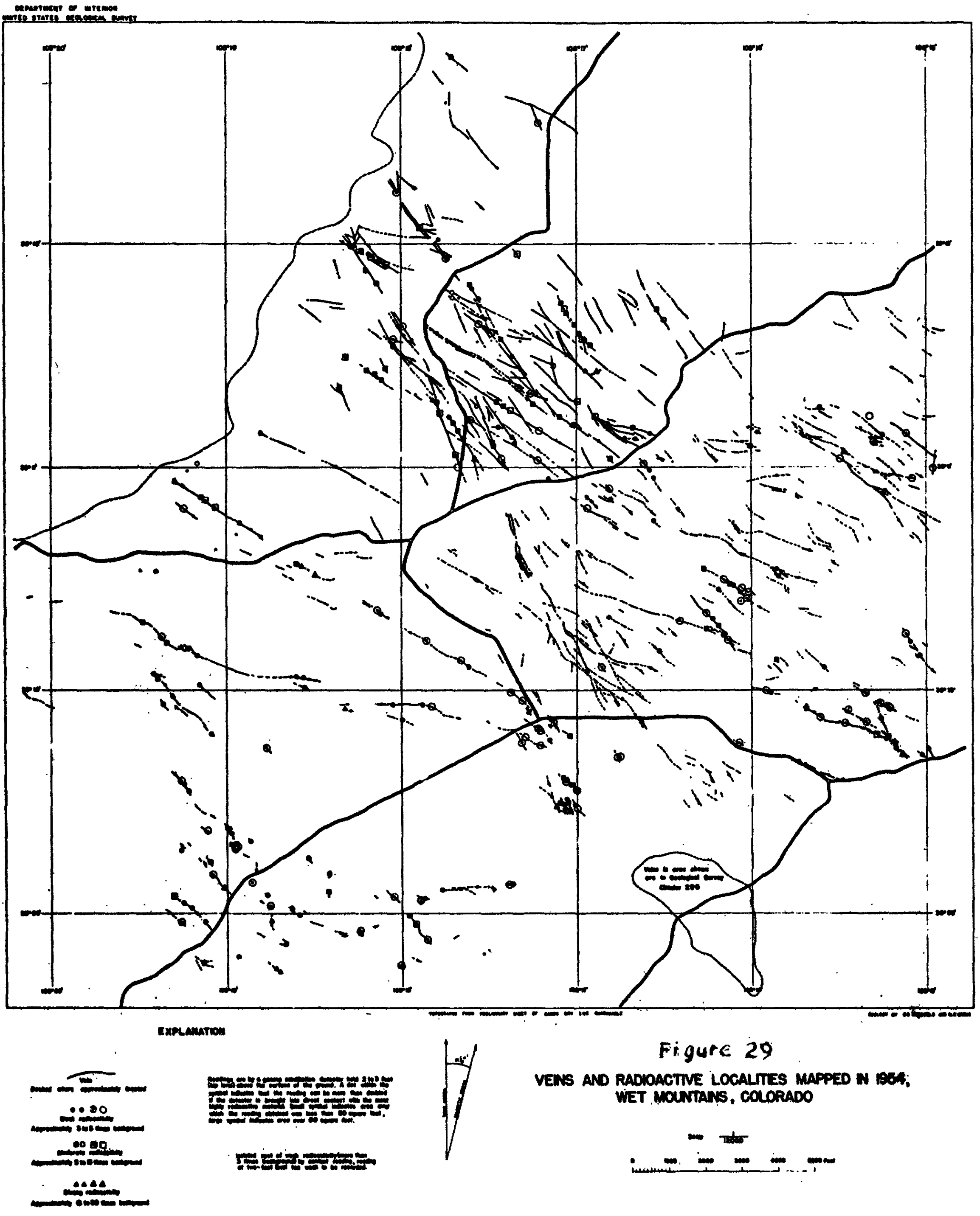


Figure 29

VEINS AND RADIOACTIVE LOCALITIES MAPPED IN 1954, WET MOUNTAINS, COLORADO done in 1954 has been compiled on a base map of the district at a scale of 1:6,000. The veins and radioactive localities in the area mapped in 1954 are shown in figure 29. The abnormal radioactivity found at many places along the veins is due almost entirely to thorium and its daughter products.

General geologic studies

Relationship of uranium and other trace elements to post-Cretaceous vulcanism

by

R. R. Coats

Field work on the project, "Relationship of uranium and other trace elements to post-Cretaceous vulcanism", was terminated June 30, 1954, and results of the work up to that time were reported in TEI-440. Later laboratory study of the problem, and statistical analysis of results, makes possible a more detailed account of the relationships involved than that given at that time. These are summarized below.

Rhyolitic and dacitic rocks from Colorado, Wyoming, Washington, California, Nevada and Arizona were studied by the project. In these rocks the content of uranium shows a significantly high positive correlation with that of niobium, beryllium, and fluorine; a less significant positive correlation with the content of lithium and tin; a significant negative correlation with the content of boron and lanthanum; and no significant correlation with the content of zirconium and lead. A study of the relation of the several elements to the geographic provenance shows significant variations with the provenance for all elements except tin and lanthanum. On the basis of these variations and on patterns of consistency five comagmatic provinces, one of which is subdivided into three sub-provinces, have been delineated in part on a map of the western United States. It is expected that the pattern of provincial distribution may prove useful for future prospecting.

Zonal relations of uranium deposits in metalliferous districts

by

S. R. Wallace

The six-weeks study during 1954 of radioactivity in the Bisbee district was a preliminary reconnaissance to determine the district's suitability for a study of the relation between uranium and zoning. The Bisbee district was selected for three reasons: (1) significant concentrations of uranium had been reported from the district, (2) the geographic position of different types of ore within the district suggested a zonal distribution of the ores, and (3) the total amount of metal deposited within the district was known to be large, suggesting that the quantity of uranium might be appreciable.

The results of the preliminary investigation suggest that most of the uranium in the district is associated with massive sulfide replacement ore bodies in limestone; apparently there is little difference in uranium content of lead-zinc ores and copper ores. The low-grade disseminated copper ore of the Sacramento Hill porphyry stock exhibits no abnormal radioactivity. Most of the high values previously reported are the result of secondary salts deposited on the walls of mine workings in and near the ore bodies. A few, very small, high-grade pods containing primary uranium minerals were discovered, but no minable concentrations of uranium ore are known in the district.

Some of the acid mine waters from Bisbee and other mining districts in the southwest are exceptionally rich in uranium, and suggest that there may be localities where concentration and flow are sufficient to encourage attempts to extract uranium from solution.

Occurrences of uranium in veins and igneous rocks

by
G. J. Neuerburg

The primary emphasis of the project is on studies of the modes of occurrence of uranium in the fabric of igneous rocks, and the possible use of such information in the search for uranium ore. In the course of such studies, attempts are being made to obtain the uranium contents of many igneous rock varieties that hitherto have received little attention.

The labile uranium contents of igneous rocks are considered to represent that part of the total uranium content that is most likely to have changed during the rock's history and that may, therefore, provide clues to the movement of uranium during the formation of ore deposits. Likewise, it is thought that Th/U ratios may provide additional information on the movement of uranium during a rock's history. On the basis of these assumptions, the labile uranium contents of about 100 samples of diverse rock types and the labile thorium contents of some of these rocks are being determined. The first phase of this investigation is concerned primarily with determining the range and nature of variation in the labile uranium and thorium contents among rocks in relation to their geologic and petrologic characters. Once this has been done, the study will be extended to selected igneous bodies spatially associated with uranium ore deposits.

The leaching procedure consists of the following: 4 grams of rock, pulverized to minus 20 mesh, are leached in 800 ml of 0.05 M HNO_3 on a steam bath at a temperature of 80-85° C for one-half hour. This procedure was adopted on the basis of experiments that showed it entailed virtually complete solution of pitchblende and a variety of hexavalant uranium minerals while dissolving less than 10 percent apatite and negligible amounts of the common minor accessory minerals. A few leaching experiments with other solvents were made and others are planned.

Analyses of a few zeolites showed uranium contents ranging from 0.9 ppm to 27.6 ppm. In 1937 Goldschmidt predicted that zeolites should not accommodate uranium in their structure. The finding of appreciable uranium in these zeolites may mean that it is held in cation exchange position. This is also implied by associated amygdaloidal analcite and natrolite, containing 0.05 ppm and 4.4 ppm uranium, respectively, on the assumption that analcite should adsorb no uranium while natrolite may readily adsorb it. If uranium is readily adsorbed by zeolites, surveys of areas containing zeolites may serve to identify volumes of rock through which uraniferous solutions have passed. This premise will be investigated.

Chemical age determinations were made on uranothorite and allanite from a pegmatite previously dated by the zircon age method. The results as shown in table 16, though highly divergent, presumably due to the weathered nature of the samples, may serve to indicate the amounts of magmatic lead accommodated in these minerals at the time of their formation. Providing the zircon age of 810 million years for the pegmatite is correct, 66.6 percent of the allanite lead and 9.4 percent of the uranothorite lead is magmatic. These results would seem to cast suspicion on chemically determined ages of allanites and uranothorites.

Table 16. Chemical age determinations of allanite and uranothorite from the same pegmatite

Mineral	U, percent	Th, percent	Pb, percent	Age in millions of years
Allanite	0.00712	0.53	0.063	2,400
Uranothorite	11.798	45.15	3.3	890

URANIUM IN CARBONACEOUS ROCKS

Lignite investigations

Northwestern South Dakota, southwestern North Dakota, and eastern Montana

by
J. R. Gill

Lignite, carbonaceous shale, and sandstone containing in excess of 0.10 percent uranium in rocks of Late Cretaceous to Miocene age occur in several widely separated areas in eastern Montana and the Dakotas. The location of a number of deposits is shown on figure 30. Also shown is the location of water samples having high uranium content, which may be useful as guides in the search for additional deposits.

One of the better deposits known in the region is in the Riley Pass area of northwestern South Dakota (fig. 31) where approximately 440 acres is estimated to be underlain by lignite averaging 1.3 feet in thickness and containing about 0.76 percent uranium. The lignite contains the uranium minerals autunite, zeunerite, and torbernite which are concentrated on cleat faces and along bedding planes as well as disseminated throughout the lignite. Uranium is probably held also as an adsorbed consitutent of the organic material; selected samples of black vitreous lignitic material without visible secondary uranium minerals contain as much as 4.4 percent uranium.

Some samples from the Riley Pass area contain as much as 0.5 percent molybdenum and 0.9 percent arsenic. Spectrographic analysis of lignite ash show a positive correlation between uranium and these elements. Although individual beds in this deposit do not show a marked top uranium preferential as do many of the thicker mildly radioactive lignites of

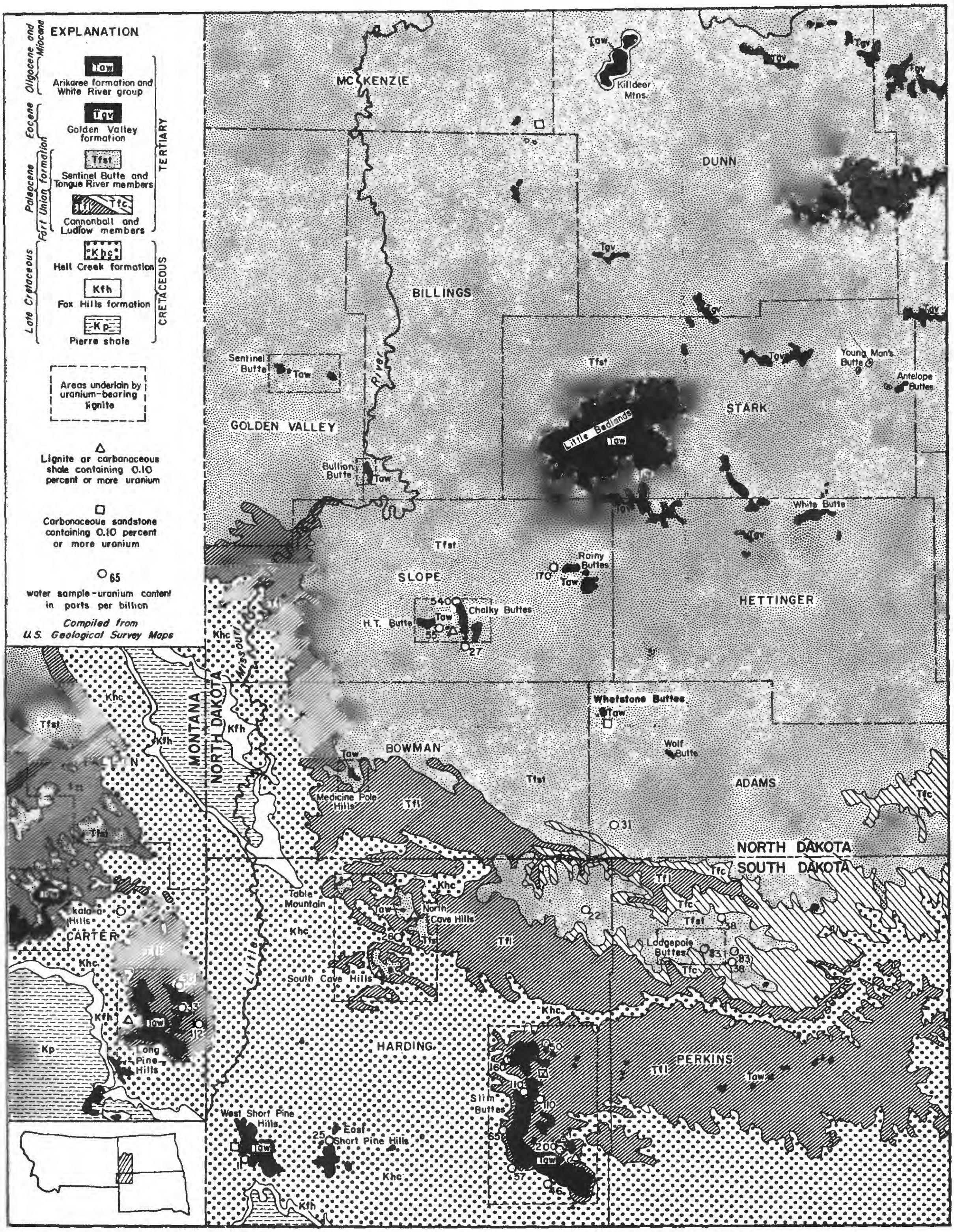


FIGURE 30. — GEOLOGIC MAP SHOWING LOCATION OF URANIUM DEPOSITS IN EASTERN MONTANA AND THE DAKOTAS

0 10 20 30 miles

J. R. Gill
1955

this region, a definite relationship between uranium content and stratigraphic position of the bed is evident as shown in the cross section in figure 31. Other local controls such as structure, physical constituents, and thickness of the lignite, and the degree of weathering prior to introduction of uranium are possibly the controlling factors in emplacement of the uranium.

Similar but smaller uranium-bearing lignite deposits occur in the Slim Buttes of South Dakota and the Killdeer Mountain area of North Dakota. Several deposits of uranium-bearing sandstone are also known in the region. At Reva Gap, the Thybo deposit (sec. 10, T. 18 N., R. 8 E.) contains a small deposit of impregnated uranophane sandstone in the Ludlow member of the Fort Union formation (fig. 32). The uranium appears to be structurally controlled by a fault or series of faults, and perhaps was deposited from uranium-bearing ground waters migrating downward from overlying mildly radioactive tuffaceous rocks of Oligocene and Miocene age.

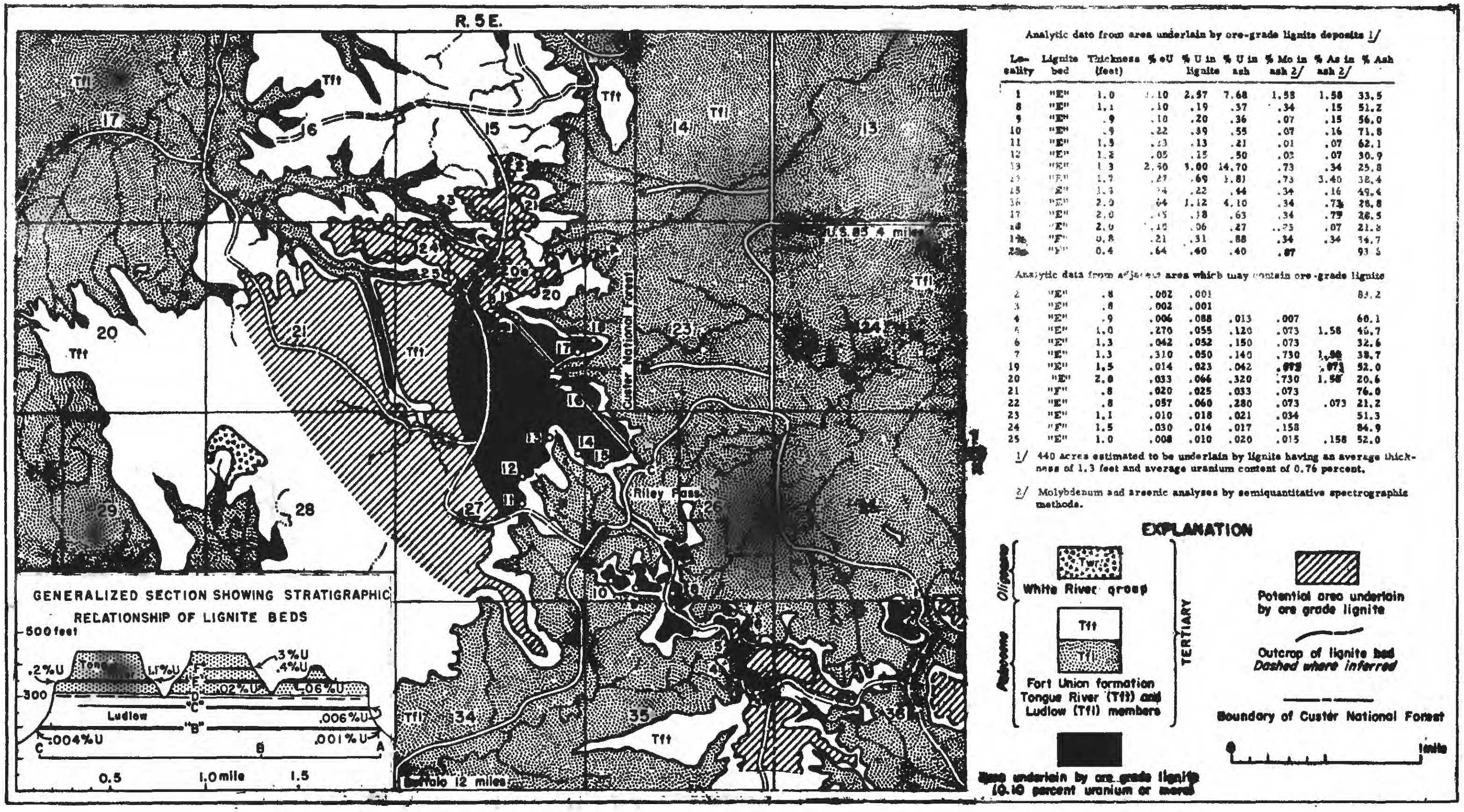
A summary of the more important results of the 1954 reconnaissance for uranium-bearing carbonaceous rocks in eastern Montana and the Dakotas is given in table 17.

Coal petrology

by

J. M. Schopf, R. J. Gray and C. J. Felix

Petrologic investigations of Dakota uraniferous lignite have beer concluded with analyses of the Harmon bed in the Medicine Pole Hills of North Dakota and similar beds in the Lodge Pole Hills of South Dakota, and uncorrelated beds from the Bar H area of the northern Slim Buttes. Results are tabulated in table 18.



Analytic data from area underlain by ore-grade lignite deposits 1/

Locality	Lignite bed	Thickness (feet)	% eU	% U in lignite	% U in ash	% Mo in ash 2/	% As in ash 2/	% Ash
1	"E"	1.0	.10	2.57	7.68	1.58	1.58	33.5
8	"E"	1.1	.10	.19	.37	.34	.15	51.2
9	"E"	.9	.10	.20	.36	.07	.15	56.0
10	"E"	.9	.22	.39	.55	.07	.16	71.8
11	"E"	1.3	.13	.13	.21	.01	.07	62.1
12	"E"	1.2	.05	.15	.50	.03	.07	30.9
13	"E"	1.3	2.50	3.00	14.70	.73	.34	25.8
14	"E"	1.7	.27	.69	1.81	.73	3.40	38.4
15	"E"	1.3	.14	.22	.44	.34	.16	49.4
16	"E"	2.0	.64	1.12	4.10	.34	.73	28.8
17	"E"	2.0	.15	.18	.63	.34	.79	28.5
18	"E"	2.0	.10	.06	.27	.75	.07	21.8
19a	"F"	0.8	.21	.31	.88	.34	.34	34.7
20a	"F"	0.4	.64	.40	.40	.07		93.5

Analytic data from adjacent area which may contain ore-grade lignite

Locality	Lignite bed	Thickness (feet)	% eU	% U in lignite	% U in ash	% Mo in ash 2/	% As in ash 2/	% Ash
2	"E"	.8	.002	.001				83.2
3	"E"	.8	.002	.001				
4	"E"	.9	.006	.088	.013	.007		60.1
5	"E"	1.0	.270	.055	.120	.073	1.58	45.7
6	"E"	1.3	.042	.052	.150	.073		32.6
7	"E"	1.3	.310	.050	.140	.730	1.58	38.7
19	"E"	1.5	.014	.023	.042	.073	.073	52.0
20	"E"	2.0	.033	.066	.320	.730	1.58	20.6
21	"F"	.8	.020	.025	.033	.073		76.0
22	"E"	.8	.057	.060	.280	.073	.073	21.2
23	"E"	1.1	.010	.018	.021	.034		51.3
24	"F"	1.5	.030	.014	.017	.158		84.9
25	"E"	1.0	.008	.010	.020	.015	.158	52.0

1/ 440 acres estimated to be underlain by lignite having an average thickness of 1.3 feet and average uranium content of 0.76 percent.

2/ Molybdenum and arsenic analyses by semiquantitative spectrographic methods.

FIGURE 31. GEOLOGIC MAP OF RILEY PASS AUTUNITE-BEARING LIGNITE DEPOSIT, NORTH CAVE HILLS, HARDING COUNTY, SOUTH DAKOTA

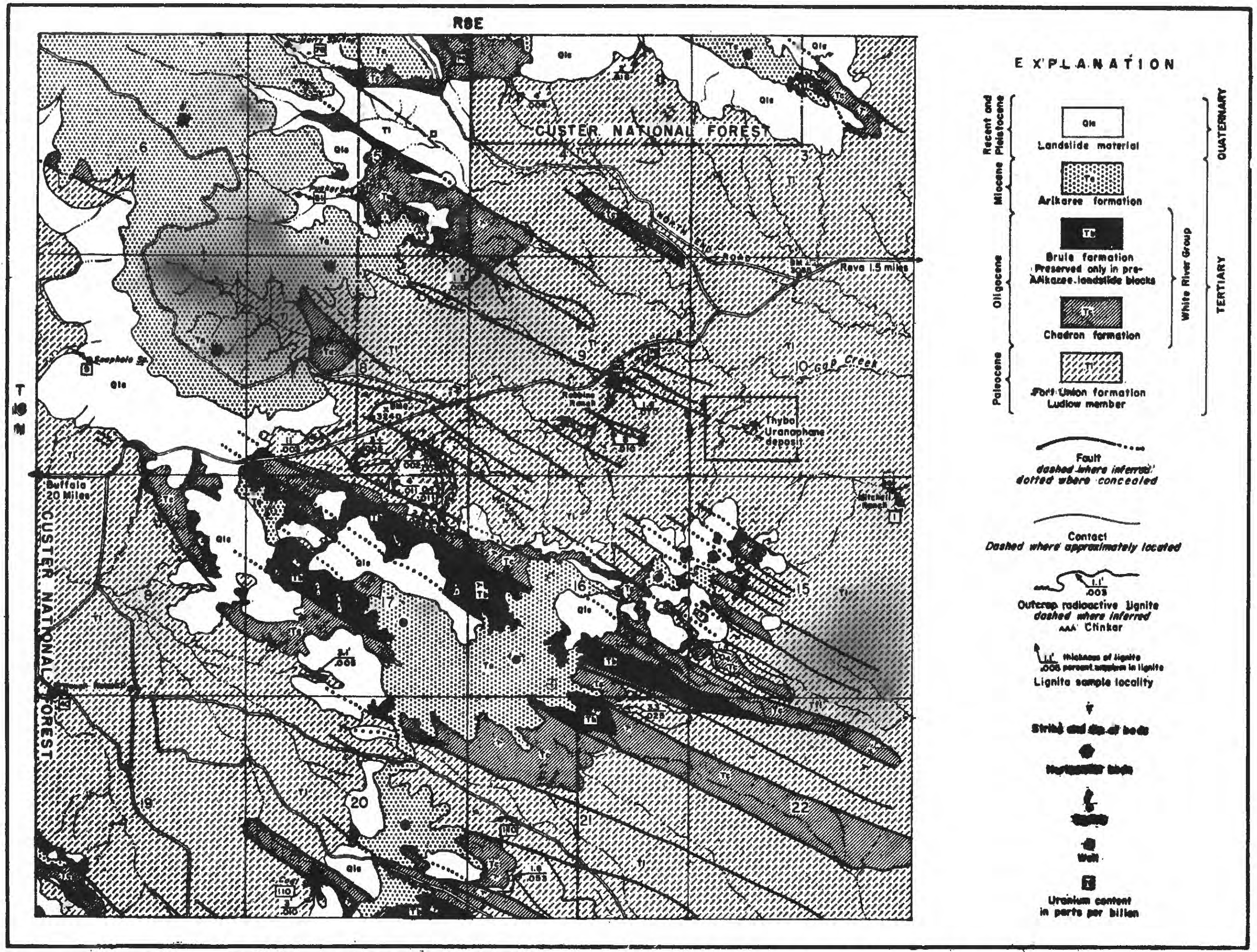


FIGURE 32--GEOLOGIC MAP OF REVA GAP AREA, SLIM BUTTES, HARDING COUNTY, SOUTH DAKOTA

0 1 mile

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Table 17. Uranium occurrences in eastern Montana and the Dakotas

Location	Type of deposit	Thickness (feet)	U content (percent)	Formation
South Dakota				
North Cave Hills sec. 22, 26, 27, 35, 36, T. 22 N., R. 5 E.	lignite	1.3	0.76	Fort Union Tongue River member
South Cave Hills sec. 23, T. 21 N., R. 4 E.	lignite ash	1.0	3.6	-do-
Slim Buttes				Fort Union
sec. 32, T. 17 N., R. 9 E.	lignite	1.0	.11	Ludlow member
sec. 30, T. 17 N., R. 9 E.	lignite	1.7	.16	-do-
sec. 10, T. 18 N., R. 8 E.	carb. sandstone	3.2	.68	-do-
West Short Pine Hills sec. 24, T. 17 N., R. 1 E.	sandstone	1-2	.10	Arikaree
North Dakota				
Killdeer Mountains sec. 14, T. 146 N., R. 99 W.	carb. shale	0.8	4.2	Fort Union Sentinel Butte shale
Whetstone Buttes sec. 32, T. 133 N., R. 98 W.	carb. sandstone	2.0	0.10	Fort Union Sentinel Butte shale
-do-	carb. sandstone	0.4 of above bed	0.34	-do-
Montana				
Long Pine Hills sec. 29, T. 2 S., R. 61 E.	carb. sandstone	0.5	0.24	Hell Creek

Table 18. Petrology of uraniferous Dakota lignites

	Anthra-xylon	Transl. Attritus	Opaque Attritus	Petrog. Fusain	Visible Impurity
	percent	percent	percent	percent	percent
Medicine Pole					
Harmon Bed	43.0	51.4	2.8	1.3	1.4
Lodge Pole					
Harmon (?) Rider	45.5	43.6	7.2	0.5	3.1
Harmon (?) Bed	41.3	47.7	4.7	5.0	1.4
Bar H Area, uncorrelated beds					
Hole 19 at 379.37'	51.3	39.4	6.1	2.8	0.3
" " " 385.37'	55.7	39.0	2.2	1.9	1.2
Hole 21 at 31.33'	51.0	29.8	9.2	2.4	0.6
" " " 41.71'	39.4	48.7	7.2	3.4	1.3
Hole 22 at 60.65'	47.0	49.2	1.4	0.9	1.5
Hole 23 at 69.75'	49.8	40.9	5.0	4.0	0.3
Hole 24 at 116.0 '	51.9	39.2	2.8	1.9	4.3
Hole 25 at 34.25'	55.6	34.5	3.5	5.4	1.0
Hole 26 at 30.38'	49.2	36.4	9.5	3.3	1.6
" " " 62.17'	51.9	26.9	13.0	6.4	1.8
Hole 27 at 45.60'	47.5	42.4	3.6	1.9	4.6
Average composition of coal in Bar H area	50.0	38.8	5.8	3.1	1.7
Average composition of Slim Buttes coal previously analyzed	51.2	36.4	3.0	5.5	3.0
Average of commercial lignite mined in N. Dak. (U. S. Bur. Mines Inf. Circ. 7691, p. 66)	58.1	30.0	8.6	3.3	---

In the previous semi-annual report (TEI-490) detailed component determinations for four layers of Dakota coal were presented. More recently twelve additional layers, including all the coal from one of the uraniferous beds, have been similarly investigated. This study indicates that a group of waxy components associated with high uranium content in the Red Desert (Wyoming) and Goose Creek (Idaho) areas is not associated with the uranium in the Dakota coal. A tendency for attrital coal to be more highly uraniferous has been noted. This tendency seems as strongly expressed in relation to translucent attritus as for any more select group of attrital components.

Most of the uranium is present in the highest coal bed closest to the tuffaceous White River formation overlying the coal-bearing succession in western North and South Dakota (see USGS maps C-33, C-34, and C-35). In the topmost coal beds uranium concentration varies considerably and shows marked preferential concentration in the upper parts of these beds. One exception (hole SD-10), still unexplained, has been noted in a previous publication (Schopf and Gray, USGS Circular 343). Elsewhere the concentration of uranium is more clearly related to position within the bed, in relation to the White River unconformity than to any discernible variation in petrologic composition of the coal.

In order to evaluate the positional relationship apart from composition, the uranium content of 150 samples (omitting SD-10 samples) was plotted according to distance from the top of the uppermost coal bed (fig. 33). The resulting distribution of points is more uniform than had been anticipated from irregularities of analyses from individual drill holes. Normal uranium content for coal of less than 10 ppm is found about 10 feet below the top of the beds that show a uranium concentration anomaly. The greatest concentration is 1 1/2 to 5 feet from the top of the bed, with a range in uranium concentration of 30 to about 130 ppm. Higher concentrations are restricted to the top 1 1/2 feet of coal. The highest uranium determination (900 ppm or .09 percent) is in a thin attrital coal streak about 6 feet <u>above</u> the top of the main coal bed closer to the overlying tuffaceous rocks.

The scattering of points is uniform enough to permit drawing of smooth average curve. The general shape of the curve is suggestive of the diffusion front beneath a perched water table.

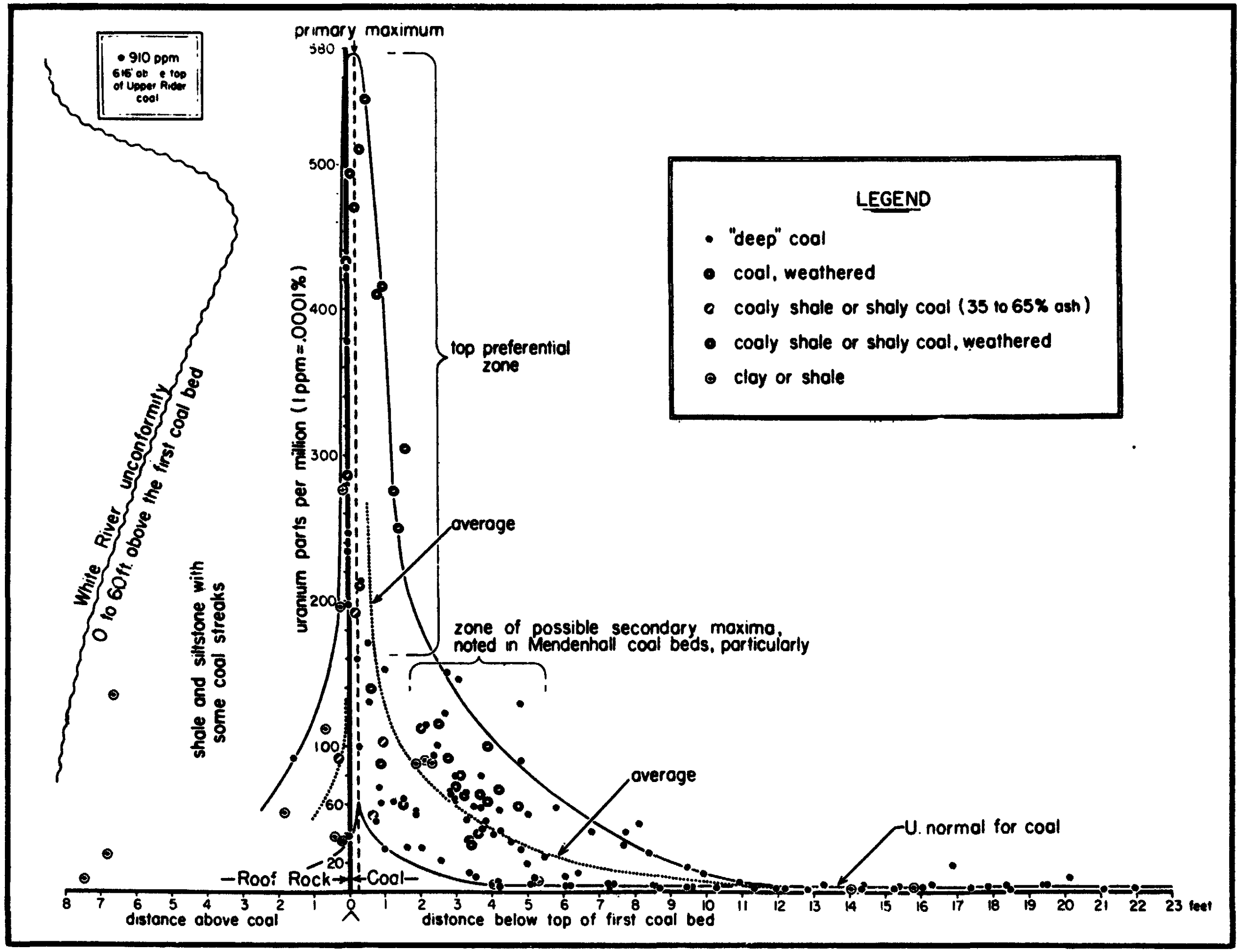

Figure 33. The uranium anomaly in coal beds below the White River unconformity in the Mendenhall area of South Dakota

Uranium in coals of the Red Desert area, Wyoming
by
Harold Masursky

Laboratory studies on possible source rocks and the origin and mode of emplacement of the uranium in coal in the eastern Red Desert area, Wyoming were completed. The Sweetwater granite of Precambrian age is considered to be a possible source for the uranium in the Red Desert coal because the granite contains 0.002 to 0.003 percent uranium whereas the arkose derived from it contains only about 0.0005 percent uranium. The uranium, which is possibly held in easily leachable intergranular films, may be mobilized during weathering and erosion of the granite and emplaced in the coal via the ground water system. A sample of the granite containing about 0.002 percent uranium was pulverized and subjected to leaching by distilled water, sodium carbonate, and nitric acid for half an hour in a steam bath to investigate the mobility of the uranium. The distilled water leached 0.12 percent of the contained uranium; the sodium carbonate leached 1.31 percent; and the nitric acid (pH 1.55) leached 7.70 percent. Six thin sections of the granite were covered by nuclear emulsion and exposed from two to six weeks to determine the distribution of uranium within the granite. Study of the alpha tracts showed that in one section there is a concentration of tracks emitted from interstitial material; in two other sections the quartz and potassium feldspar are alpha emitters.

A powdered coal sample (minus 100 mesh) was immersed in a uranyl nitrate solution containing 990 ppm uranium to test maximum extraction of uranium from solution by coal. At the end of 27 days the coal had extracted 95 percent of the uranium from the solution and contained

8.6 percent uranium. An X-ray determination of this sample did not reveal the presence of any uranium mineral. The sample was reimmersed in a uranyl nitrate solution containing 550 ppm uranium. At the end of 120 days the coal had extracted 35 percent of the uranium from solution and contained in excess of 10 percent uranium. X-ray examination again failed to show the presence of any uranium mineral. However, at high magnification (800X) a polished section showed that the fragments of coal were surrounded by minute black particles that may be such a mineral.

Black shale investigations

South Dakota and northeastern Nebraska

by

R. C. Kepferle

About 300 samples of black shale from 32 localities in South Dakota and northeastern Nebraska indicate that the Sharon Springs member of the Pierre formation in that region contains 0.002 percent or less uranium. The most uraniferous parts of the shale contain 0.005 percent or more uranium in zones averaging about 1 foot in thickness. At three localities these zones reach thicknesses of 3 to 6 feet; elsewhere they are less than 1-1/2 feet thick. The most uraniferous parts of the zones are generally about 3 inches thick and contain as much as 0.017 percent uranium.

Semiquantitative spectrographic analyses of 82 samples of the black shale from the Sharon Springs member indicate that the concentrations of molybdenum and iron tend to vary directly with the concentration of uranium, whereas the concentrations of aluminum, gallium, boron, titanium, magnesium, and sodium all tend to vary inversely with the concentration of uranium. The results of the spectrographic analyses are summarized in figure 34.

Chemical analyses of 18 samples of shale from one locality indicate a strong positive relationship between the concentrations of uranium and arsenic, and a lesser positive relationship between the concentrations of uranium and selenium.

From a study of the relationship between the concentrations of uranium and the elements which vary in concentration with respect to uranium, it appears that the uranium in fresh samples of the Sharon Springs shale was emplaced during the deposition of the shale, in a reducing environment where deposition of allogenic clastic sediments was slow.

Sharon Springs black shale in the Chadron area, by R. J. Dunham

The average uranium content of the most radioactive part of the Sharon Springs is no greater than the average uranium content of associated shales in the Chadron area. No uniform areal variation in uranium content was detected in the 100 square miles investigated. In subsurface in the Chadron area, the Sharon Springs is not significantly more radioactive than associated shale (fig. 35). The uranium content of shale outcropping in the Chadron area probably has been reduced a few thousandths of a percent by the leaching effect of oxidizing vadose water made acid by decomposing pyrite. Seep water issuing from the Sharon Springs shale in sec. 33, T. 36 N., R. 47 W., Shannon County, South Dakota, has a pH of 3.1 and contains 320 parts per billion uranium.

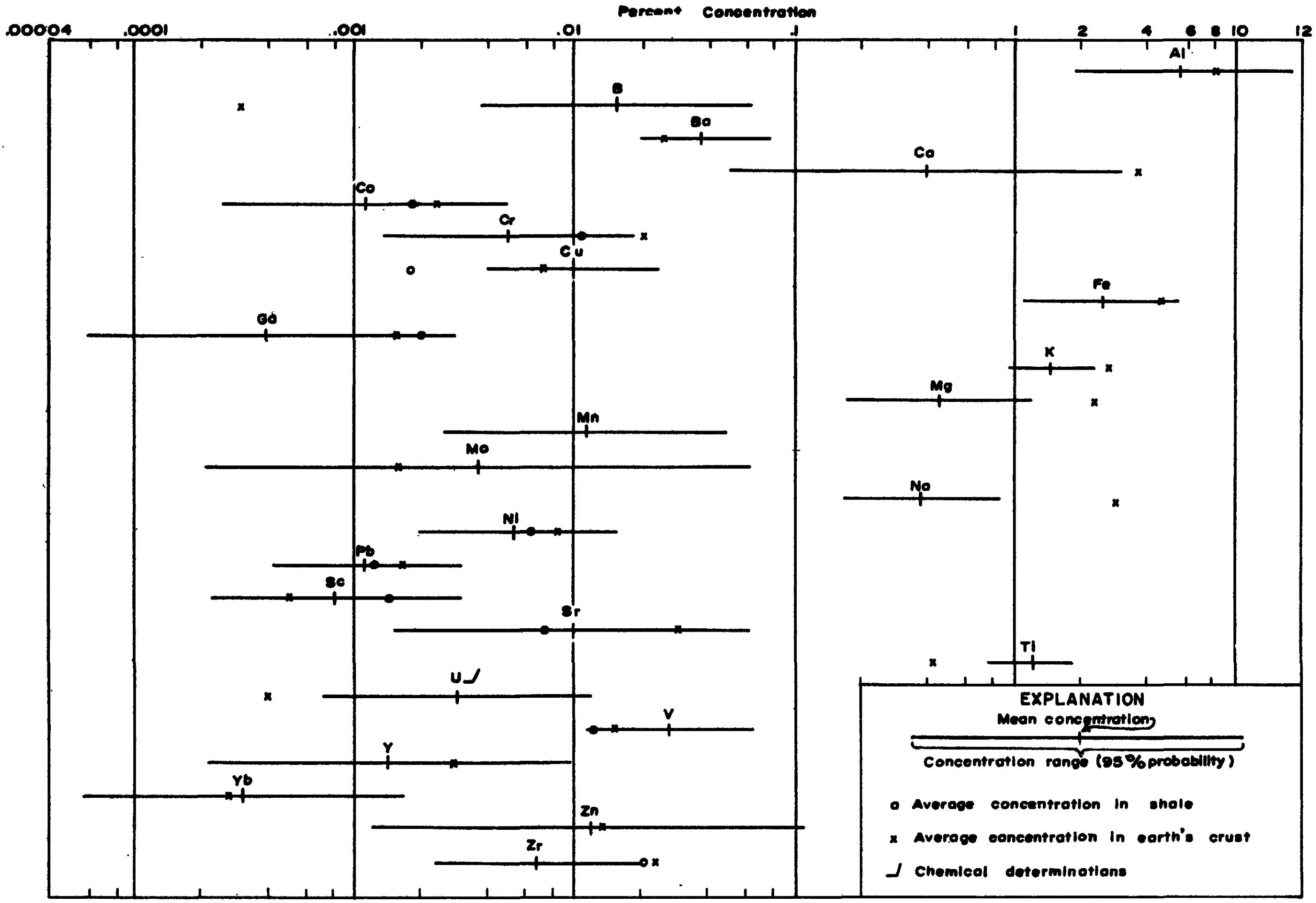

FIGURE 34. DIAGRAM SHOWING RESULTS OF SEMIQUANTITATIVE SPECTROGRAPHIC ANALYSES OF 82 SAMPLES OF BLACK SHALE FROM THE SHARON SPRINGS MEMBER OF THE PIERRE FORMATION, SOUTH DAKOTA AND NEBRASKA

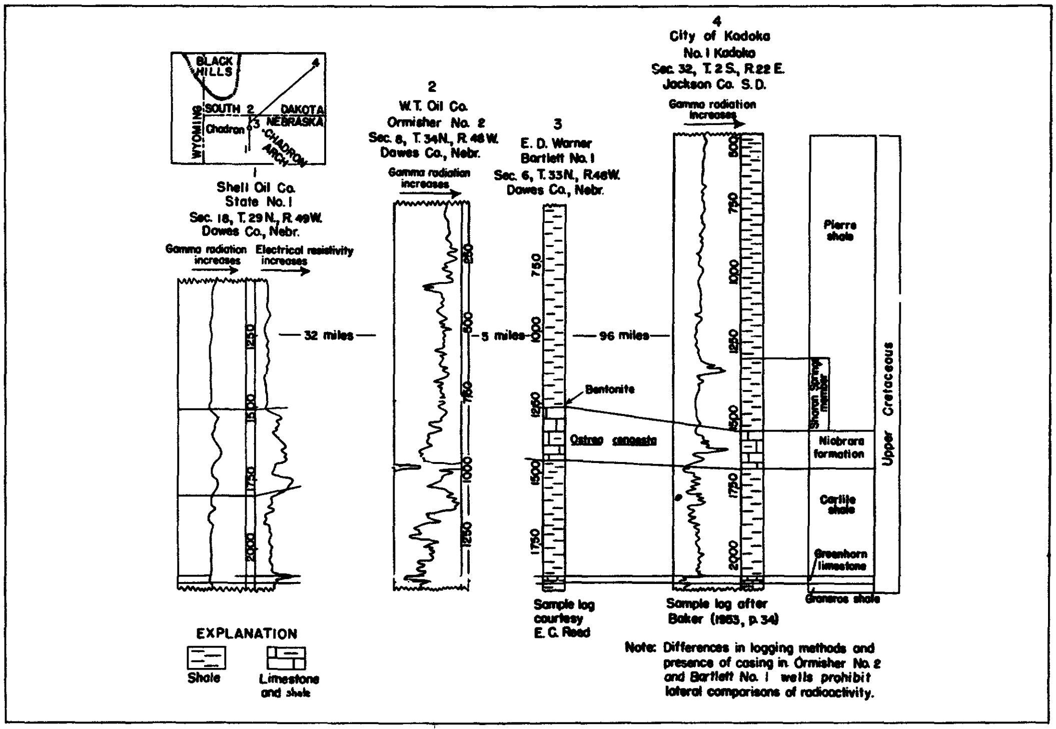

Figure 35. Stratigraphic cross section showing vertical distribution of radioactive beds of Late Cretaceous age in western Nebraska and South Dakota.

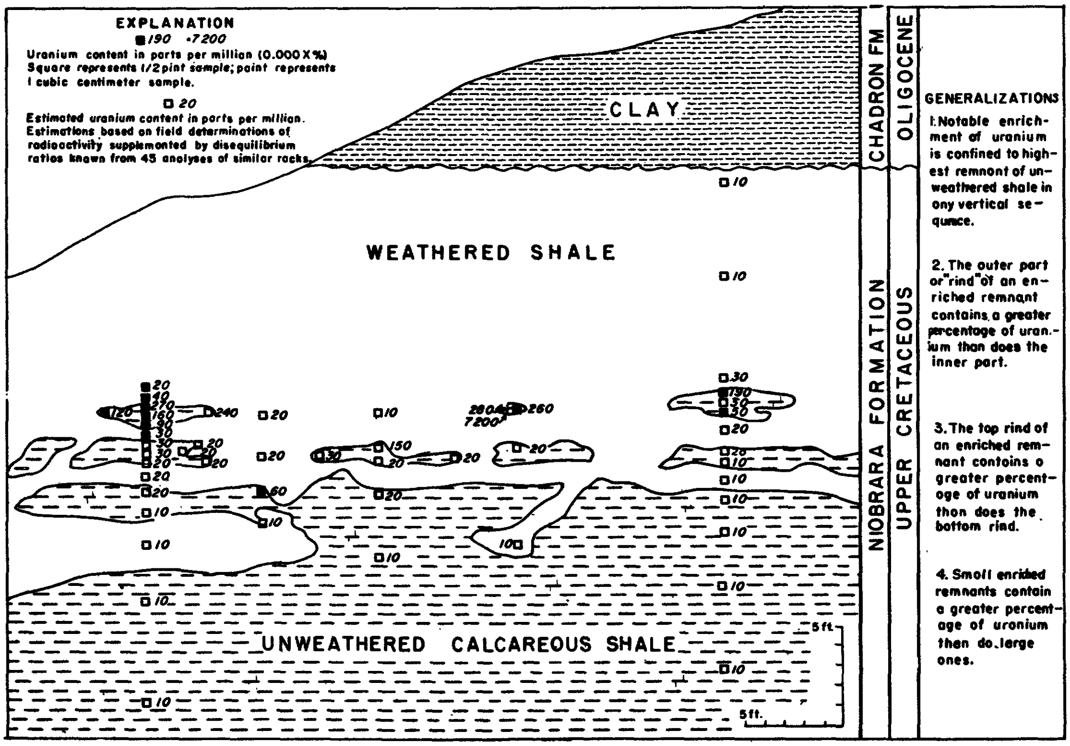

Figure 36. Field sketch showing top preferential distribution typical of uranium associated with pre-Oligocene weathered zone. SE 1/4 NW 1/4 Sec. 30, T. 35 N., R. 46 W., Sheridan County, Nebraska.

Uranium associated with pre-Oligocene weathered zone, by R. J. Dunham

Accumulations of epigenetic uranium, perhaps in the form of pitchblende, occur extensively in the Chadron area in shale of the Carlile, Niobrara, and Pierre formations of Late Cretaceous age where those formations were subjected to deep weathering in pre-Oligocene time (fig. 36). Individual particles of pitchblende (?) are small (10 microns) and intergrown with pyrite, organic matter, and clay matrix. Abundant pyrite in the sample prevented confirmation by X-ray. The identification as pitchblende is believed valid because the optical properties are those of pitchblende, and the percentage of uranium and intensity of alpha radiation are compatible with this identification.

Effects of pre-Oligocene weathering of the Cretaceous shales include kaolinization of illite, residual concentration of iron and aluminum, decalcification of calcareous shale, and oxidation of iron. Oxidation gives the dark gray shale the yellow-red colors of hydrated ferric iron, and penetrates irregularly to depths of as much as 50 feet. Most of the uranium occurs in gray unoxidized shale less than an inch from an interface with yellow oxidized shale.

The greater part of the 45 samples collected in the Chadron area represents the full thickness of enriched isolated remnants of unweathered shale enclosed in weathered shale and are similar to those shown in figure 36. Such samples generally contain about 0.01 percent U, a few contain 0.1 percent U, and one contains 1.1 percent U. The outer part or rind of a remnant contains a greater percentage of uranium than does the inner part. Select samples containing as much as 0.5 percent U can be collected from the outer quarter-inch of remnants whose channel samples contain only 0.02 percent U.

The strong top preferential distribution of uranium shown at all exposures (fig. 36) indicates that the uranium came from above. The interface between yellow oxidized material and gray unoxidized material marks a boundary between an oxidizing environment above and without, and a reducing environment below and within. Probably the uranium moved downward through the oxidizing environment in the 6-valent form, then was reduced to the 4-valent form and so precipitated almost immediately after first contact with the reducing environment. The low permeability of both weathered and unweathered material suggests that the movement was partly by diffusion. The uranium may have been derived from weathering and leaching of great thicknesses of Cretaceous shale in pre-Oligocene time, the uranium being progressively concentrated as the oxidation-reduction interface migrated farther down into unweathered shale. Alternatively, the uranium may have been derived from leaching of tuffaceous Tertiary rocks in Oligocene or later time, in which case the role of pre-Oligocene weathering was merely to prepare traps. The presence of uranium minerals in Oligocene gypsum in the Chadron area is permissive of the ash-leach hypothesis, but difficulties are presented by the impermeability of the weathered zone and by the lack of long distance diffusion in the coal beds and sandstones where the ash-leach hypothesis has been previously applied. Other evidence is permissive of the shale-leach hypothesis; where a limonite lens in the weathered zone contributed pebbles to the overlying basal Oligocene conglomerate, the limonite of both the lens and the pebbles contains 0.007 percent U. According to theory, limonite obtains its uranium by adsorption while still in the freshly precipitated gel state; thus uranium was available and being deposited during pre-Oligocene weathering.

Western Kansas and eastern Colorado
by
E. R. Landis

Available surface and subsurface data indicate that a sequence of beds in the Pierre shale and Niobrara formation in northeastern Colorado is more radioactive than other portions of those formations in that area. This sequence, however, is not recognizable in all of the wells for which gamma-ray logs were available and studied. The logs indicate that both the maximum radioactivity and the thickness of the radioactive beds vary considerably within distances of a few miles, and the stratigraphic position of the radioactive beds relative to the Pierre-Niobrara contact is also variable within short distances.

Midcontinent Devonian shales
by
V. E. Swanson

Marine black shale of Late Devonian and early Mississippian age were examined during the report period in (1) the Tahlequah-Spavinaw area of northeastern Oklahoma; (2) the Eureka Springs-Noel area in northwestern Arkansas and southwestern Missouri; (3) the Yellville area in north-central Arkansas; (4) the Ouachita Mountains of southern Arkansas; (5) the Arbuckle Mountains of southern Oklahoma; and (6) the Llano uplift of central Texas. Outcrop and well samples, cores, and gamma-ray logs of shales from these areas were accumulated.

An abnormally high-grade uraniferous black shale was found near Yellville, Marion County, Arkansas. Two select samples contain 0.12 and 0.71 percent U, respectively. The black shale is confined to a lens less than 3 feet thick in the lower Mississippian basal sandstone member of the Boone formation, and is lithologically similar to the Chattanooga shale of northern Arkansas. The shale having the highest radioactivity contains much coalified plant material. Although analytical data on additional samples collected are not yet available, the average uranium content of the shale in the lens is believed to be less than 0.02 percent U.

Chattanooga shale in Alabama, Georgia, and Tennessee

by

Lynn Glover

During the report period 21 sections of the Chattanooga shale between Chattanooga and Knoxville, Tennessee, were measured and described and selective sampling was done between Birmingham, Alabama, and Knoxville. Twenty-eight samples from eight sections were taken for geochemical determinations, and six fossil collections were made. Field work was completed in March.

The Chattanooga shale and Maury formation are progressively overlapped in the area around Birmingham (fig. 37). In eastern St. Clear and Shelby Counties, Alabama, (outcrops at and south of 3J-2, fig. 38) the Chattanooga and Maury are absent and the Mississippian Fort Payne chert lies directly on formations ranging in age from Ordovician to early Devonian. Where both the Maury and Chattanooga are present, the iron in both formations is everywhere in the form of a sulfide. Where only the Maury in present the iron in the basal sandstone is oxidized and at least part of the normally light-greenish-gray claystone of the Maury is colored a dark hematitic red. Where green and red claystone occur together the green always overlies the red. At some sections (e.g., 3H-5, fig. 38) the entire formation is reddish with only a thin

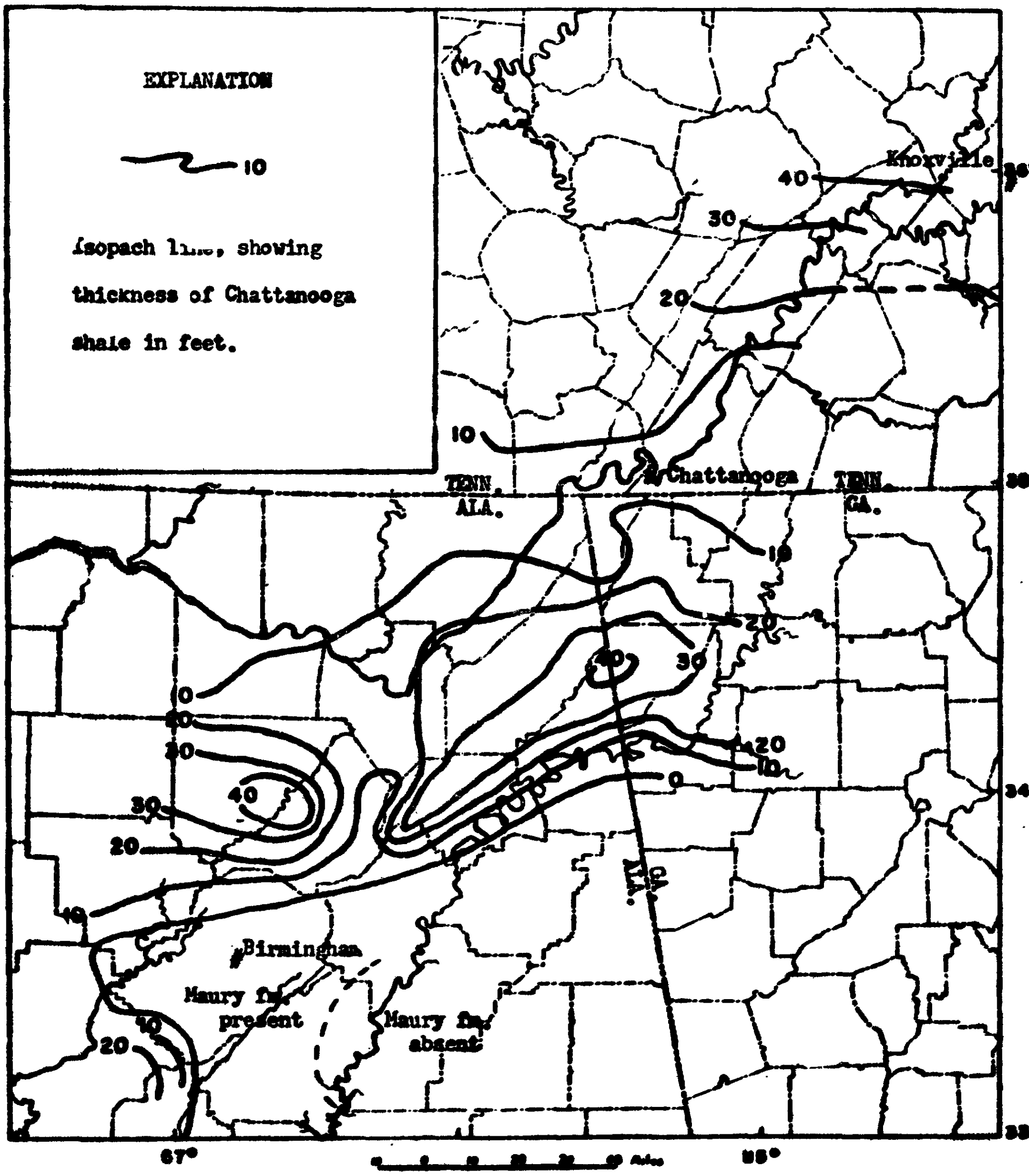

Fig. 37 Isopach map of the Chattanooga shale in the folded belt of Alabama, Georgia, and Tennessee

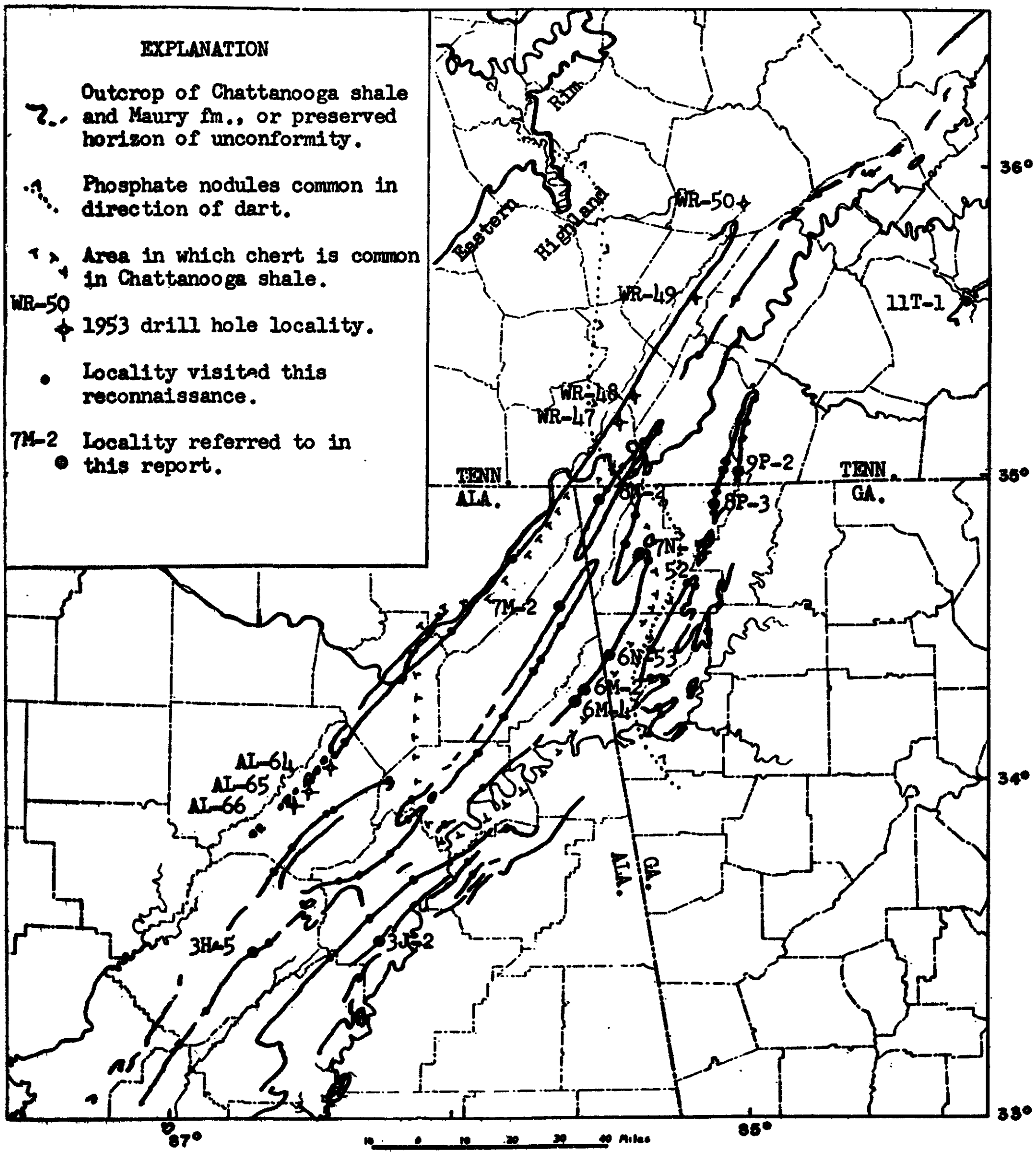

Fig.38. Outcrops of the Chattanooga shale in the folded belt of Alabama, Georgia, and Tennessee

band of green silt or small green concretions at the top. The red coloring is probably a primary feature of deposition indicating oxidizing conditions probably in the strandline belt. By contrast, the normal green coloring of the Maury would indicate moderate reducing conditions and the black Chattanooga would indicate extreme reducing conditions.

Intraformational conglomerates (8P-3), slump features (6M-2. 6M-4), calcareous-articulate-brachiopod impressions preserved in black shale along with pellets and flakes of light-colored mudstone and some sand (8P-3), absence of bedding, lenticular beds and poor sorting all suggest that minor disturbances caused considerable shifting of unconsolidated and semi-consolidated mud across the sea floor during the time of deposition of the Chattanooga and Maury shales in this area.

Two localities, 8P-3 and 11T-1, have yielded identifiable articulate brachiopods, pelecypods, ostracods and trilobites. The collection from locality 8P-3 is from an interval less than 1 foot thick in an intraformational conglomerate. The collection from 11T-1 is from the lower part of a greenish-gray silty-claystone unit. These fossils, rare in the Chattanooga shale, may afford supporting age data and possible paleoecological interpretations from a heretofore unusable type of evidence.

Phosphate nodules and chert beds have wide distribution in the region investigated. The shale intervals that contain phosphate are low in uranium. Bedded "phosphate" has been suspected in the Chattanooga shale in northeast Alabama and northwest Georgia, but an analysis of the "phosphate" from locality 7N-52 shows it to be chertified shale, containing 85.7 percent SiO_2 (much of it as chalcedony), 0.30 percent K_2O, 0.1 percent P_2O_5 and 0.012 percent U. At this locality thin layers of chert are confined to a 4-foot interval in which they alternate with shale.

North of Knoxville, Tennessee, and in the belt of outcrop along the west edge of the Great Smoky Mountains (11T-1), the Fort Payne chert and Maury formation grade laterally into the Grainger shale. The Chattanooga shale here is sandy and progressively thicker northward as it interfingers with clastic geosynclinal sediments. The uranium content of the shale in this region is very low.

A sample of highly weathered coalified material from the top of the Maury formation at 8N-2 is surprisingly high in rare earth content. The coal, less than 0.1 foot thick, contains about 10 percent ash, 1 to 5 percent of which is yttrium. The amount of coal is small, probably representing burial of only one or two isolated logs.

Next to the Chattanooga shale, the most highly radioactive unit in the region investigated is the Silurian Red Mountain formation, which locally is as much as one half as radioactive as the Chattanooga. This formation directly underlies the Chattanooga shale or Maury formation over much of the area in the southern Appalachians.

Eastern black shale reconnaissance

by
J. F. Pepper

A review of the literature to collect and summarize data on the black shale east of the Mississippi River continued with the compilation of available information on the New Albany shale of Indiana and the Misenheimer and Mountain Glen shales of Illinois.

Information also was compiled on the Dunkirk shale in western and west-central New York. A map of this area was constructed showing the variations in the radioactivity of the Dunkirk shale. Work is in progress on a map showing the variations in thickness of the Marcellus shale and the relationship of the Tioga bentonite to the Marcellus shale and to the underlying Onondaga formation.

Asphaltite and petroleum investigations

Asphaltic rocks in the western states

by
W. J. Hail, Jr.

Uranium analyses have been completed for all the samples of asphalt-bearing rocks collected during the 1953 and 1954 field seasons. The index map (fig. 39), shows the location of the 45 selected areas in the western states from which samples were collected. The samples were taken from 24 geologic formations representing rocks of Ordovician, Pennsylvanian, Permian, Triassic, Jurassic, Cretaceous, Paleocene, Eocene, Miocene, and Pliocene age. Host rocks containing the asphalt include sandstone, conglomerate, arkose, limestone, and diatomite. Analyses of selected samples shows that uranium is concentrated as an organo-uranium complex in the asphaltic portion of the sample and not in the rock residue.

Uranium was found in asphalt-bearing rocks in all of the 45 areas examined in the western states, in average concentrations ranging from 0.001 to 0.376 percent in the ash of the extracted oil. Deposits in seven of the areas yielded samples significantly high in uranium in the ash of the extracted oil. These areas, listed with the uranium content of their richest samples, are: Chalone Creek (0.50 percent uranium), McKittrick (0.15 percent uranium), Edna (1.9 percent uranium); and Los Alamos (0.33 percent uranium) areas in California; Vernal area, Utah (0.15 percent uranium); Sulphur area, Oklahoma (0.22 percent uranium);

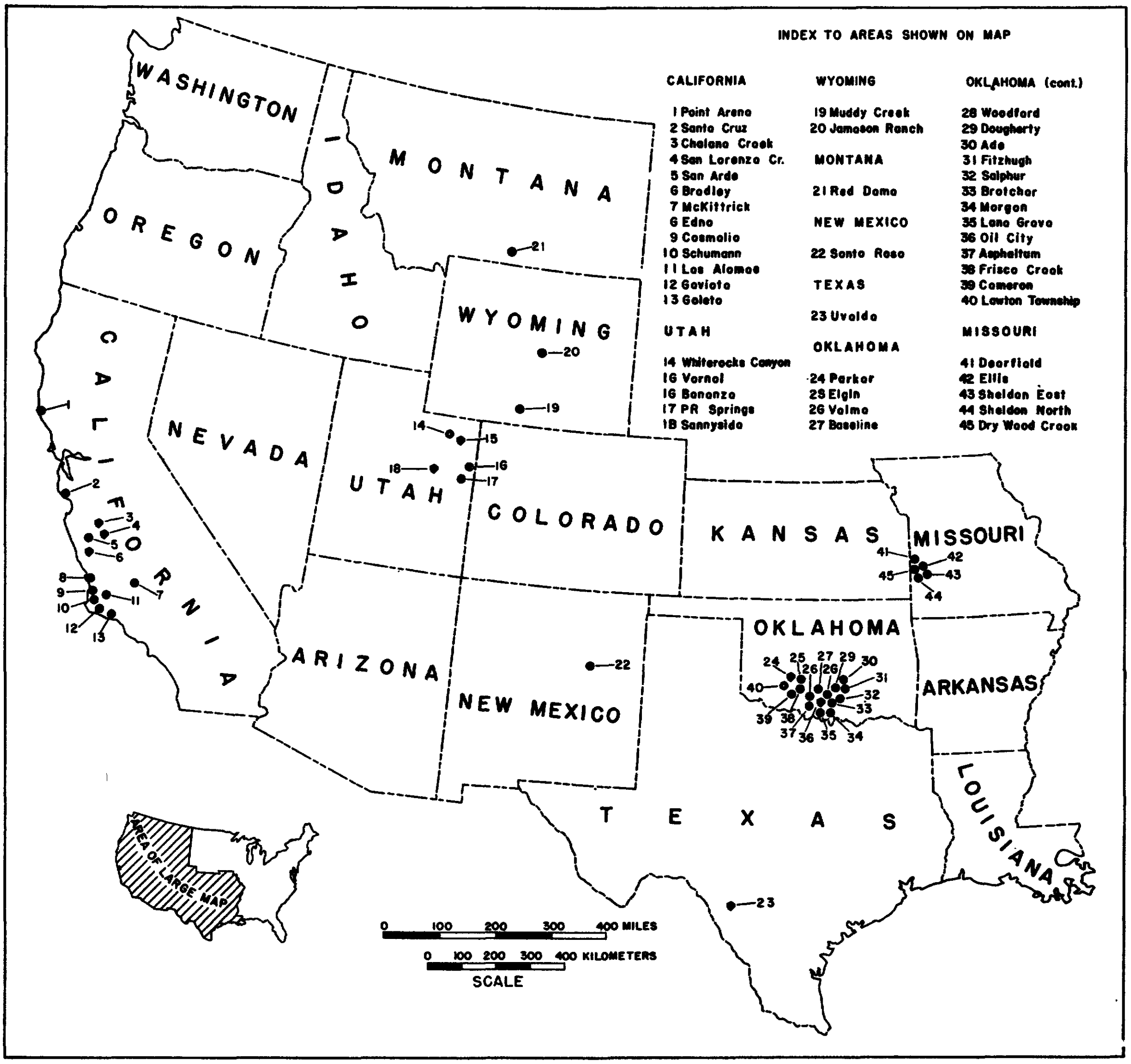

FIGURE 39.—MAP OF WESTERN UNITED STATES SHOWING AREAS EXAMINED FOR URANIUM IN ASPHALT-BEARING ROCKS

and the Ellis area, Missouri (0.40 percent uranium). The average uranium content of samples from these seven areas ranges from 0.028 percent in the Vernal area, to 0.376 percent in the Edna area. All the deposits except those in the Chalone Creek area contain large estimated reserves of asphalt-bearing rock, ranging from 15,000,000 tons to almost 2,000,000,000 tons. The most uraniferous deposits found are in the Edna area.

The average uranium content of samples from thirteen other areas ranges from 0.020 to 0.068 percent in the ash of the extracted oil. These areas are: Point Arena, Santa Cruz, San Lorenzo Creek, San Ardo, Bradley, Casmalia, and Goleta areas in California; Sunnyside area, Utah; Muddy Creek and Jameson Ranch areas, Wyoming; Santa Rosa area, New Mexico; and the Cameron and Lawton Township areas in Oklahoma.

Uranium in asphaltite and petroleum

by

A. T. Myers

A total of 728 chemical determinations were completed on 293 samples during this report period, and semiquantitative spectrographic determinations were completed for 184 samples. A distribution by sample type and constituent is shown in table 19.

The major effort of the project during this report period was directed toward the completion of analyses of selected petroliferous rock and crude oil samples in connection with studies of uranium in asphaltic rocks and petroleum in western states.

The analyses of over 150 samples of crude oil collected from wide geographic and geologic environments were completed, with the exception of some supplemental duplicate samples, and recently submitted samples

Table 19. Distribution of sample types and constituents in asphaltite and petroleum samples

Sample Type	No. of Samples
Petroliferous rock	216
Crude oil	74
Asphaltite	3
Total	293

Constituents	No. of Determinations
Percent oil 1/	212
Percent Ash (of oil)	267
Percent U in Ash (of oil)	244
Percent U 2/	3
Other 3/	2
Total	728

1/ Refers to material extracted by a hot solvent composed of 75 percent benzene, 15 percent acetone, 10 percent methanol.

2/ Other than in oil ash.

3/ Percent eU rock residue, °API Gravity.

from new locations needed to fill gaps in information.

Studies of asphaltite pellets and oil extracted from the same rock show some interesting inter-relationships, indicating that the pellets may have been derived from the oil. It also was found that the uranium was concentrated in the organic fractions of the samples and not in the host rock. Use of thermal diffusion techniques to concentrate the metalliferous fractions in these oils for further study are being continued.

Study of the loss of metals on ashing of different types of crude oil and other organic substances is nearly completed.

A paper, entitled "Properties of Porphyrins in Petroleum", by H. N. Dunning and J. W. Moore of the Petroleum Experiment Station, Bureau of Mines, Bartlesville, Oklahoma, and A. T. Myers of the USGS was published in the September 1954 issue of Industrial and Engineering Chemistry.

Uranium in petroleum in the western United States

by

H. J. Hyden and N. W. Woods

Laboratory work on samples of crude oil and oil field brines from a few oil fields in the western United States is in progress. Samples are ashed and the ash is split into two parts. One part is analyzed fluorimetrically for uranium, and the other part is analyzed spectrographically for other trace metals. Since the last report (TEI-490) 55 oil samples have been ashed and analyzed for uranium. A total of 840 semiquantitative spectrographic analyses have been completed on 14 samples of the ash of crude oils, and 126 quantitative spectrographic analyses have been completed on 42 samples.

Uranium in crude oils

The average uranium content in the ash of the crude oils, computed from the data available, is 27 ppm in sandstone reservoirs and 20 ppm in limestone reservoirs (table 20).

The content of uranium in the crude oil from the Nowata oil field, Oklahoma, is the largest of all crude oils and refinery products analyzed for this investigation. The average content of uranium in the crudes in sandstone reservoirs in Oklahoma is 81 ppm, which is much more than in crudes in other states. If the two samples from the Nowata field are excluded the average content of uranium in 11 samples is only 17 ppm. Moreover, the average content of uranium in sandstone reservoirs in the total of 63 samples is influenced considerably by the two samples from the Nowata field; the average is 27 ppm but if the two samples are excluded the average is only 15 ppm.

Table 20. Average content of uranium in ash of the crude oils from sandstone and limestone reservoirs

Location	Reservoir rock	No. of samples	Average content of U. (ppm)
Rocky Mountains			
Wyoming	sandstone	26	10
	limestone	11	11
Montana	sandstone	5	32
Utah	sandstone	6	6
Colorado	sandstone	2	38
New Mexico	sandstone	1	18
Sub total	sandstone	40	14
	limestone	11	11
Mid-Continent			
Oklahoma	sandstone	13	81
	limestone	3	13
Kansas	sandstone	4	14
	limestone	10	28
Arkansas	sandstone	4	6
	limestone	1	65
Texas	sandstone	2	17
Sub total	sandstone	23	52
	limestone	14	28
Total	sandstone	63	27
	limestone	25	20

Following is a list of samples that contained much larger than the average amounts of uranium:

Field	State	Producing bed	ppm U
West Atlantic	Arkansas	Smackover limestone	65
Wilson Creek	Colorado	Entrada sandstone	70
North Oregon Basin	Wyoming	Tensleep sandstone	75
Bears Den	Montana	Sunburst sandstone	100
Brewster	Kansas	Arkbuckle limestone	213
Nowata	Oklahoma	Bartlesville sand	400
Nowata	Oklahoma	Bartlesville sand	450

Uranium in oil field brines

The uranium content of 11 of 41 samples of brine from oil fields in northeastern Oklahoma and eastern Kansas ranges from 3 ppb to less than 1 ppb. The uranium content of 21 other samples of oil field brines and water used in water-flooding operations in the Nowata oil field in Nowata and Rogers Counties, Oklahoma, ranges from 6 ppb to less than 1 ppb. The uranium content of brines of this oil field is probably no higher than the average content of surface waters.

Uranium in refinery residues and refinery coke

Of the 13 samples of refinery asphalt residue and 3 samples of refinery coke analyzed for uranium content, 11 contained 10 ppm uranium or less. A residue sample from a refinery at Casper, Wyoming contained 230 ppm uranium, which is the largest content of uranium of all refinery samples. The crude oil processed by this refinery is produced in the Salt Creek, Wyoming field. Analyses of samples of crude oil from the five main oil-producing zones at Salt Creek, however, showed the uranium content in the ash to range from 2 to 8 ppm. It is possible that additional sampling and analyzing of crude oils in the supply area of the refinery may reveal the source of the uncommonly large uranium content in the refinery residue.

Variation in quantity of ash

Crude oil samples from 2 wells, producing from a single reservoir in an oil field, were collected from 13 oil fields to obtain data concerning the constancy of uranium content from well to well. Following is a summary of these data for the pairs of wells:

Maximum difference of uranium in ash	190 ppm
Minimum difference of uranium in ash	.1 ppm
Average difference of uranium in ash	23 ppm

Maximum difference of ash in oil	1,142 ppm
Minimum difference of ash in oil	2.7 ppm
Average difference of ash in oil	201 ppm

Re-ashing of several samples of crude oil is under way to obtain data on the reliability of the ashing procedure. The uranium content in the ash of crude oil rather than the uranium content in oil is used in this statistical investigation because the variation of uranium in the ash in a given oil pool is smaller than the variation of ash in the crude oil.

Relationship of uranium and nitrogen content

Vanadium and nickel porphyrins have been identified in crude oils by other workers (Skinner, Ind. Eng. Chem. 44, p. 1159; Hodgson, AAPG, v. 38, no. 12, p. 2572; Dunning, Ind. and Eng. Chem., v. 46, p. 2000). Porphyrins are nitrogeneous metallo-organic complexes. A statistical comparison of the quantities of uranium and nitrogen, shown by the analyses of 29 samples of crude oil (see table 21), was made to obtain data on the possibility of a uranium-porphyrin complex in crude oil. Determination of the nitrogen content in the samples of crude oil was made by the U. S. Bureau of Mines at Laramie, Wyoming. If appreciable quantities of uranium-porphyrin complexes are present in the crude oils, a large quantity of nitrogen should also be present. This condition should produce a positive correlation coefficient. However, the data in table 21 produce a very small negative correlation coefficient. A conclusion is suggested tentatively, therefore, that uranium is not present in crude oil in a porphyrin complex.

Table 21. Uranium and nitrogen content of 29 crude oils

Sample No.	ppm U in ash of oil	Percent N in oil	Sample No.	ppm U in ash of oil	Percent N in oil
1	1.0	.169	17	4.7	.23
2	5.0	.018	18	2.6	.23
3	40.0	.35	19	2.5	.092
4	1.0	.14	20	31.0	.084
5	13.0	.22	21	24.0	.05
6	75.0	.35	22	12.0	.125
7	22.0	.35	23	4.0	.103
8	6.0	.42	24	6.0	.075
9	9.5	.48	25	65.0	.24
10	2.0	.17	26	12.0	.098
11	1.6	.3	27	23.0	.044
12	3.6	.28	28	19.0	.035
13	24.0	.25	29	10.0	.049
14	1.5	.18			
15	1.4	.2			
16	3.0	.43			

Correlation coefficient U and N: –.01124

Geochemistry of uranium-bearing carbonaceous rocks

by

I. A. Breger and Maurice Deul

Colorado Plateau studies

Investigations of various types of carbonaceous materials that occur in the Temple Mountain region, Emery County, Utah, were continued in order to determine their relationships to the uranium. Studies of the crude oils were completed using the samples shown in table 22. These samples were

Table 22. Samples of oil studied

Source	Description
AEC No. 8 mine, north workings 1/	Seep through uraniferous zone. Consistency of taffy.
Marsh Bank Canyon 2/	Seep through uraniferous zone.
AEC No. 5 mine 3/	Oil seep on mine wall.
AEC No. 4 mine 3/	Oil-impregnated sandstone.

1/ Collected by L. Stieff and T. W. Stern, U. S. Geological Survey.
2/ Collected by A. D. Weeks, U. S. Geological Survey
3/ Collected by I. A. Breger and M. Deul, U. S. Geological Survey.

fractionated and analyzed to yield the data of tables 23 and 24. Because asphaltenes may contain from 0 to 11 percent sulfur, the fact that the asphaltenes from the four oils examined from the Temple Mountain area contain very similar percentages of sulfur (5.1, 5.7, 5.7, 6.3) makes it appear that all these oils were probably derived from the same pool. Uranium contents ranging from 45 to 310 ppm in the oils probably reflect the migratory history of each oil.

Because oils from nonuraniferous regions are known to contain negligible amounts of uranium, it is suggested that reconnaissance for uranium might possibly be carried out by analysis of oils that may occur in uraniferous provinces. Oils that contain appreciable percentages of uranium might then be used as guides to uranium ore. Use of a uraniferous oil as an ore guide would be based on the assumption of very narrow areal movement of the oil.

Carbonaceous pellets collected in the AEC No. 4 mine have been hand-picked from about 50 lbs. of sandstone matrix. Examination of a polished section made from one of the larger pellets shows disseminated quartz, fine-grained pyrite, and small amounts of galena. Analysis of carbon-hydrogen data for six pellets indicates that the material is coaly in

Table 23. Analysis of asphaltenes

	AEC No. 4	AEC No. 5	Marsh Bank Canyon	AEC No. 8
Ash, percent	0.34	0.28	1.83	1.07
Uranium, percent	0.000147	0.0221	0.0386	0.0922
Carbon, percent	82.21	82.84	82.71	83.31
Hydrogen, percent	7.92	8.44	8.24	9.44
Nitrogen, percent	0.98	1.07	0.40	1.0
Sulfur, percent	5.7	5.1	5.7	6.3
Oxygen, by difference, percent	3.2	2.5	3.0	---

Table 24. Distribution of uranium in the oils from the Temple Mountain area

	AEC No. 4	AEC No. 5	Marsh Bank Canyon	AEC No. 8
Original oil				
Uranium, percent	0.0000438	0.00445	0.0137	0.0310
Asphaltenes, percent	22.7	16.2	22.5	27.8
Asphaltenes				
Uranium, percent	0.000147	0.0221	0.0386	0.0922
Ash, percent	0.34	0.28	1.83	1.07
Uranium in ash, percent	0.0432	7.89	2.11	8.62
Percent of uranium in original oil held by asphaltenes, percent	76.2	80.5	63.4	82.6
Uranium in extracted sandstone, percent	0.00020	---	---	---

nature. While carbon-hydrogen analyses alone prove very little, the vacuum differential thermal analysis curve of the one sample that has been run is practically identical with curves for low-rank coals. Gilsonite, wurtzilite, Argentine asphaltite, etc., give differential thermal analysis curves of a completely different character from that obtained from the pellet.

Ore grade uraniferous sandstone impregnated with carbonaceous material is common in the Temple Mountain area. Studies to determine the relationship of the uranium to the organic and inorganic constituents of the ore from the AEC No. 9 mine continued. Analysis of stripping film exposures prepared from thin sections of the ore showed that: (1) there is no concentration of tracks at the boundaries between the carbonaceous material and the mineral fragments. This shows that the uranium is not present in the ore as a coating on the mineral grains; (2) there is a dispersion of alpha-particle tracks throughout the carbonaceous material; and (3) the quartz and pyrite grains are practically devoid of tracks. Vanadium minerals show some tracks but not nearly as many as appear in the carbonaceous material.

Specimens of ancient buried wood in various stages of degradation were exposed to circulating solutions of uranium at elevated temperatures to determine changes effected in cellular structure and the sites of absorption of the uranium. These studies are designed to obtain information regarding the nature of the solutions that may have carried uranium into the Colorado Plateau region, and are being followed by comparison of changes effected in the wood during laboratory studies with those noted in studies of uraniferous coalified wood from the Colorado Plateau.

Uraniferous coals

Preliminary studies were carried out on coalified wood from the Maury shale collected in Tennessee. This coalified wood, of lower Mississippian age, contains approximately 10 percent ash that, in turn, contains all of the rare earths but promethium. Besides 0.16 percent U in the ash, Y. Mn, Gd, and Nd are present in the 1 to 5 percent range. Studies of these coalified logs are continuing.

Twenty-one samples of coal flora that are living equivalents of Paleozoic and Tertiary plants were ashed and analyzed spectrographically by the semiquantitative method. The data are now being analyzed in an attempt to apply this fundamental information to the problem of the origin of ash-forming ingredients in coal. The major constituents of the plant ashes are the alkali metals, Na, K, Mg, and Ca, but in coal ashes these elements are usually minor, Fe, Al, and Si being the major elements present. The fate of the trace elements present in the plants, as found from analyses of plant ashes, during degradation and coalification has not been determined, but certain deductions can be made: (1) copper is present in plant ashes in amounts greater than that in most coals; (2) germanium has not been detected in any of the 21 plant ashes analyzed. This indicates that for plants to accumulate germanium a recycling of plant nutrients must be effected; and (3) the low iron content of the plant ashes, as compared to that of most coal ashes, shows that there has been a great enrichment of iron from the time the coal flora were living through the end of coalification.

Chattanooga shale

Experiments in the separation of uranium-rich fractions from carbonaceous shales were continued using an air jet pulverizer. By use of this grinding technique, a head sample of Chattanooga shale containing 0.010 percent U yielded an extremely fine-grained product containing 0.0129 percent U. This sample was further fractionated into six fractions by air elutriation. Analysis of the samples are given in table 25.

These data support previous conclusions that the uranium is now present in the Chattanooga shale as a colloidal phase disseminated through the matrix of organic material. To test this hypothesis, a 100-g sample of

Table 25. Fractionation of Chattanooga shale

Description of sample	Percent of Total	Percent U	Mg U
Original	100.0	0.0129	1.29
Coarsest fraction (cone 2)	56.0	0.0124	0.694
Cone 3	8.1	0.0118	0.096
Cone 4	5.9	0.0118	0.070
Cone 5	4.9	0.0109	0.053
Cone 6	4.2	0.0125	0.052
Finest fraction (filter paper)	20.9	0.0136	0.284

On a mass balance this is a recovery of 1.25 mg U from a 1.29-mg charge -- a 97 percent recovery.

Chattanooga shale, ground for 1200 hours in a ball mill with pebbles and water only, was mixed with additional water and permitted to settle and sediment for about 10 days at the end of which time the Tyndall effect was observed to be about the same at the top and the bottom of the column of supernatant liquid. This indicated that all the larger particles had settled and that only truly colloidal particles were left in suspension. Fifteen hundred milliliters of supernatant liquid was siphoned from the column, each 100 ml of which yielded about 70 mg of dry residue upon evaporation. Although the uranium content of the dry residue is only 0.00785 percent, much of the material was known to consist of soluble salts as indicated by an X-ray diffraction pattern which showed the presence of gypsum and plaster of paris as major constituents. Quartz and some unidentified materials were present as minor and trace constituents. In order to separate the soluble salts from the suspended colloidal material, 100 ml of the supernatant liquid was dialyzed using three changes of doubly distilled water over a 48-hour period. Upon dialysis the dried residue weighed only 3.5 mg but contained 0.019 percent U. Again this indicates a concentration of uranium in the finest fractions of pulverized

Chattanooga shale. A mass balance for uranium cannot be computed because some uranium may pass through the membrane during dialysis. It is likely that some of the uranium was rendered soluble during grinding to colloidal sizes in the presence of sulfides and oxidized sulfides.

Sharon Springs member of the Pierre shale

A sample of the Sharon Springs shale higher in uranium content than other samples from the same formation has been fractionated by ball mill grinding in mixed liquid media. A preliminary separation did not yield good mineral and organic concentrates as fractionation was complicated by the presence of abundant pyrite, about 28 percent by weight, some of which had oxidized to form soluble sulfates. The behavior of the finely ground material in water and kerosene was quite different from that of the other shale samples previously tested because the colloidal properties of the mineral-water and carbonaceous matter-kerosene systems were modified by the presence of the strong electrolytes. Analyses of the orginal shale and separates, given in table 26, indicate that further separation is required before any conclusions can be drawn regarding the association of uranium with the organic or mineral separates. While carbon and hydrogen analyses are useful for determining how complete the separations are, ash determinations are no criteria because most of the pyritic sulfur is lost during ashing. Hence, the fraction with highest concentration of pyrite may show a corresponding decrease in ash content. The peculiarities of behavior of this sample are not to be taken as typical of the Sharon Springs shale which elsewhere does not show a large percentage of pyrite.

Table 26. Fractionation of Sharon Springs shale

Description of sample	Percent U	Percent H	Percent C	Percent Ash	Percent S
Original shale	0.0122	1.23	8.04	74.53	14.89
Organic fraction	0.0128	1.78	15.78	55.39	---
"Mineral" fraction	0.0143	1.30	8.24	78.32	---
"Middlings" fraction	0.0068	1.00	2.18	72.98	---

Four carbonaceous shales have now been studied in some detail. In the cases of the Chattanooga shale and the shale from the Phosphoria formation, a concentration of uranium with the finest particle sizes indicates that the uranium is present as a separate colloidal phase. In the case of the shale from the Dakota sandstone, there is a marked association of uranium with the organic fraction. Finally, study of a sample of the Sharon Springs member of the Pierre shale indicates that the uranium may be associated with a mineral fraction.

From these considerations it appears that other than carbon content or content of organic material play important roles in determining how uranium may be present in a carbonaceous shale.

During the period covered by this report the following papers were published:

Breger, I. A., 1954, Geochemistry of naturally occurring carbonaceous substances; Trans. N. Y. Acad. Sci., Ser. 2, v. 17, p. 1-6.

Breger, I. A., Deul, M., and Rubenstein, S., 1955, Geochemistry and mineralogy of a uraniferous lignite; Econ. Geol., v. 50, p. 206-226.

The following paper was issued by the Technical Information Service of AEC as a sales item:

Cuttitta, F., and Brittin, E., Retention of uranium during oxidative ashing of naturally occurring carbonaceous substances; TEI-461.

URANIUM IN PHOSPHATES

Northwest phosphate

Facies and oil possibilities in the Phosphoria and Park City formations in eastern Utah and southwestern Wyoming

by

T. M. Cheney

The rocks of the Park City and Phosphoria formations of Permian age change progressively from phosphorite, chert, and carbonaceous mudstone in the miogeosynclinal area to carbonate rock, sandstone, and redbeds in the platform area. In southeastern Idaho and Wyoming, the facies change is from west to east. In eastern Utah, however, this facies change is from north to south: in this direction, the upper part of the phosphatic shale member of the Phosphoria formation grades progressively from phosphorite to phosphatic mudstone to chert and slightly phosphatic mudstone, and to cherty carbonate rocks and sandstone. The latter are classed with the upper member of the Park City formation.

The variation in facies from north to south across southwestern Wyoming and northeastern Utah is such that it may be favorable for the accumulation of oil in stratigraphic traps, especially on the north flank of the large Uinta Mountain anticline. The geologic environment seems somewhat similar to that in the Big Horn Basin in central Wyoming where oil is now being produced from Phosphoria equivalents.

Variation in composition of phosphate rock with depth in the Conda mine

by

L. D. Carswell and R. A. Gulbrandsen

A study of the physical and chemical composition of the minable phosphate beds at the surface and at lower levels in the Anaconda Copper Company mine at Conda, Idaho, indicates that several significant changes occur with increasing depth. Color changes with increasing depth from light gray and brown to very dark gray; hardness changes from soft and crumbly to hard; and bulk specific gravity increases from about 2.35 at the surface to at least 2.75 at nearly 1,000 feet down dip. Major chemical changes with depth are a decrease of about 4 percent in P_2O_5 content, an increase of about 3 percent in organic matter, and of about 5 percent in loss on ignition. Fe_2O_3 increases from about .45 percent to about .7 percent. Zinc increases markedly; although the amount of increase is not known quantitatively, it may be about double the surface value. No significant change in uranium or vanadium content with depth was noted. Other than the presence of calcite at depth, no mineralogic changes were apparent.

The changes in physical and chemical composition are not directly proportional to depth throughout. It appears that at a depth of about 700 feet the rocks are almost as weathered as they are at the surface; below 700 feet changes in composition appear to be directly proportional to increasing depth. The trend of the changes in composition suggests that the changes will continue to a greater depth than has now been attained.

Southeast phosphate

Exploration
by
W. L. Emerick

Radioactivity logging of drill holes

A total of 132 holes aggregating 5,207 feet were logged by the gamma-ray unit during the period. The cumulative total for the gamma-ray unit is 3,593 holes totalling 128,172 feet.

Construction of three simulated drill holes, each containing a layer of different grade of radioactive material, was completed during the period for calibration of the gamma-ray unit.

Economic geology of the land-pebble phosphate deposits, Florida
by
J. B. Cathcart

A generalized map of the thickness of the aluminum phosphate zone (fig. 40) shows clearly the absence or thinning of the zone along present streams, the erratic, spotty thickness on the ridges, and the thickening of the flat woods area between the crests of the ridges and the valleys. The three-foot isopach line is shown because material less than three feet in thickness is not considered minable. The 15-foot isopach line indicates thickest areas.

Numerical representation of the relationships between chemical constituents of the aluminum phosphate zone by means of coefficients of correlation shows a general tendency toward positive correlation between uranium and phosphate; therefore, samples or areas high in uranium are likely to be high in phosphate. The relations between uranium and alumina

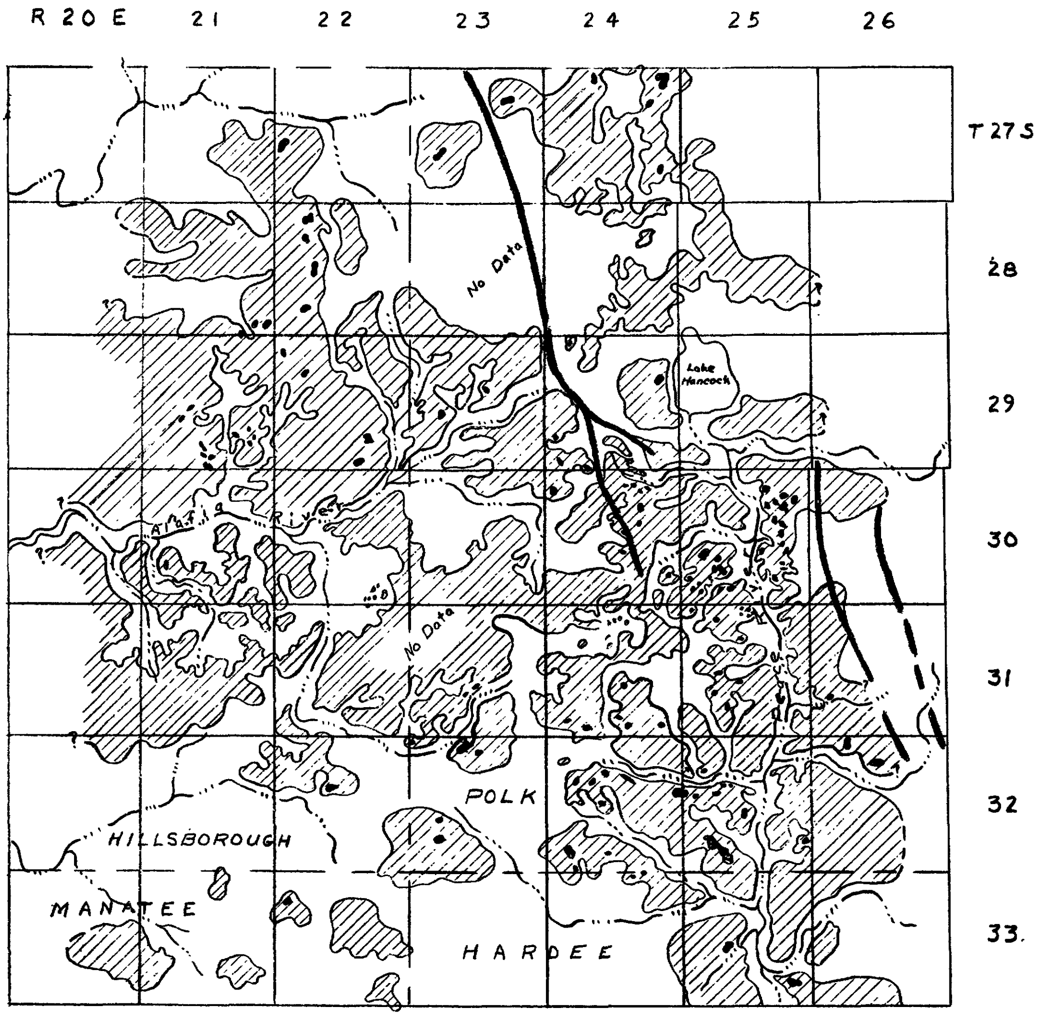

FIG. 40-DISTRIBUTION OF THE ALUMINUM PHOSPHATE ZONE,

LAND-PEBBLE PHOSPHATE DISTRICT, FLORIDA.

SCALE

0 6 12 18 24 miles

EXPLANATION

▨ Aluminum Phosphate Zone, more than 3 feet thick

● Aluminum Phosphate Zone, more than 15 feet thick

Unpatterned areas - Aluminum Phosphate Zone absent or less than 3 feet thick

Ridge crest

and calcium are not as well known; however, indications are that correlations are positive, but of lesser magnitude than the correlation between uranium and phosphate. Correlations between uranium and silica (or acid insoluble) are negative because silica is the principal diluent in the zone. Uranium is associated almost exclusively with the phosphate mineral, and uranium content varies with nodule size and phosphate content. Highest uranium contents are in the coarsest nodules which generally contain the smallest amounts of phosphate.

Geologic study of phosphate deposits and their "leached zones" in the northern half of Florida

by

G. H. Espenshade and L. A. Brubaker

Field investigation in Florida was confined mostly to two areas: the hardrock phosphate district in Hernando, Citrus, Marion, and Levy Counties, and an area of Hawthorn(?) outliers southeast of Ocala, Marion County.

Work in the hardrock district was directed toward getting a better understanding of the characteristics, distribution, and geologic control of these secondary phosphate deposits, as well as data on the distribution of uranium in the different types of phosphatic materials: (1) the phosphatic sands overlying the deposits, (2) hard secondary phosphate (the commercial product), (3) soft secondary phosphate, and (4) relic phosphate pellets. The hard and soft secondary phosphates are usually associated, mixed with variable amounts of clay and sand. The soft phosphate is generally more radioactive than the hard phosphate. The soft, clay-size phosphatic material, clay, and sand are removed in the beneficiation process and stored in slime ponds. After drying this material is re-excavated and sold as soil conditioner ("soft" or "colloidal" phosphate).

Rocks in the hardrock district are thoroughly weathered, and exposures of fresh material are scarce. Nearly all petrographic and stratigraphic data must be obtained from phosphate pits and drill holes. Twenty drill holes totalling 1,307 feet were put down with a jeep-mounted mobile auger drill. Samples were taken for stratigraphic purposes and for analysis, and the holes were logged with a gamma-ray scintillation logger. Drilling records of the numerous holes of the phosphate prospecting program of the Tennessee Valley Authority, and of the holes drilled by the Corps of Engineers along the proposed ship-barge canal route across Florida, are currently being studied. Field investigations in the hardrock phosphate district should be finished in the fall of 1955. The tentative view on the origin of these secondary phosphate deposits is that they have been derived by complex processes of weathering and erosion from phosphatic Miocene sediments which formerly extended over the area (essentially the origin first proposed by Sellards). Relic phosphate pellets similar to those in the Hawthorn and Bone Valley formations can be found in many of the phosphate deposits.

In the area of Hawthorn(?) outliers extending southeast from Ocala to Summerfield, most of the radioactive anomalies discovered by an airborne scintillometer survey (Moxham, R. M., 1954, Airborne radioactivity surveys for phosphate in Florida: U. S. Geol. Survey Circ. 230, pl. 1) were examined. Ten auger drill holes totalling 335 feet were put down on three of the strongest anomalies; samples were taken and gamma-ray logs made. High radioactivity is associated with phosphatic materials. Very porous, white uraniferous phosphatic sandstone is commonly found on the surface, and was cut at shallow depths in a few holes; it is evidently the weathering residuum of pellet phosphate rock. Uraniferous phosphate pellets in a matrix of clay with sand or lime were found in several holes, and also on the surface in places, particularly along dirt roads. The areas of phosphatic sediments are mostly on higher ground and are probably outliers of the Hawthorn formation (Cooke, 1945, Geologic map of Florida).

Occurrence of uranium in phosphate deposits

by
Z. S. Altschuler, P. S. Clarke and E. J. Young

Laboratory studies

A study was made of the uranium distribution and mineralogy of slag from an elemental phosphorus furnace. The slag is entirely α-pseudowollastonite. The crystals that develop first form a mesh of euhedral laths within which equant, subhedral laths are later deposited. The last phase to crystallize forms fibrous masses in the remaining pore space. Calcium and aluminum contents increase slightly in the later phases and the X-ray patterns of the phases change progressively. Spherules of Fe_2P occur sparsely throughout, as inclusions from the normally immiscible iron phosphide slag. Uranium content increases progressively in the later phases and as specific gravity does also, it is possible to obtain a concentration of more uraniferous material by heavy liquid fractionation.

During the preceding report period it was shown that approximately 80 percent of the tetravalent uranium in apatite could be recovered.

In this period it was established that the lack of complete recovery is due to fluoride complexing U^{+4}. Two sets of experiments were made to limit this effect by complexing fluoride with aluminum and borate. Both approaches resulted in complete recovery with synthetic apatite but yielded erratic results with natural materials. It is believed that the poor results with natural apatites are due to indirect effects on the Fe^{2}-Fe^{3} couple which in turn affects the U^{4}-U^{6}. A few last experiments are being tried before these studies are terminated. The 80 percent recovery was obtained with good consistency.

The beneficiation of uranium and individual mineral components by differential flocculation and settling was studied in fractions of aluminum phosphate zone rock submitted from the AEC. It was found that good upgrading could be obtained but that recovery was low and that it was impossible to obtain completely pure mineral separates even in the 0.X micron range.

Field studies

The relations of the aluminum phosphate zone to marine terraces, regional uplift, and soil profiles were studied in the field.

Several terrace levels have been mapped in the Land Pebble Field. (F. S. MacNeil, "Pleistocene Shorelines in Florida and Georgia", USGS Prof. Paper 221-F, pp. 95-107). The higher ones are less distinct than those closer to sea-level, and within the area enclosed by the higher terraces. The loose sand mantle was found to be mainly a residuum of lateritic weathering. Samples were collected above and below the proposed terrace scarps at several localities for size and heavy mineral analyses.

The stream capture or stream diversion just north of the Land Pebble Field indicates Pleistocene or Recent uplift. Attempts were made to obtain precise barometer elevations across the area of the stream capture; however, as the area is unmapped this was not possible due to the lack of control and the large areal variation in atmospheric pressure. Samples were collected from the bed load and the valley terrace fill along the Withlacoochee and Hillsboro Rivers, as it is possible that study of the size and heavy minerals of these deposits will reveal different source materials at different periods in the stream histories.

Examination of ground water podzols throughout the Land Pebble Field revealed that they are now in process of destruction in many localities and that their importance as agents in the leaching and weathering that produced the aluminum phosphate zone is greater than is apparent from their present distribution. Normally ground water podzols are dense, black organic accumulations with perfectly level upper boundaries. In many areas irregular, brown, patchy accumulations of iron or humic cemented sand are overlain by bleached and oxidized sands; however, a very level zone of indurated, platelike masses frequently surmounts this type of profile and in two instances this has been traced laterally into a typical ground water podzol.

URANIUM IN NATURAL WATERS
by
P. F. Fix

The initial preparatory phases of the project concerned chiefly with formulation and standardization of trustworthy techniques under known conditions in uranium-mining districts have been completed; testing them as a means of appraising new areas of unknown possibilities is in progress.

Newly discovered secondary uranium deposits in tuffaceous sandstones and shales of Tertiary age located in the Tordilla Hill area of the coastal plain near Karnes City, Texas, were studied in March. In addition to intensive investigation of an area extending 50 miles along the strike of the formation in Karnes, Gonzales, and adjacent counties, preliminary reconnaissance studies were made in the nearby drainage basins of the Nueces and Arkansas rivers, and in the Llano-Burnet uplift in Central Texas, where favorable occurrences of uranium were reported recently.

Tentative appraisal, based on laboratory reports for one-third of the samples, includes: (1) close agreement with the pattern of faulting mapped by Bailey (Univ. Texas Bulletin No. 2645, 1926), except that the water samples suggest in addition the presence of one major and several minor faults northeast of Tordilla Hill that seem to be loci of uranium mineralization; (2) indication that the entire area occupied by these formations is anomalously uraniferous and merits careful consideration for exploration; (3) the probability that most, and possibly all, of the uranium has been leached from tuffaceous strata now removed by erosion, and redeposited in lower beds by ground water circulating downward along the faults and laterally in permeable sandstone beds; and (4) close agreement with available results of airborne radiometry, except that the water samples suggest a greater extent southeastward, and a possibility of uranium mineralization in sandstone beds northeast of Tordilla Hill at depths of 40 to 65 feet below the surface. Semi-quantitative spectrographic analysis shows that anomalous amounts of molybdenum, arsenic, antimony, and iron are present in the Tordilla Hill uranium deposits, and that some of the yellow-colored mineralization results from minerals of iron, molybdenum, and perhaps arsenic rather than uranium.

Intensive investigation of the headwaters of the Arkansas, South Platte, and Gunnison rivers in Colorado began, and several streams containing strongly anomalous amounts of uranium were found. Most notable of these is Barnard Creek, tributary to the Arkansas River from the northwest at Cotopaxi. It was found to contain 66 ppb U. This is the largest uranium content detected to date in a small stream. On the basis of this high concentration, investigation to find the source of the uranium is warranted.

Refinement under close control during the past three years of standardization data for various geochemical environments was continued in Montana, Wyoming, and Colorado.

Data were analyzed during periods of weather unfavorable for field work, and new computations were made of regional and areal background concentrations of uranium in natural waters incorporating additional samples. The regional background averages 0.10 ppb U for 108 water samples from essentially non-uraniferous parts of Colorado, Idaho, South Carolina, Washington, Utah, Wyoming, Georgia, Florida, and North Carolina.

The areal background averages 0.80 ppb U, and ranges as high as 2.5 ppb U, for 203 water samples from Montana, Colorado, Texas, Utah, South Carolina, Florida, New Mexico, Idaho, Wyoming, and Alaska. The threshold of anomaly still is thought to be about 1.0 ppb U.

Work for the next semiannum is expected to continue in the same pattern, with new investigations in Texas, New Mexico, Idaho, and the Black Hills-northern Great Plains areas.

RECONNAISSANCE FOR URANIUM IN THE UNITED STATES

Airborne radioactivity surveying

By
W. J. Dempsey

The objectives and program of airborne radioactivity surveying have been changed to place major emphasis on the study of radioactivity patterns with relation to the distribution of radioactive elements and other geologic problems, and on the development and refinement of methods of analysis for increased significance of information. Specifically, studies will be made of the overall distribution of radioactivity in crystalline terranes, to determine whether a relationship exists between such distribution and known concentrations of uranium, and to test geologic hypotheses concerning the structural and stratigraphic distribution of uranium in sedimentary terranes.

During the past six months airborne radioactivity surveys totalling 3,490 traverse miles were made in four states:

State	County	Area	Traverse miles
Mississippi	Covington	Gwinville	60
"	Simpson	"	450
"	Jefferson	"	108
"	Adams	Cranfield	485
"	Franklin	"	247
"	Jefferson Davis	"	500
"	Lawrence	"	60
Tennessee	Bradley	SE Tennessee	24
"	Polk	"	901
"	Monroe	"	325
North Carolina	Cherokee	"	105
Georgia	Fannin	"	225
		Total	3,490

The surveys of the Gwinville and Cranfield oil field areas, which were supported by Geological Survey funds, were undertaken to evaluate the relationship of radioactivity measurements in the air to oil and gas accumulation. The area in southeastern Tennessee was surveyed to study the relationship and distribution of radioactivity in crystalline rock areas, and is the first project to fall within the outlines of the revised objectives of the airborne radioactivity surveying program.

A total of 2,700 traverse miles of radioactivity measurements supported by USGS funds was made to obtain basic information on the radioactivity background over various types and locations of terranes during cross-country flights as follows:

La Place, Louisiana to Moline, Illinois
Anthony, Kansas to San Antonio, Texas
El Paso, Texas to Egnar, Colorado
Norfolk, Virginia to Charleston, South Carolina
Tifton, Georgia to Jacksonville, Florida

Five Geophysical Investigations maps showing the locations of radioactivity anomalies detected during airborne radioactivity surveys were published during the past six months:

GP 119 Airborne Radioactivity Survey of the Folkston Area, Charlton County, Georgia, and Nassau County, Florida, by R. M. Moxham

GP 120 Airborne Radioactivity Survey of the Painted Desert Area, Arizona, by J. L. Meuschke

GP 121 Airborne Radioactivity Survey of the Fort Myers Area, Charlotte and Lee Counties, Florida, by J. L. Meuschke

GP 122 Airborne Radioactivity Survey of the Gardner Area, De Soto, Hardee, Manatee, and Sarasota Counties, Florida, by J. L. Meuschke

GP 123 Airborne Radioactivity Survey of the Edisto Island Area, Berkeley, Colleton, and Dorchester Counties, South Carolina, by J. L. Meuschke

Northeast district

by

Harry Klemic

North Carolina

Seven uranium occurrences in the Grandfather Mountain window area in Pisgah National Forest in western North Carolina were examined. Most of the occurrences are between Morganton and Blowing Rock, near Highways 181 and 321. Several occurrences of mildly radioactive rock were noted in roadcuts in this area. Torbernite occurs at some of these localities, and small amounts of minerals that resemble autunite and uranophane are found at others. A 1/4-inch veinlet of pitchblende with small amounts of galena and pyrite was found at one locality. One radioactivity anomaly is in an area of deeply weathered rock and the radioactivity may be due in part to thorium.

The number of uranium occurrences, and the fact that many samples of rock from this area containing more than 0.1 percent uranium have been submitted by prospectors, may be significant.

Tennessee

Three localities in the Cherokee National Forest in eastern Tennessee were visited. Two of these occurrences are in non-foliated granite of younger Precambrian age, and one is in older foliated rocks, near a fault contact with younger granites. Thorianite is said to be the chief radioactive mineral at one of the localities, and thorium may be present at the others. Thin films of a secondary uranium mineral are found on the rock at one locality.

North-central district

by

R. C. Vickers

Michigan

Pitchblende has been identified in specimens of drill core from the abandoned Francis mine in the inactive Gwinn iron district, Marquette County. Only a small percentage of the core was available for study, and the subsurface location and thickness of the radioactive material are unknown.

South Dakota

Northern Black Hills

Detailed mineralogical studies of samples of uranium-bearing Fall Rive sandstone from the Lamberton prospect, sec. 30, T. 5 N., R. 6. E., Meade County, disclose that a significant part of the uranium is in interstitial fine-grained carbonate-apatite. The association of carbonate-apatite with a sandstone-type uranium occurrence is rather unusual. Samples of the apatite-bearing sandstone contain as much as 0.007 percent uranium. Minute quantities of fluorescent uranium(?) minerals are present near some of the weathered surfaces.

Mineral separations with heavy liquids of 150-200 mesh material show that samples of the sandstone contain as much as 18 percent apatite. The extracted apatite contains about 0.3 percent uranium. If the apatite can be inexpensively separated from the sandstone, the deposits may have commerical value because of the large tonnages of apatite-bearing rock present at or near the surface.

Northwest district

by

P. L. Weis

Of the approximately 420 samples tested for radioactivity during the report period only about 35, or less than 10 percent, contain 0.10 percent or more eU. The majority of these samples are from the granitic rocks of the Loon Lake batholith which underlies a large area in northeastern Washington and northern Idaho. Unusual radioactivity has been found in this area in limestone, tuffaceous sediments, conglomerates, schists, contact metamorphic rocks, quartz veins, placer sands and gravels, and spring waters.

Autunite, as visible flakes and crystals, is the uranium mineral most commonly recognized in the samples. At least five samples contain uranophane, two contain carnotite, and one contains schroeckingerite. Sarmarskite and monazite were tentatively identified in more than ten samples from a number of places in Washington and Idaho. Euxenite and brannerite have been tentatively identified from placers in Idaho.

Uranophane has been found along fractures and shears in rhyolites and tuffs of the Challis volcanic series about 8 miles south of Salmon, Lemhi County, Idaho. Carnotite has been discovered in Tertiary sediments north of Winston, Broadwater County, Montana. Autunite was found in a sample of conglomerate tentatively identified as the Tertiary Tiger formation northeast of Usk, Pend Oreille County, Washington. Radioactivity, which in some material is as much as 0.23 percent eU, is in the fine, arkosic sand interstitial to quartz, granite, and schist pebbles and cobbles.

Autunite and samarskite (?) have been found in coarse, gneissic granite and pegmatite between Sherman Pass and Orient, Ferry County, Washington. Selected samples contain as much as 0.50 percent eU. A sample of gold-bearing quartz from the Beartooth Range, near Red Lodge, Montana, contains 0.36 percent eU.

Colorado-Wyoming district

Colorado
by
R. U. King and P. K. Theobald

F. M. D. mine, Jefferson County

Radioactivity is highest in a small adit 100 feet east of the main shaft. A sample from the adit contains 0.21 percent eU, 0.028 percent U, and 0.27 percent copper. A radiochemical analysis of this sample shows that the radioactivity is due to daughter products of uranium. Samples from a caved adit 275 feet west of the shaft and a prospect pit 200 feet west of the shaft contain, respectively, 0.019 and 0.021 percent eU, 0.007 and 0.019 percent U, and 0.32 and 1.79 percent copper.

It is unlikely that the mineralized zone at the F. M. D. mine is on the same fault that produced the breccia reef at Idledale, discussed below. It is probably along a parallel fault 3,500 feet north of the breccia reef.

Idledale area, Jefferson County

As a result of continued prospecting of the radioactive breccia reef at Idledale, ore-grade, uranium-bearing material has been discovered. (See TEI-490.) One core drill hole intersected the breccia-filled fault zone at a depth of about 200 feet and an eight-foot interval is reported to contain 0.58 percent U. In the drill core small masses of a black radioactive mineral tentatively identified as pitchblende are disseminated in a carbonate and feldspar matrix that contains angular fragments of altered wall rock and hematite-stained quartz.

The mineralogic and structural relationships of the Idledale deposit are similar to those of the uranium deposits of the Ralston Creek-Golden Gate area, as described in USGS Circular 320.

Canon City area, Fremont County

Secondary uranium minerals are associated with iron-manganese concretions in the upper part of the Dakota formation (Cretaceous) near Garden Park, about 9 miles north of Canon City. Uranophane occurs as veinlets in the interior of elongate concretions in a massive sandstone. The concretions appear to be confined to one or two horizons near the top of the massive sandstone. Dark-brown to black iron- and manganese-rich concentric bands are characteristic of the concretions that commonly enclose lighter colored, friable, porous sandstone.

Samples of similar material have been received recently from localities 10 miles to the east and 5 miles to the west, suggesting that the Cretaceous rocks of the Canon City embayment are favorable host rocks for uranium.

Wyoming

Carnotite mineralization in Upper Tertiary rocks, northeast margin of Hanna Basin, Carbon County, by J. D. Love

Carnotite mineralization was found in an erosion remnant of the North Park (?) formation along the northeast margin of the Hanna Basin, sec. 11, T. 24 N., R. 82 W., Carbon County, Wyoming. This remnant is about half a mile long, less than one-fourth mile wide, and consists of about 125 feet of white and light-colored tuff, limestone, conglomerate, sandstone, and claystone. The basal 30 feet is gray waxy bentonitic claystone containing abundant sandgrains, interbedded with bentonitic gray sandstone. At the north end of the exposure, both the sandstone and claystone contain carnotite as crystal aggregates in fractures and cavities and as disseminated crystals. A 1-foot channel sample of the claystone contains 0.05 percent eU, 0.051 percent U, and 0.16 percent V_2O_5. Analyses are not available on additional samples taken from more radioactive localities in the area. Radioactivity several times background was observed in the lower 50 feet of section.

Nevada-Utah district

Nevada

by

J. F. Powers and W. I. Finch

During the latter part of 1954 new uranium discoveries were made in Miocene-Pliocene sediments throughout the southern half of Nevada. The most important of these is the Silver Queen property, three miles west of Tonopah. Unidentified yellow secondary minerals occur along fractures and bedding planes in Esmeralda bedded pyroclastics and opalite. A twelve-foot channel sample assayed 0.135 percent U. A moderate tonnage of ore probably can be obtained from this property.

Uranium occurrences similar to the Silver Queen property are found in the Blue Bird claim in sec. 21, T. 7 N., R. 68 E., Lincoln County, in the Carol R. claims in sec. 21, T. 8 N., R. 32 E., Mineral County, and in the White Rose claim in East Walker River area, 25 miles south of Yerington.

Uranium is disseminated in water-laid sandy, clayey, or arkosic tuff of Miocene lake beds in Myer and Lander Counties. Uranium minerals are rare as the element appears to be contained in an indistinguishable phosphate mineral, possibly fluorapatite. The high-grade ore is most common along weak to strong shear zones and fractures and is associated with limonite. Carbonaceous material, gypsum, calcite and other minerals commonly associated with other uranium deposits in terrestrial sedimentary rocks are generally absent. The deposits range from bodies a few feet across that contain a few tons of ore to bodies several tens of feet across that contain a few hundred tons of ore. The uranium is thought to have been concentrated by ground water.

New Mexico

by

R. L. Griggs and E. H. Baltz, Jr.

Data from the Datil Mountains region in eastern Catron and western Socorro Counties, in the west-central part of New Mexico indicate that uranium occurs in a narrow westerly-trending belt about 60 miles long on the northern edge of the Datil Mountains.

The deposits occur in the Mesaverde formation of Late Cretaceous age and in the Baca formation of Early Tertiary age. These sedimentary rocks dip southward at low angles, and at the southern margin of the mineralized belt are overlain with angular unconformity by Tertiary volcanics of the extensive Datil-Mogollon volcanic field. The mineralization is closely associated with the volcanic rocks.

On the Hook ranch in T. 1 N., R. 5 and 6 W., the deposits are closely associated with carbon trash in highly permeable sandstone beds in the Baca formation. The uranium and vanadium content of four samples of beds ranging from one to two feet thick in this area is as follows:

Location	Chemical U (percent)	Chemical V_2O_5 (percent)
Sec. 18, T. 1 N., R. 5 W.	0.26	0.10
Sec. 18, T. 1 N., R. 5 W.	0.31	0.10
Sec. 13, T. 1 N., R. 6 W.	3.27	9.21
Sec. 24, T. 1 N., R. 6 W.	0.19	2.98

Small deposits of minable grade have also been found on the McPhaul and Drag A ranches in T. 2 N., R. 10 and 11 W. Detailed studies of three deposits have been made and the entire area has been mapped on a scale of 1:31,680. At two localities in the area, uranium and vanadium minerals are concentrated at the contact of thick permeable sandstone and underlying carbonaceous shale, both in the Mesaverde formation of Late Cretaceous age. Highest radioactivity is associated with carbonized logs and plant debris. At both localities the mineralized rocks are along shallow synclines. At a third locality uranium and vanadium minerals are concentrated near the wedge-edge of a stream channel sandstone at the base of the Baca formation of Early Tertiary age. The mineralized sandstone is enclosed by overlying carbonaceous shale of the Baca formation and by underlying carbonaceous shale of the Mesaverde formation. Surface exposures and drill-hole information indicate that the rock contains about 0.25 percent U and about 0.35 percent vanadium and ranges from 1 to 2 1/2 feet thick.

California

by
H. G. Stephens

Kern River Canyon area

The most significant deposits in the Kern River Canyon area are the Miracle mine, where an adit more than 350 feet long as been driven along a vertical, northwest-trending shear in granodiorite; the Kergon No. 1 claim, where autunite coats fractures in weathered granitic rock, and erratically distributed patches of black clayey material on the hanging wall of a northeast-trending fault contain sooty pitchblende (?), fluorite, and ilsemannite; and the Embree property on Erskine Creek about 10 miles east of the Miracle mine, where primary uranium minerals and gummite (?) have been tentatively identified in quartzite adjacent to a quartzite-gneiss contact.

Mojave mining district

Most of the known uranium deposits near Mojave are grouped south of Soledad Mountain in T. 9 N., R. 13 W. and T. 10 N., R. 13 W. Here autunite or meta-autunite and probably uranophane coat fractures in Tertiary volcanic and sedimentary rock and in Jurassic (?) quartz monzonite. Two deposits of autunite about 2 miles apart occur in the quartz monzonite footwall of an east-trending fault that can be traced for about 1 mile. In both deposits the yellow secondary uranium minerals occur as powdery coatings along fractures that are cut off by the fault.

RECONNAISSANCE FOR URANIUM IN ALASKA

by

J. J. Matzko

Samples collected from the Nixon Fork area in west central Alaska, the Shirley Lake area in southern Alaska, and the north flank of the Brooks Range in northern Alaska were examined during this report period.

The maximum radioactivity of samples collected from the Nixon Fork area was 0.06 percent eU due principally to thorium in the mineral allanite. A spectrographic analysis of this mineral indicates between 0.5 and 1 percent thorium. Soil samples collected in the area to determine if geochemical methods could be used for exploration of the mineralized zones in which the copper, gold, and radioactive minerals occur showed significant anomalies. Analyses of 24 samples indicate that the larger anomalies may be obtained on the associated lead and zinc.

Examinations made on samples collected from near Shirley Lake, Skwentna district, Tyonek quadrangle, southern Alaska, indicated a maximum of 0.021 percent uranium. No uranium minerals were identified. The more radioactive rock is a tuffaceous graywacke sandstone.

Preliminary studies made on the phosphate rock in the Lisburne limestone from northern Alaska, on the north flank of the Brooks Range, indicate between 20 and 30 percent P_2O_5 and about 0.01 percent U. The dominant rock types in the phosphatic zone are phosphorite, phosphatic limestone, and phosphatic mudstone. Minerals identified as occurring in nearly all the samples, but in varying amounts, are carbonate-fluorapatite, calcite, dolomite, quartz, feldspar, and fluorite.

ANALYTICAL SERVICE AND RESEARCH ON METHODS

Sample control and processing

by
J. J. Rowe

During the last six months, work loads were readjusted to provide equalized distribution of work between the USGS laboratories in Washington and Denver. Incoming work continued at an even level in quantity but with a change in emphasis from simple uranium determinations associated with exploration and routine studies, to analyses of more varied and difficult nature associated with the increasing concern with geologic interpretation. Minor element analyses and leaching and separations, associated with analysis for key elements, has thus served to increase the actual work load. This trend became evident during the preceding report period resulting in necessary adjustments for greater diversification in analytical facilities and procedures.

Radioactivity

Analysis and services

by
F. J. Flanagan

During the last six months 6,360 radioactivity determinations were made on samples submitted from USGS and AEC projects and the public.

Cooperative investigations with other projects continued as follows: (1) Simple statistical tests were used to show differences in radioactivity between the red and green phases of the Conway granite and that weathering has affected the green phase but not the red. (See "Distribution

Table 27. Semi-Annual Summary of Analytical Services and Sample Inventory, December 1, 1954 - June 1, 1955

	Determinations						Samples			
	Chemical			Spectrographic						
Project or source	U	Others	Radio-activity	Samples	Detn's	X-ray	On Hand Dec. 1	Rec'd Dec. - June	Completed Dec.-June	On Hand June 1
Washington Laboratory										
S. E. phosphates	779	210	3,111	6	408	3	1,819	3,043	3,069	1,793
AEC	309	65	303	54	3,672	139	89	285	357	17
Fuels Branch	822	230	864	224	14,898	36	288	975	1,157	106
N. W. phosphates	490	1,599	515	---	---	---	236	1,157	782	611
Alaskan	33	3	212	1	68	1	70	220	283	7
Miscellaneous	502	320	449	415	18,265	74	255	942	993	204
Public samples	783	---	747	16	1,088	49	526	2,057	2,287	296
Mineralogy projects	150	694	60	205	13,157	149	166	596	583	179
Geochemistry of U	776	167	77	269	9,589	167	373	925	860	438
Total	4,644	3,288	6,338	1,190	61,145	618	3,822	10,200	10,371	3,651
Denver Laboratory										
Colorado Plateau deposits	610	1,483	1,065	324	19,268	51	1,243	2,247	1,929	1,561
Plants and Soils	338	499	46	36	2,160	---	795	290	886	199
AEC	1,644	654	2,537	169	10,161	16	1,120	3,017	3,707	430
Reconnaissance	632	1,701	814	251	15,561	104	2,717	1,567	3,291	993
Fuels Branch	1,748	1,678	1,427	723	43,321	85	2,568	632	2,754	446
Public samples	53	1	142	---	---	2	66	150	196	20
Miscellaneous	49	191	216	84	4,228	130	747	546	890	403
Total	5,074	6,207	6,247	1,587	94,699	388	9,256	8,449	13,653	4,052
Grand Total	9,718	9,495	12,585	2,777	155,844	1,006	13,078	18,649	24,024	7,703

of uranium in igneous complexes"). (2) Work on the accuracy and precision of three different methods of splitting samples for grain counts from three different sample weights were compared qualitatively using the statistic χ^2. (See "Research on methods and techniques in mineralogy and petrology"). (3) Comparison of the mean percentages calculated from grain counts showed that the use of the average weights per grain instead of mineral densities yield the best estimates of the known weight percent composition. (See "Research on methods and techniques in mineralogy and petrology").

Calculation of standard deviations for the difference between uranium determinations by chemical and by radio-assay methods for the southeast phosphate continues. Using coded analytical data for the period 1948-1952 for sized samples of these phosphates, and assuming that the regression is linear, the coefficients a and b in the regression curve of uranium on radioactivity, percent U = a + b (percent eU), have the following numerical values:

Sample Mesh size	Coefficients a	Coefficients b
Whole sample	1.87	0.72
+14	0.51	0.91
-14 +40	0.05	0.91
-40 +150	-0.01	0.89
-150	-2.68	1.34

The hypothesis of linearity of regression has not been tested by an analysis-of-variance technique but inspection of the scatter diagrams for the five classes of samples above suggests that only the equation for the -150 mesh-material may depart significantly from linearity.

Research, Washington
by
W. R. Champion

Thorium analyses

A statistical analysis of the alpha star data obtained in preliminary traverses indicates that the population of three and four branched stars appear to fit the Poisson distribution. The five branched stars, for as yet unexplained reasons, do not fit the Poisson distribution.

Specifications were written and bids requested on the components for a gamma ray spectrometer. This instrument will be used for analysis of thorium, uranium, and potassium in rocks by counting a characteristic gamma ray from each.

Thin sources for alpha counting are being made by evaporation of thorium metal on a low back scattering material for the redetermination of the half-life of thorium. These samples will be used in an alpha spectrograph to determine the rate of decay of a known quantity of thorium metal.

Metamictization of zircon

The linear accelerator at Oak Ridge National Laboratory became available during this report period and bombardments will be completed pending the use of the accelerator. No work was done on this problem during the past six months.

Activation analysis

Further measurements of the ratio of Cu^{63} to Cu^{65} by neutron activation analysis at Oak Ridge National Laboratory resulted in a reproducibility of about one percent. With new equipment being obtained efforts will be directed toward improving the precision of the measurements to the degree necessary to make the method useful for observing natural fractionation.

Research, Denver

by

J. W. Rosholt

During this report period, 6,784 equivalent uranium determinations were made in the radiometric laboratory. In addition a total of 171 radiochemical determinations which included analyses for Th^{232}, Th^{228}, Th^{230}, Pa^{231}, Ra^{226}, Ra^{223}, Rn^{222}, and Pb^{210} were made. Forty very low-level equivalent uranium determinations by alpha particle detection were run on plants, plant ashes, soils, and rocks. The methods for the radiochemical analysis of Th^{230}, Pa^{231}, Ra^{226}, and Ra^{223} were improved and the results of these analyses, on several radioactive samples of low uranium content, show that disequilibrium is often very complex.

Methods for the radiochemical analysis of Th^{232}, Pa^{231}, Ra^{226} and Ra^{223} were improved. Two automatic sample-changing scintillation counters have been set up for the alpha-particle detection used in the measurement for these analyses. The method for the analysis of small amounts of Th^{232} was extended and as little as one microgram can be detected. A new value for the half-life of Th^{232} was determined, and this work is essentially completed.

Several complete disequilibrium studies were performed on natural occurring radioactive samples. The comparison of the contents of elemental uranium, Pa^{231}, Th^{230}, and Ra^{226}, show that the pattern of disequilibrium is usually very complex with considerable variation in these components. The studies also show that the parent source of the radioactivity is almost always Th^{230} (ionium) when uranium is absent or deficient. The variation of Th^{230} and Pa^{231} from the normal abundance ratio was commonly much more than was previously expected. The exceptions to this general pattern of disequilibrium are the relatively rare occurrences of recent barium sulfate, particularly in artifical filter sands, and natural hot springs deposits containing only radium isotopes and their daughter products, and Th^{232} ores. The latter occur very rarely outside of their previously known geographic and geologic environments.

Spectrography

Spectrographic methods, Washington

by

C. L. Waring

During the past six months 75 different types of minerals, rocks, and ores were received for spectrographic analysis in the Washington laboratory. Semiquantitative, small grain, and quantitative spectrographic techniques were applied. The samples were of different degrees of purity ranging from complex field-collected aggregates to pure separate minerals. Much time was spent in developing or improving methods for analyzing samples over this wide range. By using this approach a minimum amount of repeat work was necessary in cases where the sample was abnormal and where very little information was available, or where the sample was a suspected new mineral.

The search for a satisfactory basic mix material continued. Spectrographically pure lithium carbonate was purchased and preliminary tests were conducted to determine its suitability as a basic mixture.

The preliminary tests indicated a slight loss of sensitivity for some elements and improvements in sensitivities may be expected when the optimum spectrographic conditions are achieved. The basic mix would be added to both standards and samples and would tend to reduce the matrix effects.

Experiments were conducted on the use of inert gases enveloping the electrodes during the arcing of certain samples. The cyanogen bands were minimized or eliminated thereby making additional spectral lines available for study. The jets were designed and constructed to flush the arcing area with the inert gas without the necessity of placing the electrodes in a special container. Satisfactory preliminary tests were conducted with helium, carbon dioxide, and different mixtures of oxygen. This study will be continued as time becomes available.

The preparation of spectrographic standards for the determination of lead in monazite was completed. Cerous phosphate was prepared from the ammonium salt; this material contained 10 to 15 parts per million lead. If the accuracy of the spectrographic method warrants, the cerous phosphate will be treated to further lower the lead content. Other rare earths for the standards were of commercial grade and were of satisfactory spectrographic purity. The lead content of a few monazite samples was determined by the lead in zircon standards with sodium carbonate dilution. This was done to determine if there is any real difference in the lead results as found for either set of standards.

Design and construction work of a constant current power source for spectrographic analysis was initiated. The power source would produce the same current regardless of the variety of materials placed in the electrodes. It is expected that reproducibility would be improved and matrix effects minimized with such a power source.

One thousand samples were analyzed for a total of 68,000 qualitative, semiquantitative, and quantitative determinations.

The automatic scanning method was applied to additional types of materials. Of note were two samples of coalified wood from South Dakota. These samples contained 0.1 and 1.0 percent germanium and may be of economic interest. The report on this method has been sent to Spectrochimica Acta for possible publication.

Additional work was completed to provide data for a paper on hafnium content and radioactivity of zircon from igneous rocks. This paper will describe a rapid method for determining the hafnium-zirconium ratio and the hafnium content in zircon.

Spectrographic methods, Denver

by

A. T. Myers

During the six months period, a total of 98,392 determinations were made on 1,716 samples, submitted for analyses from projects of the Raw Materials program of the AEC, and related USGS projects.

The semiquantitative spectrographic method continues to be used for studies on the distribution of elements and types of studies where the results are reported to one-third of an order of decimal magnitude. The demand for this type of analyses on rock and ore samples continues to increase.

"Spectrographic determination of contamination of rock samples after grinding with alumina ceramic", by P. R. Barnett, W. P. Huleatt, L. F. Rader, and A. T. Myers, was published in the American Journal of Science, vol. 253, pp. 121-124, Feb. (1955).

Infrared spectroscopy
by
R. G. Milkey

During this report period, additional investigations were made in methods of analysis to broaden the scope of the infrared spectrophotometer: (1) the infrared polarizer, which provides polarized light for the analysis of crystal structures, was assembled and tested, (2) the attachment for specular reflectance data was assembled and tested for satisfactory performance, (3) the method of constructing liquid sampling cells was, for some samples, considerably simplified, (4) the reproducibility of quantitative analyses of solid samples was investigated; the potassium bromide imbedding window method that has been devised provides a precision for triplicate samples of less than ± 2 percent transmission units.

The library of infrared data was augmented by the addition of standard spectra, abstracts of current literature, and reprints of published articles. The data were partly codified on keysort punch cards for convenient reference.

Different types of analyses were made in support of the objectives of other projects, and new information was added for improved infrared spectroscopy. Some typical developments were: (1) spectra were obtained of many organic materials, such as asphaltite, impsonite, grahamite, boghead, pellets, distillates of sub-bituminous coal and other organo-uranium extracts, as part of the continuing investigation of the substances found in association with uranium. The unit structures present, such as hydroxyl, saturated carbon-hydrogen bonds, carbonyl, and unsaturated ring structures, were identified. Comparisons between the different spectra (particularly the pellets and the asphaltite) showed the type of significant over-all differences that will help solve the question of their origin; (2) infrared spectra were used to provide control for an industrial liquid - liquid extraction process. The analysis of samples withdrawn at different stages of the process revealed the relative concentration, purity, and rate of extraction of the solute, and indicated some of the chemical bonding that could be present in the unknown structure of the solute; (3) analyses were made of channel samples of vanadium-bearing ores, to provide information on the state of oxidation of the vanadium present; (4) analysis was made of 31 synthetic vanadate compounds and vanadium minerals, and correlations are being made between the vanadate structures and the corresponding infrared absorption peaks; (5) investigations were made into the quantitative analyses of silicates. The spectra revealed that as little as 10 micrograms of the tectosilicates can be detected, using present methods of sampling. This research will be extended to include all classes of silicates, and the absorption peaks of the spectra will also be correlated on the basis of tetrahedral linkage and varying cationic substitutions in the silicates.

Chemistry

Analysis of raw materials, Washington

by

Irving May

The trend previously noted toward greater diversification in analytical requests continued in the Washington laboratory. The accompanying table 28 summarizes the analytical activity of the project

Table 28. Breakdown of Completed Determinations

December 1, 1954 - May 31, 1955

Determination	Completed the past six months
U	3,860
Th	65
Ca	119
Al	156
Fe	272
V	153
Na	84
K	109
Rare earths	61
C	69
H	32
P	158
S	10
Se	49
As	18
Ash	339
Organic matter	452
Oil	125
Miscellaneous	384
Total	6,515

for the past six months. Despite the diversification of requests, there was a decrease of less than 10 percent in the determinations completed to the previous report period.

A flux-melting machine, designed in the USGS Denver Laboratory, was modified to permit its use with Washington gas. Preliminary testing of the machine was completed and it is now in routine use for melting uranium-alkali carbonate phosphors.

A new flame photometer unit was installed and tested for its performance in determining sodium and potassium. The new unit is simpler to operate and performs much better than older ones.

The conditions for determining small amounts of arsenic by the molybdenum blue method were studied for application of the method to rock samples. Several modifications in the conditions had to be made in order to obtain satisfactory results.

The solubility of kaolinite in dilute hydrochloric acid was studied in connection with the determination of aluminum associated with phosphate minerals in leached zone samples.

A Peruvian Government chemist was given three month's training in chemical methods for determining uranium in rocks.

A paper, "Isolation of Organic Carbon from Bones for C^{14} Dating", by Irving May, was published in Science <u>121</u>, 511 (1955).

Analysis of raw materials, Denver

by

L. F. Rader, Jr. and Wayne Mountjoy

In the Denver Laboratory, 11,666 determinations were made on 8,334 samples, chiefly drill cores or rocks except for 900 water samples. About 20 different elements are commonly determined as requested and the variety of determinations demanded is continuously increasing. However, for the period covered in this report 72 percent of the determinations made were for U, V_2O_5, and $CaCO_3$ in connection with various exploration programs in the Plateaus and adjacent areas. As such samples have high priority the backlog of work consists chiefly of requests for heavy metals, iron, selenium, arsenic, antimony or others that may show correlation with uranium and/or be of commercial importance.

Standard deviations have been calculated from replicate determinations to establish the precision of recent analyses by the following methods:

Sample type	Method	Range	No. of Samples	Standard Deviation
U in rocks	Extraction - fluorimetric	0.020 - 0.20%	110	0.0025%
U in plants	Extraction - fluorimetric	0.5 to 5 ppm	333	0.4 ppm
U in ores	Volumetric	0.28 to 0.51%	60	0.011%
V_2O_5 in cores	Volumetric	0.24 to 3.21%	60	0.014%
$CaCO_3$ in ores	Flame Photometer	3.54%	20	0.15%

The special analyses group investigated methods of analysis for Ti, Mo, Zr, Sb, and Cu in connection with requests for analysis for these elements in the presence of interfering elements that precluded the use of a conventional method without modification.

Titanium was determined in 54 samples containing up to 25 percent TiO_2, 30 to 50 percent Fe_2O_3, rare earths, and niobium, by a modification of the colorimetric method of measuring the color of the titanium-peroxide complex after adequate separation of interfering ions.

Molybdenum was determined on 11 samples as the thiocyanate complex after extraction into isopropyl ether following a double precipitation of the H_2S group in the presence of antimony chloride as a carrier. An iodine-iodide carrier proved less efficient than antimony chloride.

Zirconium was determined when present in weighable quantities by the mandelic acid method. Good recovery is achieved by making precipitations from weakly acid solutions. Trace amounts of Zr in the 54 samples mentioned under work on Ti could not be determined with mandelic acid and this study is being continued.

Arsenic: A method for the determination of arsenic similar to the method used in other USGS laboratories has been investigated for use on several hundred samples on hand. This method is essentially a distillation following decomposition of the sample. Color due to arsenic is developed with molybdenum and estimated photometrically.

Antimony is to be determined on several hundred samples by a modification of the rhodamine-B colorimetric method that is now under investigation.

Copper was determined on 600 samples colorimetrically by extraction of the neocuproine complex into N-hexylalcohol. This method was checked against the electrolytic method and is used extensively to determine copper in the range 1 to 1,000 ppm for uranium ores containing copper but little or no vanadium. The ores containing more than 0.1 percent copper are analyzed by the electrolytic method.

Uranium: Cooperative work on the leaching of uranium from Red Desert, Wyoming, schroeckingerite-bearing rock with natural waters and adsorption of the uranium from the leachate on low rank coals from the same general area is continuing.

A motor driven device to control the heating of the carbonate-fluoride flux during preparation of uranium-flux pads in the determination of uranium by the fluorimetric method was designed and built. This machine tends to produce more uranium-flux pads than hand heating, results in greater precision with the method, and speeds up the routine work by preparing 18 pads at one time. Two similar machines were added to facilities in the Washington laboratory.

Research on analytical methods

Determination of lead in monazite, by R. A. Powell and M. P. Pechini

Work continued on the development of a chemical method for determination of lead in monazites. Because of previous erratic results obtained by the direct dithizone extraction method, it was thought that rare-earth precipitation, which occurs at the same pH as lead extraction by dithizone, effectively tied up the lead, and rendered its subsequent extraction incomplete. Recent experiments have shown that this difficulty can usually be avoided and that the variations in earlier analyses were caused, in part, by the presence of sodium peroxide which was used in the attack on monazite samples.

In the first attempt to separate the lead, strontium sulfate was used as a carrier prior to extraction by dithizone. The initial approach was to use sodium borate-sodium carbonate fusion in platinum with solution of the melt in dilute nitric acid. The use of sodium peroxide flux was abandoned because although at times it gave fair precision, it was not consistant enough for the intended applications. Results of later work suggest that the difficulty with this method was caused either by incomplete solution or by contamination from the platinumware.

The next method tried involved a separation with thorium iodate used as a carrier. However, it was found that the iodate formed such a strong complex with the lead that it could not be extracted.

Barium chromate as a carrier looked very promising because it yielded complete recovery with standard lead solutions. It was found unadaptable to monazites, however, because of precipitation of rare earths which occurs at the same pH necessary for the precipitation of barium and lead chromate.

Tests showed that by increasing the amount of the complexing agents (sodium citrate and potassium cyanide) excellent recoveries of lead could be made from synthetic monazite solutions. When this modification was used with monazite samples that had been fused with borate-carbonate flux in platinum crucibles, the analytical results again were not reproducible. These tests led to the conclusion that errors were being introduced in the fusion step or contamination was coming from the platinum crucibles.

As a consequence of the above experiment, a different method was used for putting the samples into solution which completely eliminates the fusion and the use of platinumware. This method consists of an initial digestion of the sample in hot H_2SO_4 and later addition of dilute HNO_3, followed by dithizone extraction and spectrophotometric measurement.

This method was applied to 8 monazite samples, ranging in lead content from 0.04 to 0.40 percent, with a reproducibility of ± 1 percent. Two samples were spiked with 5 mg of lead each and recoveries of 99.3 percent were obtained on the spikes.

The difficulty, caused by precipitation of rare earths at the pH used for lead extraction, can now be avoided. It is related to both the sample size and the time of standing before extraction. Up to 25 mg samples extracted immediately after the complexing agents were added and the pH adjusted to approximately 9.2 gave complete recovery, while samples weighing from 30-50 mg under the same conditions were 10-45 percent low. Up to 20 mg samples extracted 10 minutes after pH adjustment gave complete recovery, but larger samples gave very low recoveries. Up to 10 mg samples were found to yield complete recoveries when extracted 1 hour after pH adjustment. Larger samples gave low recoveries. A few subsequent experiments have shown the possibility of using up to 50 mg samples by increased dilution of the sample.

Lead iodides with, and without, added spikes of lead of known isotopic composition have been prepared from several monazite samples and submitted for lead determination by the mass spectrographic isotope-dilution method as independent checks on the chemical method. The two analyses which were completed by the isotope-dilution method check with the chemical analyses very well.

Determination of uranium by the spectrophotometric method, by H. I. Feinstein

Experimental work on the thiocyanate method for the determination of uranium was completed.

While studying the interferences in the uranium thiocyanate system, it was observed that under approximately similar conditions, vanadium gave a blue color. The absorption of the vanadium thiocyanate blue in acetone-water is greater than that of the blue vanadyl ion and experiments were performed to test its applicability to the determination of vanadium. While thiocyanate is not as sensitive a reagent for vanadium as peroxide, it is about 4-5 times as sensitive as the blue vanadyl system. This has resulted in the development of a method based on the vanadium thiocyanate color that can be used in place of the volumetric procedure.

In the search for a reagent that does not have the disadvantages of thiocyanate, it was discovered that azide ion gives a yellow color with uranium and has certain desirable properties. The reagent solution is more stable, gives a more sensitive reaction and the color produced is more stable than that from thiocyanate. Accordingly, a method was developed for the determination of uranium with azide.

Preparation and purification of a salt of potassium isolated from granite samples, by C. A. Kinser

In connection with a study of the fractionation of the isotopes of potassium during the weathering of granite, KCl was prepared from the potassium contained in samples of weathered and fresh New Hampshire granite.

The separation and purification was effected by a procedure stated briefly as follows: The samples were attacked with perchloric and hydrofluoric acids and the soluble perchlorates removed by washing with alcohol. The insoluble perchlorates (mostly $KClO_4$) were ignited to chlorides. These chlorides were dissolved in water, filtered and the potassium precipitated as potassium tetraphenyl boron. This precipitate was dissolved from the filter with acetone, evaporated to dryness and ignited to the meta borate. Boron was removed by methanol and HCl leaving practically pure KCl. Further purification was accomplished by precipitating the KCl from an almost saturated solution by treatment with dry HCl gas. The KCl so obtained was washed with concentrated HCl and dried.

Spectrographic analysis of this material indicates that except for a small amount of rubidium, which will not interfere in the method to be used, the KCl samples prepared are more than 99.98 percent pure.

Analytical chemistry of thorium, by M. H. Fletcher and F. S. Grimaldi

Athe the present time thoron /2-(2-hydroxy-3,6-disulfo-1-naphthylazo)-benzenearsonic acid/ is popularly used as a reagent for the colorimetric determination of thorium. An undesirable feature that limits the use of this method is the high sensitivity of the reagent towards zirconium. For example, at the 150 γ level of ThO_2, about 0.6 γ ZrO_2 is equivalent to 1 γ ThO_2. Several organic hydroxyl acids have been studied as possible masking reagents for zirconium. It was found that tartaric acid would be a useful sequestering reagent. The thoron-thorium-tartaric acid system has been studied in detail and has proved very complex. At least 5 equilibria are involved - the thorium-thoron, thorium-tartrate, zirconium-thoron, zirconium-tartrate, and thoron-tartrate. The last equilibrium is included because thoron and tartaric acid were found to react. Optimum work conditions were established for the determination of thorium which would permit the presence of a maximal amount of zirconium (at least 350 γ ZrO_2) for the complete range of thorium concentrations usually determined with thoron. The maximum amount of other ions that can be tolerated was also determined. These ions include all of the rare earths, Sc, Y, La, Ti, Nb, Ta, Sn, W, Bi, Fe, Al, Pb, Hg, Au, U, $SO_4^{=}$, $PO_4^{\equiv}$, and F.

A direct colorimetric procedure involving no separations was found applicable for the determination of thorium in monazite concentrates.

A few facts about the tartaric acid-thoron system still require explanation and much data was collected to clarify the situation.

GEOCHEMICAL AND PETROLOGICAL RESEARCH ON BASIC PRINCIPLES

Radon and helium studies

by

A. P. Pierce

Studies on the distribution of "asphaltite" in the West Panhandle Field, Texas indicate that the helium present in one of the smaller gas reservoirs within this field can be entirely accounted for by decay of uranium present in the asphaltite of the gas-producing rocks.

Uraninite was identified in asphaltite nodules from dolomites and siltstones of Permian age in the Panhandle field. Thorite was identified in asphaltite nodules in a core from granite wash of Pennsylvanian age from Beckham County, Oklahoma. Thorium in the amount of 3.4 percent and 0.11 percent uranium was present in the nodules, making them the first true occurrence of thucolite in the United States.

Complete organic analyses were obtained upon a suite of uraniferous asphaltites from the Wichita-Amarillo Uplift, the northwest flank of the Delaware Basin, and from the Colorado Plateau. The atomic ratio of carbon to hydrogen in seven uraniferous asphaltites ranged from 1.1 to 1.3 and a ratio of 1.8 was obtained upon an eighth sample. Uraniferous "asphaltite" from marine dolomites of the Permian Seven Rivers formation had an atomic C/H ratio of 1.1 and was in gradational contact with non-uraniferous "asphaltite" having a C/H ratio of 0.7. The difference in the ratios suggests that hydrogen may have been lost from the uraniferous sample due to the effects of radiation. This process, if it occurs, would also explain the presence of submicrocrystalline carbon observed in X-ray diffraction patterns of the uraniferous asphaltite.

The oxygen content of the asphaltites ranged from 1 to 20 percent, and the sulfhur content from zero to 23 percent. A trace of nitrogen was present in two samples. Mass spectrometric analyses of the volatile gases from the asphaltites showed the presence of methane, ethane, normal butane, iso-pentane, cyclo-pentane, hydrogen, hydrogen sulphide, carbon disulphide, carbonyl sulphide, and methyl and ethyl mercaptans. Helium was not detected, and calculations based upon the uranium content of the asphaltites indicate the materials have a low helium retentivity.

A technique for making thermoluminescence photos of rock sections was developed. Thermoluminescence photographs were obtained for asphaltite-bearing dolomites of Permian age from the Panhandle Field, Texas and from the northeast flank of the Delaware Basin, New Mexico. The photos show intense "haloes" of about 500 microns thickness in the dolomite surrounding the asphaltite nodules. The haloes are believed to result from diffusion, decay and recoil of radon and its daughter products, and indicate that radon, as well as helium, escapes readily from the asphaltite nodules.

A study has been made of extensive data from the U. S. Bureau of Mines on the composition of natural gases of the United States. The results show that in natural gas fields the proportions of helium, argon and nitrogen vary within limits, and their concentrations increase with geologic age, as illustrated in figure 41. In general, the relative proportions of helium, argon and nitrogen are the same in gases rich in helium, as in gases poor in helium.

No correlation was found between the helium content and the carbon dioxide, hydrogen sulfide, methane or ethane contents of natural gas fields, indicating that the major part of these gases has accumulated independently, and probably earlier than the major part of the helium occurring with them.

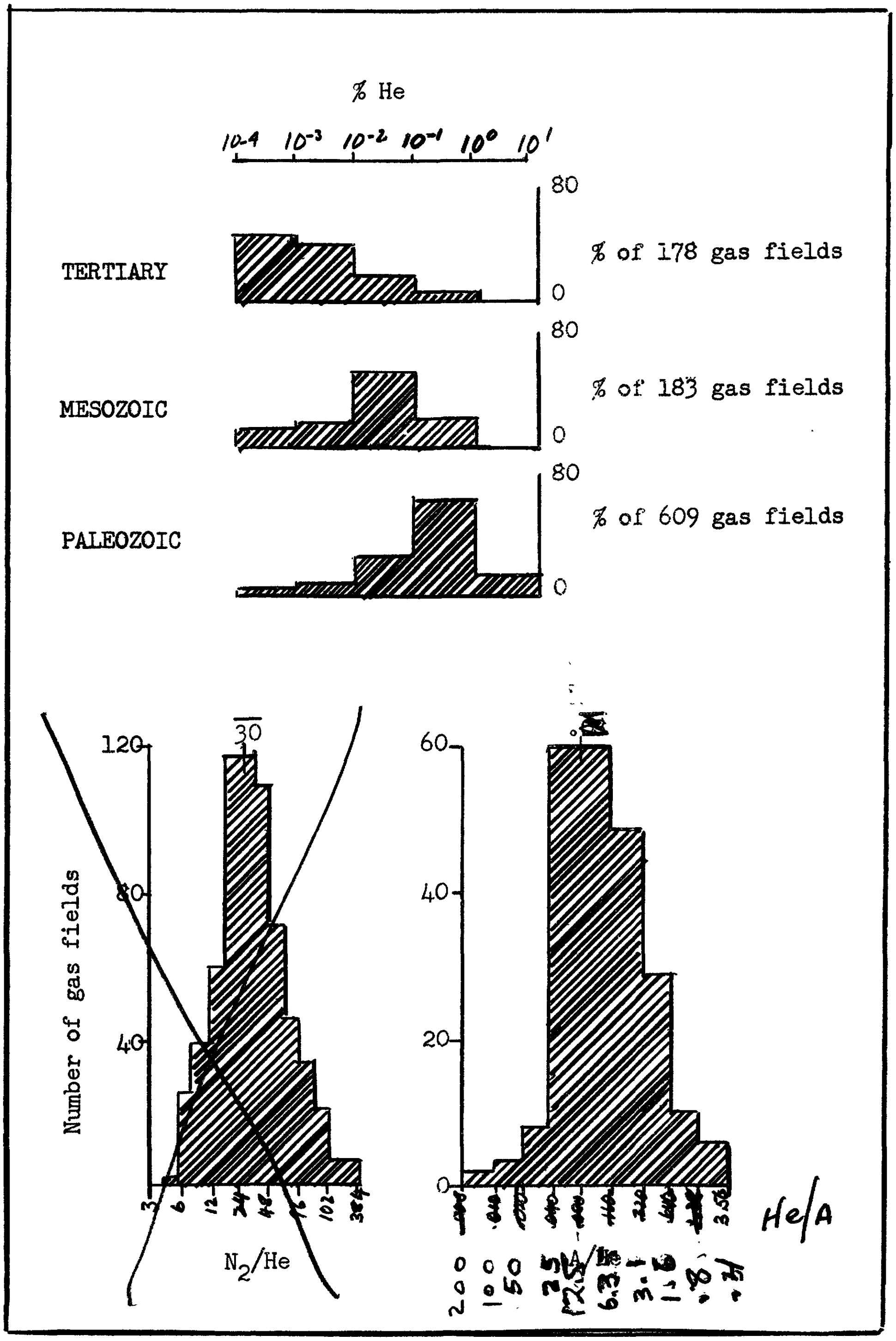

Figure 41. Histograms showing relations of ~~nitrogen~~, argon and geologic age to helium in natural gas fields of the U. S.

The present evidence indicates that the principal different sources for the helium, argon, and nitrogen are: radioactive decay of uranium, thorium (helium source), and potassium-40 (argon source); degradation of nitrogenous compounds in rocks (nitrogen source), possibly as a result of associated radioactivity; and occluded atmospheric air within rocks (nitrogen and argon source). It is believed that isotopic analyses of the argon and nitrogen in these gases will give a measure of the relative importance of these sources. The mean ratio of argon to helium in the gases is about 0.08 (see fig. 41), which is close to the calculated ratio of A^{40} to He^{40} resulting from decay of the amounts of uranium, thorium and potassium-40 in rocks having the composition of the earth's crust.

Distribution of uranium in igneous complexes

by

George Phair

Analytical methods

During the six-month period covered by this report substantial progress was made toward solution of probably the most vexing analytical problem facing the project — how to get adequate thorium data on igneous rocks in the range 1-20 ppm. The gamma ray spectrometer has been adapted successfully for U, Th, and K determinations on igneous rocks, but a few details remain to be ironed out. The lack of adequate Th standards in this very low range delayed final calibration; carefully analyzed rock pulps are not available in the quantity required (200 grams). Present standards are based upon monazite "spikes" and hence may suffer from non-uniform mixing. Nevertheless, the results reported to date show a large gain in precision over previous chemical methods and when cross checks by radiometric methods are possible the results appear to be in good agreement. The method can also be used for uranium determinations. A comparison of uranium results by fluorimetric and gamma ray spectrometer methods is given in table 29. The Front Range samples were specially

Table 29. Comparison of uranium determinations on igneous rocks by fluorimetric and gamma-ray spectrometer methods

<u>Precambrian granitic rocks from the Front Range</u>

		By Fluorimeter					By X-ray	
Sample		run 1	run 2	run 3	run 4	Av(A)	Spec(B)	A-B
GP-44	qtz. monzonite	2.6	2.6			2.6	2.4	+0.2
GP-130	qtz. diorite	1.1	1.2			1.15	1.5	-0.35
54G-78	granite	3.0	2.9			2.95	3.5	-0.40
GP-39	qtz. monzonite	2.0	2.1			2.05	2.5	-0.45
GP-34	granite	2.6	2.6			2.6	3.5	-0.90
GP-100	granite	5.1	5.5	4.8	4.7	5.0	7.9	-2.9
GP-129	mafic qtz. diorite	1.4	1.4			1.4	1.8	-0.4
GP-108	qtz. diorite	1.6	1.7			1.65	2.6	-0.95
GP-1	mafic qtz. monz.	1.8	2.0	2.1		1.96	2.2	-0.24

<u>Granitic rocks from the Southern California batholith</u>

		Fluorimeter	X-ray Spectrometer			
		A	run 1	run 2	Av(B)	A-B
G-11	qtz. diorite	3.05	3.4	2.8	3.1	-0.05
G-10	qtz. diorite	1.60	2.4	2.4	2.4	-0.80
S-1	qtz. diorite	2.2	3.5	3.3	3.4	-1.2
Valverdi	qtz. diorite	2.0	1.8		1.8	+0.2
G-13	qtz. diorite	2.5	3.0	2.7	2.85	-0.35
S-16	granodiroite	1.8	3.5	1.8	2.65	-0.85
Z-17	granodiorite	5.9	7.0	6.1	6.55	-0.65
S-13	granodiorite	2.9	3.2	3.2	3.2	-0.30
167	granite	3.0	4.2	4.2	4.2	-1.2
Z-15	granite	5.2	6.1	5.5	5.8	-0.6

ground, mixed, and split and the resulting sample homogeneity is indicated by the fluorimetric results on the separate sub-samples. In 8 out of 9 instances the agreement is better than ± 0.1 ppm. The spectrometer results are closely comparable but consistently run slightly higher. The rocks from the Southern California batholith showed a similar systematic difference between the two methods. In all, 17 out of 19 results by gamma ray spectrometer were higher than the fluorimetric analyses but in only three cases was the difference as large as 1 ppm. This consistent difference probably reflects uncertainty in the original calibration of the spectrometer.

On the basis of these promising preliminary results the main components of a 2-channel spectrometer were ordered and it is hoped that it can be put into operation during the next six months.

Data were obtained on the precision and accuracy of present methods of thorium analyses exclusive of gamma ray spectrometry as applied to igneous rocks in the enriched range (Th = .01 to .05%). Six samples of Front Range porphyries were specially ground, mixed, and split, and separate sub-samples were distributed among the various groups in the Survey concerned with making thorium analyses. The results are given in table 30.

In general the calculated thorium contents, some determined by X-ray fluorescence and some determined by radiochemical methods, gave surprisingly good agreement. Those determined by the two chemical wet methods gave nearly identical results which, however, were low by a factor of 50 percent or more compared to the lowest values obtained by the three other methods. One of these samples, P-118, previously analyzed chemically by the nephelometric method, was found to contain four times as much thorium as was reported by later nephelometric work. The one sample, P-17, that contained enough Th to permit gravimetric determination (1951) gave results which were in excellent agreement with the Th as calculated by the relation Th = 3.6(eU-U), as determined by X-ray fluorescences, and as measured radiochemically. The final precipitate from this gravimetric determination was analyzed spectrographically and found to contain less than 2 percent of

Table 30. Precision and accuracy of present methods of thorium analysis

					Thorium analyses							
					Calc. Th.		Measured thorium					
	U Wash.	U Denver	eU Wash.	eU Denver	Wash. 3.6(eU-U)	Denver 5.0(eU-U)	X-ray Fluor.	Radio-chem.	Color-metric	Nephel-ometric	Nephel-ometric	gravimetr 1951
P-17		.0049	.018	.018	.047	.065	.049	.046				.049*
P-108		.00698	.016	.012	.032	.025	.046	.031			.025	
P-118		.0030	.007	.007	.014	.020	.017	.014	$.004_4$	$.004_4$	$.026_4$ $.021_5$	
P-465	.01230	.01386		(.019) .018		.020	.033	.028	$.015_8$	$.016_7$		
P-559	.00404	.00424		(.008) (.005) .006		.009	.010	.006	$.003_5$	$.003_5$		
P-581	.00413	.00468		(.012)		.036	.035	.027	$.015_8$	$.011_4$		

*ppt. analyzed spectrographically and found to be 98 percent pure.

impurities. Because this gravimetric determination confirmed the agreement shown by the three independent methods greater significance may be attached to the results by those methods. It remains to be determined why the 20 nephelometric analyses obtained prior to 1954 gave reasonably good agreement with the calculated thorium and why those obtained later agree with the colorimetric determinations in indicating Th contents more than 50 percent lower than the calculated values. This discrepancy will be investigated. Not enough original material remains to permit a Th determination by the gamma ray spectrometer but samples will be sent to the Bureau of Mines for determination of the Th/U ratio by another X-ray fluroescence method.

Precambrian granite rocks of the Colorado Front Range

Heavy mineral separations were made on 16, 10-40 pound samples from nearly all the major Precambrian Front Range batholiths and from some of the smaller bodies. The Boulder Creek batholith was studied in more detail than the others and results on some six samples are now available. On most samples separate mineralogical studies were made on the 40-100, 100-200, and 200-325 mesh fractions. The data are reported in table 31.

On the basis of the separations made thus far, monazite occurs exclusively in the youngest batholiths, the so called "Silver Plume" correlatives. In three such samples the monazite is accompanied by xenotime. Allanite is common in the oldest batholith, the Boulder Creek body and is of scattered occurrence in the "Silver Plume" correlatives. It is lacking in the Sherman and Pikes Peak batholithic rocks so far studied. Locally, allanite crystals up to 2 inches long are common in the various phases of the Boulder Creek body.

Table 31. Accessory mineral data on Front Range batholiths

Batholiths:	Boulder Creek Batholith							Sherman			Pikes Peak	
		qtz.	grano-	qtz.				Type-granites				
Minerals	dike	dio.	dio.	monz.	granite		peg.	II	III	peg.	Granites	
Sample No.	100	129	17	19	34	69	104	88	92		101	100
Magnetite	x	x	x	x	x	x		x	x		x	
Ilmenite	x	x	x	x	x	x		x	x		x	
Garnet												
Muscovite						x						
Epidote	x		x	x	x	x						
Allanite	x		x	x	x					x		
Xenotime												
Monazite												
Sphene			x	x	x	x		x	x			
Apatite		x	x	x	x	x		x	x		x	
Fluorite									x			
Zircon	x	x	x	x	x	x		x	x		x	x
Pyrite												
Molybdenite												
Euxenite							x					

Minerals	Kenosha	Silver Plume		Indian Creek		Log Cabin		Longs Park
Sample No.	644	78	82	96	97	472	93	G-76
Magnetite.	x	x	x	x	x	x	x	x
Ilmenite	x	x	x	x	x	x	x	x
Garnet	x							
Muscovite								
Epidote				x	x	x	x	
Allanite	x	x	x	x	x	x	x	
Xenotime	x			x	x			
Monazite	x	x	x	x	x			x
Sphene				x		x		
Apatite	x	x	x	x	x	x	x	x
Fluorite								
Zircon	x	x	x	x	x	x	x	x
Pyrite		x	x	x				
Molybdenite							x	
Euxenite								

Distribution of uranium in the Conway granite, New Hampshire

In tables 32 and 33 are listed results of recent uranium analyses on some of the main rock types of the White Mountain igneous series, and on the minerals from the Conway granite member of this series. A recent development

Table 32. Uranium in the rocks of the White Mountain magma series

Order of intrusion	Square miles	Percent of magma series	No. of samples	No. of determinations	Range U ppm	Average U ppm
Youngest						
Biotite Granite	315.5	68.9	17	42	4.3-19.5	11.7
Amphibole Granite			23	46	2.3-23.0	8.8
Granite Porphyry	43.3	9.41	2	5	6.4-9.4	8.1
Quartz Syenite	47.4	10.25	3	7	4.5-7.2	5.9
Syenite	43.1	9.41	8	15	1.2-20.0	5.7
Nepheline Syenite						
Monzonites Quartz monzonite	6.0	1.0	2	4	1.8-7.6	4.7
Diorites	1.7	.4				
Norites Gabbros						
Oldest						
Total	457.0	99.37	55	119	1.2-23.0	9.1
					Average of 119 determinations	

Table 33. Uranium content, in parts per million, of redstone-type Conway granite, New Hampshire

	Biotite Granite		Amphibole Granite	
Mineral	Range, ppm	Average, ppm	Range, ppm	Average, ppm
Feldspar	2.0-5.3	3.1	1.3-2.2	1.8
Quartz		2.3		5.0
Magnetite	.82-32.0	15.8	1.0-25.7	9.6
Amphibole	16.-43.	29.0	1.0-48.8	20.4
Fluorite		14.0		63.0
Biotite	37.-39.	38.0		19.7
Ilmenite	47.-50.	48.5		9.8
Zircon	252.-1750.	1202.0	755.-2350.	1249.0
Allanite	540.-656.	617.0		785.0
Astrophyllite				15.0
Rock	9.0-18.2	11.8	7.2-11.6	8.7

of particular interest is the discovery of native iron in the green phases of the Conway granite -- the second reported occurrence of native iron in a felsic igneous rock. The separated iron contained up to 500 ppm uranium. Special care was taken to avoid contamination by tramp iron; iron was found in samples ground entirely on a ceramic bucking board.

Uranium and thorium contents of accessory allanites from igneous rocks

Petrographic, chemical, X-ray, and spectrographic studies of accessory allanites from igneous rocks exclusive of pegmatites are nearing completion. The indices of refraction are generally found to be higher than those described in the literature but the mean index varies with degree of metamictization. The ThO_2 content appears to be rather constant ranging from 0.06 to 0.6 percent in 10 samples; in 9 out of the 10, ThO_2 is below 0.2 percent. The uranium content is more variable and seems to have a greater effect on the index of refraction by causing greater radiation damage. Allanite was found to be present in 31 out of 81 rocks studied and to be present only in acid and intermediate types.

Distribution of radioactivity in alkalic rocks of Sussex County, N. J.

The main conclusions drawn from studies of the alkalic rocks in Sussex County, New Jersey are: (1) the relatively high uranium contents (19-44 ppm) of these rocks show no relationship to the amounts of zircon or sphene, constituents in which the rocks appear to be abnormally enriched; and (2) in both the stock rocks and dike rocks uranium increases with SiO_2.

Weathering, transportation and redeposition of uranium

by

R. M. Garrels

Chemical work was completed on channel samples from several mines in addition to that from the Mineral Joe mine, Jo Dandy mining area, discussed in the preceding semiannual report. All work, so far, is consistent with the conclusion of the preceding report that, "apparently oxidation ... occurred through the agency of moist air". All channels in ore show major additions of iron, uranium, and vanadium. Minor element anomalies are not so consistent, but chief added elements are strontium, barium, molybdenum, and selenium. It is now clear that oxidation reactions, except very near the surface, take place in situ. The major problem yet to be solved is the extent to which uranium and vanadium migrate as a result of the vertical and lateral movement of capillary water, and the extent to which they are removed from the outcrop by direct action of rain.

Studies on the rate of solution of the vanadiferous silicates show that it is possible to determine the number and composition of the phases present. Characterization of the species is accomplished from information on (a) rate-time curves, (b) chemical analyses of resultant solutions, and (c) X-ray spectrometer analysis of the residues at various stages. At least three kinds of vanadium silicates are present; true vanadium micas, vanadium chlorites, and vanadium hydrous micas. The roscoelites apparently are but slightly affected by weathering, whereas the vanadium chlorites and vanadium hydrous micas are susceptible to increase in valence of their contained iron and vanadium. Chlorites and hydrous micas so far analyzed contain V^4 and various proportions of Fe^2 and Fe^3. It now appears that many ores are accompanied by a mild alteration of quartz, feldspar, and sedimentary clay minerals to kaolin and to the vanadium silicates.

Experimental work was devoted largely to determination of the reducing capacity of wood in various stages of degradation and coalification. Fresh spruce, in water solution at 150° C for three days, shows a reducing capacity about 1,000 milliequivalents per 100 grams; lignite shows a small (600 milliequivalents) but still substantial capacity. Experiments will be continued on reducing capacity as a function of pH and nature of the wood. Checks have been obtained on most of the boundaries of the summary diagram for vanadium. It was found that the V^3 and V^4 hydroxides precipitate metastably. The calculated difference in free energy between hydroxides and the oxides corresponds well to expected values. Major current emphasis is on the unraveling of the mixed V^{4-5} oxides and metal V^{4-5} oxides.

Work will continue chiefly on (1) preparation of uranium and vanadium compounds under controlled oxidation conditions with emphasis on the nature of the various solids, (2) further studies of the reducing capacity of woody materials, and (3) further studies of the vanadium clay minerals with emphasis on the interpretation of the environment of ore deposition.

During the report period a paper was delivered at the A.A.P.G. meeting in New York entitled, "Chemical equilibria under restricted marine conditions".

Mineral synthesis

by
George Jansen

The study of the solubility of carnotite was continued. However, re-examination of previous data was necessary because of confirmation of the idea that many of the solutions were colloidal.

Work was started on the system $CaO \cdot UO_3 \cdot V_2O_5 \cdot H_2O$ of which tyuyamunite $[Ca(UO_2)_2 \cdot (VO_4)_2 \cdot 5\text{-}10H_2O]$ is one of the better known natural representatives. Cursory examination of the system showed that in only one instance tyuyamunite formed when it was expected; in all other cases, rauvite was formed instead of tyuyamunite. However, many crystalline uranium and vanadium compounds attain equilibrium with their solutions only slowly; it is thought that rauvite is an intermediate phase not in equilibrium with its environment. The stable phase is probably tyuyamunite.

Copper, aluminum, and iron vanadates were prepared by direct precipitation from acid solutions. The copper vanadate volborthite, $Cu_3V_2O_8 \cdot 3H_2O$, was identified by X-ray powder diffraction pattern. No X-ray patterns could be obtained from the aluminum or iron vanadates but chemical analyses suggested the empirical formulas $Al_2V_2O_8 \cdot 8H_2O$ and $Fe_2V_2O_8 \cdot 5H_2O$. Calcium ions were added to volborthite solutions to see if calcium would substitute for copper, producing calciovolborthite. Spectrographic analysis of the precipitates showed less than 0.1 percent calcium, insufficient for calciovolborthite.

Sodium-hewettite, $Na_2V_2O_{16} \cdot 3H_2O$ was synthesized by direct precipitation from acid solutions and by substitution, sodium exchanging with the calcium in hewettite, $CaV_6O_{16} \cdot 9H_2O$.

The growing of the highly insoluble vanadates steigerite, fervanite, carnotite, and tyuyamunite by diffusion techniques was attempted but initial runs were unsuccessful.

Work continued on the system $Na_2O.ZrO_2.SiO_2.H_2O$ and a number of runs were made to provide further data on phase boundaries. It was decided that modifications of methods and equipment previously used would have to be introduced to avoid the high proportion of leaks encountered at 500° C in Morey bombs. Accordingly, a high pressure system was constructed for this purpose. Upon completion of a safety gauge and electrical connections, the system will be ready for operation. It is anticipated that work will then proceed rapidly.

Growth runs in HF solutions were continued. More dilute solutions are now being used in the hope that they will be more favorable for the growth of large crystals.

Isotope geology and nuclear research

Geochronology
by
L. R. Stieff

During the report period 71 samples of uranium, thorium, and lead minerals were prepared for chemical and isotopic analyses as part of the Geochronology program. Lead iodides were prepared from 10 of these samples, isotopic analyses on 47 lead iodides were received from the Mass Assay Laboratory, Oak Ridge, and 21 lead isotope analyses were made with the 6-inch mass spectrometer in the USGS Laboratory.

Essential agreement was obtained between lead isotope dilution techniques and wet chemical methods in the determination of lead in monazite.

This special study of lead in monazite was undertaken in an effort to resolve significant discrepancies between the quantitative spectrographic, and chemical methods. The first two samples analyzed for chemical lead gave values of 1.73 - 1.77 mg/g and 3.88 - 3.83 mg/g as compared to the isotope dilution of lead values of 1.75 and 3.69 mg/g of sample respectively. Optical emission spectrographic values are appreciably lower.

Construction of the USGS laboratory 12-inch radius mass spectrometer for precise isotopic analyses in the high mass range is progressing satisfactorily. The electro magnet, pole pieces, coils, spectrometer tube, source and collector were completed. Many of the analytical problems inherent in the use of the 6-inch radius spectrometer for high mass work should be reduced by use of the 12-inch radius instrument. The new spectrometer is expected to be in operation by July or August.

A paper entitled "The relation of lead isotope age data to theories of origin of the Colorado Plateau uranium deposits" was presented at the March Symposium on Uranium at Grand Junction, Colorado. Three additional papers on the Colorado Plateau age studies and several general problems in geochronology are nearing completion. During the report period a paper entitled "Preliminary description of Coffinite, a new uranium mineral", by T. W. Stern and L. R. Stieff, was published in Science, v. 121, no. 3147, April 22, 1955.

Stable isotopes

by

Irving Friedman

The mass spectrometer used for the analysis of deuterium was placed in operation. A large number of analyses of water were completed, with results as described below.

Cloud physics studies

During the course of a rainstorm there appears to be a relationship between deuterium content and raindrop size. A difference in D/H ratios with rain and atmospheric moisture (water vapor) collected at different altitudes in Hawaii was found. Snow collected from an airplane over Washington showed no appreciable variation with altitude. During a frontal storm, precipitation at a station decreases in deuterium content as the cold front advances. These conclusions are tentative only.

Ocean water analysis

Several hundred ocean water samples representing carefully selected stations in the Arctic and Atlantic oceans were analyzed for D/H ratios. The salinity-deuterium relationship closely follows the salinity-temperature pattern in the major ocean water masses of the Atlantic. Particular discrepancies can be explained by a consideration of isotopic fractionation during the freezing of water, and by analysis of the role of mixing of fresh and sea water in particular areas of the oceans. The collection and analysis of sea ice and the water from which it was frozen shows that experimental results on the isotopic fractionation during the freezing of water apply under natural conditions.

By D/H analysis it was possible to show that at one station near Greenland the ocean water was being diluted with glacial ice, while at another station melted sea ice was the diluent.

Water in rocks

The D/H analysis of water contained in glassy rocks yielded information bearing on the origin of water in perlites. The preliminary data show that the D/H ratio of water in obsidians from various localities falls in a narrow range, and the variations within that range are not related to petrographic province or geographical position. The water in the perlite that encloses certain obsidian pellets or marekanite has a lower deuterium content that the water in the enclosed obsidian, but falls in the same range; i.e., when the obsidian is high in deuterium, the perlite is also high.

Isotope geology of lead
by
R. S. Cannon, Jr.

Some of the broader problems fundamental to the interpretation of lead isotope data now in hand, especially the isotopic evolution of lead in the earth, and the significance of unusual isotopic compositions of lead in galena have been given attention in recent months. The isotopic composition of lead in galenas associated with uranium ores is being studied in terms of alternative possibilities as to geochemical history of the uranium with which they are associated.

A few new isotope analyses throw new light on one of the better known occurrences of galena lead of unusual isotopic composition. Galenas from the Sudbury district, Ontario, are known to contain lead of two diverse compositions, one of them notably unusual, but the information that has been reported in the literature does not reveal the geologic associations of the two kinds of lead. In November 1953 L. T. Silver and the writer collected in the Sudbury district 3 galenas of known geologic occurrence. Isotopic analysis of these 3 samples implies that lead integral in ore of the district's two major types of ore deposits is quite ordinary, whereas the unusual type of lead was in galena from an inconspicuous set of quartz seams which cut the Sudbury norite but the geologic origin and affilitations of which are uncertain. Isotopic analyses were obtained (but not yet studied) of four samples of galena collected from sedimentary formations ranging in age from Mississippian to Triassic from around the perimeter of the Colorado Plateau.

An effort is being made to complete chemical evaluation of the samples collected in 1952-1954 as potential materials for study of isotope variations in the rock-lead of igneous and sedimentary rocks. This work is being done in cooperation with the California Institute of Technology. As part of this task fluorimetric determinations of uranium in nearly 100 rocks were made. In 11 samples from basaltic and andesitic lava flows, mostly younger than Tertiary, an average of 1.1 ppm U was found with a range from 0.5 to 2.3 ppm U. In 58 limestones and dolomites known or believed to be of marine origin a wide range of uranium content was found, the average being 1.4 ppm U. These analyses show an interesting trend toward higher uranium values in samples of younger geologic age. These data are generalized in table 34, together with analyses of 9 recent marine carbonate sediments from the Atlantic and Pacific Oceans.

Table 34. Fluorimetric determinations of uranium in carbonate sediments and rocks, averaged according to geologic age

	No. of samples	Geologic age		Average U (ppm)
	37	Precambrian		0.7
	11	Paleozoic		2.0
	6	Mesozoic		2.4
	1	Tertiary		4.4
	3	Pleistocene		4.6
	9	Recent		2.0
Total	67		Average	1.5

In 1954, while engaged in field work collecting samples for this program, radioactive deposits containing carnotite in sands and clays of the Santa Fe formation of late Tertiary age were discovered in the upper Rio Grande Valley, New Mexico. With R. L. Smith and H. L. Cannon a brief study was made to evalute the practical and scientific implications of this uranium occurrence.

Nuclear geology
by
F. E. Senftle

The mass spectrometer for copper analyses was operated regularly during the past six months. Trial runs to work out the "bugs" and increase precision of analyses consumed much of this time. About 12 samples were analyzed. While some minor variations in the Cu^{63}/Cu^{65} ratio were noted, no significant changes were found. Two new sources for the mass spectrometer were built and an amplifier is now under construction for use with a proposed double collection system.

The study of the adsorption of Cs^{137} ions on natural and synthetic quartz was terminated. A note on this work will appear shortly in the American Mineralogist.

Recent radiochemical results published by P. Kuroda in the Transactions of the New York Academy of Science indicate that the U^{235}/U^{238} ratio may vary in nature. To check this, two of his samples (PK-2, PK-5) were obtained for isotopic analyses. U_3O_8 was also prepared from samples (P-8, P-11, P-14, GS-64 and GS-78) from the Colorado Plateau. The analyses obtained at Oak Ridge from these samples were:

Batch Number	Weight percent U^{235}	Limit of Error
PK-2	0.7112	± 0.0020
PK-5	0.7114	± 0.0018
P-8	0.7147	± 0.0025
P-11	0.7115	± 0.0022
P-14	0.7118	± 0.0022
GS-64	0.7161	± 0.0023
GS-78	0.7115	± 0.0022

The results indicate that the ratio is constant to better than one percent.

Potassium analyses of the weathered and unweathered phases of the Conway granite show a slightly higher content in the weathered phase. A sample of each phase was chosen and the potassium carefully extracted. A specific gamma activity analysis will be made on each sample to see if the K^{40} content has been altered in the process.

Preliminary experiments to determine the rate of production of helium in lithium minerals by cosmic radiation were undertaken. Very large pulses were observed in $LiCo_3$ by the formation of Be^8 and its subsequent disintegration in two high energy alpha particles. Considerable instrumentation will be required before any reliable measurements can be made.

MINERALOGIC AND PETROGRAPHIC SERVICE AND RESEARCH

Services

Washington laboratory

by
E. J. Dwornik

The high level of public sample submissions for determination of radioactivity examinations continued. During the present report period, approximately 2,200 individuals submitted a total of 3,500 samples. Table 35 illustrates the increased trend.

Table 35. Tabulation of public samples December 1953 to June 1955

Report period	No. of sources	No. of samples examined
Dec. 1953-June 1954	650	1,040
June 1954-Dec. 1954	1,350	2,160
Dec. 1954-June 1955	2,200	3,500

It is noted that the increase in the number of samples coincides with the increase in publicity concerning uranium prospecting in the newspapers and popular magazines.

All the samples require at least routine mineralogical, petrological, and radioactivity examinations. However, when the sample shows significant radioactivity, more detailed analytical work is usually required. Additional chemical, X-ray, or spectrographic analyses are made at the request of the AEC.

The samples under the special sample program are those submitted by geologists doing reconnaissance work on potential radioactive ores. These samples therefore require detailed mineralogical and petrological analyses. Approximately 200 samples in this category were analyzed, an increase of 60 samples over the previous report period.

Denver laboratory

by

L. F. Rader, Jr.

During the report period 480 samples were processed in the Denver mineralogy laboratory. About 380 samples were examined by X-ray powder diffraction photographs and X-ray diffractometer analyses. The relatively high proportion of the X-ray analyses is largely due to need for identification of minerals in fine-grained aggregates, particularly secondary uranium minerals.

Several samples from the Karnes County, Texas, uranium area were studied. Two of them were essentially from the first ore found. They were selected specimens, with about 8 percent U, and showed in addition, strong qualitative tests for molybdenum and arsenic; later chemical and spectrographic analyses showed about 4 percent Mo, 1 percent As, and 1 1/4 percent P; also, 0.01 to 0.02 percent Sn. The various uranium minerals present are difficult to identify, since they are in intimate fine-grained mixtures with very similar physical properties. The presence of molybdenum was first noted through recognition by optical means of a mineral closely resembling ferrimolybdite. At present a sample is being studied in which arsenopyrite has been tentatively identified; this occurs as fine-grained crystals in a dark, thoroughly cemented, quartzite.

As a result of geochemical and botanical studies in the southern Black Hills, South Dakota, it was found that barium has a negative correlation with a large number of elements in the ash samples from a suite of plants. This may be important in alpha studies of plant materials, in that radium tends to accompany barium.

Some exploratory studies were started on the nature and distribution of the carbonate cements in sandstones of the Colorado Plateau type, using in particular X-ray diffractometer techniques; dolomite was found in one sandstone from the JJ mine, Paradox Valley, Colorado.

X-ray services

by

George Ashby

Mineral identification and other X-ray diffraction services were continued, together with research in support of this service. During the last six months, 767 determinations were made on 653 samples.

In the same interval two new methods of analysis were added to the project services. A method for determination of unit cells in fine-grained minerals was developed in cooperation with the electron microscopy laboratory. By comparing X-ray powder diffraction data with electron diffraction point patterns, the unit cells of potassium chlorate and an unnamed uranium-silicate were determined.

A high temperature mount was constructed for the diffractometer to permit recording of diffraction patterns from samples at elevated temperatures.

Crystallography of uranium and associated minerals

by

H. T. Evans, Jr.

Significant advances were made during this work period in crystal chemistry and structure studies of uranium and vanadium as it applies to the Colorado Plateaus. Outstanding results are:

Structure studies of minerals of the type $xMeO.yUO_3.zH_2O$

Crystallographic and crystal structure studies of this group of minerals were continued. Among the species examined were becquerelite, schoepite, billietite, masuyite, fourmarierite, and vandendriesscheite. The structures of all of these minerals are related in a simple way: they are based on a common pseudohexagonal arrangement of linear vertical uranyl ions linked together into infinite horizontal sheets by the hydroxyl ions, with the sheets held together in the crystal in the vertical direction by water molecules, or in the case of lead- or barium-containing minerals, also by ions of these metals. From structural considerations, we rewrite the formula $yUO_3.zH_2O$ as $yUO_2(OH)_2.(z-y)H_2O$ and the formula $xBaO.yUO_3.zH_2O$ as $xBa(OH)_2.yUO_2(OH)_2.(z-x-y)H_2O$. The structure results are in agreement with the observed perfect (001) cleavage of the minerals, and the essentially zeolitic nature of the water in excess of that required for the hydroxyl groups.

Crystal structure of duttonite

The crystal structure of duttonite, $VO(OH)_2$ was determined from crystals in specimens from the Peanut Mine, Bull Canyon, Colorado. They were found to be orthorhombic with a body-centered lattice, and cell dimensions and symmetry indicated a unit cell content of $4VO(OH)_2$. Application of Fourier methods revealed a structure in which VO_6 octahedrons form straight chains by sharing edges, and then sheets by sharing apical oxygen atoms between chains. Adjacent sheets are joined by hydrogen bonds. Of particular interest is the appearance of a short V-O bond in this structure corresponding to the well known vanadyl chemical radical, $(VO)^{++}$. A subsequent microchemical analysis confirmed the formula found from the X-ray studies.

Thermodynamics of vanadium in solution

All of the thermodynamic and chemical data available was assembled in a pH-oxidation potential phase diagram. Most of the vanadium mineral species found on the Colorado Plateaus have been entered on this phase diagram (see fig. 42). It is now apparent that sufficient fundamental information has been obtained over the last three years to follow the alteration sequences from species to species as they flow across the phase diagram, starting from montroseite as the focal point. The proper location of each species on the diagram has depended to a large degree on crystal structure information as given by work done on this investigation. A typical example is provided by the case of duttonite, referred to above.

Instrumentation and computing techniques

With the initiation of these studies, plans were made to develop more advanced techniques for the experimental theoretical and computational portions of work in the solution and refinement of crystal structures. These plans have been held in abeyance in order to devote as much time as possible to the actual solution of problems. It is now possible to begin carrying out some of the original plans for instrumentation. Three main projects have been taken up along this line: (1) the Fourier Analog Computer was further developed. Essential parts were purchased and construction of test sections began; (2) equipment for the measurement of single crystal intensities by means of scintillation counters was designed,

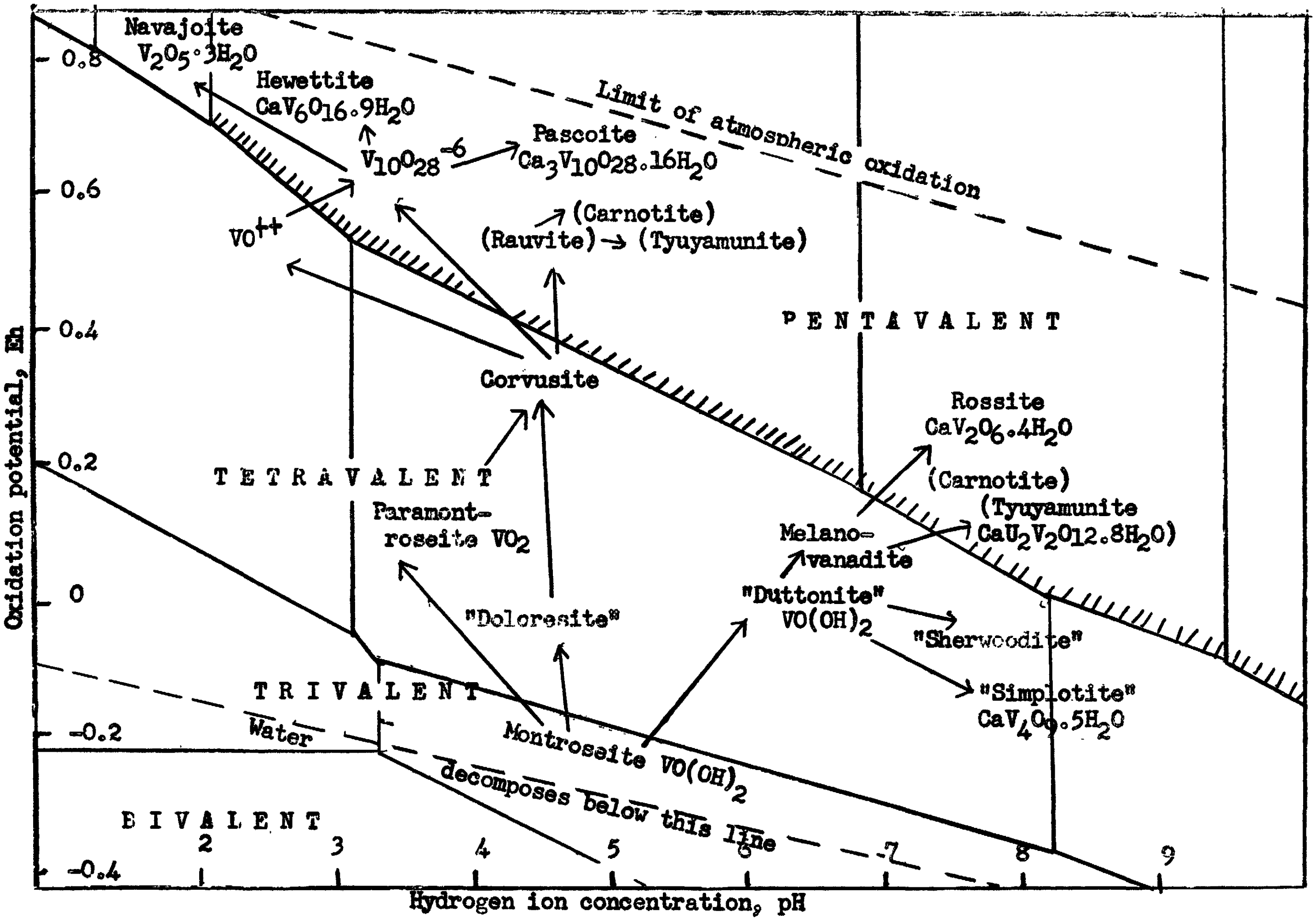

Fig. 42.—pH-oxidation potential diagram for vanadium, showing stable environs for minerals of the Colorado Plateau and alteration sequences.

and basic parts ordered. It is planned to replace all the classical film techniques which were used heretofore by such instrumentation. It is hoped that eventually the process of intensity measurement may be made fully automatic; and (3) the basic computations (data processing, Fourier synthesis, structure factors, least square analysis, etc.) that are now accomplished in a routine but relatively slow manner by USGS IBM installation, are being programmed for a magnetic drum calculator of medium size.

Papers published during the period include:

"The Crystal Structure of Rutherfordine, UO_2CO_3", by C. L. Christ, J. R. Clark, and H. T. Evans, Jr., Science 121, 472-3 (1955).

"The Crystal Structure of $KVO_3 \cdot H_2O$", by C. L. Christ, J. R. Clark, and H. T. Evans, Jr., Acta Crystallographica 7, 801-7 (1954).

Electron microscopy,

by
Malcolm Ross

The study of the crystal structures of vanadium minerals from the Colorado Plateau was continued. Additional electron micrographs and electron diffraction patterns were made of two hewettite minerals, steigerite, navajoite, corvusite, montroseite, doloresite, uvanite, and rauvite. Single crystal patterns were obtained from most of these minerals.

After an examination of some of the vanadium minerals it became evident that new techniques of crystal structure analysis by electron diffraction could be developed. Interplanar distances of the hewettite minerals were calculated from measurements of the ring patterns. On the basis of the spot patterns obtained from the same materials, the ring patterns were indexed. All rings could be indexed as hk0 planes.

The d_{010}, (b_o), and the d_{100} for a sodium hewettite were found to be 3.62A° and 12,20A°, respectively. The unit-cell constants of a monoclinic hewettite mineral, which is presumably the same as the one in this laboratory, were calculated by Barnes and Qurashi to be: $a_o =$ 12.18 ± .02A°, b_o = 3.614 ± .005A°, c_o = 7.80 ± 0.03A°, and β = 95° ± 20, (Barnes and Qurashi, 1952, Am. Mineral. 37, p. 416).

The excellent agreement between the d_{100} measured from an electron diffraction ring pattern, and the calculated a constant derived by Barnes and Qurashi, led to a detailed study of other known monoclinic crystals. Potassium chlorate, cupric bromide, talc, lithium sulfate, aluminum chloride, and anthracene were examined. Data thus far obtained from electron diffraction patterns indicate that the a and b cell constants of certain monoclinic crystals (those with pronounced basal cleavage) may be derived directly from the photographic plate measurements. Furthermore, the extinction criteria of the hk0 indices can be found from the spot pattern extinctions.

Spot and ring patterns of navajoite and corvusite were measured and tentative values assigned for the a and b constants. In addition, the extinction criteria of the hk0 indices were derived. If enough data can be obtained from the X-ray powder patterns an attempt will be made to index the two minerals and assign them to a space group.

Electron diffraction patterns and electron micrographs were taken of a new unnamed uranium silicate. The fine-grained nature and platy habit of the mineral were revealed by the electron micrographs. Interplanar distances computed from measurements of the ring patterns corresponded fairly well with those calculated by X-ray methods. From a selected area diffraction spot pattern, the rings were indexed and extinction criteria of the hk0 indices derived.

New methods of standardizing electron diffraction patterns were sought with particular emphasis being placed on the preparation of mounts with internal standards. Various crystalline materials were tested for suitability as standards, but none were superior to aluminum.

The routine work performed for other projects included particle size determinations, examination and identification of clay samples, radioactive minerals, and synthetic vanadium minerals. In addition, electron micrographs and electron diffraction patterns of various minerals and chemicals were obtained and catalogued for use as reference standards.

Electron micrographs and d-spacings calculated from electron diffraction patterns of available uranium and vanadium minerals were assembled.

A total of 87 electron diffraction patterns and 205 electron micrographs were made.

Properties of uranium-bearing minerals

by

A. D. Weeks

A new mineral, $V_2O_4 \cdot 2H_2O$ or $VO(OH)_2$, from the Peanut mine, Montrose County, Colorado was analyzed chemically. Work continued on the chemical analyses of a new iron vanadyl vanadate from Colorado and on synthetic phosphuranylite and voglite.

The USGS Bulletin 1009-F "Glossary of uranium and thorium-bearing Minerals" by J. W. Frondel and Michael Fleischer was published.

The paper "An automatic micromuffle for the determination of ash in carbonaceous material", by Robert Meyrowitz and C. Massoni was published in the March issue of Analytical Chemistry.

Study of the optics and X-ray powder patterns of hydrated uranium oxides continued.

Research on techniques in mineralogy and petrology

by

E. J. Dwornik

Satisfactory results obtained from comparative tests on the multiple cone sample splitter have led to further use of the cone design in the construction of a slotted cone sampler. This instrument was designed to obtain a representative sample of approximately 10 percent from laboratory samples of more than 1 kilogram. It has the additional advantage over the multiple cone splitter of sampling both coarse sand and fine powders with equal facility. Tests are being conducted to determine the accuracy and precision of this sampling method for use in the laboratory.

A mechanical sieve shaker, designed and constructed in the laboratory shop was installed for the Uranium in Igneous Rocks project. This mechanism, which uses nests of sieves 13" x 20", is capable of sieving large quantities of material in a fraction of the time needed for sieving in the Ro-tap. Essentially the machine consists of a sieve holder containing 4 sieves and tray, which is oscillated on a set of tracks mounted in a laboratory hood. The driving mechanism was obtained and adapted from a Wilfley Table. Use of this device effected a 30 percent saving in the time-consuming sieving operations of the project.

A "hindered settling" column was designed and constructed for additional mineral separation studies. It is made from welded sections of glass tubing, has baffles, and uses a water medium. It proved successful in removing rock dust from samples and can, to a limited extent, concentrate sized minerals that differ in specific gravity by 0.5.

GEOPHYSICAL SERVICE AND RESEARCH ON METHODS AND PRINCIPLES

Development and maintenance of radiation detection equipment

by
W. W. Vaughn

The Radiation Laboratory is a continuing function with responsibility for the maintenance, modification and development of radiation equipment to meet the needs of the geologist.

During the reporting period a study has been made to relate phototube cathode area to the phosphor area being scanned. It was found that the counting rate remains essentially the same when the cathode area is increased, that is, approaching the area of the phosphor being scanned, provided the tubes all have equal gain. However, the resolution is much better with tubes of larger cathode area, commensurate with the size of the phosphor.

Tests are being made on the possibility of making spectral energy measurements in drill holes. The apparatus consists of a linear amplifier and a single-channel differential pulse height analyzer with a 1-volt window. The resolution for cesium is 10.5 percent and is not materially affected with 1,000 feet of coaxial cable and an impedance matching circuit (see USGS Circular 353) between the probe and recording amplifier.

A standard scintillation probe shell used on the 1,000 foot portable gamma-ray logging units was tested under pressure and collapsed at a pressure equivalent to approximately 1,382-foot head of water. The probe was 1 1/2 inches in diameter by 14 inches long with a wall .032-inch thick.

The instrumentation for a gamma-ray absorption experiment (see Absorption and scattering of gamma radiation) has been assembled and tested. Basically, the equipment consists of a scintillation counter and modified Nuclear-Chicago scaler in cascade. The scalers have a 1-millivolt input sensitivity. Special voltage regulation is provided.

A detailed comparison of two carborne scintillation counters using different types of scintillation material was made. One instrument uses a plastic phosphor, the other a thallium-activated sodium iodide crystal. The plastic phosphor is approximately 5 inches in diameter by 8 inches long, while the sodium iodide crystal is 3 inches in diameter by 1 1/2 inches long.

Tests were made with the standard (sodium iodide crystal) carborne scintillation counter to determine calibration and instrument response to a known field of radiation. The effect of the vehicle's speed, the high voltage supplied to the phototube, and the discriminator level of the circuit relative to the ability of the instrument to detect a point source of radiation were studied.

A study has been made of the temperature dependency of the ratemeter used with the jeep-mounted scintillation logging unit. The temperature drift increases with counting rate, and is considered excessive. It will be necessary to make the instrument more temperature-independent before optimum field data can be obtained with this equipment. Related studies are being made to determine the effects of time and source voltage fluctuations on the stability of the circuit.

Tests of a liquid scintillation core scanner indicate the necessity of shielding the scintillator from room background in order to obtain optimum results. The seals (Teflon, Tygon, and Polyethylene) used to contain the toluene solvent are very effective. The Teflon and Tygon show pronounced cold flow characteristics, but seal effectively in a confined arrangement. Teflon washers were used in a counter bore with copper backing washers which sealed the longitudinal bolts, clamping the bells at the end. A polyethylene gasket was used to seal the bells. The Tygon was used to seal the photomultiplier glass circumference to the inside of the sleeves on the core scanner, in a packing-gland arrangement. The Tygon "glands" were made from a section of 2-inch ID Tygon tubing, machined at low speed with a knife edge. The Phenoline 300 used to coat the interior of the core scanner flaked and peeled, and destroyed the reflective characteristics. Due to the generally unsatisfactory performance of this unit, a new scintillation core scanner has been designed and built and is now under test. This unit uses sodium iodide as the phosphor and is shielded by approximately 2 inches of lead.

A number of the 6- and 12-volt carborne-airborne scintillation counters have been modified to improve the long term stability, decrease the load on the vibrapack and to make certain critical components more accessible. Generally speaking, these units have given very satisfactory service. One of the 12-volt units was run continuously for a two-month period to monitor fall-out from the A-bomb tests in Nevada. This test showed up defects in the voltage regulation which have been eliminated. The detecting element used for monitoring fall-out is located on the roof of the Radiation Laboratory and is connected to the amplifier-ratemeter through 50-foot cables.

The portable gamma-ray scintillation logger has been modified so that adjustment made on the surface while the instrument is in operatio will reduce the sensitivity by as much as 40 times without seriously affecting the energy response of the instrument. With these adjustments, it is possible to use the instrument to log ore-grade materials as well as to use it as a tool for studying stratigraphy and lithology.

A jeep-mounted recording scintillation gamma-ray logger has been fabricated and is under test.

An automatic sample changer using the scintillator principle, for studying alpha emission from large area samples, was designed and a working model constructed. The turntable will accommodate eight samples. Simplicity is of prime importance in this type of equipment. The instrument will count each sample for a pre-determined time in a repetitive manner. Knowing the time interval between each count and the magnitude of the count over a long period of time, decay curves for all samples can be derived.

The radioactive fall-out from the atomic bomb test in Nevada this spring has seriously handicapped work in the Radiation Laboratory. The radioactivity in this area associated with each test was monitored and recorded for future reference.

Gamma-ray logging studies

by
Carl M. Bunker

Equipment and operational techniques used in gamma-ray logging in the Florida phosphate district have been reviewed and some modifications were made, to obtain more accurate grade and thickness estimates of the radioactive phosphate, and to obtain better resolution so that the equipment can be used for making more accurate lithologic logs.

Three simulated drill holes were constructed for calibration purposes. Three grades of ore were placed in them in various thicknesses. Upon completion of the logging of the simulated drill holes a calibration chart showing the variation in count rate with grade and thickness of radioactive material will be prepared to supplement an instruction manual for interpreting gamma-ray logs obtained from exploratory drill holes.

A jeep-mounted scintillation type gamma-ray logging unit designed by the Geological Survey's Radiation Laboratory has been under test for the past few months. Time and temperature drift and other instrumentation problems were encountered which have delayed its calibration. Tests to determine the cause for the instability are continuing.

A portable scintillation logging unit developed by the Geological Survey has been used in the field for several months to obtain qualitative data from exploratory drill holes. Although the equipment is not expected to be as stable as the jeep-mounted unit, calibration for quantitative grade and thickness estimates will give the field geologist much data not obtainable at present.

A study of the correlation between gamma-ray log interpretations and the radiometric and chemical analyses of drill cores has been completed. The results indicate that the gamma-ray log data is approximately thirty percent higher than the chemical analyses of the drill core. Still unanswered is the question of whether or not the core samples are representative of the material surrounding the drill hole. The study pointed out instrumentation and interpretation problems which are expected to be solved in the near future.

A study to evaluate the usefulness of combined gamma-ray-electric logging is in progress. Drill hole logging data obtained during the 1954 field season from the Chinle formation near Holbrook, Arizona is being employed in this study. An attempt is being made to develop criteria for recognizing and outlining areas favorable for the deposition of secondary uranium minerals utilizing the combined techniques. The tentative conclusion is that in the Holbrook area, at least, the radioactive material lies in sandstone lenses of low resistivity. There are a few extreme and unexplained exceptions to this general rule. It may not be possible to pick favorable strata from electric log data only, but a combined technique may yield more diagnostic data.

Physical behavior of radon

by

A. S. Rogers

A study of the radon content of well waters in an area of unconsolidated valley-fill and lake sediments from North Salt Lake City to Centerville, Utah, was completed. The area investigated (about 5 miles by 5 miles) roughly parallels the adjacent Wasatch Mountains and includes the north-trending Warm Springs and Limekiln faults.

Contours of radon concentrations in waters from 130 wells show well-defined linear highs over the two known faults in the area. Several additional parallel highs suggest that a series of en echelon faults occur in the unconsolidated sediments.

The general radon "background" in the well waters increases to the north from about 300 micromicrocuries per liter to about 600-800 micromicrocuries per liter. This is apparently due to a lithologic change in the adjacent Wasatch Mountains from Tertiary conglomerates to Precambrian gneisses and schists to the north which are the source of the unconsolidated sediments.

No apparent relation exists between the radon concentration of the ground water and the depth or rate of discharge of the well. Additional work is planned near Ogden, Utah and Denver, Colorado, to obtain additional information on the relation of radon to ground water and other geologic problems.

During the report period additional work has been undertaken on analysis of brines from the Texas and Oklahoma Panhandle gas fields. Radium, boron and fluoride determinations are in progress.

Absorption and scattering of gamma radiation

by

A. Y. Sakakura

Gamma-ray distribution from thick sources

In order to obtain a quantitative knowledge of scattering and absorption in air of gamma-rays from thick sources, the gamma-ray transport equation (Boltzmann) in two media must be solved numerically. Coding and programming the problem (integro-differential equation in three variables) has been underway since July 1954 at the AEC Computing Facility at New York University. Considerable revision of the coding accomplished during the previous fiscal half-year was required, especially in the evaluation of the kernel of the integral equation in order to avoid errors caused by discontinuities in the primary energy solution. The coding is now complete.

After some trial runs, in the next few weeks, computation of the problem as a whole will begin. Most of the computations should be finished in the first half of the next fiscal year, provided that sufficient machine time is available.

Gamma-ray distribution in continuous media with cylindrical cavities

All equipment for experimentation in the measurement of gamma-ray intensity in cylindrical cavities was constructed. The experimental phase will commence in June and should be completed by September.

RESOURCE STUDIES

The principal objective of "resource studies" is to analyze and correlate all available data on the geology of radioactive elements in order to develop an understanding of the principles and controls governing their deposition and occurrence. Results of such studies carried on during the report period are presented under the several topical headings below.

General studies

by

A. P. Butler, Jr.

The areal distribution of domestic uranium deposits known today is much wider than was known in 1948. Although many concealed deposits have been found, most of the uranium deposits in terrestrial sedimentary rocks have been discovered at or near the outcrop and the presently known deposits probably constitute only the smaller part of the uranium resources present at minable depths. Because deposits larger than 100,000 tons contain about 70 percent of the known domestic reserves, it is inferred that a large part of the undiscovered uranium resources are in deposits large enough to be looked for even though they may be at depths of hundreds of feet. It is also inferred that resources of uranium in deposits in terrestrial sandstone in regions of newer discoveries, including the Black Hills uplift and the Tertiary basins of Wyoming, compare favorably with those of the Colorado Plateau.

Among the uranium deposits in terrestrial sedimentary rocks, either copper, vanadium, or uranium may predominate in different deposits in rocks of Triassic age and older; vanadium or uranium, but not copper, predominate in deposits in rocks of Jurassic and Cretaceous ages; and only uranium predominates in deposits in rocks of Tertiary age.

Recently discovered deposits in lignite and associated carbonaceous shales in the western Dakotas appear to be of importance second only to deposits in terrestrial sandstone.

About 90 percent of the known minable uranium deposits, regardless of their particular mode of occurrence, are in a vaguely defined belt that trends northeasterly from southern Arizona to western North Dakota (fig. 43).

Uranium in sandstone

by

W. I. Finch

A preliminary study has been made of the distribution of uranium deposits in terrestrial rocks outside of the Colorado Plateau (fig. 44). Such deposits in late Paleozoic rocks occur circumferentially about the eastern border of the Plateau, and in Mesozoic rocks in the southern and northern parts of the Black Hills uplift. Large deposits in lower Tertiary rocks of the Wyoming Basins and northern Great Plains lie in a northwest-trending belt about 175 miles wide and 500 miles long. The ore-bearing formations in this belt are progressively younger from north to south.

In general the uranium deposits in Paleozoic and Mesozoic formations outside of the Colorado Plateau occur in sandstone with minor amounts of mudstone that were deposited by streams, and contain greater amounts of vanadium or copper than uranium. On the other hand, the deposits in Cenozoic formations occur in arkose, tuff, and tuffaceous sandstones that were deposited in closed basins or lakes, by streams, or under near

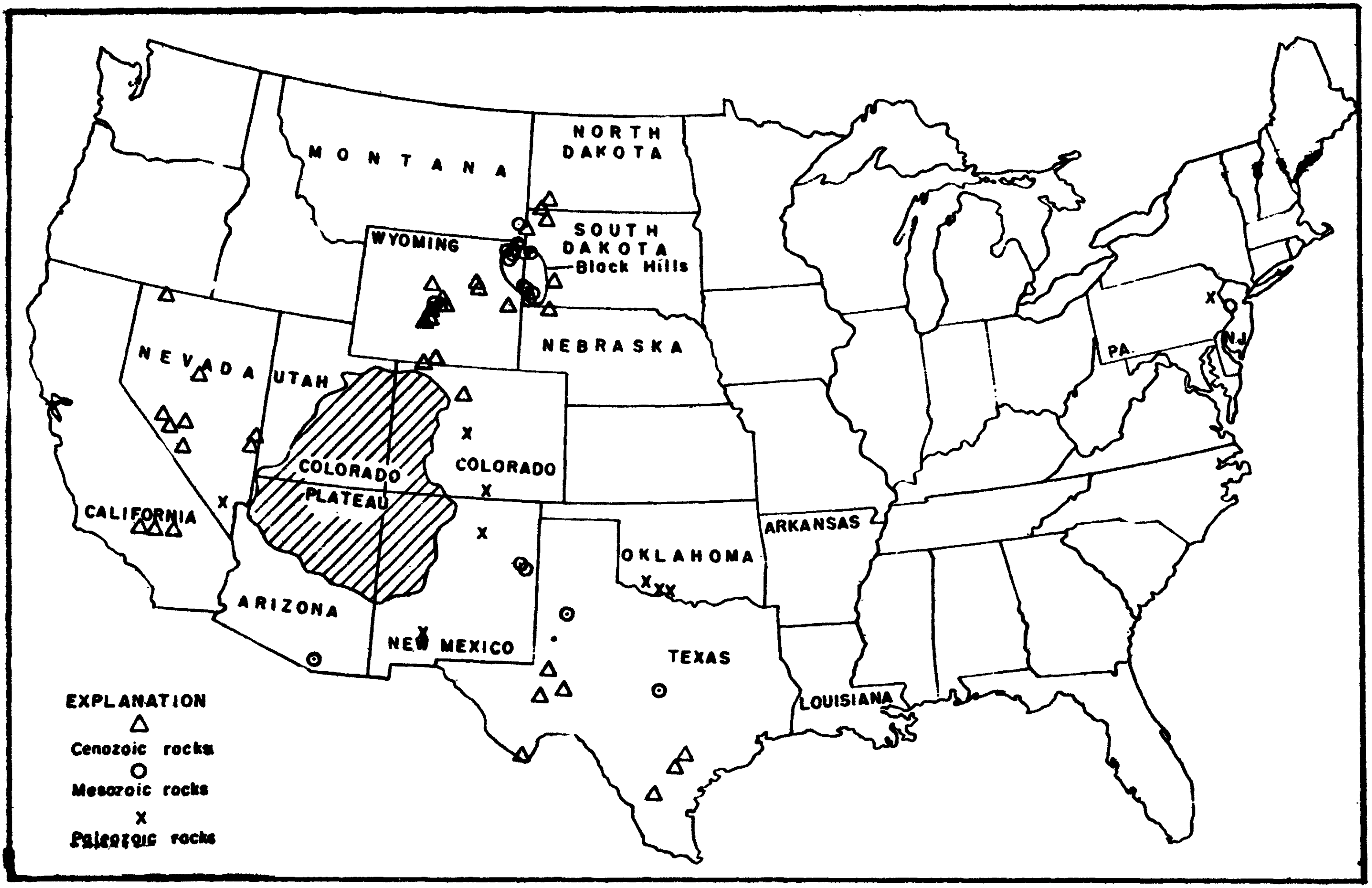

FIGURE 43 INDEX MAP SHOWING DISTRIBUTION AND STRATIGRAPHIC POSITION OF URANIUM DEPOSITS IN TERRESTRIAL SEDIMENTARY ROCKS IN THE UNITED STATES EXCLUSIVE OF THE COLORADO PLATEAU

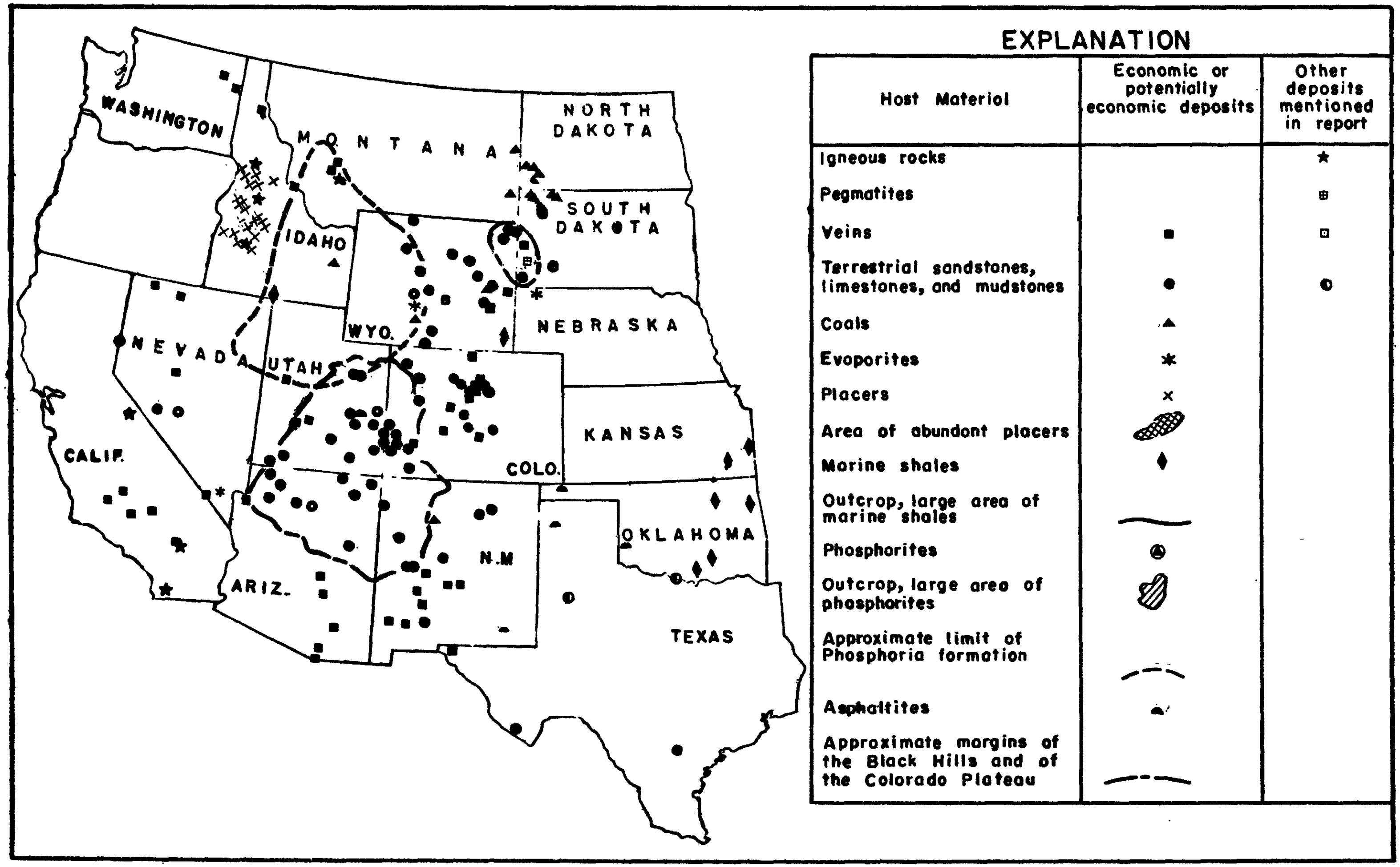

FIG. 44 INDEX MAP SHOWING DEPOSITS AND PRINCIPAL OCCURRENCES OF URANIUM IN THE WESTERN UNITED STATES

shore conditions, and most commonly contain less vanadium or copper than uranium.

Vein deposits

by
G. W. Walker and F. W. Osterwald

Analysis of geologic data concerning uranium deposits at Marysvale, Utah, and brief field examinations of some of the major deposits of the district, indicate that: (1) the uranium-bearing veins are largely localized in faults and at the contact between quartz monzonite and rhyolite, (2) the wall rock alteration that accompanies most vein narrows preceptibly with depth and is absent adjacent to veins exposed in lower mine workings, (3) the wall rock alteration may be a result of near surface oxidation of pyrite rather than a result of hydrothermal solutions, and (4) some of the hydrated, hexavalent uranium minerals, the umohoite, and some of the sooty pitchblende may be the result of the action of thermal solutions either by direct precipitation or by hydrothermal alteration of primary pitchblende.

Work was continued during the period on the compilation and analysis of available geologic and economic data regarding domestic uraniferous vein deposits. A summary study was made of all available geologic and economic data on uraniferous veins in Europe and North Africa. Other work included continuation of studies on: (1) the relation of uranium deposits to the major tectonic units in the Cordilleran Foreland and (2) the distribution and genetic relations of uranium in a contact-metamorphic iron deposit in New Mexico.

Phosphate

by

J. B. Cathcart

Investigations have shown that the following U - P_2O_5 relations are found in the various types of rock in the land-pebble phosphate district of Florida.

The "bedclay" (residual concentration of phosphate particles and quartz sand) in the lower part of the Hawthorn formation of middle Miocene age has a low phosphate content and an average uranium content of about .005 percent.

The upper residual part of the Hawthorn formation and the lower phosphorite part of the Bone Valley formation of Pliocene age comprise the calcium phosphate zone, or "matrix." The coarser phosphate particles of the matrix have a higher uranium content, 0.010 to 0.020 percent, and a lower P_2O_5 content (about 31.5 percent) than the finer phosphatic material, which has a uranium content of 0.005 to 0.015 percent and an average P_2O_5 content of 34 percent. A direct relation between P_2O_5 content and U content is present, however, within a size fraction: in pebble samples of the same size, the U content tends to increase as the P_2O_5 content increases.

In places, the upper part (clayey sand) and the top of the lower part (phosphorite) of the Bone Valley formation have been leached by acid ground waters forming a zone characterized by aluminum phosphate minerals. This zone, locally termed the "leached zone", contains between 0.010 and 0.015 percent uranium, and has a low phosphate content.

Black shales

by

V. E. Swanson

Review of basic data and of other studies on the uranium content of marine black shale indicate that the most uraniferous parts of a marine shale unit are characterized by: (1) abundant organic matter (plant debris) and thus are dark colored, (2) abundant pyrite, (3) presence of phosphatic material (nodules, oolites), (4) low quantity of calcareous sediments, and (5) relative thinness in comparison to time-equivalent rock units.

Shales that were deposited in eugeosynclinal and most miogeosynclinal environments are essentially non-uraniferous; under specific environmental conditions shales deposited on the marginal area between the miogeosyncline and the continental platform may be significantly uraniferous, and shales deposited over broad areas on the platform in epicontinental seas are generally the most uraniferous.

Additional studies of the tectonic and paleogeographic environments of deposition of marine shales, based on detailed geologic and geochemical studies, may lead toward a better understanding of environmental conditions of deposition, which in turn may provide criteria useful in the search for uraniferous shales. Hence certain interrelated factors should be evaluated, such as the chemistry, depth, and circulation of the sea water; the rate and amount of subsidence; the rate of deposition; and the topography, rock composition, and distances of the source areas from places where the sediments were deposited.

Hydrocarbons

by

K. G. Bell

A preliminary appraisal based on analyses of a large number of asphaltic sandstones indicates that these materials generally are not potential sources of uranium. Samples from a few districts show uranium contents that offer possibilities for by-product extraction.

Several large deposits of asphalt-impregnated sandstone in Santa Barbara and San Luis Obispo Counties, California, which contain higher than average amounts of uranium have been examined in an effort to determine what geologic factors have influenced the concentration of uranium. A radiometric reconnaissance of the district showed weak anomalies in parts of the Monterey formation and in some igneous rocks. Gamma-ray logs of oil wells of the district show weak radioactivity anomalies. Some of these anomalies can be correlated with phosphatic strata of the Monterey formation, and others probably are caused by slightly uraniferous tuffaceous strata. Migrating crude oils may have acquired their uranium contents from the phosphatic and tuffaceous strata. No crude oils from the district have been analyzed for uranium content.

Carbonate rocks

by

K. G. Bell

A review of analytical data pertaining to limestones and dolomites reveals that little attention has been given to syngenetic uranium contents of these rocks. Nearly all of the samples that have been analyzed were selected because they showed anomalous radioactivity, and the uranium contents generally can be attributed to epigenetic deposition.

Additional study is needed to determine what amounts of uranium can be deposited in limestones and dolomites by syngenetic processes, and the precise conditions of deposition.

Coal and lignite

by

J. D. Vine

The principal deposits of uranium-bearing coal are in low-rank coals of Cretaceous and Tertiary age in the northern Great Plains and Rocky Mountain regions. The distribution of uranium in any given bed of coal is erratic. In most deposits uranium is thought to have been introduced into the coal by ground water solutions and fixed by the organic matter of the coal. Uranium minerals, including autunite, torbernite, zeunerite, and possibly coffinite form in coal only when the amount of uranium available is in excess of that which can be held by the organic matter. The association of uranium-bearing coal with rocks of volcanic origin in some areas indicates that volcanic rocks may be one source for uranium.

Igneous rocks

by

G. J. Neuerburg

Uranium is thought to have six modes of occurrences in the fabric of igneous rocks: (1) uranium minerals, (2) uranium substituting in minor amounts of cations in the structures of rock minerals, or located in structural defects of rock minerals, (3) uranium held in cation-exchange positions, (4) uranium adsorbed on crystal surfaces, on surfaces of crystallographic discontinuities, or on surfaces of irregular cracks within crystals, (5) uranium dissolved in fluid inclusions contained within rock minerals, and (6) uranium dissolved in intergranular fluids.

There is reason to believe that the amound of uranium in each of its modes of occurrence differs appreciably from rock to rock, in places within small outcrops. Because of the varying accessibility and reactivity of uranium in each of its fabric occurrences to natural solutions, it is inferred that the uranium in each mode of occurrence may have changed in amount and physical state to different degrees and in different ways during the history of an igneous rock.

Uranium that is readily soluble in dilute acids, so-called labile uranium, is thought to have changed most during the history of any igneous rock. Studies now in progress of labile uranium contents may aid in deciphering the significance of variations in uranium content among igneous rocks. Uranium that is not dissolved may represent substantially the uranium that was fixed in the structures and structural defects of rock-mineral crystals at the time of their completed crystallization, or at the time of their last recrystallization.

The labile uranium content of an igneous rock is of economic interest because the element in that form is most easily extracted from igneous rock by hydrometallurgical techniques.

Thorium deposits

by

W. S. Twenhofel

Compilation and analysis of existing geologic data pertaining to thorium deposits in the United States has resulted in the following summations and generalizations:

1. Placer concentrations of monazite are derived directly from monazite-bearing igneous and metamorphic rocks, or by the reworking of

sediments originally derived from such rocks.

2. Most vein deposits of thorium are associated with and genetically related to alkalic igneous rocks.

3. The principal thorium vein minerals are thorite (hydrothorite) and monazite.

4. Barite, carbonates, quartz, and especially iron oxides, are commonly associated with thorium minerals in veins.

5. The principal thorium-bearing veins are found in the western United States and are believed to be either Precambrian or Cretaceous-Tertiary in age.

Natural radioactivity

by

F. W. Stead

Comparison of recent measurements of the spectral energy distribution of gamma radiation from essentially pure thorium (aged samples, 1902 and 1906), from uranium (uraninite), and from the Chattanooga shale (large block) indicates that the gamma-ray spectrum from naturally occurring materials such as rocks and soils is much degraded by internal scattering and absorption within the source. Except for small natural sources exceedingly high in uranium, thorium, and potassium, estimating the relative amounts of these elements and their daughter radioisotopes by spectral energy measurements at the outcrop appears to be remotely, if at all, possible. This is partially confirmed by experimental measurements over the low-uranium high-potassium salt beds at Wendover, Utah, where the effective or degraded energy spectrum from the potassium salt beds was approximately the same as from rocks containing larger amounts of uranium such as the Chattanooga shale. Although the unique high-energy gamma ray from thorium "C" may serve to indicate the presence of thorium and also to estimate crudely the relative amount of thorium in a rock, evaluation of the variation in activity of rocks must probably be based on the overall activity, rather than on integral or differential spectral measurements of thick source behavior of gamma radiation.

Public information

During the reporting period, public interest in uranium deposits remained at a high level as manifested by the continued large number of inquiries received asking for information on uranium deposits and related geology. During the previous six-month period, about 4,500 replies pertaining to uranium were dispatched; during the present reporting period, about 7,300 replies pertaining to uranium were dispatched in response to inquiries from various public sources.

During the report period a map compiled by W. I. Finch, entitled "Preliminary geologic map showing the distribution of uranium deposits and principal ore-bearing formations of the Colorado Plateau region" was published by the USGS as map MF-16.

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