H. Nacke

Geologic investigations of radioactive deposits, semiannual progress report, June 1 to November 30, 1955

Trace Elements Investigations Report 590

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Geology and Mineralogy

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GEOLOGICAL SURVEY

GEOLOGIC INVESTIGATIONS OF RADIOACTIVE DEPOSITS

SEMIANNUAL PROGRESS REPORT

June 1 to November 30, 1955

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Trace Elements Investigations Report 590

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

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INTRODUCTION

This report is a statement of progress during the six-months period from June 1 to November 30, 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.

During the period the Geological Survey's program has been directed to an increasing extent toward the understanding of geologic conditions favorable for the concentration of uranium, rather than the search for minable deposits as such. This shift in emphasis is reflected in the decreased amount of exploration drilling during the period, and the accompanying increase in geologic programs of a long-range nature.

The program is now directed toward a comprehensive understanding of the many factors involved in uranium geology, and the publication of reports that will make available information on all phases of the uranium program. Many investigations have progressed to the point where final reports are in preparation for future publication with the permission of the Atomic Energy Commission; for other investigations of a continuing nature it will be several years before final reports can be prepared. Formal publications (as distinguished from administrative Trace Elements Reports) published during the period include 10 Geological Survey Bulletins or Bulletin Chapters; 116 Geological Survey maps; 15 reports published in scientific journals; seven Trace Elements Reports sent to the Technical Information Service of the Atomic Energy Commission for distribution and sale to the public; and four Trace Elements reports placed on open file. In addition, a large number of papers by geologists in the program were presented before scientific societies, and the 61 papers prepared for the United Nations International Conference on the Peaceful Uses of Atomic Energy during the preceding report period were published by the United Nations.

HIGHLIGHTS, GEOLOGIC INVESTIGATIONS OF RADIOACTIVE DEPOSITS JUNE 1 - NOVEMBER 30, 1955

Uranium in sandstone-type deposits in the Colorado Plateau

Geologic mapping

Geologic mapping and related office work were continued during the period in the following areas: Southwestern Colorado; Western San Juan Mountains, Colorado, Ute Mountains, Colorado; La Sal Creek, Utah-Colorado; Lisbon Valley, Utah-Colorado; Moab and Inter-River areas, Utah; Orange Cliffs, Utah; San Rafael Swell, Utah; Circle Cliffs, Utah; Elk Ridge, Utah; Abajo Mountains, Utah; East Vermillion Cliffs, Arizona; Grants, New Mexico; and Laguna, New Mexico. The diatremes on the Navajo and Hopi Reservations, Arizona, were also studied during the period.

In the Bull Canyon district of the Southwestern Colorado area, trace elements studies show that lead, zinc, copper, selenium, molybdenum, silver, tin and barium are associated with the uranium deposits. A structure contour map of the district shows a possible relationship between the distribution of uranium deposits and the tectonic structures.

In the Slick Rock district, Southwestern Colorado area, carbonate studies suggest that a spatial relationship of carbonate and uranium ore exists, and that this relationship may be a useful ore guide. Fracture studies may help in interpreting the geologic history of the district.

In the Uravan district of the Southwestern Colorado area, surface and mine mapping in the Sharkey area, northwestern Long Park, indicates no genetic relationship between fractures and the early ore minerals. All faults that intersect ore bodies displace the ore layers. In several places uranium and vanadium apparently have been leached from faulted ore layers and redeposited in fault zones and along joint surfaces.

Sedimentary rocks of the Placerville district in the Western San Juan Mountains, Colorado have been warped into folds of northwest trend that appear to be continuous with the salt anticlines of southwestern Colorado and southeastern Utah. These rocks have been intruded by sills and stocks of andesite and diorite probably during a single period of intrusion, apparently during mid-Tertiary time.

Fossil and lithologic marker zones in the Mancos shale, found during recent stratigraphic studies, may be useful in interpreting the structure of the Ute Mountains complex.

Deposits in the Brushy Basin member of the Morrison formation, in the Sage Plain area, consist of uraniferous claystones about 20 feet below a lens of conglomerate and about 150 feet below the top of the Brushy Basin member.

In the La Sal Creek area, Utah-Colorado, the structures mapped reflect the interplay of tectonic forces involved in the intrusion of salt on the east side of the area and igneous rocks on the west. The distribution of uranium within one and possibly three northwest-trending belts has no apparent relation to the tectonic structures or the igneous rocks, but the deposits appear to have been localized by sedimentary structures within the ore-bearing sandstone of the Salt Wash member of the Morrison formation.

Copper and manganese deposits along the Lisbon Valley fault in the Lisbon Valley area, Utah-Colorado, are in part localized by faulting, but uranium deposits in a somewhat similar structural setting do not show a demonstrable genetic relation to faults.

In the Orange Cliffs area, Utah, uranium occurs in the so-called Moss Back or the Monitor Butte member of the Chinle formation close to the Moenkopi formation. Copper minerals, in places associated with uranium, occur at the base of the Chinle formation.

The Chinle formation in the San Rafael Swell area, Utah, has been divided, from bottom to top, into a "mottled siltstone" unit, the Monitor Butte mudstone member, the so-called Moss Back sandstone member, and the Church Rock shale member. These units are cut by diabase dikes and in places are breached by small elliptical collapse structures. Uranium occurs in all stratigraphic units of the Chinle formation but the largest mines in the area are in sandstone and conglomerate of the so-called Moss Back member.

Field work in the Circle Cliffs area, Utah, has shown that the larger Shinarump channels are more favorable for uranium deposition than the smaller channels.

In the Elk Ridge area, Utah an easterly trending belt of continuous Shinarump conglomerate swings abruptly to the northeast under South Elk Ridge. This entire belt is believed to be favorable for uranium deposits. Known deposits are associated with asphaltite, iron and copper sulfides, and oxides of molybdenum.

In the Abajo Mountains area, Utah sedimentary strata ranging in age from middle(?) Triassic to late Cretaceous have been intruded by latite and diorite porphyry. Small deposits of copper, gold, and silver occur along the contact between the igneous bodies and some of the sedimentary units or in localized zones of quartz-filled fractures that cut the igneous rocks. Uranium-vanadium deposits are in sandstone in the Salt Wash member of the Morrison formation, but they show no obvious relation to the igneous rocks.

Uranium deposits in the Grants area, New Mexico, occur in the Todilto limestone and Morrison formation (both Jurassic) and in the Dakota limestone (Cretaceous). The ore in the Morrison occurs in gray sandstone whose color may be a guide to favorable ground. Ore deposits in the Todilto are associated with small-scale folds in the limestone. Deposits are most numerous where favorable parts of these formations are intersected by wide northeasterly trending fault zones.

The Laguna area, New Mexico is known to contain one pre-Dakota and two post-Dakota systems of folds. Coextensive with the pre-Dakota folds are concentrations of vertical sandstone pipes in the Summerville, Bluff, and Morrison formations, and relatively intense minor folding in the Todilto limestone. These relations may be significant, as uranium ore occurs in one sandstone pipe and in some of the Todilto folds.

Of the two types of uranium deposits in the diatremes of the Navajo and Hopi Reservations, Arizona, one consists of sandstone impregnated with various copper, uranium, vanadium, and arsenic minerals; the mineralization occurs in the sandstone walls of dikes extending out from diatremes filled with mica-serpentine tuff. The second type consists of limestone, claystone, and monchiquite tuff impregnated with uranium-bearing minerals, and occurs in beds deposited within diatremes filled chiefly with monchiquite tuff. About 35 diatremes in the area are known to contain uraniferous material.

During the report period nineteen photogeologic maps of quadrangles within the Colorado Plateau were completed and 44 such maps were published.

Stratigraphic studies

Stratigraphic studies of Triassic formations have been conducted in the San Juan Mountains, Colorado; the Defiance uplift and the St. Johns area, Arizona; the Uinta Mountains, Utah; and in southwestern Utah and southern Nevada. Between Cedar City, Utah and Las Vegas, Nevada, the Moenkopi formation was found to be 1,800 feet thick. Six members are recognized in Utah, but only three can be distinguished in Nevada. The Chinle formation recognized by Longwell and Hewett in Nevada contains correlatives of the Moenave and Kayenta formations in its upper part. Triassic rocks of the San Juan Mountains are assigned to the Dolores formation, which contains the equivalents of upper Chinle and lower Wingate strata.

Stratigraphic studies of the Entrada sandstone during the report period confirmed the identity of the fossiliferous Carmel formation of the San Rafael Swell with the non-fossiliferous reddish sandstone comprising the Carmel near the Utah-Colorado border; indicated that deposition of crossbedded sands like those of the Entrada sandstone began in the Moab area during Carmel time; and showed that the Carmel-Entrada contact is complicated by pre-consolidation slumping, folding and faulting.

Studies of the petrology of the sandstones of the Morrison formation, made in the sedimentary petrology laboratory, indicate three general source areas for these sediments: a southwestern area of partly metamorphosed limestone and other sedimentary rocks; a southeastern area of granite, metamorphic rocks, and some silicic volcanic rocks; and a northwestern area of silicic volcanic rocks, some granite, and metamorphic rocks. From the distribution of detrital minerals it is concluded that the major compositional differences between members of the Morrison formation are the result of derivation from different source areas.

Resource appraisal

In southeastern Utah ground that appears favorable for significant uranium deposits occurs in several broad belts or channel systems. The Salt Wash member of the Morrison formation is relatively favorable in four belts in the Green River and Henry Mountains districts and in the Cedar Mountain area of the Uinta district. The so-called Moss Back member of the Chinle formation is relatively favorable in the southern part of the San Rafael district and in the Cedar Mountain area. The Monitor Butte member of the Chinle formation is relatively favorable in a broad belt paralleling the northeastern line of pinchout of the unit in the Henry Mountains, Green River, and San Rafael districts, and in the Cedar Mountain area of the Uinta district.

In northwestern New Mexico uraniferous deposits occur in crystalline rocks of Precambrian age, in igneous rocks of Tertiary age, in sandstone of Permo-Triassic, Jurassic, Cretaceous and Tertiary age, and in limestone of Pennsylvanian, Permian and Jurassic age. The deposits in crystalline rocks generally are associated with rare-earth minerals and thorium. Deposits in igneous rocks occur in both acidic and basic intrusive and extrusive rocks, generally along shear zones. Deposits in sandstone have a wide range areally and stratigraphically. In the Permo-Triassic rocks they occur generally with copper minerals in association with carbonized wood. The deposits in Jurassic rocks are mostly at several localities in the Brushy Basin and Westwater members of the Morrison formation and association of the deposits with faults, fractures and folds is suggested. Deposits in sandstones of Cretaceous and Tertiary age are generally associated with carbonaceous materials. The most important deposits in limestone are in the Todilto limestone of Jurassic age, and nearly all are associated with fold structures.

Mineralogic studies

Uranium minerals in the deposits of the Jo Dandy group, Bull Canyon district, Colorado, are partly oxidized above the water table and unoxidized below the water table. There are indications that the oxidizing solutions were acid in the vicinity of carbonized wood, but alkaline or only slightly acid in mineralized claystone.

Analyses of about 400 samples of rocks from Triassic formations indicate that montmorillonite and kaolinite are more abundant in coarser-grained rocks, whereas illite, chlorite, and other clay minerals are more abundant in the finer-grained sediments.

Studies of minerals from the Colorado Plateau and the Wind River Basin, Wyoming, indicate that selenium is related to certain stratigraphic zones, and that cobalt has been introduced by ore solutions. The problem of secondary enrichment is related to the uranium-vanadium content and structural control of the ore deposits.

Geophysical studies

Compilation of aeromagnetic data covering about 20,000 square miles of the Colorado Plateau is about three-quarters completed, and magnetic contour maps of the southern part of the area are being edited. Regional gravity surveys were begun in the Elk Ridge and Orange Cliffs areas, Utah, and others were completed in the La Sal-Lisbon Valley areas, Utah, and the Carrizo Mountains area, Arizona.

The seismic refraction method was used successfully to map the trends of faults hidden by alluvial cover in Lisbon Valley, Utah and the Gas Hills, Wyoming. Experimental electromagnetic measurements made in Lisbon Valley, Utah, and Oljeto Wash, Arizona, indicate that this method may be useful in mapping both hidden fault traces and buried Shinarump channels. Experimental resistivity measurements made in Oljeto Wash indicate that resistivity horizontal profiling may be valuable in mapping buried Shinarump channels under Chinle overburden.

Original-state core studies

In drill holes penetrating ore-grade material in carnotite, blue-black and uraninite terrane of Jurassic and Triassic age maximum resistivity is in sandstone immediately below the ore zone and exceeds the rather high resistivity in sandstone immediately above the ore, whereas in adjacent barren or poorly mineralized areas these resistivity relationships are reversed. Upward passage of ground water through the ore and concentration of salts in the immediately overlying sandstone is indicated.

Uranium in sandstone-type deposits outside the Colorado Plateau

Black Hills uplift, South Dakota and Wyoming

In the southern Black Hills, South Dakota, geologic mapping has resulted in a better understanding of the distribution of the uranium ore-bearing lithologies in the Inyan Kara group. A prominent conglomeratic channel sandstone containing one of the larger uranium deposits in the area has been delineated through parts of six quadrangles. In the southeastern part of the area mapped, a prominent red sandstone which can be used as a marker bed in the middle of the Inyan Kara group has been discovered.

In the Carlile quadrangle, Wyoming, carnotite-type uranium deposits occur at the Carlile mine, and a local unit of massive sandstone in the Lakota sandstone of Early Cretaceous age is mineralized. Concentration of uranium minerals in the sandstone seems to be controlled by carbonaceous seams that locally thicken and coalesce.

Wind River Basin, Wyoming

Core drilling by the Atomic Energy Commission and refraction seismic work by the Geological Survey indicate that the principal mineralized area in the Gas Hills is underlain by a complex basin or series of basins which probably are the result of both pre-Wind River erosion and post-Miocene faulting.

In the Hiland-Clarkson area, east of the Gas Hills, the Wind River formation is divided into three facies: a "lower" variegated claystone and siltstone facies; a "middle" drab claystone and arkosic sandstone facies; and an "upper" conglomeratic sandstone facies. The uranium-bearing sequence in the Clarkson Hill area, which rests unconformably on the Fort Union formation, may be older than the Wind River formation.

Washakie Basin, Wyoming and Colorado

In the Maybell-Lay area, Colorado, uranium deposits occur on the steep north flank of an asymmetrical syncline and are adjacent or in close proximity to normal faults of post-Miocene age, indicating that localization of uranium may have been controlled by these structures. Changes in permeability and porosity of the host rock are also thought to have been important factors in controlling the deposition of uranium.

Recent drilling in the Crooks Gap area, Wyoming, indicates the existence of uraninite(?) bodies at depth, perhaps localized by synclinal structures.

Arizona

Work continued during the report period on field measurements and correlation of the Dripping Spring quartzite in southeastern Arizona and on studies of selected deposits. The abnormally high background radioactivity of the upper member of the formation is caused by its high potassium content. Studies to date indicate that the uranium deposits are genetically related to diabase bodies.

Uranium in veins, igneous rocks, and related deposits

Two major groups of uranium occurrences are known in the Ralston Buttes district, Colorado, where long northwesterly trending fault systems split into relatively wide zones containing complex networks of faults. Most of the deposits appear to be localized where the faults cut Precambrian rock units rich in hornblende, biotite, or lime silicate minerals. The Ralston Creek mine in the northwestern part of the district is the major uranium producer on the eastern slope of the Colorado Front Range.

In the Thomas Range, Utah, several series of silicic volcanic rocks containing as much as 0.009 percent uranium make up the greater part of the range. The uranium occurring in uraniferous fluorspar deposits in carbonate rocks and that in deposits in the volcanic rocks are believed to have been derived from the magma which formed the volcanic rocks during the last stage of crystallization.

Studies designed to relate the leachibility of uranium to petrographic characters of igneous rocks, made on 202 samples of a wide variety of rocks, indicate that uranium content, uranium solubility, and rock solubility are fundamentally controlled by geologic processes affecting the rock during and after crystallization. Results to date show no systematic relation to petrography as a sole controlling variable.

Uranium in carbonaceous rocks

A regional investigation of the higher grade uranium-bearing lignite deposits in the Dakotas and eastern Montana shows that the intensity of mineralization is influenced by shallow post-Oligocene synclinal structures, permeability of strata overlying the host rocks, and proximity of the lignites to the pre-Oligocene erosion surface. Detailed studies of the uraniferous "E" bed in the Riley Pass area of the North Cave Hills, Harding County, South Dakota, indicate that mineralization is spotty and that the bed locally pinches out. The mineralized mudstone at the Lonesome Pete mine in the South Cave Hills is phosphatic, and much of the uranium may be held in the phosphate.

Uranium contents of different oil types have been compared and the content of uranium in the ash appears to be uncontrolled by the oil type. It is suggested that the vanadium, nickel, and nitrogen contents of crude oils are interrelated, and that vanadium and nickel are present primarily in porphyrin complexes. The uranium content is not associated with nitrogen content, and is not present in crude oil primarily in a porphyrin complex.

Airborne radioactivity surveying

Approximately 22,500 traverse miles were flown during the report period in the study of the correlation between airborne radioactivity data and areal geology. The surveys were made in Alaska, Maine, Michigan, Montana, Wyoming, Nebraska, Kansas and Texas.

In Karnes County, Texas a sharp background change of from 220 to 400 c.p.s. across several miles was observed at 500 feet. Results of the flights are being contoured in order to study the relationship between background variations and surface geology.

Analytical service and research on methods

During the report period 21,100 samples were received by the Washington and Denver laboratories. A total of 20,167 samples were processed, and on November 30, 8,776 samples were on hand for analysis.

The spectrographic lead method normally used for the Larsen method of age determinations was expanded to include granite, diabase, and other types of material standards. Work was initiated on a spectrographic standard method to determine the major, minor, and trace elements of certain types of samples. Controlled atmosphere tests were continued on the excitation of samples in a cloud of carbon dioxide, helium or oxygen. This procedure makes available for study a portion of the spectra ordinarily covered by cyanogen bands. Carbon dioxide is the most satisfactory of the gases tested.

A total of 15,426 chemical determinations were made during the report period at the Washington and Denver laboratories. A new volumetric method for determination of uranium was developed, titanous sulfate being used to reduce uranium prior to titration. Nickel and cobalt do not interfere, the acid hydrogen sulfide group need not be removed, and the Jones reductor is eliminated. The new method enables analyses to be made more rapidly than has previously been possible.

Three variations of a direct thoron method for the determination of thorium in ores containing more than one percent ThO_2 and less than 4 percent TiO_2 were developed. The dithizone method for determination of lead in monazite was extended to samples as large as 50 mg and results agree well with independent mass spectrometric determinations.

Geochemical and petrologic research on basic principles

Geologic studies in the West Panhandle field, Texas, indicate that the relatively high concentrations of helium and radon in the natural gases are related to widespread occurrences of epigenetic uranium-bearing asphalt that probably was formed during migration and accumulation of the reservoir fluids and gases.

Spectrographic data indicate that the Silver Plume-type granites of the Colorado Front Range are high in rare earths compared to the differentiated rocks of the Boulder Creek series, and also show high thorium contents.

Reducing capacities of fresh wood, degraded wood, and lignite in vanadium(V) solutions at elevated temperatures and pressures were determined during the period, and it was shown that reduced vanadium minerals may be deposited by reduction with woody material.

In the study of stable isotopes, water was extracted from tektites and the D/H ratio determined. The D/H ratio gives little information as to the origin of tektites, but the low water content (0.002 to 0.007 percent), suggests extra-terrestrial origin.

Mineralogic and petrographic service and research on basic principles

The number of samples handled during the report period was the highest since the inception of the program. More complex minerals appeared, and in particular considerable interest was shown in the multiple oxide types and in thorium minerals. The use of autoradiographs, the visual arc spectroscope, and other techniques increased the information available.

The structural study of uranyl complexes continued with refinement of the structure of liebigite, in which the planar configuration of carbonate groups about the uranyl group in the $UO_2(CO_3)_3^{-4}$ ion was confirmed. A study of the structure of johannite revealed the position of uranium and copper atoms in the crystal. A new vanadium mineral from South Dakota was found to be a primary mineral of trivalent vanadium ($V_2O_3 \cdot 2H_2O$), analogous to montroseite ($V_2O_3 \cdot H_2O$). To facilitate these structure studies, new instrumentation and methods were developed to speed computations. These included the construction of a Fourier Analog computer and the programming of computations on high-speed electronic computers.

Geophysical service and research on methods and principles

In several areas the carborne scintillation counter containing a 3-inch by 1 1/2-inch sodium iodide crystal has been used effectively to locate hidden faults. A scintillation core scanner using four 2-inch by 2-inch sodium iodide crystals shielded by 2 inches of lead was constructed. This instrument is much more sensitive than equipment used previously, making it possible to detect differences of 0.001 percent eU in drill cores.

Radon concentrations in waters from 325 wells in the North Ogden, Utah area appear to be related to possible fault traces and also to the chemical composition of the water. Samples from springs, wells, and streams in the Black Hills of South Dakota show radon concentrations in general agreement with the geologic environments from which they were taken. Water samples from Hillsborough and Polk Counties, Florida, show marked changes in radon concentration with depth in shallow drill holes. Unusually high radon concentrations occur with the uraniferous "leached zone" of the phosphatic Bone Valley formation.

URANIUM IN SANDSTONE-TYPE DEPOSITS IN THE COLORADO PLATEAU

Geologic mapping

Field work was completed prior to this report period in the following areas: Carrizo Mountains, New Mexico; Southwestern Colorado; Monument Valley, Arizona; Monument Valley, Utah; Capitol Reef, Utah; White Canyon, Utah; Red House Cliffs, Utah. During the report period the following reports and maps resulting from these projects were published by the Geological Survey:

Geologic quadrangle (GQ) map 55, Gateway, Colorado, by F. W. Cater, Jr.,
GQ map 57, Atkinson Creek, Colorado, by F. W. Cater, Jr.,
GQ map 58, Red Canyon, Colorado, by E. J. McKay,
GQ map 59, Gypsum Gap, Colorado, by F. W. Cater, Jr.,
GQ map 60, Pine Mountain, Colorado, by F. W. Cater, Jr.,
GQ map 61, Calamity Mesa, Colorado, by F. W. Cater, Jr.,
GQ map 64, Horse Range Mesa, Colorado, by F. W. Cater, Jr.,
GQ map 65, Naturita, Colorado, by F. W. Cater, Jr.,
GQ map 66, Joe Davis Hill, Colorado, by F. W. Cater, Jr.,
GQ map 68, Egnar, Colorado, by F. W. Cater, Jr.,
GQ map 69, Hamm Canyon, Colorado, by F. W. Cater, Jr.;
Bulletin 1009-H, Geology of the Happy Jack mine, White Canyon area, San Juan County, Utah, by A. F. Trites, Jr., and R. T. Chew, III.

During the report period field and office work was continued on the following geologic mapping projects:

Gateway, Colorado; Western San Juan Mountains, Colorado; Sage Plain, Utah-Colorado; Ute Mountains, Colorado; Laguna, New Mexico; Grants, New Mexico; East Vermillion Cliffs, Arizona; La Sal Creek, Utah-Colorado; Lisbon Valley, Utah; Moab-Inter-river area, Utah; Elk Ridge, Utah; Abajo Mountains, Utah; Orange Cliffs, Utah; San Rafael Swell, Utah; and Circle Cliffs, Utah. The location of these projects is shown on figure 1 .

The principal objective of these projects is to obtain data on guides to, and controls of, uranium deposits, leading to prediction of ground favorable for the discovery of concealed deposits. Geologic mapping is a necessary means to this end, and will also lead to a better plateau-wide understanding

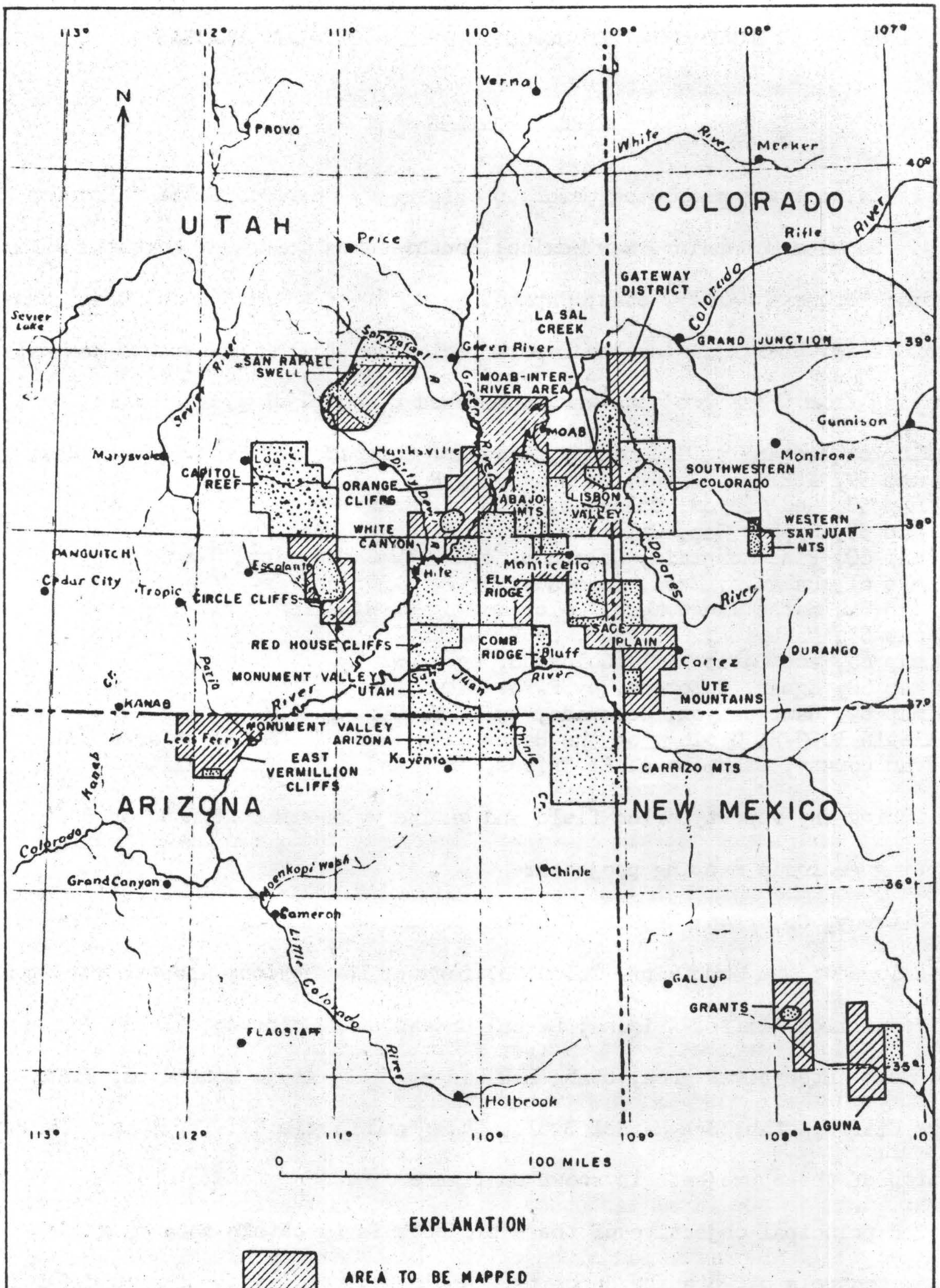


Figure 1-- INDEX MAP OF PART OF THE COLORADO PLATEAU SHOWING LOCATION OF MAPPING PROJECTS

of major geologic features pertinent to the localization of uranium districts, "trends," or areas.

Southwestern Colorado area

Areal mapping of eighteen 7-1/2 minute quadrangles within the Uravan Mineral belt in southwestern Colorado (fig. 1) was completed in 1952. Detailed surface mapping of selected areas, mine mapping, field and laboratory research on the origin and controls of uranium deposits, and drilling has been continued in these quadrangles. During the report period drilling in the Uravan district was completed, the final drilling project in the Bull Canyon district was started, and drilling continued in the Slick Rock district. Geologic investigations have been continued in the Gateway district and in the three districts where drilling was in progress.

Bull Canyon district, by R. M. Wallace

Most of the uranium-vanadium deposits in the Bull Canyon district occur in the Salt Wash member of the Morrison formation. Both oxidized and unoxidized deposits are being mined in the district. Uranium minerals usually occur as oxides, and the vanadium minerals either as oxide complexes or silicates. Iron occurs as sulfides, oxides, hydroxides, carbonates, and vanadates. Trace element studies show that lead, zinc, copper, selenium, molybdenum, silver, tin, and barium are associated with the uranium. Petrogenesis studies are continuing.

Two mines in the basal sandstone of the Salt Wash member in Hamm Canyon, and two mines in the upper sandstone of the Salt Wash member in Bull Canyon were mapped and detailed studies of mineralogy and sedimentary structures within and bordering the deposits are being continued. Preliminary results of these mine studies indicate that the deposits in the basal sandstone are diffused, low grade, and show only indefinite relations to sedimentary structures. Deposits in the upper sandstone are commonly associated with sedimentary structures such as cross and festoon bedding. These deposits appear to be more localized, and contain a higher percentage of uranium than those in basal sandstone.

Slick Rock district, by D. R. Shawe

The Slick Rock district is in the western parts of San Miguel and Dolores Counties, Colorado, and comprises an area of about 500 square miles. Principal uranium-vanadium production is from a thick continuous sandstone layer near the top of the Salt Wash member of the Morrison formation of Jurassic age. Sandstone considered favorable for ore is light gray or light brown, contains abundant carbonaceous material, and is underlain by gray-green mudstone lenses as contrasted with the brown, and red-brown colors of unfavorable Salt Wash sandstone and mudstone.

Sketch sections of about 8 miles of rim exposures indicate that indefinite contacts exist between the Salt Wash and Brushy Basin members of the Morrison formation, and between the Brushy Basin member and the Burro Canyon formation. Stratigraphic studies indicate the absence of an erosional interval between the Burro Canyon and Dakota formations in the district, and the presence of several erosional intervals in the Burro Canyon formation.

Special studies, including investigations of the distribution of carbonate in the Salt Wash member, fractures in the Slick Rock district, and stratigraphic study of all the formations exposed in the Slick Rock district were continued. Principal results of the carbonate study are: (1) carbonate may be a useful ore guide because concentrations of carbonate are spatially related to ore bodies; (2) acid-bottle tests permit an accurate evaluation of the carbonate content of the principal rock types of the Salt Wash, including light red-brown sandstone, light gray sandstone, light gray-green mudstone, and red-brown mudstone; (3) each of the principal rock types in the top unit of the Salt Wash contains an average of about 3 percent carbonate, except red-brown mudstone which contains about 7 percent carbonate; (4) no relationship is apparent between variations in concentrations of uranium and vanadium and variations in concentration of carbonate; (5) no relationship is apparent between permeability and carbonate content; (6) local areas on the Colorado Plateau may have predominately different carbonate types, such as calcite in Disappointment Valley, dolomite in the Legin area, and dolomite, siderite, or ankerite in the Uravan area; (7) carbonate was probably redistributed during mineralization as shown by the higher-than-average amounts of carbonate in altered (light-gray) sandstone near mudstone contacts, the apparent depletion of carbonate in altered (gray-green) mudstone relative to unaltered (red-brown) mudstone, and the concentration of carbonate near ore bodies; and (8) oxidation probably caused little redistribution of carbonate as indicated by the similarity of distribution of carbonate around both oxidized and unoxidized ore bodies.

Fracture studies indicate that the attitude, spacing, and orientation of fractures in the Slick Rock district are different in different formations; this may reflect different origins for some fractures.

Uravan district, by R. L. Boardman

The Survey's program of exploration and related geologic studies in the Uravan district, Montrose County, Colorado, started in 1948 and continued through November 30, 1955. The Survey completed its diamond-drill exploration in the district on August 20, 1955. Since 1948, the Survey has drilled about 3,225 holes totaling approximately 1,300,000 feet in the district. Nearly all of the significant uranium-vanadium deposits found by this drilling, as well as the principal mines in the district, are in sandstone lenses in the upper part of the Salt Wash member of the Jurassic Morrison formation.

Detailed geologic surface and mine studies completed in the northwestern Long Park area in the Uravan district indicate no genetic relationship between faults in the area and the early ore minerals. All faults that intersect the ore bodies here displace the ore layers. Brecciated ore material is common in the fault gouge. In several places, uranium and vanadium apparently have been leached from faulted ore layers and redeposited in fault zones and along joint surfaces.

During the summer and early fall of 1955 about 25 square miles were mapped along the southwestern flank of the Uncompahgre Plateau in the northeastern part of the district. Sedimentary rocks ranging in age from Triassic to Cretaceous are exposed and sharply folded along the southwestern edge of the Uncompahgre Plateau and are broken by numerous northwest-trending strike faults. Particular attention was given to the Salt Wash member of the Morrison formation and to the detailed structures affecting this member. Where exposed in this area the uppermost part of the Salt Wash consists of one or more sandstone lenses that total from 10 to 80 feet in thickness. These sandstone lenses are similar in appearance and characteristics to upper Salt Wash sandstone lenses elsewhere in the district. Carbon and green mudstone are present locally in the sandstone lenses. Ripple marks, current lineations, and cut-and-fill structures are common in the sandstone. No traces of uranium and vanadium minerals have been found, however. The Kayenta formation of Jurassic (?) age is absent in most of the northeastern part of the Uravan district and where present is only a few feet thick. The eastern edge of deposition of Kayenta sediments appears to cross the western part of the district.

A paper, "Sedimentary features of upper sandstone lenses in the Salt Wash member and their relation to uranium-vanadium deposits in the Uravan district, Montrose County, Colorado", by R. L. Boardman, E. B. Ekren, and H. E. Bowers, was published in the Proceedings of the United Nations International Conference of the Peaceful Uses of Atomic Energy.

Western San Juan Mountains, Colorado

by

A. L. Bush

The Western San Juan Mountains geologic mapping project comprises an area of about 300 square miles, consisting of the following five 7-1/2 minute quadrangles: Placerville, Little Cone, Gray Head, Dolores Peaks, and Mt. Wilson. The principal objective of the mapping project is to relate the vanadium-uranium deposits of the Placerville district to the base and precious metal deposits and the extrusive and intrusive igneous rocks of the San Juan volcanic province.

During the report period, geologic mapping was concentrated in the Little Cone quadrangle, which is now 50 to 60 percent completed. Underground mapping of auriferous pyrite replacement deposits in limestone in the Placerville district was continued; these deposits are spatially related to the vanadium-uranium deposits.

The sedimentary rocks of the Placerville district have been broadly warped into northwest-trending folds which appear to be continuous with the "salt anticlines" of southwestern Colorado and southeastern Utah. The sedimentary rocks have been intruded by numerous sills that range in thickness from a few feet to several tens of feet. Stock-like intrusives also cut the sedimentary beds. Most of the intrusive rocks are andesites and diorites, and probably represent a single period of intrusion. Some of the sills extend for several miles from the nearest known stock-like bodies. In some places the Mancos shale, the major host of the concordant intrusives, has been baked and converted to a hornfels near the intrusives, but generally the effects of contact metamorphism are absent. Most of the igneous activity is probably of mid-Tertiary age, but volcanism at least as young as the Pleistocene, and possibly younger, is indicated by a basaltic lava that flowed over upland surfaces that were formed at the end of the Tertiary. The vanadium-uranium deposits are offset by faults that are tentatively dated as mid-Tertiary or younger.

Ute Mountains, Colorado

by

E. B. Ekren

Mapping of the Ute Mountains laccolithic complex began in June 1955 to provide information on possible relations of uranium deposits to the igneous intrusions; one 7-1/2 minute quadrangle (Sentinel Peak NW) was completed during the report period. Samples of sediments and intrusive rocks were collected for thin-section study and chemical analysis.

A study of the uranium deposits of the Ute Mountains area, Montezuma County, Colorado, was completed. Two types of deposits were found: (1) deposits localized along faults and (2) bedded deposits. Commercial ore has not been found in either type. Faults containing radioactive material are located near the crest of the McElmo dome north of McElmo Creek in the northern portion of the project area. Most of the faults appear related to the McElmo dome structure.

Mapping of the Dakota and Burro Canyon formations of Cretaceous age and the Brushy Basin member of the Morrison formation of Jurassic age has shown a general northeast-trending pattern of faults and gentle domes on the southwestern flank of the Ute Mountains. Reconnaissance of the southern and southeastern flanks of the mountains indicates that doming was active there also. The faulting and folding appear related to intrusion of the laccoliths.

As a result of stratigraphic studies of the lower part of the Mancos shale of Cretaceous age southwest of the Ute Mountains, three fossil or lithologic zones can be recognized. These marker beds will be useful in making a structural interpretation of the Ute complex.

Gateway district, Colorado and Utah

by

L. J. Eicher

Work in the Gateway district consists of two parts: (1) a comprehensive study of the geology and ore deposits of the western part of the district compiled from surface and subsurface data, and (2) geologic mapping of four 7-1/2 minute quadrangles in the northwestern quarter of the Gateway 15-minute quadrangle.

The western part of the Gateway district is west of the Dolores River on the northeast flank of the La Sal Mountains and on the southwest flank of the Sagar's Wash syncline. The town of Gateway, Colorado, is on the eastern boundary.

During the report period field work was completed in the western part of the district, except for field checking, on the mapping of formational contacts on aerial photos, measurement of columnar sections, examination of mines and prospects, and detailed mapping of selected mines. Formations mapped include the Entrada, Summerville, and Morrison formations of Jurassic age, the Burro Canyon and Dakota formations of Cretaceous age, and gravels and alluvium of Quaternary age.

Mapping and exploratory drilling disclosed that Lumsden Canyon, which transects the major uranium-vanadium producing area in the western part of the Gateway district, developed along a vertical fault zone. The fault zone strikes N. 70° to 80° E., and beds have been displaced as much as 90 feet.

Sage Plain area, Utah and Colorado

by

L. C. Huff

During the report period geologic mapping was completed in eight 7-1/2 minute quadrangles in the Sage Plain area. Rocks exposed in the Sage Plain are flat-lying, and range from the Navajo sandstone of Jurassic age to the Mancos shale of Upper Cretaceous age. Pediment gravels and loess of Pleistocene age mantle the upland extending from Monticello, Utah, to Dove Creek, Colorado. A summary description of the character, distribution, and thickness of these formations is given in table 1.

Private interests were actively prospecting in the Sage Plain during the past year. Previously, uranium deposits were known to occur only in the Salt Wash member of the Morrison formation, but during the report period private interests developed new uranium deposits in the Brushy Basin member of the Morrison formation in the Aneth 1NW quadrangle. These deposits consist of uraniferous claystones and concretionary mudstones about 150 feet below the top of the Brushy Basin member and about 20 feet beneath a lens of Brushy Basin conglomerate.

Table 1 .--Generalized stratigraphic section of rocks exposed in the Sage Plain area, Colorado-Utah

System	Series	Formation	Thickness (feet)	Description	Distribution
Quaternary	Pleistocene and Recent (Wisconsin and later)	Alluvium	0-50	Silt and sand, some interbedded gravel.	Forms alluvial plains and low terraces along major streams.
		Loess	0-50	Well-sorted, red silt, overlies deeply-weathered soil zone developed on older rocks.	Forms agricultural soils on upland.
	Pleistocene (pre-Wisconsin)	Pediment gravel	0-50	Boulders, cobbles, and pebbles in sandy matrix.	Forms upland surface near Monticello; locally underlies loess.
		---Unconformity---			
Cretaceous	Upper Cretaceous	Mancos shale	0-200±	Gray marine shale, prominent Gryphea zone near base.	Forms gentle hills above upland surface.
		Dakota sandstone	50-150	Brown sandstone, carbonaceous claystone, coal; plant fossils abundant. Thin conglomerate locally at base.	Crops out at crest of "rim rock" cliff which separates upland from canyons.
		---Unconformity---			
	Lower Cretaceous	Burro Canyon formation	20-150	Light-colored, conglomeratic sandstone; greenish mudstone; silicified sandstone and limestone locally at top.	Forms "rim rock" cliff which separates upland surface from canyons.
Jurassic	Upper Jurassic	Morrison formation: Brushy Basin member	250-430	Varicolored mudstone; some sandstone and conglomerate lenses. Contains vanadium-uranium deposits.	Forms slope below upland and above steep-walled inner canyons; generally covered with colluvium.
		Morrison formation: Westwater Canyon member	0-120	Yellowish and greenish gray lenticular sandstone and interbedded mudstone.	Forms intermediate slope below gentle Brushy Basin slope and above Salt Wash Cliffs in southern half of area. Member grades northward into Brushy Basin member.
		Morrison formation: Salt Wash member	200-450	Light-colored, lenticular sandstone interbedded with reddish siltstones and mudstone. Contains vanadium-uranium deposits.	Forms series of steep cliffs and narrow benches of inner canyons.
		Junction Creek sandstone	0-255	Light-brown, massive, cross-bedded sandstone.	Forms steep cliff only in Yellow Jacket canyon in eastern part of area.
		Summerville formation	90-110	Even-bedded, reddish sandstone interbedded with reddish siltstone and mudstone.	Forms step-like slope below Salt Wash cliffs.
		Entrada sandstone	115-165	Massive, crossbedded, yellowish sandstone.	Forms rounded cliffs along base of canyon walls in upper Montezuma canyon and its tributaries.
	Middle and Upper Jurassic	Carmel formation	45	Irregularly bedded, red mudstone and sandstone.	Crops out in Upper Montezuma canyon.
		---Unconformity---			
Jurassic and Jurassic?		Navajo sandstone	26+	Light-colored, massive, crossbedded sandstone.	Scattered outcrops in upper Montezuma canyon near Verdure fault and along Montezuma Creek.

Geologic mapping has been completed in eight 7-1/2 minute quadrangles, and mapping of the remaining seven quadrangles is planned for the next field season. A detailed geologic and geochemical study of the productive mines of the middle Montezuma Canyon, with some coordinated core drilling to obtain subsurface information and samples, is also planned.

La Sal Creek area, Utah-Colorado

by

W. D. Carter, J. L. Gualtieri, and J. C. Warman

The La Sal Creek area, comprising about five 7-1/2 minute quadrangles, is in parts of Grand and San Juan Counties, Utah, and Montrose County, Colorado (fig. 1). During the report period the geology of about 220 square miles or 80 percent of the area was mapped on aerial photos and will be transferred to topographic maps as they become available. These maps will show the distribution of the rocks, tectonic structures, and ore deposits of the La Sal Creek area.

Consolidated sedimentary rocks of Triassic, Jurassic, and Cretaceous age that are exposed in the area are intruded by igneous rocks of Tertiary age. Most of the sedimentary rocks are continental deposits of mudstone, sandstone and conglomerate. Contacts between most of the various formations are, in general, well established and common criteria that distinguish one formation from another are recognized by most geologists on the Colorado Plateau. However, the contact between the Cretaceous Burro Canyon and Dakota formations is not easily recognized and the correlation of these two formations from place to place is difficult. The criteria that distinguish these two formations in the La Sal Creek area are summarized below.

The Burro Canyon formation of Lower Cretaceous age consists of two units: (1) a basal unit, about 110 feet thick, composed of light gray to light brown, crossbedded sandstone containing pebble conglomerate lenses which conformably overlies the variegated shale and mudstone layers of the Brushy Basin member of the Jurassic Morrison formation, (2) an upper unit, about 140 feet thick, composed of light green mudstone, siltstone and shale containing thin beds of siliceous limestone, chert, and quartzite. A light gray quartzite bed, a few feet thick, marks the top of the upper unit.

A regional unconformity, noted by geologists for many years, separates the Burro Canyon and older formations from the overlying Dakota formation. The base of the Dakota has been described (Coffin, R. G., Colo. Geol. Survey Bull. 16, 1921) as "the sandstone or conglomerate which underlies the lowest carbonaceous shale or coal horizon". In the La Sal Creek area, the Dakota sandstone and conglomerate fills broad depressions (channel scours) in the surface of the Burro Canyon formation. These depressions may be as much as 180 feet deep and several thousands of feet wide. Angular and subangular pebbles, cobbles and boulders of sandstone, chert and quartzite, derived from the Burro Canyon formation, have been found in the basal portion of the Dakota sandstone and conglomerate. The presence of these fragments of Burro Canyon lithology in the basal sandstone and conglomerate of the Dakota indicates that the Burro Canyon formation was lithified prior to erosion and deposition during Dakota time. Carbonaceous material and plant impressions, usually associated with the Dakota formation, are present in this sandstone and conglomerate unit which interfingers with and grades upward into "the lowest carbonaceous shale or coal horizon" and forms a logical base in the sedimentary sequence of Dakota deposition. The features and relations of the Burro Canyon-Dakota contact, described herein, may be of use to other geologists mapping the Cretaceous rocks of the Colorado Plateau.

Portions of two major structural features have been mapped, one along the west border of the area and the other along the east border. Along the west edge of the area the sediments have been folded into anticlinal domes by the intrusion of stocks and laccoliths of the La Sal Mountains in early Tertiary time. Structural irregularities in these regional domal structures are mapped as steeply plunging anticlinal noses with sedimentary beds dipping gently on the flanks and dipping steeply on the distal ends. These structures are believed to have been formed by laccolithic lobes of igneous rock projecting at depth from one or more of the La Sal Mountain stocks. The east edge of the area is bordered by the collapsed salt anticlines of Paradox Valley. This grabenlike structure was formed by the intrusion and later withdrawal of salt. Complex step faults have been mapped along both sides of the "graben", and faults, transverse to the regional structure, have been mapped in the northwest end of the "graben". All faults are believed to be the result of the solution of salt by Recent streams. Between the major structures bordering the east and west sides of the area, the sediments are gently folded into anticlines and synclines. The axes of these structures are somewhat sinuous and reflect the interplay of tectonic forces which formed the Paradox anticline and the La Sal Mountain anticlinal domes. Near Paradox Valley the axes trend northwest paralleling the axis of the major structure and near the mountains these axes swing westward and coalesce with the mountain structures.

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 of the Salt Wash member. These deposits are concentrated in an elongate patch or belt of favorable host rock that is a few thousand feet wide and at least six miles long. This favorable belt, trending east-northeast, represents a zone of major Salt Wash sandstone deposition, for the sandstone beds comprising this upper unit have an aggregate thickness of 90 feet in many places. Where the sandstone is unfavorable to ore deposits it is usually less than 30 feet thick. Recent discoveries of mineralized ground north of the known favorable area and near the La Sal Mountains, in addition to outcrops of favorable host rock noted in the course of mapping, indicate the possibility of at least three additional favorable areas in the La Sal Creek area. Trends of sedimentary structures in the ore-bearing sandstone measured throughout the area indicate that these favorable areas will roughly parallel the belt discovered along La Sal Creek. The distribution of ore deposits in this region bears no obvious relation to the major structures or igneous rocks; however, the ore deposits are closely related to sedimentary features in the Morrison formation.

Lisbon Valley area, Utah-Colorado

by

G. W. Weir

The project includes about 750 square miles in northeastern San Juan County, Utah, and adjacent counties in Colorado. The geology of about 75 percent of the area has been mapped on aerial photos and is being transferred to topographic base maps.

Much field study was given to stratigraphic problems that must be solved to work out detailed structure which may be important in appraising the uranium potential. The unconformity at the base of the Upper Cretaceous Dakota sandstone was found to be marked by a distinctive basal conglomerate in part derived from the underlying Burro Canyon formation of Lower Cretaceous age.

Relief due to channeling at this contact exceeds 50 feet but regional angular unconformity with the Burro Canyon has not been verified.

Quartzite (silicified sandstone) is the dominant rock type in the Burro Canyon formation along and north of Lisbon Valley but is uncommon in the southern part of the area. The silicification is pre-Upper Cretaceous as shown by the cobbles and boulders of quartzite in the basal conglomerate of the Dakota. Thus, the age and distribution of the quartzite make it unlikely that the silicification is related either to the Lisbon Valley fault or to the igneous rocks of South Mountain as suggested by the writer in a previous report (TEI-540). The age and distribution of the silicified rocks does not appear to correspond to the most probable ages and distribution of known ore deposits.

The Jurassic Carmel formation contains some sandstone identical to typical Entrada sandstone. The Carmel-Entrada contact in the southwestern part of the area must be revised.

The lower Chinle, which contains large uranium ore deposits along Big Indian Wash, is in places not a distinct unit readily separated from the overlying Chinle. The base of the lowest persistent red sediments is tentatively regarded as the best contact for mapping the division of the Chinle.

Erosion prior to deposition of the Chinle removed the Moenkopi formation and part of the Cutler formation along Big Indian Wash. The unconformity at the base of the Chinle commonly shows about 3° angular discordance with the underlying Cutler. Uranium prospects in the Cutler are at different stratigraphic horizons but are about the same distance below the unconformity.

The Lisbon Valley fault system is the main structural feature of the middle part of the area. Near the Rattlesnake Ranch the fault splits into northerly and northwesterly trending segments. The northwesterly trending segment is more persistent and can be traced as a fault zone to the vicinity of Muleshoe Wash. Displacement along the fault decreases northwestward from near Lisbon Canyon where the Mancos formation of Upper Cretaceous age abuts the Hermosa formation of Pennsylvanian age. Many manganese prospects are known in the northwest end of the fault system and copper mines and prospects are common along the fault near Lisbon Valley. Two large uranium deposits, the Rattlesnake mine in the Morrison formation in the northwest central part of the area, and the School Section No. 36 mine in the Chinle formation in the southeast part of the area occur within the fault system. Practically all the copper and manganese deposits are clearly localized by the faulting but the uranium deposits do not show a demonstrable genetic relation to the faults.

Geochemical work done during the 1955 field season consisted mainly of studying the distribution of copper near the Lisbon Valley fault. In addition, soil and stream sediment samples were collected near outcrops of vanadium ore in the Salt Wash member of the Morrison formation and core samples were collected from 12 drill holes located at various distances from uranium deposits in the Chinle formation.

The background concentration of copper in the stream sediments of the Lisbon Valley area is about 10 ppm by semiquantitative field tests. Analyses of stream sediments near known copper deposits suggest that copper concentrations of 30 to 40 ppm or higher are probably anomalous. Most of the sediment sampling was done between the Big Indian copper deposit at the north end of Big Indian Wash and the Pioneer copper mine near the south end of Lisbon Valley. Further sampling will be done to determine the distribution of copper both to the northwest and southeast of the area so far studied. Both uranium and copper deposits near the Lisbon Valley fault system are being studied in detail to determine possible inter-relations.

The soils and stream sediments from near vanadium ore, as well as the drill core collected, have not yet been analyzed. The soils and stream sediments are to be used to determine the mineral fraction in which vanadium travels away from its source. The core samples will be used in a study of the distribution of trace elements around uranium deposits in the Chinle formation.

Moab and Inter-River areas, Utah

by

E. N. Hinrichs

Mapping and geologic studies in the Moab area, begun in June 1954, were continued during the field season of 1955. During the report period the geology of about 137 linear miles of Triassic rocks was mapped on air photos. This completes this phase of the work in the Moab area. The Triassic section in the Moab area consists of the following formations in ascending order: Moenkopi formation, Chinle formation, and the Wingate sandstone. The Chinle formation in the Moab area has been tentatively divided into four mappable members which are from the bottom up: the Monitor Butte, the so-called Moss Back, the Owl Rock, and the Church Rock.

Twelve channels or groups of small channels cut into the Moenkopi formation and filled with conglomeratic sandstone of the so-called Moss Back member of the Chinle formation were found during the 1955 field season. These channels range in depth from 5 to about 15 feet and in width from 15 to 140 feet; they do not have a common orientation. Three of the channels contain economic uranium deposits. Abnormal radioactivity was found at only one of the remaining channels. At this locality small amounts of a light-colored fine-grained mineral fill narrow fractures in gray-green Moenkopi within two feet of the Chinle contact.

Mines and prospects in the Rico, Cutler, and Chinle formations were examined and sampled and several were mapped by plane-table and Brunton-and-tape methods. Mapping near Indian Creek suggests that two large-scale features may influence the localization of the recently discovered ore deposits in channels in the so-called Moss Back member of the Chinle formation. First, the ore-bearing channels filled with permeable sediments of the so-called Moss Back member are in the lowest part of a broad structural low; and second, the ore-bearing channels are in an area where the so-called Moss Back within a relatively short lateral distance is characterized by abrupt changes in thickness. Minerals collected from one of the two producing mines have been tentatively identified in the field as uraninite, beta-zippeite, erythrite, and ilsemannite.

In most of the area the Cutler formation is composed of dark colored sandstone or conglomerate in shades of brown, red, and lavender. Locally, however, these sediments are colored gray or gray-green. These zones of light-colored rock are generally parallel to bedding and may be caused by several agents. Many of these "bleached" areas are slightly radioactive and are on minor structural noses or terraces.

Orange Cliffs area, Utah

by

F. A. McKeown and C. C. Hawley

Field work in the Orange Cliffs area (fig. 2) in the eastern parts of Garfield, Wayne, and Emery Counties, started in the latter part of July and was terminated October 31. During this time about 175 square miles were mapped geologically on topographic base maps at a scale of 1:24,000.

Rocks ranging from the White Rim member of the Cutler formation of Permian age to the Navajo formation of Jurassic age crop out in the mapped area. The units just above the Moenkopi formation, however, are of principal interest because: (1) they are the only rocks in the Orange Cliffs area known to contain uranium; and (2) a knowledge of their continuity and facies changes is necessary to interpret part of the geologic history of the area and predict areas favorable for uranium deposits. Both the so-called Moss Back and the Monitor Butte members of the Chinle formation are recognized in the Orange Cliffs area; they were formerly mapped as the Shinarump conglomerate. The Monitor Butte member pinches out in a zone that trends northwest from the vicinity of Sunset Pass at the head of South Hatch Canyon. The so-called Moss Back member grades into limy and sandy siltstones and discontinuous limestone pebble conglomerates in the vicinity of the mouth of Hatch Canyon, especially South Hatch Canyon. This area of little or no typical so-called Moss Back appears to be roughly circular and about 5 miles in diameter (fig. 2). In all directions away from it within the Orange Cliffs area the so-called Moss Back is present and is generally blanketlike with only a few well-defined channels. Uranium occurs in either the Monitor Butte or the so-called Moss Back members, whichever is the closer to the Moenkopi.

The Orange Cliffs area is on the outermost, gentle northwest-dipping part of the nose of the Monument upwarp. A structure contour map, with a contour interval of 50 feet, shows several minor structures on the flank of the upwarp. In Happy Canyon two structural terraces are superimposed on the regional northwest dip. About 5 miles south of Elaterite Basin, an anticline whose axis trends northeast and with a closure of about 50 feet, may be present. This latter feature is at the limit of the mapped area and more detailed work is necessary to determine accurately the shape, closure and size of the anticline. Possible relationship of these fold structures to uranium deposits will remain obscure until more information is obtained.

In North and South Hatch Canyons many small westerly trending faults are aligned en echelon to the northwest. This is parallel to the direction of all other known faults and the major set of joints in the Orange Cliffs area. A few of the faults contain a little asphaltic material, but no faults are known to be radioactive or to have uranium or copper minerals.

Altered rock is common in most formations throughout the area, though the type and amount of alteration may differ from place to place. Generally six types of altered rock are recognized. These are given descriptive names and briefly tabulated in table 2:

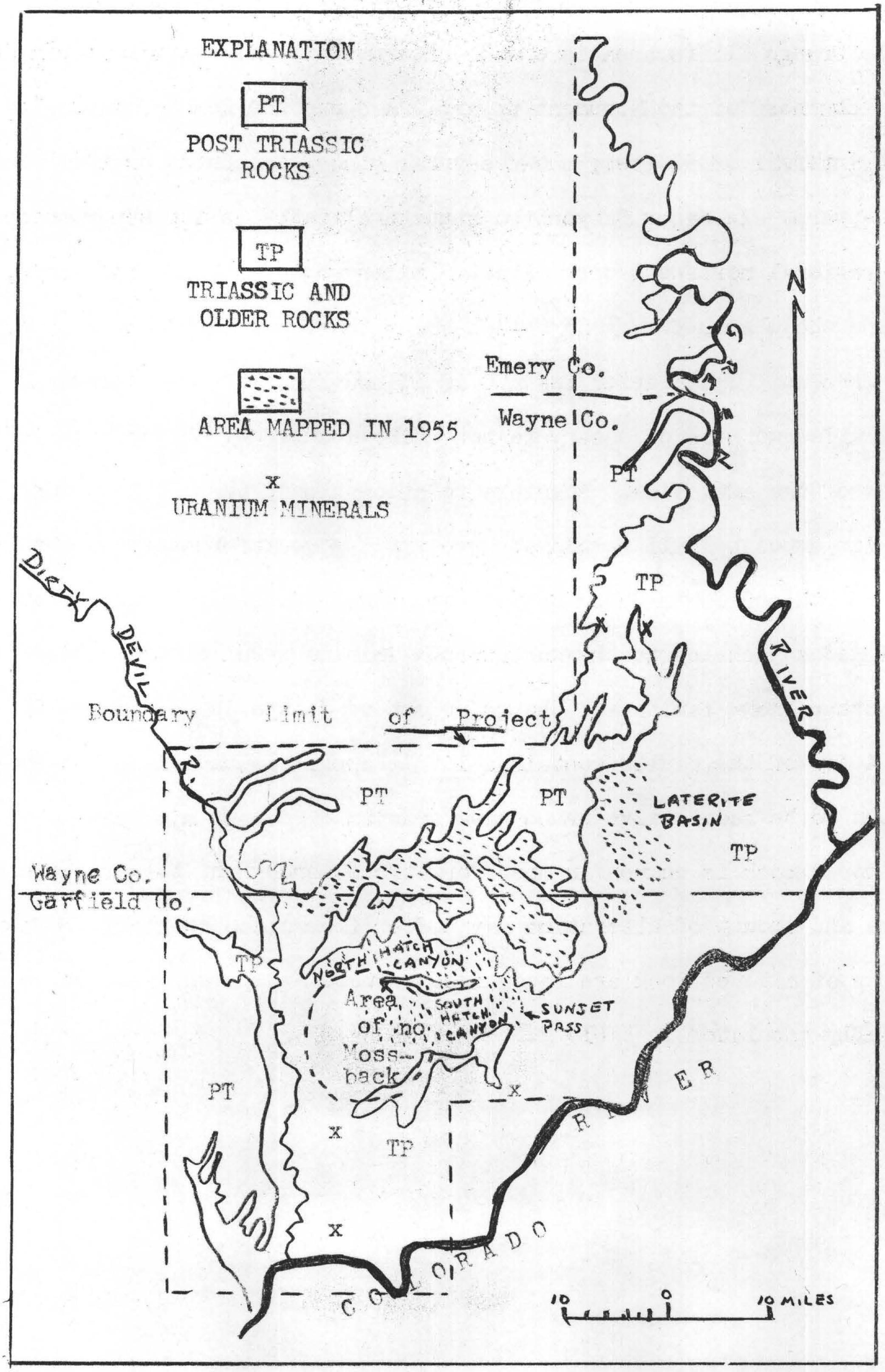


FIGURE 2. INDEX MAP OF THE ORANGE CLIFFS AREA, UTAH

Table 2. Types of altered rock in the Orange Cliffs area

Name	Description	Principal occurrence
Purple-white	Clayey and sandy siltstones whose color is changed from brownish red to purple and greenish white. The colors are commonly in a mottled pattern.	Commonly at the top of the Moenkopi formation.
Gray-green	Red or gray claystone and siltstone that has been changed to a gray-green color.	Just below many sandstones. In particular, a gray-green zone is everywhere present under the so-called Moss Back unit of the Chinle formation.
Red-buff	Red sandstone and siltstone that has been bleached to buff.	Along joints and bedding planes in the Moenkopi formation and Organ Rock tongue of the Cutler formation.
Speckled	Specks, about 1/16 to 1/8 inch across, of limonite in sandstone.	At and near uranium occurrences in the vicinity of the south end of South Block.
Pink	Sandstone with anomalous pink shade.	At uranium occurrences in the southern part of the Orange Cliffs area.
Silicification	Sandstone cemented with silica and sandstone or siltstone with flat nodules or discontinuous layers of red and yellow chert. The chert commonly contains a little chalcocite, chalcopyrite, and secondary green copper minerals.	Generally in the base of the so-called Moss Back unit and in purple-white zones; where purple-white is not present chert is rare.

A suite of purple-white altered rocks were analyzed for iron. The analyses show that the purple parts contain 2 to 3 times (about 7 to 10 percent) as much iron as the white and red parts. However, there is no significant difference in the iron content or ferrous-ferric ratio between the red and white parts.

Although the relation of the various types of altered rock to uranium occurrences is obscure, the speckled and pink alteration seem to be directly related to uranium because the only known outcrops of such altered rock in the Orange Cliffs area are at or near uranium occurrences. The significance of the other types of alteration is not known.

Commercial uranium deposits have not been found, but uranium and copper minerals occur at many places in the Orange Cliffs area. Specimen quantities of uranium minerals occur in the Monitor Butte and so-called Moss Back members of the Chinle formation and in chert in purple-white altered rock just below the so-called Moss Back. A little torbernite occurs in Happy Canyon and a radioactive yellow mineral (probably carnotite) is present at several occurrences south of South Block. Some carbonized wood is uraniferous.

Traces of copper minerals are commonly present at the basal contact of the Chinle formation. In places they are associated with uranium minerals but most rock containing copper minerals is not radioactive. Secondary copper minerals are the most abundant; chalcocite and chalcopyrite occur in chert. Manganese oxide(?) is generally associated with secondary copper minerals.

The southern part of the Orange Cliffs area seems more favorable for the discovery of economic uranium deposits than other parts because uranium minerals are more abundant, and the intensity of most types of rock alteration seems greater. Further, it may be significant that in the southern part of the Orange Cliffs area, the rocks begin to dip more steeply toward the Henry Basin and superimposed on this structural change is the pinchout-zone of the Monitor Butte member of the Chinle formation; the facies change of the so-called Moss Back is also in this area.

San Rafael Swell area, Utah

by

R. C. Robeck and H. B. Dyer

During the report period work was concentrated on the southwestern part of the San Rafael Swell between Green Vein Mesa and Chimney Canyon, which is about 5 miles northwest of the Delta mine. Data from the field are being compiled in the office.

In the area mapped, the Chinle formation can be divided into four units. In ascending order they are the "mottled siltstone" units, the Monitor Butte member, the so-called Moss Back member and the Church Rock member.

The mottled siltstone unit is present in about 80 percent of the area mapped. In the southern part of the area the unit averages about 5 feet thick and is composed mostly of silt, but toward the north it thickens slightly and contains several sandstone-filled channels whose axes trend north. The unit is too thin to be differentiated on the map.

The Monitor Butte member averages about 70 feet thick in the southern part of the area and pinches out in the northern part of the area. Local variations in thickness are due to "channels" at the base of the overlying so-called Moss Back member. The Monitor Butte member is composed mostly of shale and mudstone, but it also contains two northeast trending sandstone lenses, from one of which uranium ore was shipped.

The so-called Moss Back member is highly variable in thickness and locally fills channels scoured in underlying formations. Some channels are discontinuous spoon-shaped depressions while others are continuous for at least 1,000 feet along the outcrop. Uranium ore has been produced from five channels.

The Church Rock member is about 150 feet thick in the area mapped. In the north it contains many thin sandstone lenses. Uranium ore has been mined from one of the sandstone lenses in and near a collapse structure.

Northwest trending analcite diabase dikes crop out in the southern part of the mapped area. They are not present in or adjacent to any known uranium deposits. It seems unlikely that they could have been the source of the uranium in the deposits.

Uranium minerals occur in all members of the Chinle formation. The mottled siltstone unit is locally radioactive but no ore production seems likely from this unit. Although many of the exposed sandstone lenses in the Monitor Butte member contain relatively small amounts of uranium ore, concealed lenses offer the promise of larger quantities, for the large deposit at the Delta mine is in a sandstone lens in the Monitor Butte member.

The best guides to ore in the southern 80 percent of the mapped area are deep channels filled with so-called Moss Back sediments. The three largest mines occur where the so-called Moss Back member has channeled out 20 to 40 feet of the underlying Monitor Butte member and rests on the mottled siltstone unit of the Moenkopi formation. Some ore has been produced from shallower channels but not in significant quantities. Although both deep and shallow channels are exposed in the northern 20 percent of the mapped area no more than specimen quantities of uranium ore have been produced from them. These channels appear to be wider than those in the southern part of the mapped area but other favorable criteria (carbon, copper minerals, pyrite nodules, etc.) are present.

Four collapse structures occur in the area. They appear to lie in a linear belt which trends just east of north. The rocks in all four collapse areas contain uranium and copper minerals and uranium ore has been produced from one of them. The significance of collapse structures in localizing ore deposits, however, is unknown.

Circle Cliffs area, Utah

by

E. S. Davidson

Field mapping in two 7-1/2 minute quadrangles, Circle Cliffs 4 NE and 1 SE, started late in July 1954, was largely completed during this field season. A total of 13 formations, from the Permian White Rim member of the Cutler formation to the Cretaceous Emery sandstone member of the Mancos shale, and many mines and prospects are included in the two quadrangles.

Several new rock units have been recognized as a result of the past two seasons' work. One of these units is a mottled red and white siltstone to very fine-grained sandstone which unconformably overlies the Moenkopi formation and underlies the Shinarump conglomerate. It is best exposed in the east-central part of the Circle Cliffs. This unit appears to have no relation to uranium deposition in the Circle Cliffs area, and is regarded as an unfavorable host for uranium.

The other newly recognized units mark the Permian-Triassic contact. Recognition of these units contributes to a better understanding of the depositional history of these rocks in the Colorado Plateau and permits mapping of minor structures in the Circle Cliffs area.

The stratigraphically lowest unit cropping out in the Circle Cliffs is a fine-grained white sandstone with eolian-type cross-bedding. Above this sandstone is about 50 to 60 feet of flat-bedded fine-grained white sandstone with a few limy sandstone beds in the eastern part and limestone beds in the central part of the Circle Cliffs. The lower crossbedded sandstone has been referred to as Coconino, but because of the red beds underlying it in the Ohio oil well in the center of the area, is probably more correctly referred to as the White Rim member of the Cutler formation. The overlying flat-bedded white sandstone with unconformable top and bottom contacts, included by previous workers in the Kaibab limestone, is included with the White Rim member because of its lithologic similarity to the underlying crossbedded sandstone. About 40 feet of Kaibab limestone overlies the flat-bedded sandstone and their contact is a fair horizon to use in mapping faults and minor folds. Though slight radioactivity is noted on joint surfaces, no significant uranium deposits are known in the White Rim or the Kaibab in the Circle Cliffs.

The Kaibab is unconformably overlain by two discontinuously outcropping rock units, both of which locally channel or cut out most of the Kaibab. The lower unit, probably Triassic in age, ranges from a limy, fine-grained, light-gray sandstone to a light-gray sandy (mainly fine-grained quartz grains) limestone. This unit has a very high proportion of bedded and fragmental chert. The upper unit, probably equivalent to the Sinbad limestone member of the Moenkopi formation of the San Rafael Swell area, and the Timpoweap member of the Moenkopi formation of the Grand Canyon region includes a mustard yellow, poorly sorted, limy sandstone and an overlying oolitic limestone of the same color. The sandstone is composed mainly of medium- to very coarse-grained quartz grains and abundant 1- to 2-inch chert fragments cemented by dark yellow lime. Typical Moenkopi siltstones and sandstones overlie these two Triassic rock units and this contact, because it is regular, and crops out well and extensively, affords the best horizon in the Circle Cliffs to trace minor faults and folds.

Gentle folds and swells are the dominant minor structures on the steeper east flank of the Circle Cliffs anticline and block faults, generally yielding grabens with up to 40 feet of displacement, are more common on the west flank. The major axes of the minor structures are parallel to the axis of the Circle Cliffs anticline. Some of the faults on the west flank die out into folds resembling the Waterpocket fold, suggesting that the Waterpocket fold itself may be, at depth, a fault with considerable displacement. Because of the nature of the faulting, especially on the west flank, the forces causing the faulting are thought to be tensional rather than compressional. The asphaltic gray Moenkopi, predominant on the east flank of the anticline, is displaced by the faults, indicating that the asphalt or oil was emplaced before the faulting occurred.

Most of the uranium-mineralized rock discovered in the area is in channels filled with Shinarump conglomerate that were cut into the top of the Moenkopi formation. The lower, normally shaly, Chinle has a high proportion of sandstone over the Shinarump channels, especially in the southern half of the area, and this "build up" of sandstone is a good guide to unexposed channels. The wider channels seem to be more favorable than small tributarylike channels, and most of the better prospects are in channels that are moderately deep (20 to 50 feet). Ore may occur almost anywhere with relation to the channel structure, from the base to the top of the bank. Copper stains and secondary uranium minerals are indications of the passage of mineralizing solutions and, when found, are regarded as favorable sites for exploration.

Elk Ridge area, Utah

by

R. Q. Lewis and R. H. Campbell

During the 1955 field season mapping was completed in six and one-third 7-1/2 minute quadrangles, an area of about 380 square miles. Total area mapped since the program was begun in 1953 is approximately 860 square miles, covering fifteen 7-1/2 minute quadrangles and parts of two others. Approximately 120 square miles in two 7-1/2 minute quadrangles remain to be mapped. New 7-1/2 minute quadrangle topographic maps at a scale of 1:24,000 are now available for all of the area except the two Carlisle sheets (3 SE and 3 SW) in the northwest. The geology will be transferred to the new topography during the next report period.

The pinchout line of the belt of continuous Shinarump conglomerate, which crosses South Elk Ridge, was checked by drilling. It was found to swing abruptly to the northeast under South Elk Ridge, departing from the easterly trend which has been noted in White Canyon and Deer Flat. Nearly all of the active mining in the area is in the Shinarump in this belt. Uranium ore has been produced from ore bodies in the western, central, and eastern parts of the belt in the Elk Ridge area, and was discovered in one of the cores obtained during drilling by the Geological Survey. This suggests that the entire length of the belt is favorable. The uranium deposits within the Shinarump belt are in Shinarump sandstone and conglomerate that fill shallow scour channels cut into the surface of the Moenkopi formation.

The uranium is associated in most of the deposits with petroliferous material (asphaltite). The asphaltite occurs in blebs and disseminated along bedding planes and crossbedding laminae, and in places completely saturates the interstices of the sandstone. Iron and copper sulfides and oxides of molybdenum are commonly with the uranium. Preliminary studies of ores suggest that the content of copper and iron may vary in direct proportion to the uranium. Secondary uranium minerals identified include meta-autunite and metazeunerite.

North of a line approximately coincident with latitude 37° 52' north, the so-called Moss Back member of the Chinle formation assumes the same stratigraphic position as that occupied by the Shinarump conglomerate on South Elk Ridge; that is, it is in contact with the underlying Moenkopi formation or separated from it by only a few feet of lower Chinle mudstone. Scattered mineralization in the base of the so-called Moss Back and in the lower Chinle mudstone in this area indicates that some economic deposits may be found; to date, however, only one has been discovered.

Many normal faults resulting in numerous horsts and grabens trend northeastward across the northwestern part of the Elk Ridge area. These faults displace the present land forms and post-date the ore deposits. Minor fold structures are numerous, but their possible relation to ore localization is not clear.

Abajo Mountains area, Utah

by

I. J. Witkind

The Abajo Mountains area in San Juan County, southeastern Utah, is an oblong area covering 700 square miles. The mountains, which are west of Monticello, Utah, are roughly circular in outline and occupy the center of the area. They are flanked by upturned sedimentary strata that range in age from middle(?) Triassic (Moenkopi formation) to late Cretaceous (Mancos shale).

The igneous rock that forms the main mass of the mountains is best described as hornblende latite porphyry which locally coarsens to a diorite porphyry. Mapping began in June 1954 and by the end of October 1955, all of the north half, or about 55 percent of the area, was mapped.

Although slightly more than half of the area has been mapped, no relationship has been detected, as yet, between the igneous intrusives and the uraniferous deposits. Small deposits of other metals (principally copper, gold, and silver) are along the contact between the igneous bodies and some of the sedimentary units. These metals are also found in quartz-filled fractures that cut the igneous rocks.

Uranium-vanadium deposits are localized in several sandstone beds in the Salt Wash member of the Morrison formation. These beds are about 150 feet above the base of the Salt Wash and contain two types of uranium-vanadium ore bodies. Most bodies are small, discrete, irregular-shaped podlike masses averaging 15 feet by 3 feet by 10 feet; the second type comprises larger, more continuous, tabular bodies averaging 40 feet by 3 feet by 200 feet.

Most of the deposits are in sandstone sediments that fill shallow sinuous channels scoured into the underlying claystone and mudstones. These channels are about 200 feet wide, are scoured 5 to 10 feet into underlying strata, and are of unknown length. Other uranium deposits are in unusually thick sandstones. Locally the claystone and mudstone interval that separates the sandstone lenses of the Salt Wash changes laterally into a sandstone facies. The result is a thick accumulation of medium- to coarse-grained massive cross-bedded sandstone that is as much as 80 feet thick, and ranges in width from 200 to 1,000 feet. Uranium ore bodies are scattered, apparently at random, through this thickened sandstone lens.

East Vermillion Cliffs area, Arizona

by

R. G. Peterson

Geologic mapping in the East Vermillion Cliffs area was begun in July 1955. Rocks exposed in the area range from the Redwall limestone of Mississippian age to the Dakota sandstone of Cretaceous age.

The Shinarump conglomerate, varying in thickness from a knife-edge to 120 feet, forms a relatively continuous outcrop for about 50 miles along the East Vermillion Cliffs. To the west the Shinarump is discontinuous and locally absent.

Geologic investigations to date show that most of the uranium deposits in the area are concentrated in the Shinarump conglomerate and the Moenkopi formation at or near their contact in channel scours. No uranium deposits have been found in either formation except in these channels. Many Shinarump-filled channels cut into the Moenkopi formation in the area, however, do not contain uranium deposits. No dissimilarities have as yet been found between barren and mineralized channels other than the occurrence of uranium minerals.

The remaining uranium deposits in the area occur as spotty pockets in sandstone lenses in the Petrified Forest member of the Chinle formation. Carbonized wood is associated with the uranium in these Chinle uranium deposits; however, not all carbonized wood in the Chinle sandstone lenses contains or is associated with uranium.

Ostracodes found in the Dinosaur Canyon member of the Moenave formation were identified by I. G. Sohn as a single species of Darwinula(?), a fresh water Triassic ostracode. Discovery and identification of these fossils supports the tentative assignment of the age of the Moenave formation to the Triassic.

Grants area, New Mexico

by

R. E. Thaden

Sedimentary rocks in the Grants area range from the San Andres formation (Permian) to the Mesaverde formation (Cretaceous). Known commercial ore deposits are in the Todilto limestone, in the Westwater Canyon and Brushy Basin members of the Morrison formation, all of Jurassic age, and in the Dakota sandstone of lower Cretaceous age.

Most ore deposits in the Morrison formation are in gray sandstones of the Westwater Canyon member. These sandstones are predominantly orange-brown, and the gray color of the ore-bearing beds may have resulted from bleaching. Except in color, the gray parts are not megascopically different from orange-brown sandstone, either in contained material or in sorting and packing. The gray parts seem largely to be restricted to places where the sandstone intertongues with claystone.

Ore deposits in the Todilto limestone are associated with anticlinal flexures of small magnitude, and with domes. The average closure on these structures is, perhaps, four feet. The anticlines, with rare exceptions, do not involve the underlying Entrada sandstone (Jurassic), but most extend into the basal limy sandstone of the overlying Summerville formation (Jurassic). The anticlines, roughly, are in two sets, a major set trending about N. 45° W., and a minor set trending about N. 10° E. They are asymmetric, with axial planes dipping southerly and westerly, respectively, and may indicate differential translocation of overlying beds to the north and to the east with respect to underlying beds.

In addition to the anticlines, the upper part of the Todilto has numerous small domes, possibly sedimentary structures formed by dilation. The small domes and anticlines are irregularly distributed within the Todilto, but their distribution does not correlate closely with the distribution of ore deposits. Some major concentrations of folds have no associated ore bodies, and some areas where folds are few in number contain many or large ore bodies.

The Grants area is cut by zones of faulting; within the zones, the strongest faults trend northerly, and weaker faults trend easterly. The fault zones are several miles wide and trend northeasterly. It is within these zones generally, and in favorable Morrison sandstone lithology and more intensely folded Todilto limestone within these zones particularly, that the ore deposits are most numerous. The orientation of the long axis of many deposits suggests that the minor faults which trend easterly are the most important local influence upon the position and shape of the ore bodies.

A paper, "Guides to uranium deposits in the Morrison-Laguna area, New Mexico", by L. S. Hilpert and V. L. Freedman, was published in the Proceedings of the United Nations International Conference on the Peaceful Uses of Atomic Energy.

Laguna area, New Mexico

by

R. H. Moench and W. P. Puffett

Geologic mapping was begun in the Laguna area in July 1955. To date about 150 square miles have been mapped on aerial photographs. In addition, an extensively mineralized area, about 1 square mile, was mapped at a scale of 1 inch = 200 feet. Sedimentary rocks from Chinle through Mesaverde formations are exposed in the area. Basaltic flows and plugs, as well as diabasic sills and dikes, are abundant.

Essentially five types of uranium deposits occur in the area. The most important are the large blanket-like deposits that occur in an arkosic sandstone near the top of the Morrison formation. The second type, of which only one example is known, is a cylindrical vertical sandstone pipe, in which the uranium minerals occur in concentric fractures. In the third type, found in the Todilto limestone, and locally near the top of the Entrada sandstone, the uranium minerals occur in the crests and flanks of small folds. The fourth type, of which only one example is known, is a mineralized fracture or vein, in an arkosic sandstone near the base of the Morrison formation. The fifth type includes a number of economically insignificant mineralized pockets of carbonaceous materials and carbonized logs in the arkosic sandstone of a basal maroon siltstone of the Morrison formation. The mineralogy of all the deposits apparently is simple, though much work remains to be done. A striking feature is the spatial association of diabasic sills with the important uranium deposits.

In the course of the mapping it was found that three fold systems--two post-Dakota and one pre-Dakota--exist. First, a belt of north-trending monoclinal folds and associated faults mark the boundary between the Colorado Plateau and Basin and Range provinces. The second fold system comprises a gentle northwestward regional dip, and local gentle basins, domes, anticlines and synclines, with axes that bear northeast and northwest. The third fold system, developed prior to the deposition of the Dakota sandstone, consists of a series of gentle depressions, with axes that bear slightly west of north. Coextensive with the pre-Dakota folds are large concentrations of vertical sandstone pipes, which to date have been seen only in the Summerville, Bluff, and Morrison formations, and relatively intense folding in the Todilto limestone. Because one sandstone pipe and some Todilto folds are mineralized, the pre-Dakota folds may have some economic significance.

In the area mapped on a scale of 1 inch to 200 feet, an attempt is being made to determine the relationship between mineralized Todilto folds and the regional folds and the relationship, if any, between the diabase sills and their associated contact metamorphism, and the uranium deposits.

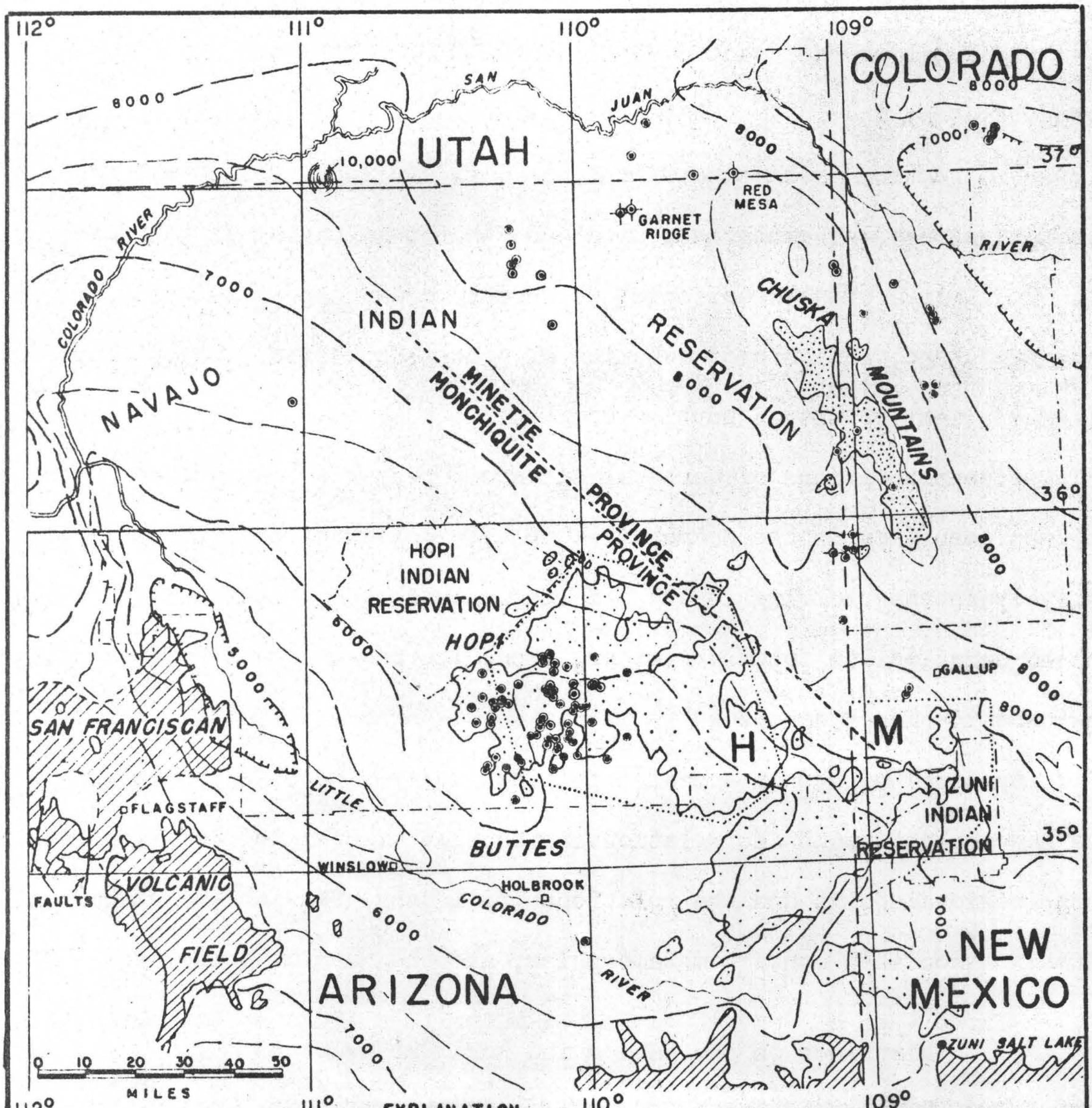
Diatremes on the Navajo and Hopi Reservations

by

E. M. Shoemaker

About 300 volcanic vents are scattered over the Navajo and Hopi Reservations in Arizona, New Mexico, and Utah. The majority of these vents are funnel-shaped and filled with pyroclastic debris, a type of structure to which the name diatreme has been applied. The diatremes are associated with flows and tuffs of Pliocene age that rest on a surface of low relief (fig. 3).

Volcanic rocks associated with the diatremes are nearly all alkaline basalts which, in their intrusive phase, would fall under the classification



EXPLANATION

BIDAHOCHI FORMATION (PLIOCENE)
CHUSKA SANDSTONE (PLIOCENE?)
} AFTER C.A. REPENNING AND J.H. IRWIN, 1954, AMER. ASSOC. PETROLEUM GEOLOGIST, BULLETIN 38, P. 1832

OLIVINE BASALT AND SCATTERED CALC-ALKALINE STRATOVOLCANOES (PLIOCENE?) MODIFIED FROM GEOLOGIC MAP OF THE U.S.A. BY U.S. GEOLOGAL SURVEY, 1932

DIATREME (FUNNEL-SHAPED VOLCANIC VENT FILLED CHIEFLY WITH ALKALINE BASALT TUFF AND OTHER PYROCLASTIC DEBRIS)

DIATREME CONTAINING MICA-SERPENTINE OR KIMBERLITE TUFF

CONTOUR ON PLIOCENE SURFACE DASHED WHERE RESTORED (CONTOUR INTERVAL 500 FEET)

H — CONTOURS AFTER J.T. HACK, 1942, GEOLOGICAL SOCIETY OF AMER. BULL.53.P.340

M — CONTOURS AFTER F.T. MCCANN, 1938, AMERICAN JOURNAL OF SCIENCE, 5th SERIES. VOLUME 36, P. 275

CONTOURS FOR REMAINDER OF MAP ARE AN ORIGINAL INTERPRETATION

FIGURE 3. INDEX MAP OF NAVAJO AND HOPI RESERVATIONS AND VICINITY, SHOWING THE DISTRIBUTION OF DIATREMES, SEDIMENTARY AND VOLCANIC ROCKS OF PLIOCENE(?) AGE, AND CONTOURS ON THE PLIOCENE SURFACE.

of the two lamprophyres, monchiquite and minette. Minettes are found in the northeast half of the Navajo-Hopi region and monchiquites mainly in the southwest half; the region may thus be broadly divided into a minette province and a monchiquite province (fig. 3). Both the monchiquites and minettes are characterized by high concentrations of uranium-thorium-cerium group rare earths and niobium, as contrasted with olivine basalts of the Colorado Plateau (TEI-540, p. 76-85). Serpentine tuff, commonly phlogopite-bearing, is found in some widely scattered diatremes in the minette province.

Reconnaissance study has revealed two general types of uranium deposits in the diatremes from which ore has been produced. One type consists of sandstone impregnated with various copper, uranium, vanadium, and arsenic minerals and occurs in the sandstone walls of dikes extending out from diatremes filled with serpentine tuff. The second type consists of limestone, siltstone, claystone and monchiquite tuff impregnated with uranium-bearing minerals, and occurs in beds deposited within diatremes filled chiefly with monchiquite tuff.

The first type of deposit is known at two localities in the northern part of the Navajo Reservation, one at Garnet Ridge and another near Red Mesa (fig. 3). At Garnet Ridge the uranium ore occurs in the Navajo sandstone of Jurassic and Jurassic(?) age as small concretion-like deposits adjacent to a discontinuous dike of mica-serpentine tuff that extends northwest of the Garnet Ridge diatreme (fig. 4). Malachite ($Cu_2(OH)_2(CO_3)$), chrysocolla (approximately $CuSiO_3 \cdot 2H_2O$), volborthite ($Cu_3(VO_4)_2 \cdot 3H_2O$?) and metatyuyamunite ($Ca(UO_2)_2(VO_4)_2 \cdot 5\text{-}7H_2O$) have been identified in the mineralized sandstone, and the ore also contains trace amounts of introduced silver, cobalt, nickel, lead, and thallium. Selected samples contain as much as 2 percent U, but most of the exposed mineralized sandstone is of marginal or sub-ore grade. A few

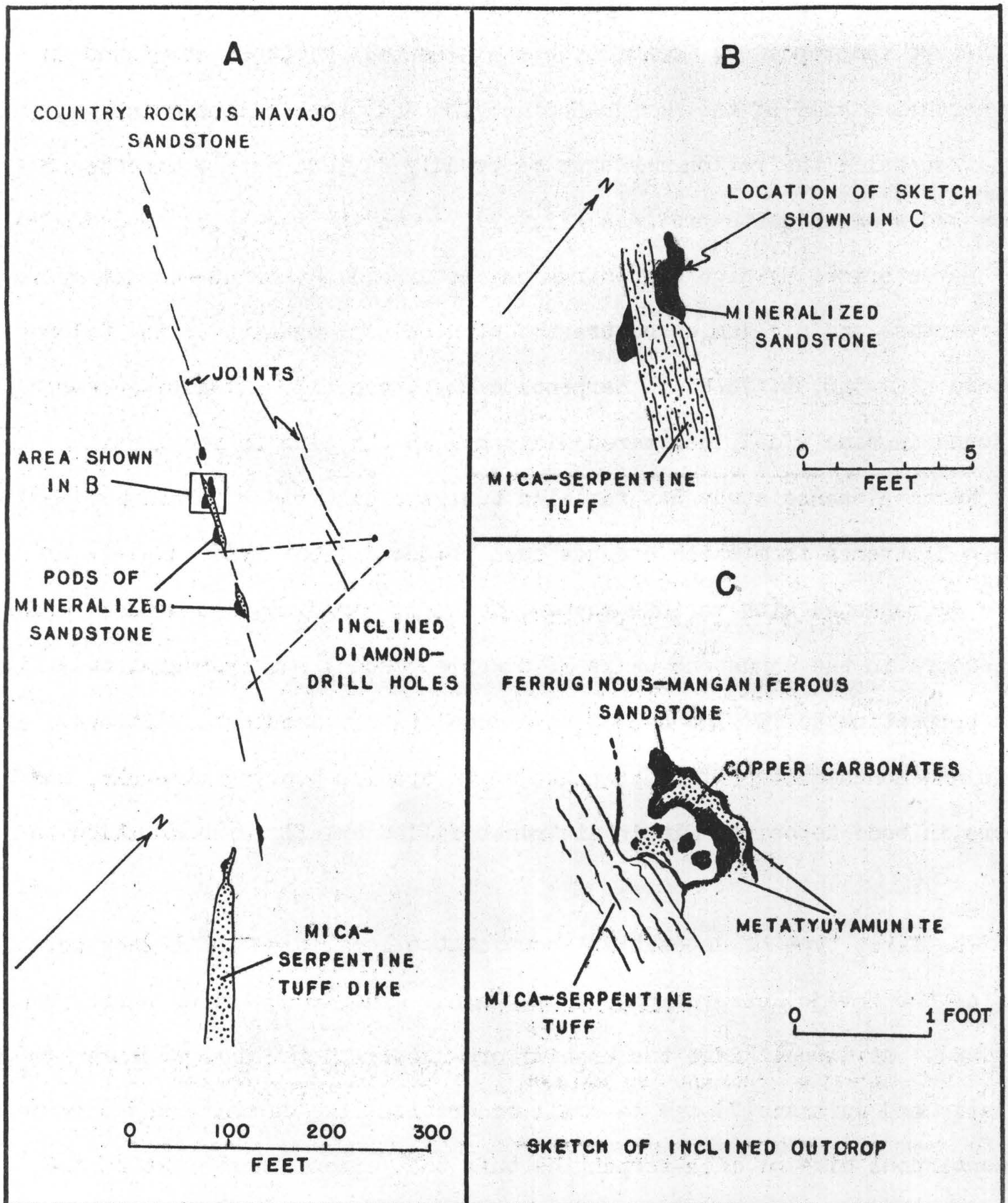


Figure 4. SKETCH OF RELATIONS OF ORE PODS AT GARNET RIDGE DIATREME.

tons of ore have been obtained for shipment by careful hand sorting. Spectrographic analysis of core drilled through the tuff dike shows that calcium, strontium, nickel, vanadium, copper, and lead are dispersed in the sandstone walls of the dike (fig. 5).

At Red Mesa, copper and other metals occur in the Navajo sandstone at several places along mica-serpentine tuff dikes extending both north and south of a small diatreme. Malachite, cuprite (Cu_2O), olivenite ($Cu_2(AsO_4)(OH)$), and conichalcite ($CaCu(AsO_4)(OH)$), have been identified in the mineralized sandstone. Locally the mineralized rock is moderately uraniferous although the uranium-bearing mineral has not been identified.

About 35 diatremes are known to contain uraniferous sedimentary rocks in the Hopi Buttes area (fig. 6). The most abundant mineralized rocks in the diatremes are bedded silty or tuffaceous limestones, containing 0.001 to 0.02 percent uranium. Most diatremes with considerable exposures of limestone are conspicuously or detectably radioactive from the air. Concentrations of uranium higher than 0.02 percent are found in some limestones, but more commonly in siltstones and claystones. The highest grade deposits so far examined are in laminated siltstones and unconformably overlie beds of coarse tuff, tuff-breccia, and agglomerate (fig. 7). At the Morale claim (fig. 6) ore-grade concentrations of uranium are also found in the coarse-grained deformed rocks beneath the unconformity.

Though the uraniferous beds within the diatremes are relatively continuous (figs. 7, 8) the distribution of uranium within the beds is highly erratic. No consistent relation has been found between lithology and the distribution of uranium within beds. In some diatremes there is a suggestion that the uranium occurs more abundantly close to the walls of the vent.

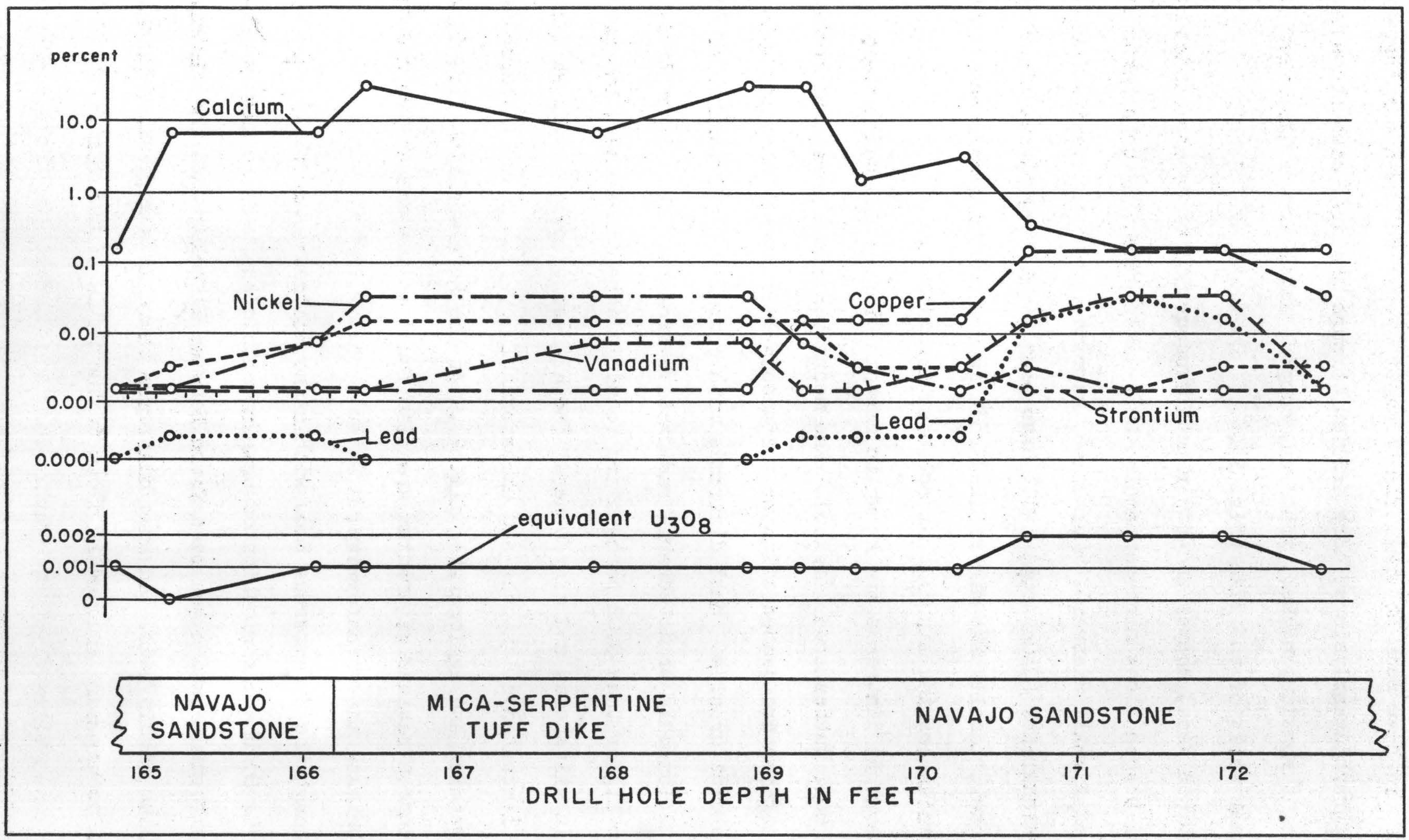


FIGURE 5. DIAGRAM SHOWING ELEMENT CONCENTRATION AND RADIO-ACTIVITY IN DRILL CORE ACROSS MICA-SERPENTINE TUFF DIKE AT GARNET RIDGE DIATREME.

The mineral forms in which the uranium is present in the mineralized rocks is not fully known. Carnotite ($K_2(UO_2)_2(VO_4)_2 \cdot 1\text{-}3H_2O$) and liebigite ($CaU(CO_3)_4 \cdot 10H_2O$) have been found in a few specimens, but most of the more intensely mineralized rock contains no visible uranium minerals and the material is so fine-grained that microscopic identification of the minerals is difficult. The vanadium content of most of the uraniferous rocks is low. A correlation found in a few analyzed samples between the concentrations of uranium and phosphate coupled with an apparent absence of known fluorescent uranium phosphates suggests the bulk of the uranium may be contained in very fine-grained apatite. In addition to uranium and phosphorous, small amounts of molybdenum and nickel are concentrated in the mineralized rocks.

A paper, "Occurrence of uranium in diatremes on the Navajo-Hopi Reservation, Arizona, New Mexico, and Utah", by E. M. Shoemaker, was published in the Proceedings of the United Nations International Conference on the Peaceful Uses of Atomic Energy.

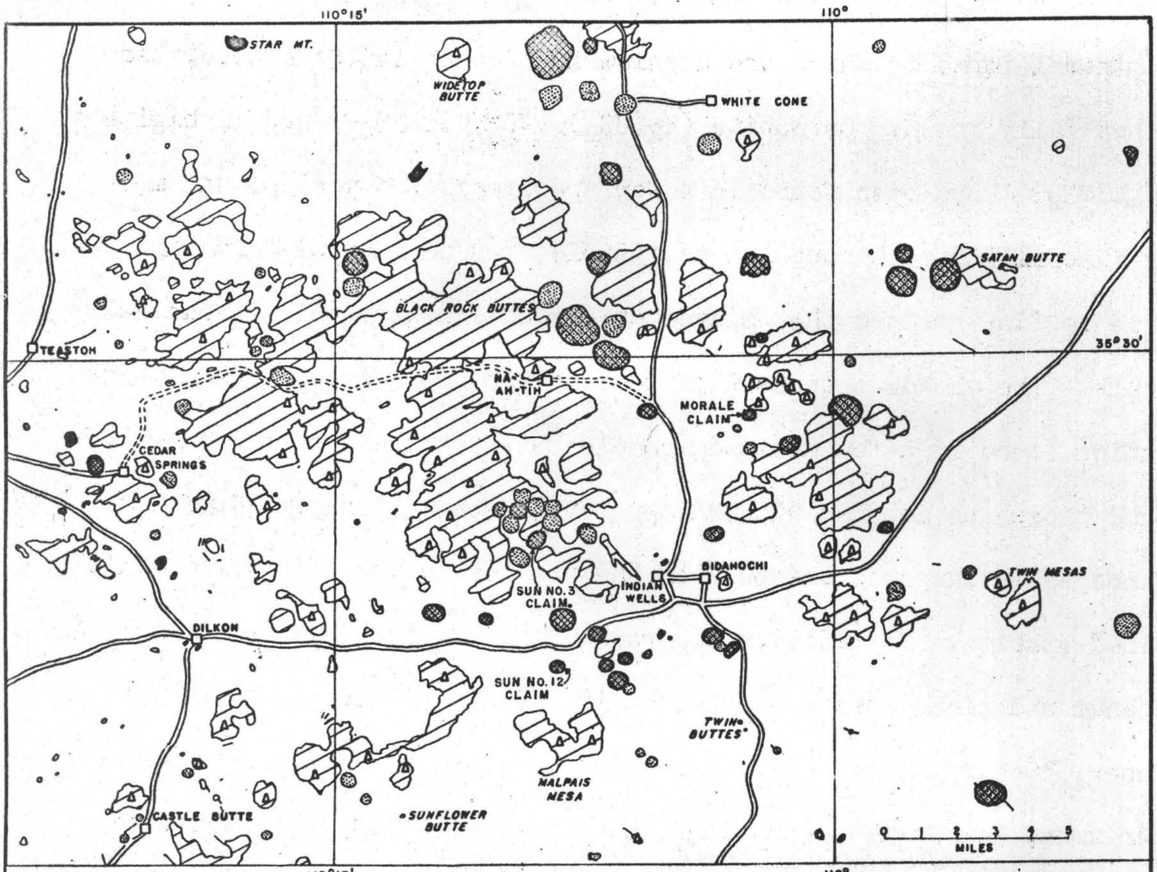
Photogeologic mapping

by

W. A. Fischer

During this report period 1:24,000 scale photogeologic maps of nineteen 7-1/2 minute quadrangles were completed. Forty-four photogeologic maps were published and 20 were released as TEM reports.

Photogeologic maps are compiled from existing vertical photography, which ranges in scale from approximately 1:20,000 to approximately 1:60,000. These maps show primarily the distribution and structure of geologic formations within the area as interpreted from photographs. They are compiled on planimetric bases taken from topographic base maps, where such base maps exist; in



EXPLANATION

EXTRUSIVE ALKALINE BASALT

INTRUSIVE MONCHIQUITE (FILLING VOLCANIC NECK)

DIATREME (FILLED CHIEFLY WITH PYROCLASTIC DEBRIS)

DIATREME KNOWN TO CONTAIN URANIFEROUS SEDIMENTARY ROCKS

PROBABLE LOCATION OF BURIED DIATREME OR VOLCANIC NECK

SOURCES OF DATA: OUTLINE OF EXTRUSIVE AND INTRUSIVE ROCKS MODIFIED AFTER UNPUBLISHED MAPS BY C.A. REPENNING AND OTHERS, U.S. GEOLOGICAL SURVEY. DIATREMES AFTER J.T. HACK, 1942, GEOL. SOC. AMERICA BULL., V. 53, PLATE 1, AND P. 368, WITH ADDITIONS BY E.M. SHOEMAKER

Figure 6. MAP OF VOLCANIC ROCKS IN THE HOPI BUTTES AREA.

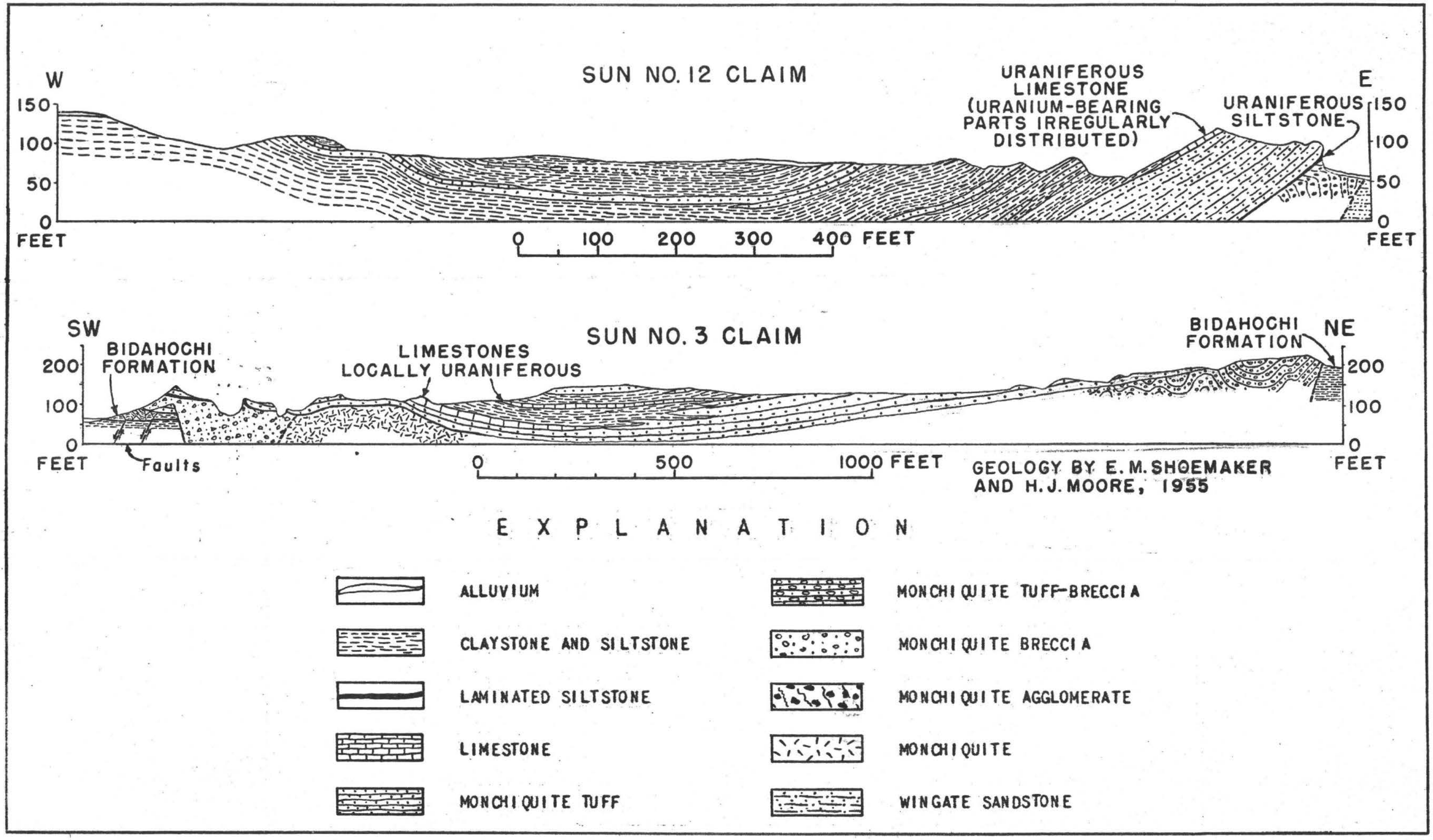


FIGURE 7. CROSS-SECTIONS OF DIATREMES OF THE SUN NO. 3 AND SUN NO. 12 CLAIMS.

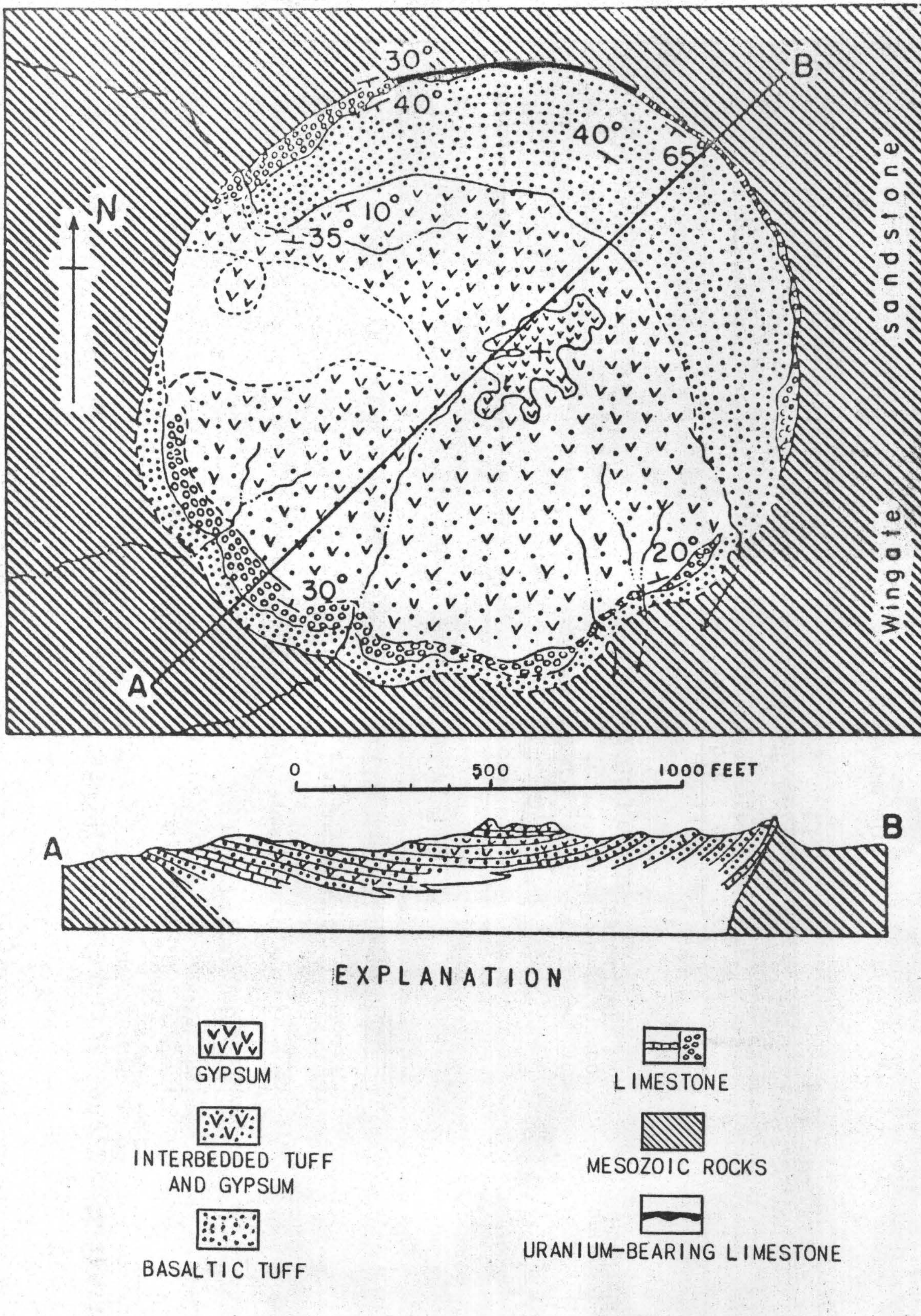


Figure 8. MAP AND CROSS-SECTION OF DIATREME NORTH OF BIDAHOCHI.

lieu of these base maps, available planimetric base maps such as those of the Soil Conservation Service are used. Where no base maps exist, geologic data is compiled to point control from Stereo-templet or other templet triangulation nets.

In addition to the 1:24,000-scale quadrangle maps, an isopachous map showing local thinning of the Moenkopi formation, and by inference showing local thickening (swales and channels) in the overlying Shinarump conglomerate, was completed. Stratigraphic thickness measurements of the Moenkopi formation were made photogrammetrically and were field checked for accuracy in part of the area. Isopachous mapping of the Moenkopi formation is now being extended over the large area between Monument Valley and White Canyon.

The progress of photogeologic mapping in the Colorado Plateau is shown in the index map, figure 9.

Subsurface geologic investigations by drilling

by

D. A. Phoenix

Diamond drilling designed to test geologic concepts began in June 1955. Drilling is finished or underway in four areas on the Colorado Plateau. These areas are: Oljeto Wash area, Navajo County, Arizona; Clay Gulch, San Juan County, Utah; Disappointment Valley, San Miguel County, Colorado; and Kirk's Basin-Taylor Creek areas, Grand County, Utah.

Drilling was completed in the Oljeto Wash and Clay Gulch areas during the report period. Data from the drilling in Clay Gulch are not yet available. In the other areas drilling is in progress.

The Oljeto Wash area is in Monument Valley about 8 miles south of the Oljeto Trading Post, Arizona. The area occupies a structural basin formed

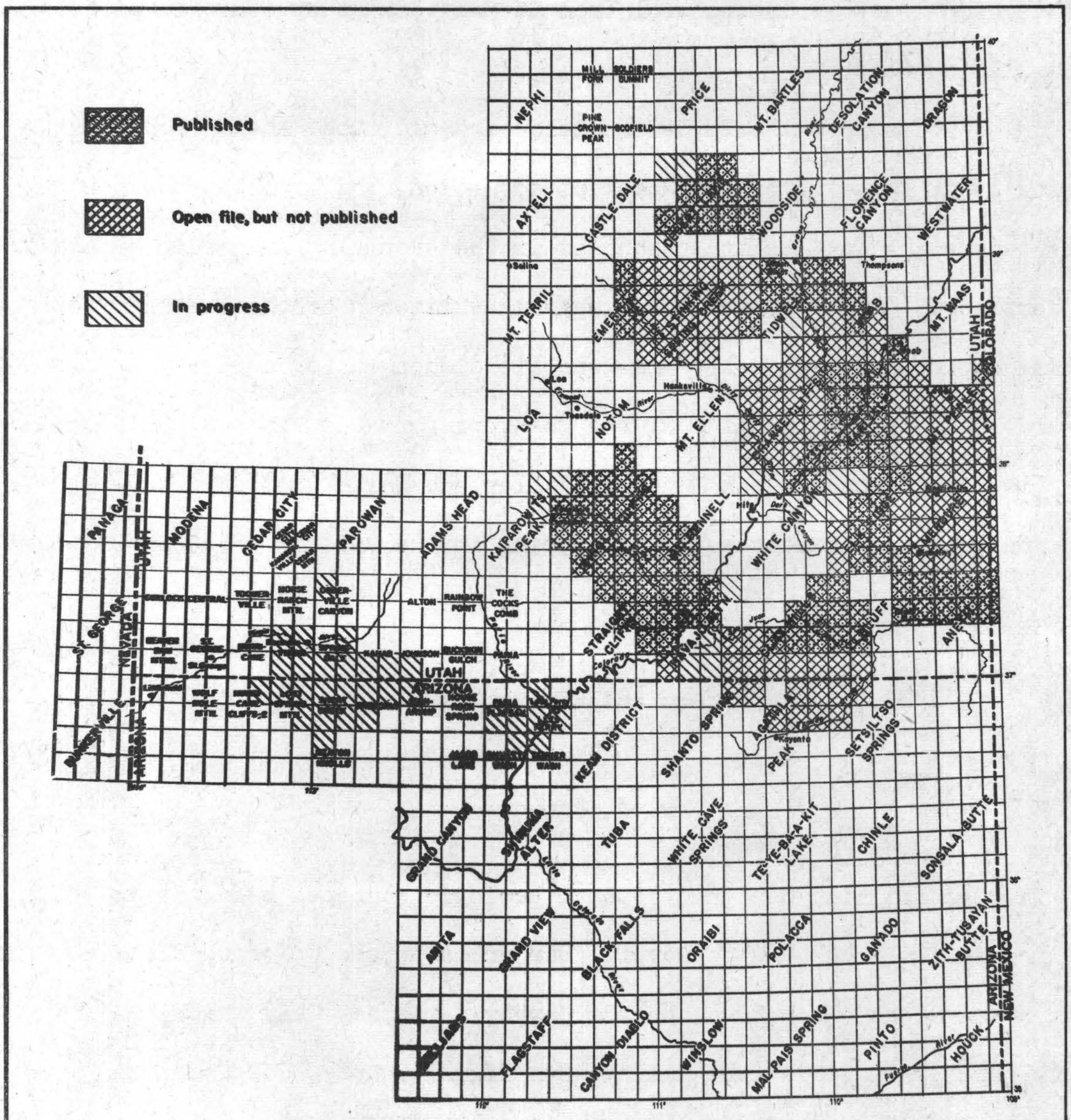


Fig. 9 Index map of part of the Colorado Plateau area, showing location of photogeologic quadrangle maps published, in open file but not published, and in progress as of November 30, 1955.

by the Oljeto Wash syncline (fig. 10).

Geologic studies in the Oljeto Wash area were made to obtain additional data necessary to the interpretation of geophysical measurements of the uranium-bearing Shinarump conglomerate. The distribution of the rock units and structures of the area is shown on figure 10; detailed mapping is in progress. Subsurface data was obtained from drill core recovered from the holes shown on figure 10. Strip logs of drill core have been compiled to show variations in grain size, cementation and mineralogy of the Shinarump conglomerate and related formations. These data will be compared and related to various in-hole geophysical measurements and used to evaluate the favorableness of the Shinarump conglomerate for uranium deposition.

The drilling had several objectives. In the southern part of the Oljeto Wash area drill holes were widely spaced, between 150 and 400 feet deep, and were drilled mainly to determine the thickness and character of sediments above the Shinarump conglomerate. In the northern and central part of the area drill holes were closely or moderately spaced, generally less than 100 feet deep, and were drilled to test the configuration of the contact between the Shinarump conglomerate and the Moenkopi formation as previously determined by geophysical methods. One drill hole in the northern part of the area penetrated the Shinarump conglomerate, the Moenkopi formation, and the upper part of the Cutler formation in order to compare the physical properties of these formations.

Groups of strata exposed in the area from oldest to youngest consist of the Organ Rock tongue, the DeChelly sandstone, and the Hoskininni tongue, all members of the Cutler formation of Permian age; and the Moenkopi formation, Shinarump conglomerate, and Chinle formation of Triassic age. Over much of the area these rocks are covered by Quaternary alluvium. The geophysical

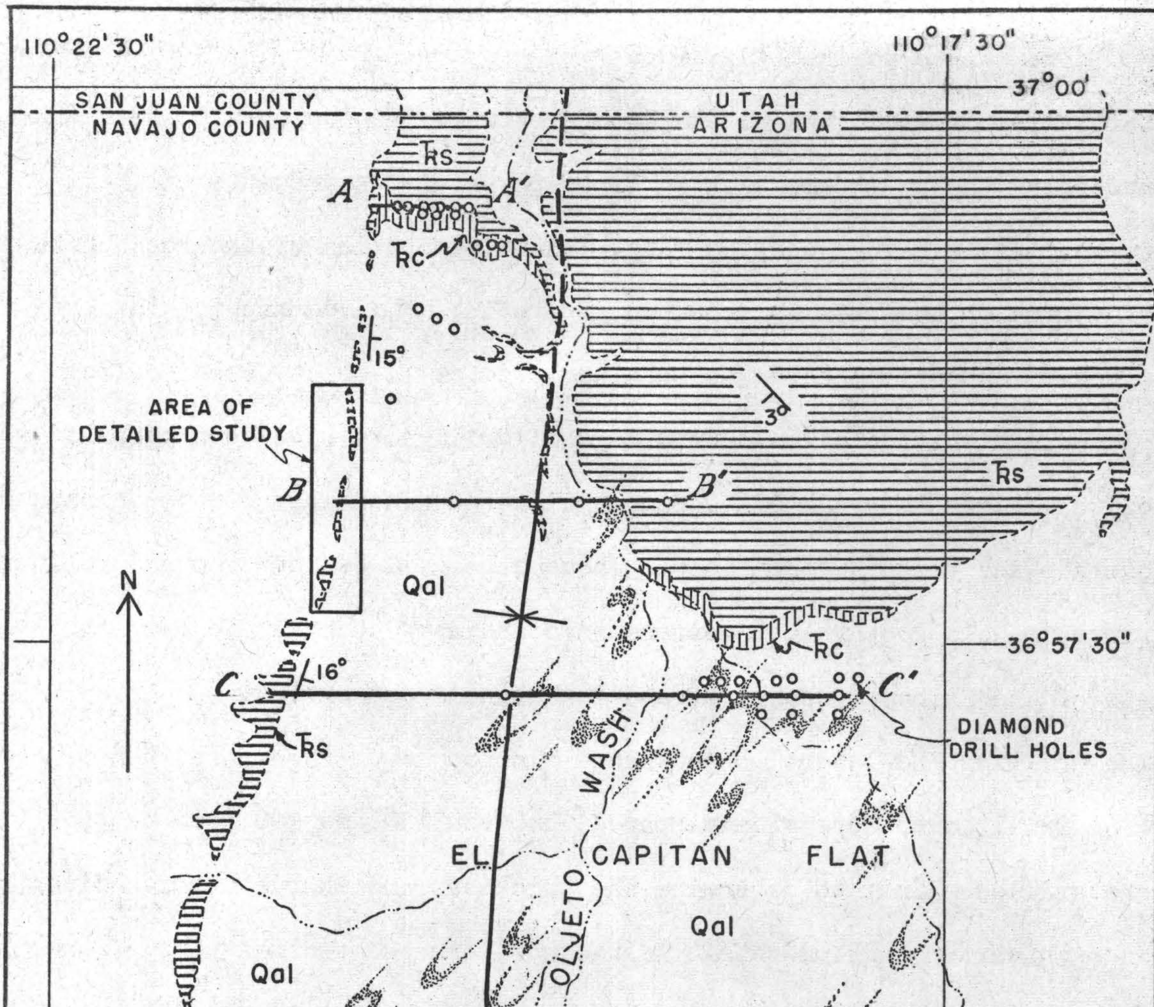


FIGURE 10 INDEX MAP OF THE OLJETO WASH AREA, NAVAJO COUNTY, ARIZONA

studies have been mainly concerned with the characteristics of the sediments of Triassic and Quaternary age, and the geologic studies to date have also been concerned with the physical properties and areal distribution of these rocks. (For results of geophysical studies see pp. 134-137.)

The Moenkopi formation of Triassic age consists mainly of thin-bedded, red-brown, compact siltstone. Beds of light-colored sandstone are conspicuous near the base of the formation and in addition the formation contains thin beds of dense silty limestone. Locally the red-brown siltstone is altered to a light-gray or gray-green color. The change in color is noticeable as a band 2 or 3 feet thick beneath the Shinarump conglomerate and as thin bands 1 to 6 inches thick throughout the Moenkopi formation. The gamma-ray activity is more intense in the altered zones than in other parts of the Moenkopi formation.

The Shinarump conglomerate consists of two units, a lower coarse-grained sandstone conglomerate unit and an upper fine-grained unit composed of sandstone and siltstone (fig. 11). Laterally the Shinarump conglomerate varies in thickness and lithology. The average thickness is about 40 feet; a maximum thickness of 130 feet occurs in the axial portion of a channel-like depression in the Moenkopi formation.

In the southern part of the Oljeto Wash area the Shinarump conglomerate is covered by Chinle formation and is saturated with water. The rock is light-gray, contains pyrite as seams and nodules associated with organic material, and is cemented by a soft white clay. In the northern part of the area the Shinarump conglomerate is only locally covered by the Chinle formation. Here the Shinarump is cemented with clay, calcite, and quartz; pyrite is generally absent, and the sediments are stained brown or yellow-brown except near concentrations of organic debris where they are light-gray. Locally

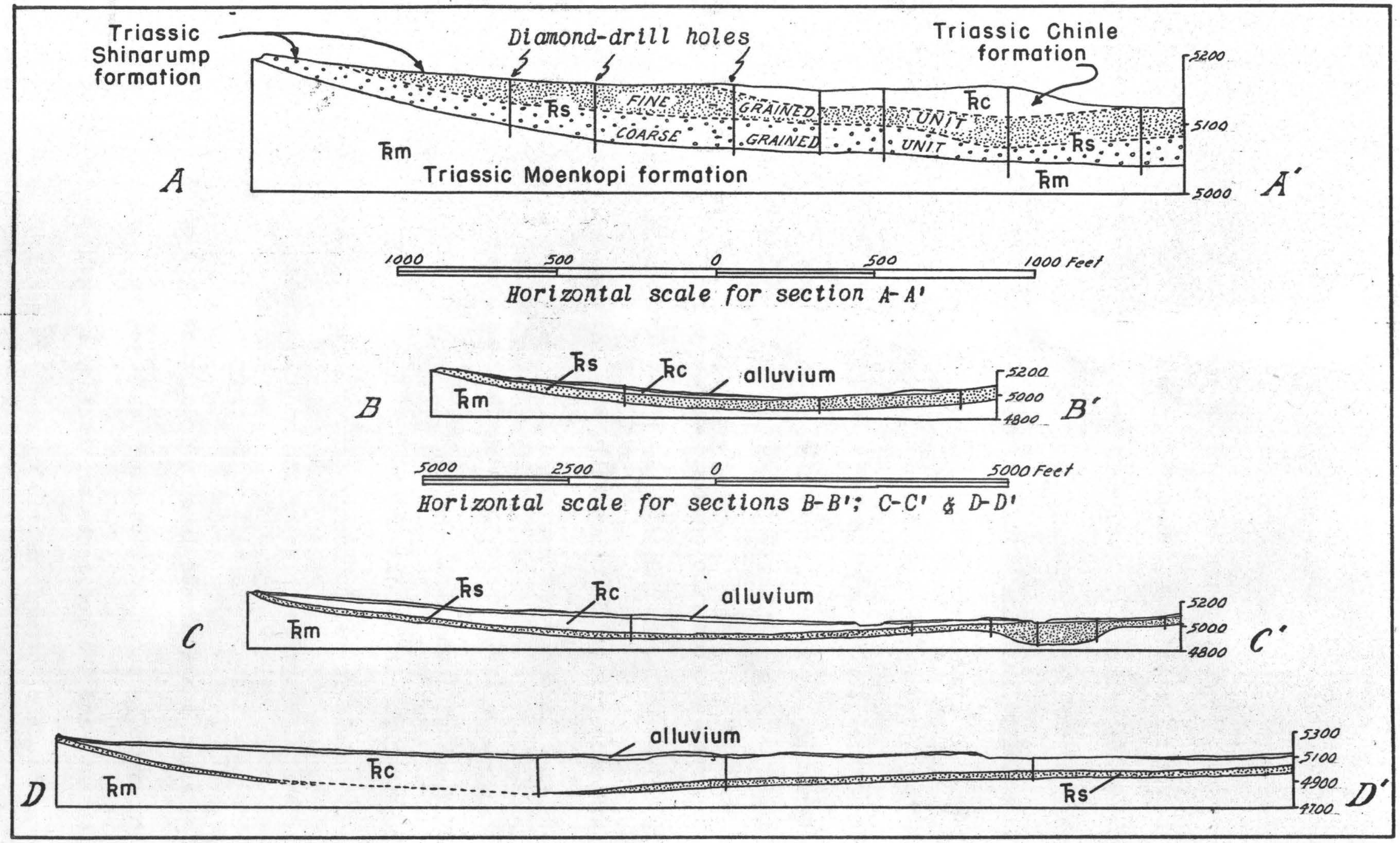


FIGURE 11. GEOLOGIC CROSS-SECTIONS THROUGH THE OLJETO WASH AREA.

the sediments are highly cemented with manganese and iron oxides.

The lower part of the Chinle formation in the Oljeto Wash area is about 350 feet thick and consists mostly of blue and green mudstone. Locally, sediments near the base of the Chinle formation coarsen downward and the contact between the Chinle formation and the underlying Shinarump conglomerate is difficult to determine. Elsewhere, mudstones of the Chinle formation rest directly upon the Shinarump conglomerate.

Mineralized rock was encountered in some of the moderately spaced drill holes in the central part of the Oljeto Wash syncline. These holes cut the Shinarump formation where it fills a channel in the top of the Moenkopi formation. The channel was located by seismic measurements prior to drilling. The drilling and geophysical data indicate that the channel is at least 700 feet wide and one-half mile long. The depth of the channel in its axial portion is about 100 feet, but it becomes shallow and is difficult to identify from drill core and from geophysical measurements.

Stratigraphic studies

Triassic studies

by

J. H. Stewart

Regional studies of Triassic stratigraphy were extended during the report period into the San Juan Mountains of southwestern Colorado and into the area between Cedar City in southwestern Utah and Las Vegas in southern Nevada. The Defiance Uplift of northeastern Arizona, the St. Johns area of east-central Arizona, and the Uinta Mountains of northeastern Utah were studied briefly.

The Moenkopi formation is about 1,800 feet thick in most of the area from Cedar City, Utah, to Las Vages, Nevada. In the Cedar City-St. George area of southwestern Utah, the Moenkopi consists of six members which are in ascending order the Timpoweap, Lower red, Virgin limestone, Middle red, Shnabkaib, and Upper red members. Some of these members were correlated by lithology and stratigraphic position into the part of the Basin and Range province in northwestern Arizona and southern Nevada, where the members had not been previously reported. Three divisions of the Moenkopi can be seen in this part of the Basin and Range province. The lower division is a reddish siltstone unit that is equivalent to the Lower and Middle red members. The Timpoweap member may be present locally at the base of this division. The Virgin limestone member could not be recognized. The middle division is the Shnabkaib member composed of greenish siltstone, white gypsum, and gray limestone. The middle member of the Moenkopi in the Goodsprings quadrangle, southern Nevada, as described by Hewett (U. S. Geol. Survey Prof. Paper 162) probably correlates with the Shnabkaib. The upper division is the Upper red member and is composed mostly of reddish siltstone.

The Shinarump conglomerate and Chinle formation have been recognized in the Basin and Range province of northwestern Arizona and southern Nevada by Longwell (U. S. Geol. Survey Bull. 798) and Hewett (U. S. Geol. Survey Prof. Paper 162). The Chinle formation of Longwell and Hewett consists of two parts, a lower unit of bentonitic claystone and clayey sandstone that is correlated with the Petrified Forest member of the Chinle formation. The upper unit consists of brownish siltstone and minor sandstone which correlate with the Moenave and Kayenta formations of the Colorado Plateau.

The Triassic rocks in the San Juan Mountains, Colorado are all included in the Dolores formation. In the southern San Juan Mountains, the Dolores can be divided into three parts: (1) a basal ledge-forming, greenish, very fine-grained sandstone about 50 feet thick, (2) a unit of reddish and greenish siltstone and minor sandstone about 200 feet thick, and (3) a unit of reddish coarse siltstone about 500 feet thick which contains minor light-brown very fine-grained sandstone. These three units are continuous across the southern part of the San Juan Mountains but become inseparable in the northern San Juan Mountains. The Dolores formation thins to the east across the San Juan Mountains to a wedge edge in the eastern part of the mountains. This thinning is caused mainly by erosional truncation of the Dolores formation. The Dolores formation contains the equivalents of the Rock Point member of the Wingate sandstone and the upper part of the Owl Rock member of the Chinle formation of the Defiance Uplift, and the Church Rock member of the Chinle formation of southeastern Utah.

A paper, "Direction of transportation of the sediments constituting the Triassic and associated formations on the Colorado Plateau", by F. G. Poole and G. A. Williams, was published in the Proceedings of the United Nations International Conference on the Peaceful Uses of Atomic Energy.

Entrada study

by

J. C. Wright

Study of the San Rafael group, including the Entrada sandstone, was begun in late June 1955. The group is geologically critical because it includes the only marine, fossiliferous strata of the Jurassic period on the Colorado Plateau; and it is economically important because of the uranium deposits in the Todilto limestone, in northwest New Mexico, and the vanadium-uranium deposits in the Entrada sandstone at Rifle and Placerville, Colorado.

During the field season the group was carefully re-examined at its type area on the north end of the San Rafael Swell, Emery County, Utah; and the units were traced in detail to their equivalents along the Colorado-Utah border.

The work confirmed the identity of the fossiliferous Carmel formation of the San Rafael area with the non-fossiliferous structureless reddish sandstones comprising the Carmel formation near the Colorado-Utah border; showed that deposition of cross-bedded sands like those of the Entrada sandstone began locally in the Moab area during Carmel time, and that the Carmel-Entrada contact is complicated by preconsolidation slumping, faulting, and folding of the beds; and confirmed in some detail the intimate intertonguing in the Green River Desert of the eastern cross-bedded sandstone facies of the Entrada sandstone with its equivalent western earthy siltstone facies. Review of the contorted and disrupted bedding, graded bedding, and absence of good lamination in the earthy siltstone facies of the Entrada sandstone suggests turbidity flows as the chief mechanism of deposition.

General stratigraphic studies

by

L. C. Craig

The general stratigraphic project began in the summer of 1955 and is designed to provide summary information concerning the stratigraphy of formations of the Colorado Plateau not yet studied in detail. Preliminary results of the detailed studies of the Morrison, Triassic, and Entrada formations have shown the coincidence of uranium abundance with specific stratigraphic characteristics. Analysis of these characteristics in other stratigraphic units by the general stratigraphic study may permit the delineation of new areas favorable for the development of new uranium mining districts.

During this report period files have been established that will contain the basic data for the general study and much of the original data of the detailed projects has been summarized in these files. With the completion of this, the first segment of the general studies will be the compilation of existing information on and field study of the Upper Cretaceous and Tertiary formations.

A field review of the Morrison formation, partial preparation of a report on the Jurassic and Lower Cretaceous formations as a contribution to a report by F. W. Cater on the general geology of part of southwestern Colorado, and partial preparation of a detailed report on the Morrison formation of the Colorado Plateau constitute the main accomplishment of the report period. Both reports are planned for Geological Survey publication in the Professional Paper series. In addition a paper, "The application of stratigraphy to the search for uranium on the Colorado Plateau", was presented to the Nuclear Science Congress, December 1955, and prepared for publication.

Sedimentary petrology laboratory

by

R. A. Cadigan

The laboratory has been engaged in petrographic analyses of sedimentary rock samples submitted by the stratigraphic and other projects on the Colorado Plateau.

The petrographic study of the Morrison formation has been a study of differences in rock composition and texture of Morrison sandstones. Differences have been classified as stratigraphic--differences between strata in a vertical direction, and regional--differences within the same or equivalent strata in different parts of the Colorado Plateau region.

The Morrison formation may be divided stratigraphically into an upper part composed of the Brushy Basin and Westwater Canyon members and a lower part composed of the Salt Wash and Recapture members. It may also be divided regionally into a northwestern and a northern area, occupying south and east-central Utah and west-central and southwestern Colorado, and a southern and southeastern area, occupying the Four Corners area and northwestern New Mexico. The Morrison is represented in the northern area by the Brushy Basin and Salt Wash members and in the southern area by the Westwater Canyon and Recapture members (plue some Brushy Basin). These two groups of strata intertongue and overlap in the Four Corners area.

Microscopic study of representative heavy mineral suites from 257 Salt Wash, 60 Recapture, 58 Westwater Canyon, and 48 Brushy Basin member samples produced the average proportions shown in table 3.

Table 3. Average heavy mineral ratios in sandstones of the Morrison formation

(Abbreviations used are: O, opaques; NO, non-opaques; Z, zircon; T, tourmaline; G, garnet; S. staurolite; R, rutile; A, apatite; E, epidote.)

Member	Average heavy mineral ratios given in percent								
	All heavies		Non-opaque heavies						
	O	NO	Z	T	G	S	R	A	E
Southern area:									
Westwater Canyon	72.6	27.4	59.9	15.2	13.9	7.7	1.7	0.7	0.8
Recapture	69.2	30.8	49.8	22.8	18.7	5.0	2.1	0.2	1.5
Northern area:									
Brushy Basin	62.8	37.2	60.6	19.7	14.3	2.2	2.7	0.4	0.0
Salt Wash	53.6	46.4	62.0	23.2	8.5	1.7	3.6	0.8	0.0

A comparison of the mean ratio figures for opaques, non-opaques, rutile, staurolite, and epidote shows a common order of magnitude for the Westwater Canyon and Recapture members which suggests a regional pattern of distribution for these mineral varieties which is related to a regional arrangement of the four members of the Morrison formation.

A special analysis of sixteen samples was made to obtain an order of magnitude of the average total heavy mineral content of Morrison sandstones. Computed on the basis of percent of detrital minerals above 0.032 mm. grain size, the approximate proportions are: Westwater Canyon member, 0.25 percent; Recapture member, 0.20 percent; Salt Wash member, 0.10 percent; Brushy Basin member, 0.09 percent. The greatest variation was observed in the Westwater Canyon and the least in the Brushy Basin. Averages for the Morrison formation are 0.16 percent of the detrital components, and 0.15 percent of the total rock.

Sandstones of the Westwater Canyon and Recapture members thus appear to contain more heavy minerals than the Salt Wash and Brushy Basin members. Regional difference in total heavy minerals provides a clue to the reason for the regional difference in ratio of opaque to non-opaque heavy minerals suggested by the data in table 4. It is suggested that a suite of heavy minerals with a high proportion of opaques was introduced from the southeast.

Several heavy minerals in the Morrison formation have a regional pattern of distribution which may be interpreted in terms of nearness and direction to a source of sediment. Table 4 tabulates and summarizes the mineral-direction-source-rock interpretations obtained from the study of the regional variations in the heavy mineral suite. Directions are taken with respect to the center of the Colorado Plateau region.

Table 4. The provenance and directions of source associated with various heavy minerals in the Morrison formation

Heavy minerals	Apparent source direction: Dominant	Apparent source direction: Other	Inferred source
Opaques	1) southeast	2) south	1) 2) granite, authigenic
Apatite	1) northwest	2) southeast	1) silicic volcanics 2) volcanic rocks
Epidote	1) southeast	2) northwest	1) 2) granite and crystalline metamorphic rocks
Garnet	1) southeast	2) northwest	1) 2) granite and crystalline metamorphic rocks
Rutile	1) north	2) southwest	1) residual end product of sedimentary transport* 2) reworked sedimentary rocks.
Staurolite	1) southwest		1) metamorphic limestone
Tourmaline	1) southwest	2) northwest	1) reworked sedimentary and metamorphic rocks 2) granite
Zircon	1) southeast 3) west	2) northeast	1) granite, 2) residual end product of sedimentary transport* 3) volcanic rocks

* Believed to have been derived from sedimentary rocks.

Three general source directions are inferred. A southwestern source area contained partly metamorphosed limestone and other sedimentary rocks. A southeastern source contained mostly granites, crystalline metamorphic rocks, and some silicic volcanic rocks and ash. A northwestern source contained mostly silicic volcanic rocks and ash, some granites, and crystalline metamorphic rocks.

Regional variation in composition of the sandstones of the Morrison formation is borne out by the results of thin section study. Sixty-six thin sections of representative Morrison sandstones were analyzed by point-count method with 400 counts per section. The sections were apportioned among the members as follows: Salt Wash, 23; Brushy Basin, 15; Recapture 14; Westwater Canyon, 14.

All detrital minerals and mineral groups were lumped into one of four general detrital components as follows:

1. Quartz (includes quartz grains, quartz overgrowths, meta-quartzite and quartz schist fragments)
2. Feldspar (includes potash, sodic and calcic feldspars, kaolinite group of clays, wads of kaolin mud)
3. Tuff (includes silicified and altered tuff grains, chert, montmorillonite, mixed layer clays, rhyolitic rock fragments)
4. Micas (includes illite, sericite, chlorite, heavy minerals, fragments of micaceous metamorphic rocks, miscellaneous grains)

A tabulation of average compositional values is given in table 5.

Table 5. Average composition based on thin section analyses of 66 Morrison formation sandstones, by members in terms of mean percentage of four general components

Member	Quartz	Feldspar	Tuff	Micas
Southern area:				
Westwater Canyon	63.5	31.9	1.6	3.0
Recapture	65.3	21.4	2.4	10.9
Northern area:				
Brushy Basin	66.9	9.5	18.7	4.9
Salt Wash	72.6	10.9	13.5	3.0

To summarize and compare composition of the sandstone of the members of the Morrison formation, a single statistic is used which combines average composition with variation; this statistic is the estimated range of mean at the 95 percent confidence limit. The graph, figure 12, shows the range of the mean composition of sandstone in terms of the four general components, quartz, feldspar, tuff, and micas. The estimated range of the mean computed

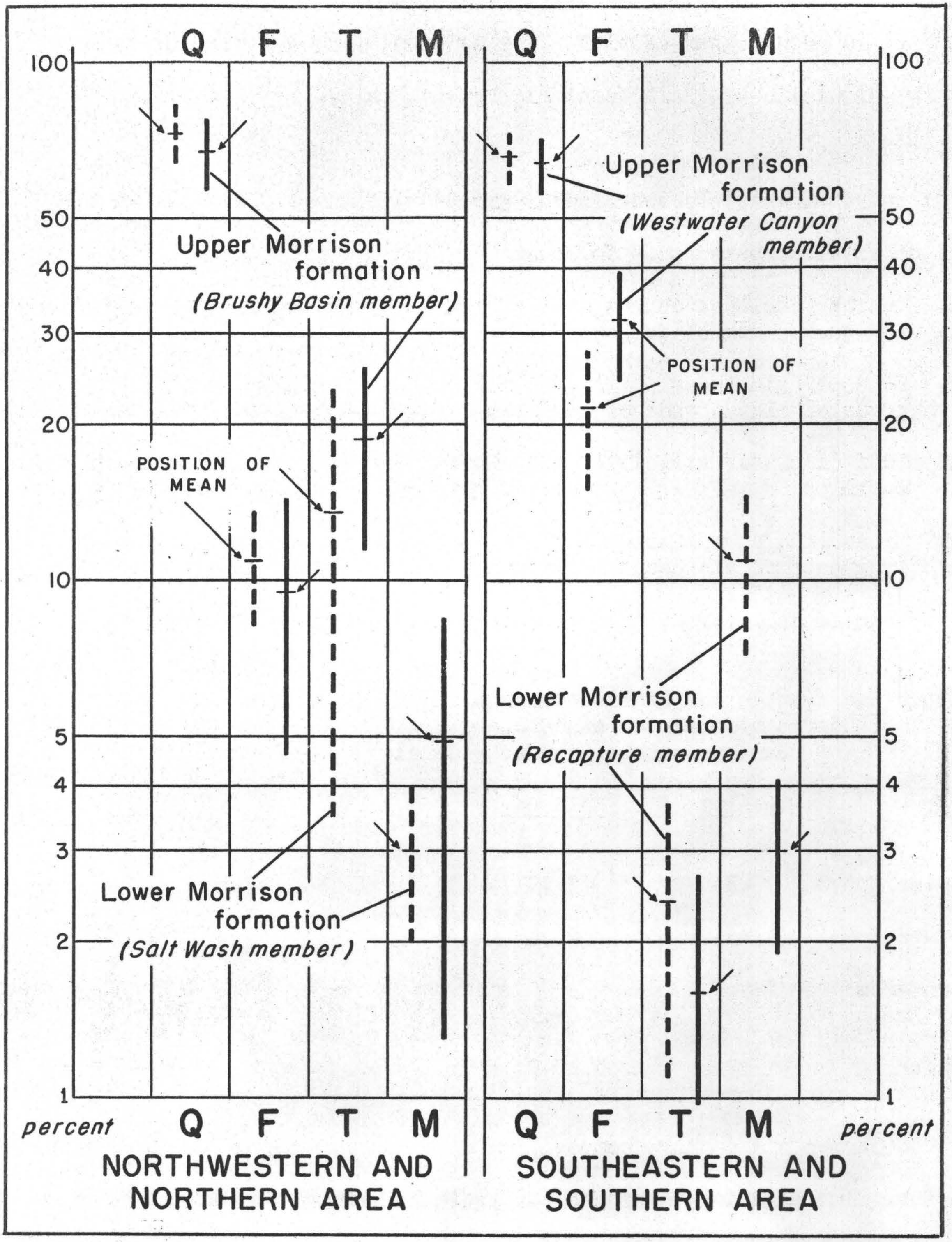


FIGURE 12 THREE-FOLD COMPARISON OF THE ESTIMATED RANGE OF THE MEAN COMPOSITION OF SANDSTONES IN TERMS OF THE DETRITAL MINERAL COMPONENTS.

for a <u>definite number of samples</u> is limited by maximum and minimum values beyond which the population mean would not be expected to occur more than 5 times out of 100.

The range of the mean when shown graphically in this manner gives much statistically significant information. First, the general location of the bar with respect to the vertical scale gives the order of magnitude of quantity. Second, the length of the bar reflects the relative amount of variation and gives an indication of the dependability of any mean value computed for a similar set of samples; a long bar indicates that there is a large variation. Third, it is possible to distinguish significant and nonsignificant differences between two stratigraphic units in terms of one component. For example, although the computed mean of the tuff content is 18.7 percent for Brushy Basin sandstones and 13.5 percent for Salt Wash sandstones, from figure 12 we see that the ranges of means of tuff content of sandstones of the two units overlap in the area where the two means occur; therefore, no significant difference exists between the two means. However, there is significantly more variation in the occurrence of tuff in the Salt Wash sandstones. Fourth, the conventional comparison of composition can be made easily among the stratigraphic units involved.

Conclusions to be drawn from figure 12 are that the amount of feldspar varies significantly on a regional basis; Recapture and Westwater Canyon sandstones contain significantly more feldspar than Salt Wash and Brushy Basin sandstones. The greatest variation in feldspar content occurs in Brushy Basin sandstones (caused by regional variation within the unit). The amount of tuff in Morrison sandstones varies significantly on a regional basis. A small overlap between range of mean tuff content of Salt Wash and Recapture sandstones is caused by the large variation in the occurrence of tuff in the Salt Wash (caused by a regional variation in tuff content in the Salt Wash itself). The amount of tuff in Brushy Basin sandstones is significantly greater than that in Westwater Canyon and Recapture sandstones.

The mean amount of micas in the sandstones differs significantly between the Recapture and Westwater Canyon members and between the Recapture and Salt Wash members, but not between the Brushy Basin, Salt Wash, and Westwater Canyon members.

To summarize, the sandstones of the Morrison are more arkosic in the southeastern and more tuffaceous in the northwestern part of the Colorado Plateau, which constitutes a major regional difference. On the other hand, the upper part of the Morrison formation (the Westwater Canyon member) is more arkosic in the southeast than the lower part (the Recapture member) and more tuffaceous (Brushy Basin member) in the northwest than the lower part (Salt Wash member) which constitutes a major stratigraphic difference.

It is concluded that most of the major compositional differences between members of the Morrison formation are related to regional location of the sandstones rather than to their stratigraphic position. The differences are directly the result of the derivation of sediments from different source areas. The differences in mean composition are greatest along the edges of the area of deposition and least in the center of the area of deposition, which may be due to amalgamations of sediments from the different sources and to the close-spaced interlayering of tongues of sediment of different composition.

The major stratigraphic difference, the evidence of more tuff and feldspar in the upper Morrison sandstones than in the lower permits the following interpretations: assuming that the amount of tuffaceous and arkosic sediments bears a direct relation to tectonic activity, it may be concluded that deposition of the upper part of the Morrison formation occurred during a time of more intense tectonic activity than that going on during deposition of the lower part of the Morrison formation.

Some preliminary compositional data is available on Triassic and associated formations studied in the general area of southeastern Utah. The data shown in table 6 are based on thin-section analyses by standard and abbreviated point-count methods. Only data on the Shinarump conglomerate, the so-called Moss Back sandstone, and the Monitor Butte and Petrified Forest members of the Chinle formation are to any extent reliable. Data on other formations are reliable only within broad limits.

Table 6. Average composition based on thin section analyses of sandstones and siltstones of Triassic and associated formations in the southeastern Utah part of the Colorado Plateau, in terms of four general detrital components

Formations and members	Number of samples	Quartz (%)	Feldspar (%)	Micas (%)	Tuff (%)
Wingate sandstone	2	49	29	9	13
Chinle formation					
Church Rock member	2	50	27	23	0
Owl Rock member	1	38	30	17	15
Petrified Forest member	2	52	8	7	33
So-called Moss Back sandstone*	6	72	16	7	5
Monitor Butte member*	17	74	16	4	6
Shinarump conglomerate*	28	76	19	2	3
Moenkopi formation	2	57	26	13	0
Cutler formation					
Hoskinnini tongue	3	73	26	1	0
DeChelly sandstone member	1	70	17	3	10
Organ Rock member	1	51	27	22	0
Cedar Mesa	1	75	24	1	0
Composition mean by units	13	61	22	9	8
Mean of nonuranium-producing units	9	57	24	11	8
Mean of uranium-producing units	3	74	17	4	5

*Uranium-producing.

A strong similarity exists between the three major uranium-producing units, the Shinarump conglomerate, the Monitor Butte member of the Chinle formation, and the so-called Moss Back sandstone. To show that this similarity is not simply a matter of sampling and that it departs from the average of the stratigraphic column, means were computed for all units (composite mean), for nonuranium-producing units only, and for uranium-producing units only.

The uranium-producing units show more of the quartz components, and less of the feldspar, micas, and tuff components. It is interesting to note that another unit which approximates the uranium-producing units in composition is the DeChelly sandstone member of the Cutler formation.

Grains of a mineral from the Browns Park formation of northwestern Colorado, reported as sodalite (noselite variety) in the preceding semi-annual report were subjected to X-ray and spectrographic analyses and found to be amorphous and rich in sodium, magnesium, and silica. It is concluded that the "mineral" consists of well-rounded detrital grains of sodium-magnesium-silica-rich volcanic glass.

Ground-water studies

by

D. A. Jobin

The transmissive character and horizontal and vertical transmissive capacity of the exposed sedimentary rocks of the Colorado Plateau and the physical distribution of uranium deposits with respect to these hydrologic properties have been studied by extensive sampling and permeability measurements.

Two types of hydrologic units, (1) eolian or marine sandstone, and (2) fluvial sandstone and conglomerate, together account for most of the regional transmissive capacity possessed by rocks of the Colorado Plateau. Marine and eolian sandstones are characterized by relatively moderate to great mean thickness and permeability and relatively even local gradients of thickness and permeability and consequently by relatively high regional transmissive capacity. Fluvial sandstones and conglomerates are characterized by relatively small to moderate thickness and permeability and abrupt and extreme fluctuations in local gradients of thickness and permeability, and consequently by relatively low to moderate regional transmissive capacity. Most of the known uranium deposits occur in fluvial hydrologic units. The two major uranium-producing hydrologic units are(1) the Shinarump and lower Chinle sandstones, and(2) the Morrison sandstones.

Exclusive of the effects of fractures and faults, the major uranium-producing hydrologic units have large differences between horizontal and vertical permeability, moderate mean vertical permeability, and are overlain by relatively thick and impermeable shales and mudstones. There is also a suggestion that, where open fractures coexist with a series of fluvial strata separated by relatively thin mudstone and shale strata, uranium has been deposited throughout the entire fluvial series.

The spatial distribution of uranium deposits within favored strata appears to be strongly influenced both by the proximity to zones of high vertical transmissive capacity and by the horizontal transmissive character and capacity of the host rocks.

For each of the major uranium-producing hydrologic units the spatial distribution of the total number of uranium deposits, the total number of 3-mile-square areas with outcrops that contain one or more uranium deposits,

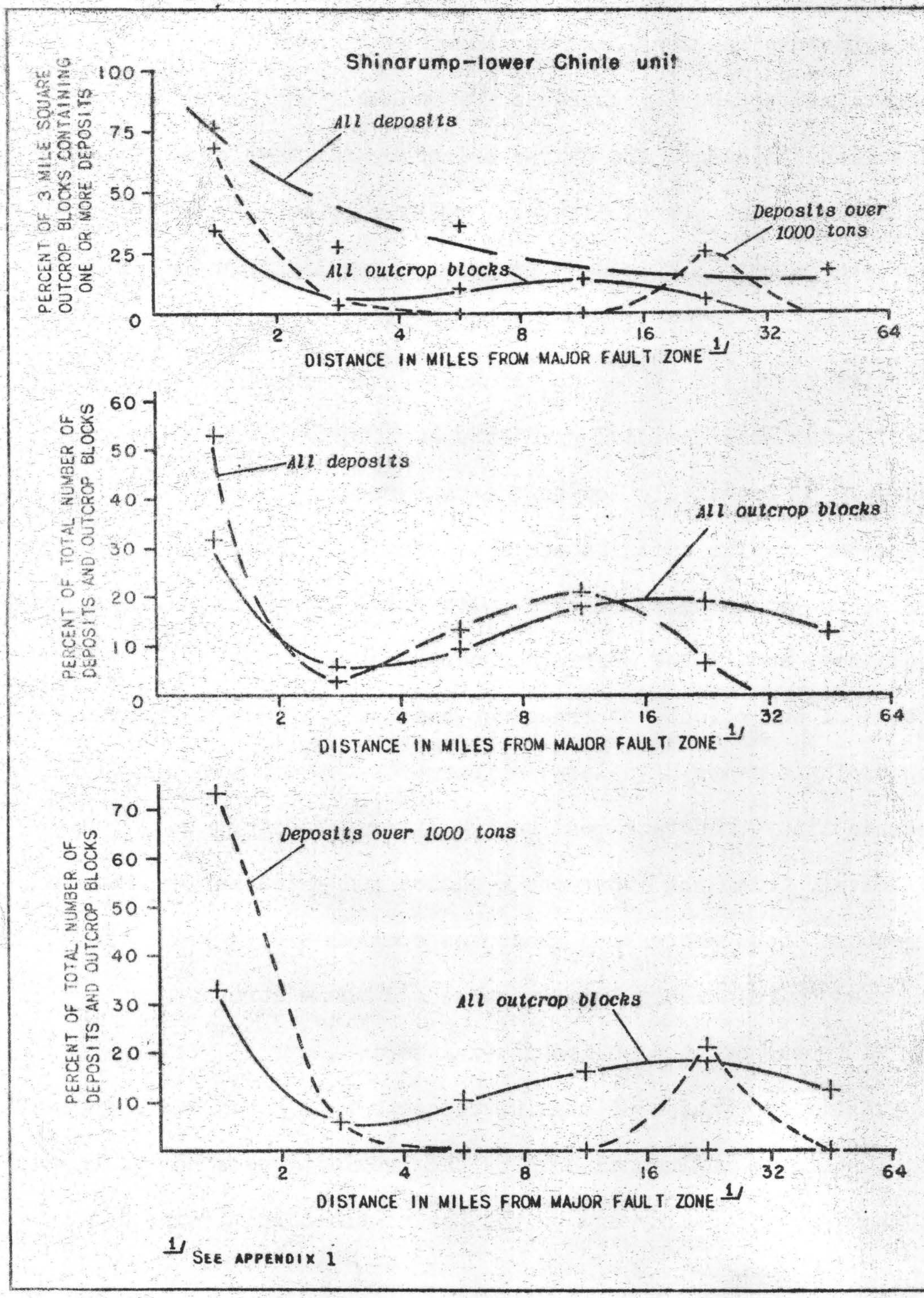


FIGURE 13 DISTRIBUTION OF URANIUM DEPOSITS AND OUTCROP BLOCKS OF THE SHINARUMP-LOWER CHINLE SANDSTONES AND CONGLOMERATES AS A FUNCTION OF DISTANCE FROM MAJOR FAULT ZONES.

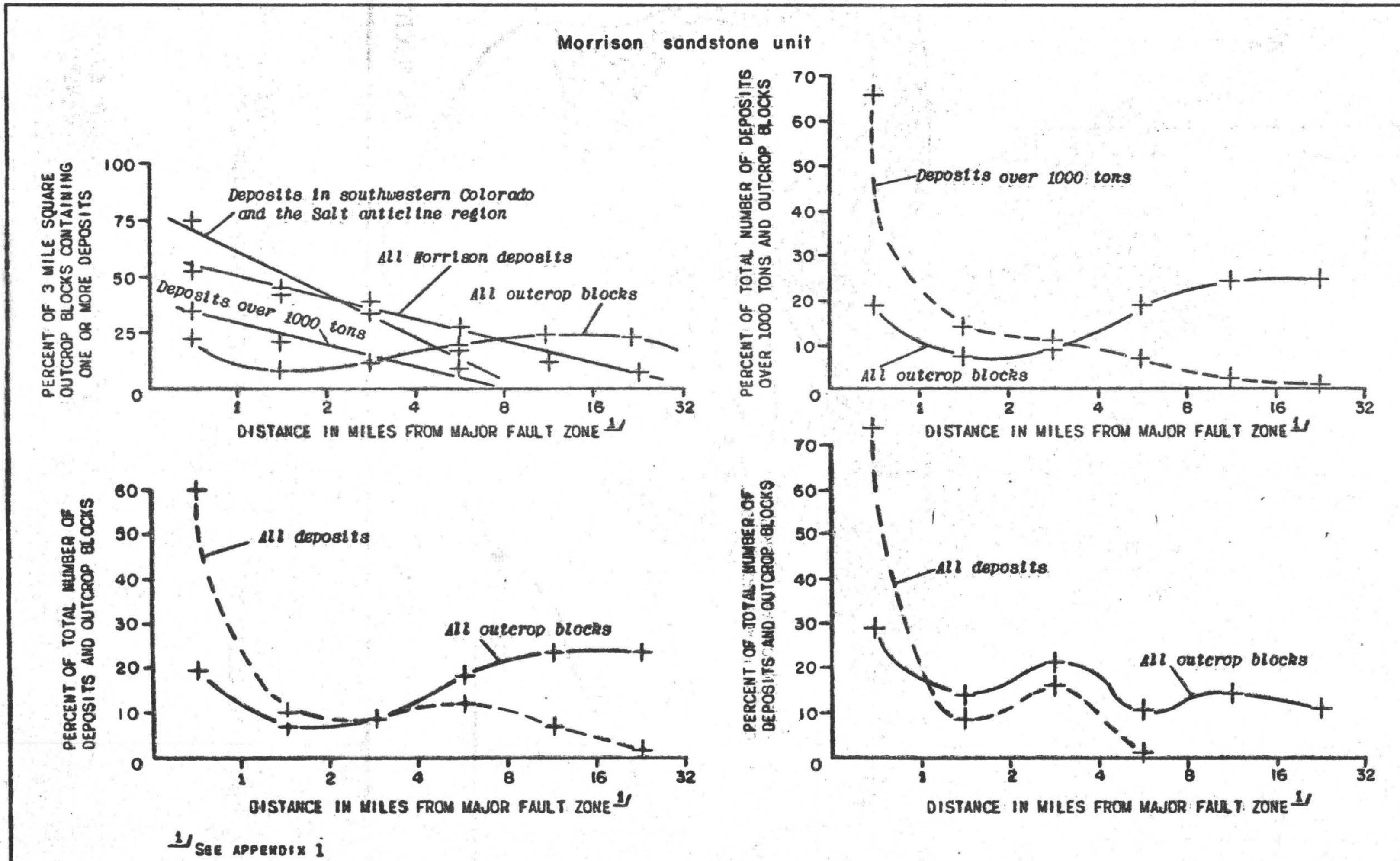
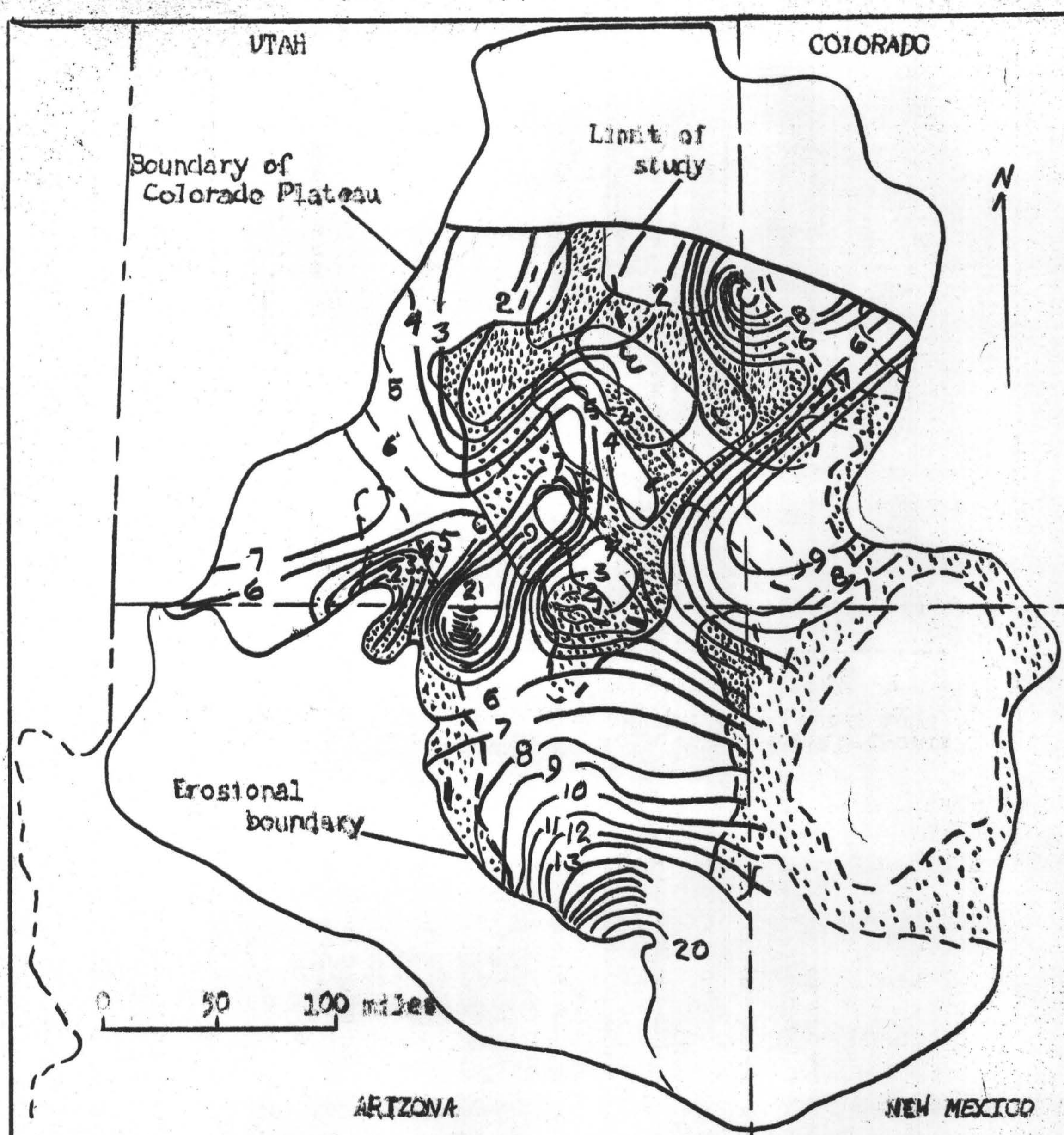


FIGURE 14. DISTRIBUTION OF URANIUM DEPOSITS AND OUTCROP BLOCKS OF THE MORRISON SANDSTONES AS A FUNCTION OF DISTANCE FROM MAJOR FAULT ZONES.



EXPLANATION

—— 6 ——

ISOPLETH OF HORIZONTAL TRANSMISSIVE CHARACTER EXPRESSED IN NATURAL LOGARITHMS: 0 EQUALS IDENTITY WITH STANDARD OF REFERENCE

AREAS OF CLOSELY SPACED URANIUM DEPOSITS

AREAS OF GREATEST VERTICAL TRANSMISSIVE CAPACITY: CLOSELY STIPPLED AREAS INDICATE COINCIDENCE OF HORIZONTAL AND VERTICAL TRANSMISSIVE CHARACTERISTICS CONSIDERED MOST FAVORABLE FOR ORE DEPOSITS

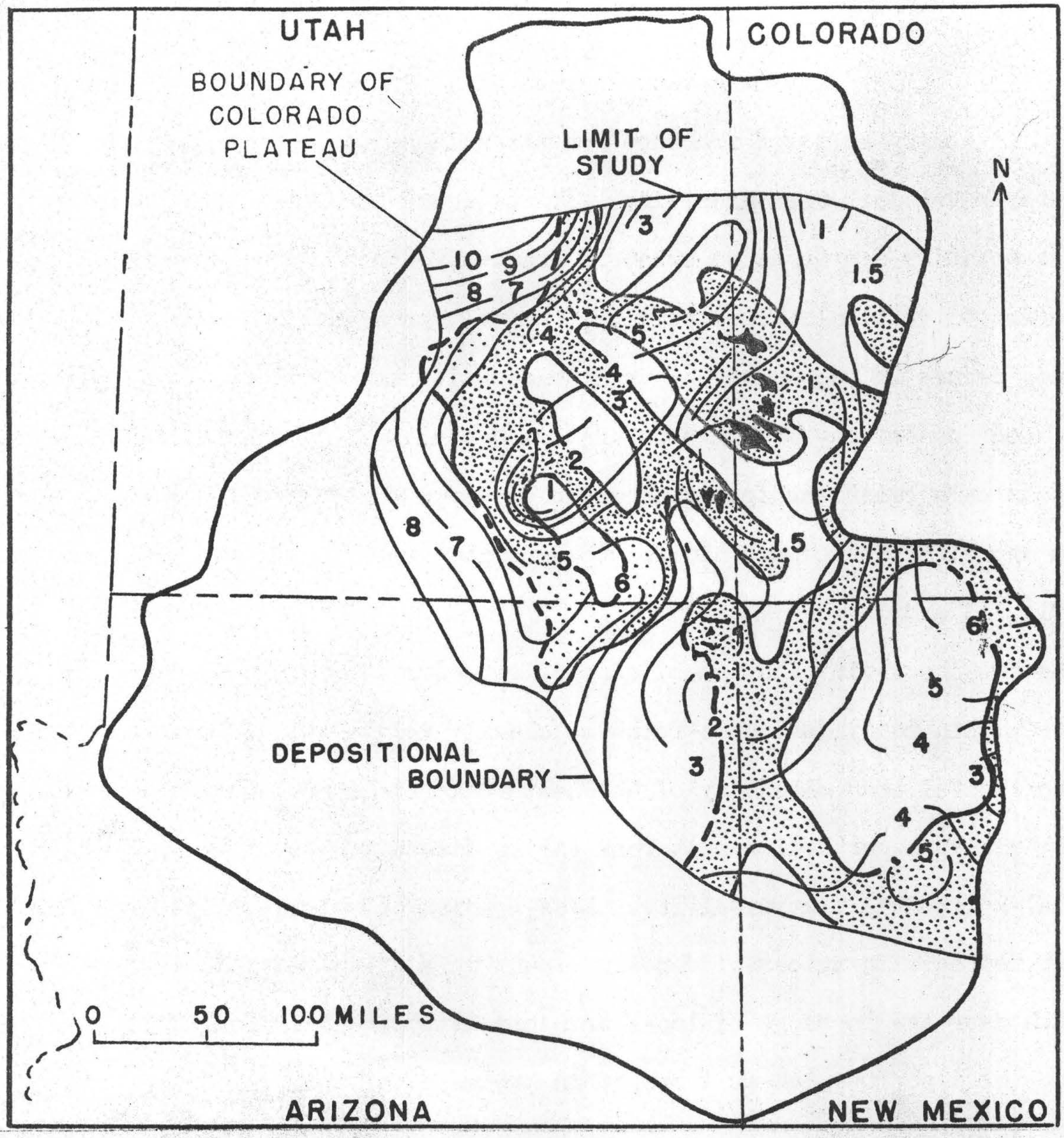
Figure 15—Shinarump-lower Chinle unit classified as to horizontal and vertical transmissive character with reference to most productive mining areas

and the total number of 3-mile-square areas with outcrops were determined relative to major fault and fracture zones considered to be the loci of considerable vertical transmissivity. It was found that, although each of these entities decreases somewhat in frequency of occurrence away from zones of major vertical transmissivity, the most pronounced decrease in frequency occurs in the number of uranium deposits and the number of 3-mile-square areas containing one or more uranium deposits (fig. 13 and 14).

These same relationships are brought out even more clearly when the uranium deposits plotted are limited to deposits larger than one thousand tons (fig. 13 and 14).

The frequency distribution by size of representative suites of uranium deposits within individual host rocks is clearly related to the range of local horizontal transmissivity of the host rock; the range in size of deposits within a particular host rock varies directly with the range in its local horizontal transmissivity. Less consistent relationships are the apparent decrease in number of deposits found in a given mineralized host rock with decrease in range of local transmissivity and the similar decrease in number of deposits with an increase in the mean value of regional transmissive capacity.

The regional variation of transmissive character and capacity of the major uranium-producing hydrologic units was studied with reference to the transmissive character and capacity of the most productive parts of each unit as a standard of comparison. Relatively little of the Shinarump-lower Chinle unit is similar in horizontal transmissive character and capacity to its most productive parts (fig. 15). In contrast most of the Morrison sandstones are essentially similar in horizontal transmissive characteristics and capacity to their most productive parts (fig. 16).



EXPLANATION

—7—

ISOPLETH OF HORIZONTAL TRANSMISSIVE CHARACTER EXPRESSED IN NATURAL LOGARITHMS; O EQUALS IDENTITY WITH STANDARD OF REFERENCE

AREAS OF CLOSELY SPACED URANIUM DEPOSITS

AREAS OF GREATEST VERTICAL TRANSMISSIVE CAPACITY; CLOSELY STIPPLED AREAS INDICATE COINCIDENCE OF HORIZONTAL AND VERTICAL TRANSMISSIVE CHARACTERISTICS CONSIDERED MOST FAVORABLE FOR ORE DEPOSITS

FIGURE 16 MORRISON SANDSTONE UNIT CLASSIFIED AS TO HORIZONTAL AND VERTICAL TRANSMISSIVE CHARACTER WITH REFERENCE TO MOST PRODUCTIVE MINING AREAS.

The most likely places for the discovery of uranium deposits in the principal uranium-producing hydrologic units are thought to be where areas of considerable vertical transmissive capacity coincide with areas in each hydrologic unit that most closely resemble in horizontal transmissive character the known productive parts (fig. 15 and 16).

A paper, "Regional transmissivity of the exposed sediments of the Colorado Plateau as related to the distribution of uranium deposits", by D. A. Jobin, was published in the Proceedings of the United Nations International Conference of the Peaceful Uses of Atomic Energy.

Resource appraisal

Appraisals of our uranium resources can be made only by synthesizing all available geologic and economic data to determine the relations of known uranium deposits to stratigraphic units, lithologic character, tectonic structures, and geochemical environment. Such appraisals allow the selection of new areas for study in which the combination of geologic factors suggests the presence of concealed uranium deposits and also aids in recommending fields for research, thus assisting in planning a coordinated program of geologic investigations on the Colorado Plateau.

This appraisal of geologic data is undertaken in three arbitrary geographic units that together encompass the entire Colorado Plateau. These units of the work are reported separately below.

Northwestern Colorado and Northeastern Utah

by

R. T. Chew, III

Field work during the report period in the extreme eastern part of the Colorado Plateau and in the Thompson district, Utah, suggests that the Chinle and Morrison formations along the northeastern edge of the Colorado Plateau are unfavorable for the occurrence of large uranium deposits. The Chinle formation northeast of the Uncompahgre uplift contains very few sandstone lenses that appear to be favorable host rocks. A few minor deposits are known in limy conglomerate lenses and conglomeratic sandstone lenses near the base of the Chinle. The fluvial sandstones which comprise the Salt Wash member of the Morrison formation over most of the Plateau thin eastward from the Uncompahgre uplift to a knife edge. Most of the lower Morrison along the Grand Hogback consists of limy siltstone that contains only a few very thin fairly persistent sandstone lenses. Although small deposits are associated with zones of carbon trash and fossil bone, none of them appears to contain more than a few tons of mineralized rock.

Favorable host rocks in the Salt Wash member of the Morrison formation are considered to be in areas where: (1) the Salt Wash is about 250 feet thick; (2) sandstone comprises 75 percent or more of the Salt Wash; (3) the individual sandstone lenses are at least 30 feet thick; and (4) the individual sandstone lenses contain an appreciable amount of mudstone and siltstone.

Application of these criteria in field studies completed in the Thompson district suggests that the most favorable area for the occurrence of undiscovered uranium deposits may be northeast of the Yellow Cat area near Cisco where the Salt Wash is beneath about 600 feet of younger rocks. Three drill cores from holes drilled in this area contain thick Salt Wash sandstones, abundant pyrite, and thin seams of vanadium(?) minerals associated with carbon trash.

The Salt Wash contains little or no sandstone in the extreme northeastern part of the Thompson district and few deposits can be expected there.

Utah and Arizona

by

H. S. Johnson

During the report period field work was essentially completed for the Green River and San Rafael districts, the Cedar Mountain area of the Uinta district, and for the Henry Mountains district.

Green River district

In the Green River district, reconnaissance of the Morrison formation indicates two favorable northerly trending belts or channel-systems in the Salt Wash member in T. 21, 22, and 23 S., R. 14 E. (fig. 17). Within these belts Salt Wash sandstone lenses reach thicknesses of 40 to 80 feet and contain small to medium sized uranium deposits. Outside these favorable belts Salt Wash sandstone lenses in the Green River district are commonly less than 40 feet thick and contain few if any significant deposits.

The so-called Moss Back member of the Chinle formation is (except where missing in the southernmost tip of the district) a relatively thick blanket-like deposit of comparatively uniform lithology over the district as far north as the northern boundary of Wayne County. The lack of known deposits in this unit, its uniform lithology, and its blanketlike character suggest that it is unfavorable for uranium deposits in this area.

The Monitor Butte member of the Chinle formation pinches out to the northeast in the southern part of the Green River district and may have fairly

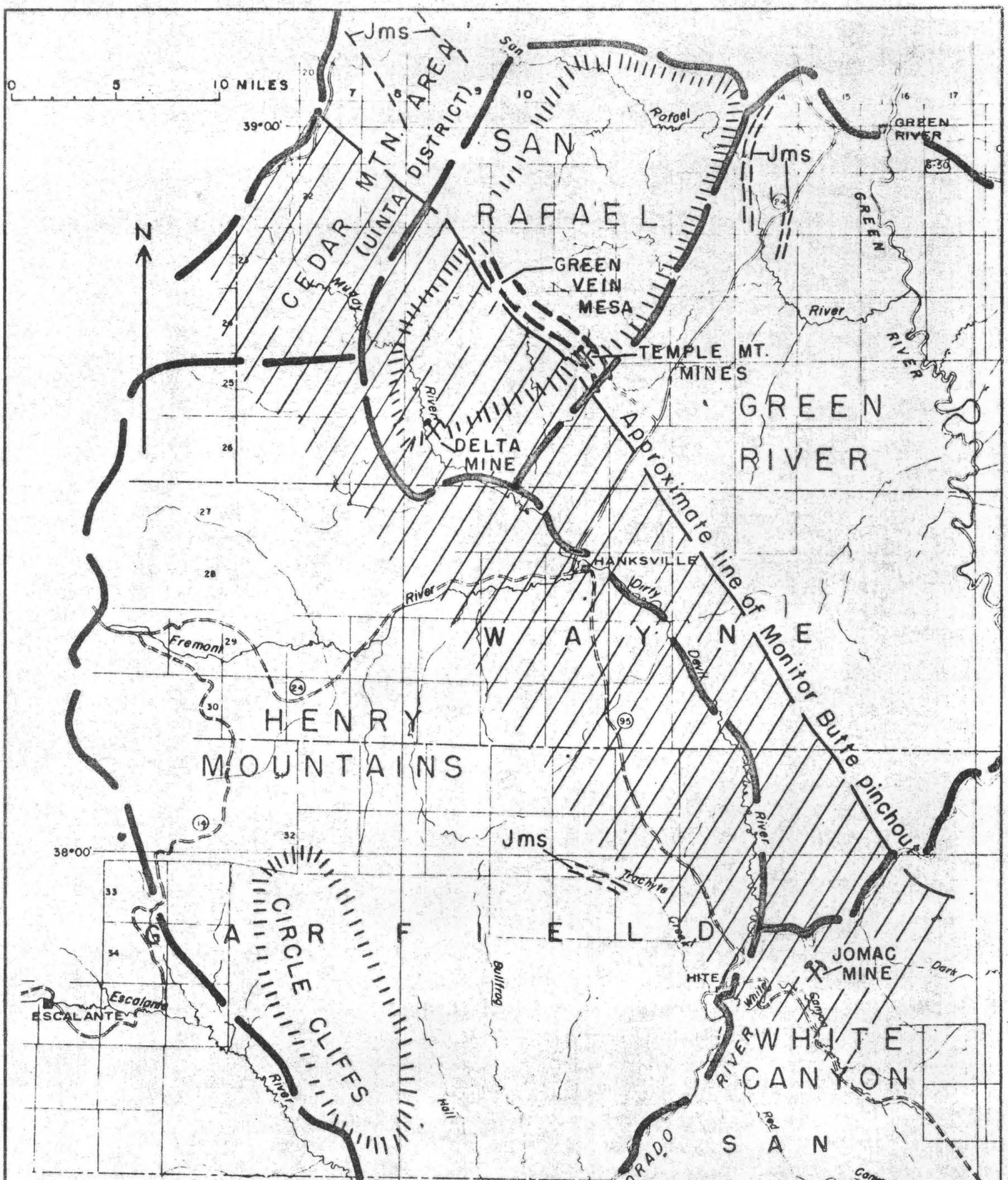


FIGURE 17. INDEX MAP OF PART OF UTAH SHOWING INFERRED BELTS OR CHANNEL SYSTEMS THOUGHT TO BE RELATIVELY FAVORABLE FOR URANIUM DEPOSITS.

large potential resources in a broad belt paralleling the line of pinchout. This relatively favorable ground in the Monitor Butte is discussed in a later paragraph dealing with Triassic formations in the Henry Mountains district.

San Rafael district

Results of investigations in the San Rafael district indicate that about 90 percent of the potential uranium resources of the district may be expected to occur in the Chinle formation in large deposits. (For purposes of this study the clusters of ore bodies in the Temple Mountain area are considered as one large deposit in which the individual ore bodies are separated by mineralized ground.) Assuming that major stratigraphic and lithologic controls of ore deposits transgress major tectonic structures, as suggested by work to date, and also that, broadly speaking, potential resources are evenly distributed within areas of favorable ground, about 40 percent of the district's potential resources may be expected at depths less than 1,000 feet.

The Monitor Butte member of the Chinle formation thins from a maximum thickness of about 100 feet in the vicinity of the Delta mine in the San Rafael Swell to a line of pinchout just south of Temple Mountain and Green Vein Mesa. It is possible that the pinching out of this unit is responsible for a broad belt of relatively favorable ground covering the south third of the Swell and extending southeasterly into the Green River and Henry Mountains districts and northwesterly into the Cedar Mountain area of the Uinta district. Within this broad belt significant uranium deposits may occur in sandstone lenses approaching 30 feet in thickness.

The so-called Moss Back member of the Chinle formation is considered relatively favorable for significant deposits along the northwesterly trend of a favorable belt or channel-system passing through Temple Mountain and Green

Vein Mesa in the San Rafael Swell and, in the so-called Moss Back channels in that part of the Swell south of Temple Mountain and Green Vein Mesa.

Reconnaissance in the Cedar Mountain area west of the San Rafael Swell indicates that the Salt Wash there is unfavorable for significant uranium deposits except in a belt that trends northwestward through T. 20 S., R. 8 and 9 E. Within this belt sandstone lenses in the Salt Wash reach thicknesses of 30 to 40 feet. Outside this belt Salt Wash sandstone lenses in the Cedar Mountain area are usually less than 20 feet thick. Small deposits can be expected in the belt.

Sparse uranium-, vanadium-, and copper-bearing materials have also been found in the Ferron sandstone, Cedar Mountain formation of Stokes, Summerville and Entrada formations as well as in the Morrison formation, in the Cedar Mountain area. Except for the Morrison, none of these formations is thought to have any appreciable potential resources.

The Monitor Butte and so-called Moss Back members of the Chinle formation underlie the Cedar Mountain area at depths greater than 1,000 feet and may contain fairly large potential resources. The Monitor Butte member is considered relatively favorable in the southern third of the Cedar Mountain area and could contain large uranium deposits if sandstone lenses approaching 30 feet in thickness are present. The so-called Moss Back member is thought to be relatively favorable over essentially the same area and could contain large uranium deposits in channels or channel-systems similar to the one passing through Temple Mountain and Green Vein Mesa in the neighboring San Rafael Swell.

Henry Mountains district

Reconnaissance along the outcrop of the Morrison formation in the Henry Mountains district indicates that the Salt Wash is most favorable for significant uranium deposits in the vicinity of Trachyte Creek. Here, the clustering of known deposits and orientations of logs, stream lineation, and festoon crossbedding suggest a favorable Salt Wash belt or channel-system trending about N. 60° W. in T. 32 and 33 S., R. 11 E. The westerly projection of this inferred belt under Brushy Basin and Mancos shale cover has not been well explored, but is likely to contain potential reserves several times larger than production to date from the Trachyte Creek area.

Ore deposits in the Circle Cliffs area, in the Henry Mountains district, are essentially confirned to channel-fill Shinarump as opposed to unfavorable blanket-type Shinarump. Deposits also tend to occur on the flanks rather than in the center of channels, and the preferred host rock is a cobble-conglomerate of Moenkopi cobbles in a Shinarump sandstone matrix, or fractured siltstone in the upper 2 or 3 feet of the Moenkopi formation.

Many large Shinarump channels are known in the Circle Cliffs area, and the presence of relatively high grade uranium-copper ore in some of these channels suggests that abundant mineralizing solutions have passed through the rocks. The small size and sparseness of known deposits in this area are probably due to the lack of favorable host rock. Most of the Shinarump channel-fill sands are relatively clean; mud and carbonaceous material are lacking. The ore minerals may have been precipitated from migrating ore solutions because of decreased permeability or physical-chemical reactions in remnant patches of the favorable cobble conglomerate or in the favorable fractured Moenkopi siltstone in the flanks of channels. The fractured zones in the Moenkopi may be related to slumping on the banks of old Shinarump stream channels.

Potential resources in the Circle Cliffs area are probably not large, and deposits of greater than medium size seem unlikely.

Reconnaissance of the Triassic formations in the northeastern part of the Henry Mountains district indicates that with the possible exception of the Monitor Butte member of the Chinle formation potential resources are probably small. The Shinarump conglomerate is not present on the outcrop north of the vicinity of Hite, Utah. The Monitor Butte member of the Chinle contains small uranium deposits between the vicinity of Hite and the line of pinchout of this unit trending northwest through the upper end of Hatch Canyon in the southern Green River district. The many small deposits in the Monitor Butte in this area suggest that the wedging out of the Monitor Butte may provide some sort of major stratigraphic control of the ore deposits. If this is so, there may be a relatively favorable belt of Monitor Butte ground as much as 25 miles wide and paralleling and bounded on the northeast by the northwesterly trending line of pinchout of the unit. It is interesting to note that the Delta mine in the San Rafael district and the Jomac mine in the White Canyon district both would fall in this projected belt. Such a belt, if valid, could possibly contain considerably greater potential resources than the small deposits now known in the area would seem to indicate.

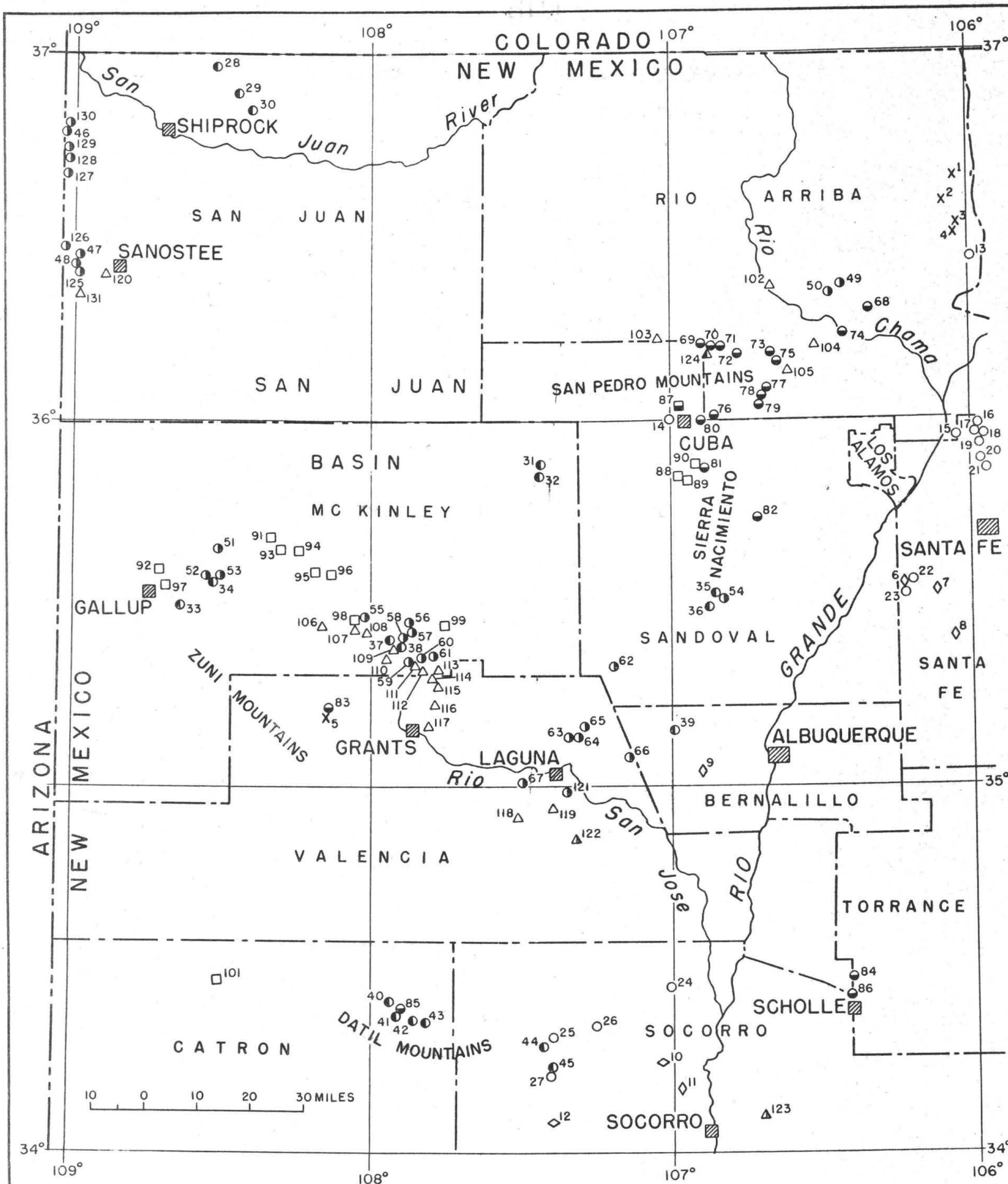
Northwest New Mexico

by

L. S. Hilpert and A. F. Corey

The known or available occurrences of uranium-bearing rocks in northwest New Mexico are shown on figure 18 which shows the occurrences by type and age of host rocks. Table 7 lists the occurrences by name (where available), location, and by the host formation.

Because of the varied sources of information, strict grade cutoffs could not be used. Generally, however, all surface anomalies represent deposits with



EXPLANATION

SEDIMENTARY ROCKS	Coal and carbonaceous shale	Limestone	Sandstone
TERTIARY	⊟		○
CRETACEOUS	□		◐
JURASSIC		△	◑
PERMO-TRIASSIC			⊖
PERMIAN		▲	
PENNSYLVANIAN		▲	

CRYSTALLINE ROCKS
X PRECAMBRIAN
IGNEOUS ROCKS
◊ TERTIARY INTRUSIVE
◇ TERTIARY EXTRUSIVE

Figure 18. INDEX MAP SHOWING THE LOCATIONS OF URANIFEROUS DEPOSITS IN NORTHWEST NEW MEXICO.

Table 7.--Name, location, and host rocks of uraniferous occurrences in northwest New Mexico

No. on Map	Name	Location			Host rock
		Section	Township	Range	
1	Tusas	24	28 N.	8 E.	"Ortega" quartzite
	Tusas	18	28 N.	9 E.	"Ortega" quartzite
	J.O.L.	24	28 N.	8 E.	"Ortega" quartzite
2	Rancho AAA	10	27 N.	8 E.	"Ortega" quartzite
3	Cooperative Mines	36	27 N.	8 E.	"Ortega" quartzite
	Cooperative Mines	31	27 N.	9 E.	"Ortega" quartzite
4	Apache	12	26 N.	8 E.	"Ortega" quartzite
5	-----	NW-1/4 7	11 N.	12 W.	Granite gneiss
6	Hiser-Moore No. 1	8	15 N.	7 E.	Espinaso andesite
7	-----	20	15 N.	8 E.	Granite
8	Ortiz Mine Grant	35	14 N.	8 E.	Monzonite
9	-----	1	9 N.	1 W.	Rhyolite
10	-----	10	1 S.	2 W.	Andesite
11	Carter-Tolliver-Cook	5,6	2 S.	1 W.	Diorite
12	-----	6	3 S.	5 W.	Rhyolite
	-----	1	3 S.	6 W.	Rhyolite
13	-----	3	25 N.	9 E.	Santa Fe formation
14	-----	NW-1/4 1	20 N.	2 W.	Wasatch formation
15	-----	24	20 N.	8 E.	Santa Fe formation
16	-----	NW-1/4 13	20 N.	9 E.	Abiquiu(?) formation
17	Rogers	17	20 N.	9 E.	Abiquiu(?) formation
	Rogers	20	20 N.	9 E.	Abiquiu(?) formation
	Rogers	N-1/2 29	20 N.	9 E.	Abiquiu(?) formation
18	-----	SE-1/4 22	20 N.	9 E.	Abiquiu(?) formation
19	-----	33	20 N.	9 E.	Santa Fe formation
	-----	32	20 N.	9 E.	Santa Fe formation
20	-----	SW-1/4 17	19 N.	9 E.	Santa Fe formation
21	-----	NE-1/4 28	19 N.	9 E.	Abiquiu(?) formation
22	La Bajada	NW-1/4 9	15 N.	7 E.	Abiquiu(?) formation
	-----	NE-1/4 8	15 N.	7 E.	Abiquiu(?) formation
23	-----	19	15 N.	7 E.	Santa Fe formation
	-----	20	15 N.	7 E.	Abiquiu(?) formation
	-----	19	15 N.	7 E.	Santa Fe formation
	-----	N-1/2 17	15 N.	7 E.	Abiquiu(?) formation
24	Charley No. 2	NE-1/4 35	3 N.	2 W.	Popotosa formation
25	Hot Shot	18	1 N.	5 W.	Baca formation
26	King	4	1 N.	4 W.	Baca formation
27	Hogsett-Hurst-Henderson	24	1 S.	6 W.	Baca formation
28	-----	28	32 N.	16 W.	Menefee fm. of Mesaverde group
	-----	28	32 N.	16 W.	Menefee fm. of Mesaverde group
29	-----	E-1/2 19	31 N.	15 W.	Menefee fm. of Mesaverde group
	-----	SE-1/4 19	31 N.	15 W.	Menefee fm. of Mesaverde group
	-----	SE-1/4 19	31 N.	15 W.	Menefee fm. of Mesaverde group
30	Boyd	3	30 N.	15 W.	Pictured Cliffs sandstone
31	Farr Ranch	13	19 N.	6 W.	Fruitland formation
	Farr Ranch	14	19 N.	6 W.	Fruitland formation
32	Farr Ranch	25	19 N.	6 W.	Fruitland formation
	Farr Ranch	26	19 N.	6 W.	Fruitland formation
33	Largo No. 2	NE-1/4 33	15 N.	17 W.	Dakota sandstone
	Becenti	NW-1/4 28	15 N.	17 W.	Dakota sandstone
34	Christian 16 (U mine)	SE-1/4 4	15 N.	16 W.	Dakota sandstone
35	Morris-Peters	17	15 N.	1 E.	Mancos shale
	Morris-Peters	20	15 N.	1 E.	Mancos shale
	Morris-Peters	21	15 N.	1 E.	Mancos shale
36	-----	31	15 N.	1 E.	Dakota sandstone
37	Small Stake	31	14 N.	10 W.	Dakota sandstone

Table 7.--Name, location, and host rocks of uraniferous occurrence in northwest New Mexico (Con't)

No. on Map	Name	Location: Section	Township	Range	Host rock
37 (cont'd)					
	Silver Spur No. 1	31	14 N.	10 W.	Dakota sandstone
	Silver Spur No. 5	NE-1/4 31	14 N.	10 W.	Dakota sandstone
	-----	31	14 N.	10 W.	Dakota sandstone
38	Junior	4	13 N.	10 W.	Dakota sandstone
39	Angell	30	11 N.	1 W.	Mesaverde group
	Angell	25	11 N.	2 W.	Mesaverde group
40	McPhaul Ranch	12	2 N.	11 W.	Mesaverde group
41	Tietzen-Red Basin	20	2 N.	10 W.	Mesaverde group
	Hot Spot	20	2 N.	10 W.	Mesaverde group
42	-----	26	2 N.	10 W.	Mesaverde group
	-----	27	2 N.	10 W.	Mesaverde group
	-----	35	2 N.	10 W.	Mesaverde group
43	-----	31	2 N.	9 W.	Mesaverde group
44	-----	24	1 N.	6 W.	Mancos shale
	Beall claims	26	1 N.	6 W.	Mancos shale
	Rusty Atom claims	26	1 N.	6 W.	Mancos shale
45	-----	7	1 S.	5 W.	Mancos shale
	-----	13	1 S.	6 W.	Mancos shale
46	King No. 2	26	30 N.	21 W.	Salt Wash member of Morrison formation
47	Deneh Nezz	32	26 N.	20 W.	Recapture member of Morrison formation
	Deneh Nezz	33	26 N.	20 W.	Recapture member of Morrison formation
48	Deneh Nezz	4	25 N.	20 W.	Recapture member of Morrison formation
	Deneh Nezz	5	25 N.	20 W.	Recapture member of Morrison formation
	Joe Ben No. 1	6	25 N.	20 W.	Salt Wash member of Morrison formation
	Joe Ben No. 3	6	25 N.	20 W.	Salt Wash member of Morrison formation
	Enos Johnson	5	25 N.	20 W.	Recapture member of Morrison formation
	Enos Johnson No. 1	5	25 N.	20 W.	Recapture member of Morrison formation
	Enos Johnson No. 2	5	25 N.	20 W.	Recapture member of Morrison formation
	Enos Johnson No. 3	5	25 N.	20 W.	Recapture member of Morrison formation
49	Lucky Dog and Horny Toad	S-1/2 29	25 N.	5 E.	Westwater Canyon member of Morrison fm.
	Lucky Dog and Horny Toad	N-1/2 32	25 N.	5 E.	Westwater Canyon member of Morrison fm.
50	Doe	W-1/2 1	24 N.	4 E.	Morrison formation
51	Foutz No. 3	SE-1/4 3	16 N.	16 W.	Westwater Canyon member of Morrison fm.
52	Foutz No. 2	NE-1/4 5	15 N.	16 W.	Westwater Canyon member of Morrison fm.
	Foutz No. 1	NW-1/4 4	15 N.	16 W.	Westwater Canyon member of Morrison fm.
53	Foutz Prospect No. 2	34	16 N.	16 W.	Recapture member of Morrison formation
	Pyramid	SE-1/4 32	16 N.	16 W.	Morrison formation
54	Collins	21	15 N.	1 E.	Morrison formation
	Collins	22	15 N.	1 E.	Morrison formation
	Collins	27	15 N.	1 E.	Morrison formation
	Collins	28	15 N.	1 E.	Morrison formation
55	Evelyn	NW-1/4 9	14 N.	11 W.	Brushy Basin member of Morrison fm.
	Francis	N-1/2 8	14 N.	11 W.	Brushy Basin member of Morrison fm.

Table 7.--Name, location, and host rocks of uraniferous occurrence in northwest New Mexico (Con't)

No. on Map	Name	Location: Section	Township	Range	Host rock
55	(cont'd)				
	Alta	SW-1/4 5	14 N.	11 W.	Westwater Canyon member of Morrison fm.
56	-----	15	14 N.	10 W.	Westwater Canyon member of Morrison fm.
	-----	SW-1/4 11	14 N.	10 W.	Westwater Canyon member of Morrison fm.
57	-----	NE-1/4 26	14 N.	10 W.	Westwater Canyon member of Morrison fm.
	-----	23	14 N.	10 W.	Westwater Canyon member of Morrison fm.
58	Dakota	NE-1/4 4	13 N.	10 W.	Brushy Basin member of Morrison fm.
59	Garcia No. 1	NE-1/4 24	13 N.	10 W.	Brushy Basin member of Morrison fm.
	Section 24	NE-1/4 24	13 N.	10 W.	Brushy Basin member of Morrison fm.
60	Mesa Top	20	13 N.	9 W.	Brushy Basin member of Morrison fm.
	Poison Canyon No. 1	SE-1/4 9	13 N.	9 W.	Brushy Basin member of Morrison fm.
	Poison Canyon No. 2	NE-1/4 19	13 N.	9 W.	Brushy Basin member of Morrison fm.
	Beacon Hill	SE-1/4 18	13 N.	9 W.	Brushy Basin member of Morrison fm.
61	Section 16	16	13 N.	9 W.	Brushy Basin member of Morrison fm.
62	Dory	30	13 N.	3 W.	Westwater Canyon member of Morrison fm.
63	Jackpile	N-1/2 2	10 N.	5 W.	Brushy Basin member of Morrison fm.
	Windwhip	E-1/2 34	11 N.	5 W.	Brushy Basin member of Morrison fm.
	Windwhip	W-1/2 35	11 N.	5 W.	Brushy Basin member of Morrison fm.
64	Woodrow	SE-1/4 36	11 N.	5 W.	Brushy Basin member of Morrison fm.
65	Bibo Strip	N-1/2 29	11 N.	4 W.	Brushy Basin member of Morrison fm.
	-----	S-1/2 19	11 N.	4 W.	Brushy Basin member of Morrison fm.
	-----	20	11 N.	4 W.	Brushy Basin member of Morrison fm.
	-----	30	11 N.	4 W.	Brushy Basin member of Morrison fm.
66	Abeyta	22	10 N.	3 W.	Brushy Basin member of Morrison fm.
	Chaves	SE-1/4 22	10 N.	3 W.	Recapture member of Morrison formation
67	Paraje	NW-1/4 17	9 N.	6 W.	Brushy Basin member of Morrison fm.
68	Las Minas de Pedro	SE-1/4 19	24 N.	6 E.	Poleo sandstone member of Chinle fm.
69	Corral No. 1	NE-1/4 25	23 N.	1 W.	Abo formation
	Corral No. 6	NE-1/4 25	23 N.	1 W.	Abo formation
	Max Jacques	NW-1/4 30	23 N.	1 E.	Agua Zarca ss. member of Chinle fm.
	Whiteflo	NW-1/4 30	23 N.	1 E.	Abo formation
	Yellow Bird No. 2	SE-1/4 30	23 N.	1 E.	Abo formation
70	E and B No. 3	SW-1/4 29	23 N.	1 E.	Abo formation
	E and B No. 1	NW-1/4 29	23 N.	1 E.	Abo formation
	T.J.B.D. No. 1	SW-1/4 29	23 N.	1 E.	Abo formation

Table 7.--Name, location, and host rocks of uraniferous occurrence in northwest New Mexico (Con't)

No. on Map	Name	Location: Section	Township	Range	Host rock
71	O'Brien No. 1	NE-1/4 28	23 N.	1 E.	Abo formation
72	-----	SW-1/4 31	23 N.	2 E.	Agua Zarca ss. member of Chinle fm.
73	Manuel Berella	E-1/2 36	23 N.	2 E.	Agua Zarca ss. member of Chinle fm.
	Lucky Strike	NE-1/4 1	22 N.	2 E.	Agua Zarca ss. member of Chinle fm.
74	J. C. Roybal	NE-1/4 17	23 N.	5 E.	Agua Zarca ss. member of Chinle fm.
75	Hillfoot No. 1	NW-1/4 8	22 N.	3 E.	Abo formation
	Red Bird	NE-1/4 8	22 N.	3 E.	Abo formation
	Red Head	NE-1/4 8	22 N.	3 E.	Abo formation
76	Eureka	NE-1/4 32	21 N.	1 E.	Agua Zarca ss. member of Chinle fm.
77	Joe	N-1/2 1	21 N.	2 E.	Agua Zarca ss. member of Chinle fm.
78	R. A. No. 1	SE-1/4 11	21 N.	2 E.	Agua Zarca ss. member of Chinle fm.
	R. A. No. 2	N-1/2 11	21 N.	2 E.	Agua Zarca ss. member of Chinle fm.
79	-----	NW-1/4 23	21 N.	2 E.	Agua Zarca ss. member of Chinle fm.
80	Copper City	NW-1/4 1	20 N.	1 W.	Poleo sandstone member of Chinle fm.
81	San Miguel	NE-1/4 24	19 N.	1 W.	Poleo sandstone member of Chinle fm.
82	Spanish Queen	SE-1/4 3	17 N.	2 E.	Abo formation
83	Ingerson Copper	6	11 N.	12 W.	Abo formation
	Ingerson Copper	7	11 N.	12 W.	Abo formation
	Mirabel	NE-1/4 7	11 N.	12 W.	Abo formation
84	Abo	22	3 N.	5 E.	Abo formation
	Rattlesnake Nos. 1-4	SE-1/4 15	3 N.	5 E.	Abo formation
85	Red Basin No. 1	20	2 N.	10 W.	Abo formation
86	Prospect No. 17	3	2 N.	5 E.	Abo formation
	Prospect No. 17	4	2 N.	5 E.	Abo formation
87	-----	20	21 N.	1 W.	Wasatch formation
88	North Butte	29	19 N.	1 W.	Mesaverde formation
	North Butte	30	19 N.	1 W.	Mesaverde formation
	North Butte	31	19 N.	1 W.	Mesaverde formation
89	North Butte	32	19 N.	1 W.	Mesaverde formation
	South Butte	33	19 N.	1 W.	Mesaverde formation
90	Butler	23	19 N.	1 W.	Dakota sandstone
	-----	14	19 N.	1 W.	Dakota sandstone
91	-----	28	17 N.	14 W.	Hosta member of Mesaverde fm.
92	Car-Ball No. 13	NE-1/4 26	16 N.	18 W.	Dilco member of Mesaverde fm.
93	-----	NW-1/4 2	16 N.	14 W.	Gibson member of Mesaverde fm.
94	-----	SW-1/4 5	16 N.	13 W.	Gibson member of Mesaverde fm.
95	-----	SW-1/4 26	16 N.	13 W.	Gibson member of Mesaverde fm.
96	-----	N-1/2 32	16 N.	12 W.	Gibson member of Mesaverde fm.
97	Hogback No. 3	NE-1/4 12	15 N.	18 W.	Dakota sandstone
	Hogback No. 4	NE-1/4 12	15 N.	18 W.	Dakota sandstone
98	-----	SE-1/4 12	14 N.	12 W.	Gibson member of Mesaverde fm.
99	-----	NW-1/4 24	14 N.	9 W.	Gibson member of Mesaverde fm.
	-----	N-1/2 14	14 N.	9 W.	Gibson member of Mesaverde fm.

Table 7.--Name, location, and host rocks of uraniferous occurrences in northwest New Mexico (Con't)

No. on Map	Name	Location: Section	Township	Range	Host rock
101	Hogback No. 4	22	3 N.	16 W.	Mesaverde formation
102	Alex Nos. 51 and 52	N-1/2 31	25 N.	3 E.	Todilto limestone
103	-----	15	23 N.	2 W.	Todilto limestone
	-----	15	23 N.	2 W.	Todilto limestone
	-----	15	23 N.	2 W.	Todilto limestone
104	Wasson	NE-1/4 28	23 N.	4 E.	Todilto limestone
105	Alex Nos. 3, 5, 8	NE-1/4 22	22 N.	3 E.	Todilto limestone
106	West Eagle Nos. 1-3	NE-1/4 24	14 N.	13 W.	Todilto limestone
	Eagle Nos. 1-6	SW-1/4 18	14 N.	12 W.	Todilto limestone
107	Red Top No. 1	19	14 N.	11 W.	Todilto limestone
	Billy the Kid	SE-1/4 19	14 N.	11 W.	Todilto limestone
	Section 19	NE-1/4 19	14 N.	11 W.	Todilto limestone
	Tom Elkins	SE-1/4 24	14 N.	12 W.	Todilto limestone
	Lawrence Elkins	SE-1/4 24	14 N.	12 W.	Todilto limestone
108	T No. 10	W-1/2 28	14 N.	11 W.	Todilto limestone
	T No. 2	W-1/2 28	14 N.	11 W.	Todilto limestone
	Section 21	SW-1/4 21	14 N.	11 W.	Todilto limestone
109	Section 24	NE-1/4 24	13 N.	11 W.	Todilto limestone
	Section 19	NW-1/4 19	13 N.	10 W.	Todilto limestone
	Section 18	18	13 N.	10 W.	Todilto limestone
	Section 18	SW-1/4 18	13 N.	10 W.	Todilto limestone
	Section 13	SW-1/4 13	13 N.	11 W.	Todilto limestone
110	Red Point No. 1	NW-1/4 16	13 N.	10 W.	Todilto limestone
111	Section 23	SE-1/4 23	13 N.	10 W.	Todilto limestone
	Section 26	NE-1/4 26	13 N.	10 W.	Todilto limestone
	Section 25	25	13 N.	10 W.	Todilto limestone
112	Rimrock	NE-1/4 36	13 N.	10 W.	Todilto limestone
	Section 30	SW-1/4 30	13 N.	9 W.	Todilto limestone
	Flat Top No. 4	SE-1/4 30	13 N.	9 W.	Todilto limestone
	Section 31	NW-1/4 31	13 N.	9 W.	Todilto limestone
	Section 30	N-1/2 30	13 N.	9 W.	Todilto limestone
113	Christmas Day	34	13 N.	9 W.	Todilto limestone
114	Christman Day	4	12 N.	9 W.	Todilto limestone
	Red Bluff No. 7	4	12 N.	9 W.	Todilto limestone
	Red Bluff No. 8	4	12 N.	9 W.	Todilto limestone
	Red Bluff No. 10	SE-1/4 4	12 N.	9 W.	Todilto limestone
	Gay Eagle	SE-1/4 4	12 N.	9 W.	Todilto limestone
	U.D.C. No. 5	4	12 N.	9 W.	Todilto limestone
	Black Hawk	SE-1/4 4	12 N.	9 W.	Todilto limestone
	Bunny	SE-1/4 4	12 N.	9 W.	Todilto limestone
	Red Bluff No. 3	N-1/2 4	12 N.	9 W.	Todilto limestone
	Red Bluff No. 5	4	12 N.	9 W.	Todilto limestone
	Last Chance	NE-1/4 8	12 N.	9 W.	Todilto limestone
	Red Bluff No. 9	4	12 N.	9 W.	Todilto limestone
	Section 9	9	12 N.	9 W.	Todilto limestone
115	La Jara No. 1	SE-1/4 15	12 N.	9 W.	Todilto limestone
116	Tom 13	SE-1/4 4	11 N.	9 W.	Todilto limestone
	Section 33	SE-1/4 33	12 N.	9 W.	Todilto limestone
117	Section 20	20	11 N.	9 W.	Todilto limestone
	Cedar No. 1	E-1/2 20	11 N.	9 W.	Todilto limestone
118	Balo	S-1/2 18	8 N.	6 W.	Todilto limestone
119	Crackpot	NW-1/4 8	8 N.	5 W.	Todilto limestone
120	Reed-Henderson No. 1	17	25 N.	19 W.	Todilto limestone
121	Sandy	SE-1/4 22	9 N.	5 W.	Entrada sandstone
	Sandy	27	9 N.	5 W.	Entrada sandstone
122	Sonora Nos. 1-4	1	7 N.	5 W.	San Andres fm.
	Sonora Nos. 1-4	12	7 N.	5 W.	San Andres fm.
123	Lucky Don	NE-1/4 35	2 S.	2 E.	San Andres fm.
124	Paradise	SW-1/4 32	23 N.	1 E.	Madera ls. member of Magdalena gr.
	Pajarito Azule	NE-1/4 31	23 N.	1 E.	Madera ls. member of Magdalena gr.

Table 7.--Name, location, and host rocks of uraniferous occurrences in northwest New Mexico (Con't)

No. on Map	Name	Location			Host rock
		Section	Township	Range	
125	Carl Yazzi No. 1	NE-1/4 17	25 N.	20 W.	Salt Wash member of Morrison formation
126	Key Tohe	SW-1/4 24	26 N.	21 W.	Recapture member of Morrison formation
	-----	NW-1/4 25	26 N.	21 W.	Recapture member of Morrison formation
	-----	NE-1/4 26	26 N.	21 W.	Recapture member of Morrison formation
127	Nakai Chee Begay	10	28 N.	21 W.	Salt Wash member of Morrison formation
128	Begay No. 1	23	29 N.	21 W.	Salt Wash member of Morrison formation
	Begay No. 1	24	29 N.	21 W.	Salt Wash member of Morrison formation
129	Salt Rock Lease	11	29 N.	21 W.	Salt Wash member of Morrison formation
130	Beclabito Lease	23	30 N.	21 W.	Salt Wash member of Morrison formation
131	Tyler		24-25 N.	20 W.	Todilto limestone

0.005 percent or more uranium, or 0.01 percent or more equivalent uranium. Deposits plotted from in-hole anomalies contain 0.02 percent or more uranium or equivalent uranium. No radioactive hot springs or their deposits are shown, and no data have been compiled from anomalies in oil wells and shot holes. Also, many deposits have not yet been compiled, or cannot be shown in some rather large blocks of ground under present or recent exploration by private companies.

The deposits listed on figure 18 by types of host rock are summarized below.

Precambrian crystalline rocks

Deposits in crystalline Precambrian rocks are in two widely separated areas. Several are in eastern Rio Arriba County. The uranium in these deposits is in samarskite, euxenite and other rare-earth minerals in Precambrian pegmatites. Radioactivity also is associated with other minerals such as columbite and tantalite; this radioactivity, however, may be produced by thorium. The other occurrence is in a copper-quartz-fluorite vein in the Zuni Mountains, Valencia County where the uranium may be associated with the fluorite.

Tertiary igneous rocks

Deposits associated with igneous rocks are mostly along the Rio Grande Valley in Socorro, Bernalillo and Santa Fe Counties. They occur mostly along shear zones in both acidic and basic intrusive and extrusive rocks and generally contain copper-bearing minerals. Little is known of the uranium mineralogy.

Sandstone

Permo-Triassic.--The oldest sandstones that contain uranium deposits in northwest New Mexico are those in the Permo-Triassic "Red Beds", including the Abo formation of Permian(?) age and the Poleo sandstone and Agua Zarca members of the Chinle formation of Triassic age. Areally they are in the Sierra Nacimiento, San Pedro Mountains, Zuni Mountains, Datil Mountains, and near Scholle, in Rio Arriba, Sandoval, Valencia, Catron, and Torrance Counties, respectively. The uranium generally is associated with carbonized wood fragments. A few deposits, which are relatively free of carbonized wood, occur along faults. Copper is associated with the uranium in most deposits, and is contained in malachite, azurite, chalcocite, chrysocolla, and locally, covellite and native copper. Little is known of the uranium mineralogy.

Jurassic.--Almost all uranium deposits in sandstone of Jurassic age are in the Morrison formation. In western San Juan County they are mostly in the basal Salt Wash member and a few are in the overlying Recapture member. Between Gallup and Laguna, in McKinley and Valencia Counties, they are mostly in the Brushy Basin and Westwater Canyon members; these are the most important deposits economically in northwest New Mexico. East of Laguna, several deposits occur in the basal Recapture member. Several other occurrences are in the Westwater Canyon member in Sandoval and Rio Arriba Counties. Locally deposits are in the top of the Entrada sandstone under mineralized Todilto limestone. Only two of these deposits which appear to be significant are shown (No. 121, fig. 18).

The sandstone deposits are generally tabular and follow the bedding, though in detail, or locally, they may cut across it. Roll-type structures are uncommon and, where present, have rather indistinct roll surfaces.

The larger deposits in the Brushy Basin member of the Morrison occur where the containing sandstone is relatively thick. The same relationship holds for the deposits discovered this year in the Westwater Canyon member north of Grants near Ambrosia Lake. There the Westwater Canyon member is generally much less than 200 feet in thickness, but in the vicinity of the deposits discovered this year the thickness generally exceeds 200 feet and in some places may even exceed 300 feet. The deposits also are on a structural dome, and there is a reasonable possibility that the localization of the deposits has been influenced partly by the dome structure.

At least one deposit (No. 52, fig. 18) is related to fractures in the host rock. The mineralogy, however, is obscure and it is not known whether the fracturing preceded or followed the initial mineralization. If it followed the initial mineralization, the relationship may be one of secondary rearrangement of the ore minerals along the joints. North of Laguna a deposit (No. 64) occurs in the sheared and brecciated periphery of a vertical pipe-like slump feature in the Brushy Basin member that has been referred to by many as a "breccia pipe". Several deposits, such as No. 55, are largely impregnations of logs with relatively little uraniferous material in the adjoining host rock.

Northwest of Grants and near Laguna the host rocks are broken by numerous faults and joints and, in the Laguna area, the host rocks have been intruded by numerous basaltic sills and dikes of probable late Tertiary age. It appears that the distribution of the deposits is most dense where the fracturing is also most intense and, at least near Grants, the elongation of the deposits conforms roughly in orientation with the general strike of the fractures. As yet, however, no deposits are known that can be demonstrated to lie directly along fractures and to have had their initial emplacement controlled by fractures. At one deposit (No. 63) north of Laguna the margins of a basaltic sill and off-shoots from it are altered locally and impregnated with uranium minerals. The minerals that have been identified are probably secondary and the alteration may be a secondary effect following emplacement of the sill rather than associated with the initial uranium mineralization. This interpretation seems most reasonable in view of the probable late Tertiary age of the sill and the generally indicated older age of uranium mineralization in the Colorado Plateau.

The uranium minerals in the Jurassic sandstone deposits are mostly pitchblende, coffinite and, near the surface, carnotite, tyuyamunite, and uranophane. Although vanadium generally occurs with uranium in a ratio of about 1:1, the vanadiferous mineral or minerals that accompany the primary uranium has not been identified. In western San Juan County most of the deposits have a much higher content of vanadium. The mineralogy of these deposits probably is similar to those in the Salt Wash in western Colorado.

Cretaceous.--Of the few sandstone-type deposits in Cretaceous rocks, the only ones of much significance are in the Dakota sandstone between Gallup and Grants in McKinley County. They generally consist of disseminations of carnotite and tyuyamunite in association with pockets and seams of carbonized wood. Some pyrite and limonite are generally present. Deposits in the Mesaverde formation and Mancos shale are mostly low-grade concentrations in sandstone in close association with carbonaceous seams or in coal-bearing members. Only carnotite or unidentified yellow uranium minerals have been described in these deposits.

Tertiary.--Sandstone-type deposits in rocks of Tertiary age are found mostly in Santa Fe County in the Santa Fe formation. They occur in beds of tuffaceous sandstone as disseminations of carnotite associated with carbonaceous plant fragments and abundant claystone galls and seams. Limonite staining generally marks the outlines of the deposits. In addition to the deposits in the sandstone, many are closely associated with tuffaceous claystone and siltstone. They contain relatively little carbonaceous debris, and the uranium minerals seem to be mostly autunite and perhaps some schroeckingerite.

Near La Bajada, Santa Fe County, (No. 22) uranium is reported in tuffaceous rocks of the Abiquiu(?) formation or older rocks of Tertiary age. The host rocks are cupriferous and contain rare earths and thorium. The metals may be associated with nearby intrusives of andesitic and basaltic rocks. One deposit (No. 24) occurs in Socorro County in the Popotosa formation. It is reported to consist of disseminated autunite and perhaps carnotite in a fractured bentonitic mudstone. The deposit is close to a fault that separates the Tertiary rocks from Precambrian crystalline rocks. Also in Socorro County are several deposits (Nos. 25-27) near the base of the Baca formation. The uranium is associated with limonite-stained zones in sandstone, and some carbonaceous matter is present. No uranium minerals have been identified. Near Cuba, Sandoval County, the basal part of the Wasatch formation is uraniferous. The mineralogy is not known.

Coal and carbonaceous shale

Cretaceous.--Deposits in coal and carbonaceous shale of Cretaceous age are in the Dakota sandstone and the Mesaverde formation. Those in the Dakota are of most importance. They are all in carbonaceous shale lenses, and, except for a few in Sandoval County, are near Gallup. Locally the uraniferous material extends into the adjacent sandstone, and a few deposits could be classified arbitrarily as of the sandstone-type. Generally, however, where the deposit is dominantly in carbonaceous shale, the uranium minerals are inconspicuous and, although some carnotite is discernible, the uranium is more probably tied up with humic compounds in the coal. The Dakota deposits are associated with carbonaceous shale that immediately underlies the lowermost prominent sandstone unit.

Deposits in the Mesaverde formation are widespread and generally consist of local seams or beds of carbonaceous shale. Near Cuba, Sandoval County, the uranium (Nos. 88 and 89) is associated with a thin bed of bituminous coal. Locally carnotite is visible near the base of the overlying sandstone.

Near Cuba, Sandoval County, carbonaceous shales near the base of the Wasatch formation locally contain uranium (No. 87). The mineralogy is not known.

Limestone

Deposits in limestone have been found in the Madera limestone, of Pennsylvanian age in the Sierra Nacimiento, Rio Arriba County; in the San Andres limestone of Permian age, Socorro and Valencia Counties; and in the Todilto limestone of Jurassic age, in San Juan, McKinley, Valencia, and Rio Arriba Counties.

Pennsylvanian.--The uranium in the Madera limestone actually occurs in arkosic sandstone members within the limestone and is associated with secondary copper minerals. The uranium occurs in close association with thin seams and lenses of carbonaceous material.

Permian.--Deposits in the San Andres limestone, of Permian age, occur in Socorro and Valencia Counties. Those in Socorro County (No. 123) are along faults and fractures in the limestone. The uranium shows mostly as tyuyamunite. Those (No. 122) in Valencia County occur in a rather impure shaly zone in the San Andres limestone. The uranium occurs as yellow fracture coatings. In the vicinity some lead, copper, and perhaps nickel and silver, mineralization is reported.

Jurassic.--Deposits in the Todilto limestone, with the possible exception of those in Rio Arriba County, are nearly all associated with fold structures. Some of these folds are confined to the Todilto and the lowermost beds of the overlying Summerville formation and some also affect the uppermost few feet of the underlying Entrada formation. Some of these folds may be reflections of underlying faults; at least near Grants, some axial trends of the folds are parallel to known faults. In Rio Arriba County the few deposits visited did not show fold structures. The Todilto limestone containing these deposits, however, consists of an upper massive crystalline zone similar to the one occupying the same relative position near Laguna and Grants. In this zone, the bedding is indistinct and the crystalline testure is much coarser than in the underlying beds.

South of Laguna the deposits are in an area where the Todilto limestone has been intruded by basaltic sills and dikes which are probably part of the same set that is associated with the deposits in the Jurassic sandstones north of Laguna. These intrusive rocks are younger than the fold structures in the Todilto and also appear to be younger than the uranium mineralization.

The uranium in the Todilto limestone deposits is mostly in uraninite (and perhaps coffinite) and the secondary minerals, tyuyamunite, uranophane, and some carnotite. Although the vanadium in these deposits has a ratio to the uranium of about 1:1, the primary vanadiferous minerals have not been identified. The gangue minerals are mostly pyrite, barite, and fluorite. Calcite occurs also in coarsely crystalline form in veins and vugs.

Botanical studies

Research

by

Helen Cannon

Outdoor plot experiments were completed during the season in Santa Fe, on the variations in absorption of uranium, vanadium, selenium, and sulfur from carnotite ores. The plot experiments were expanded to obtain information on absorption by plants of thorium and radium, and the tracer metals Co, Ni, Cu, Zn, and Pb.

Botanical reconnaissance trips were made to the Holbrook, Cameron, and Sanostee deposits of Arizona, the Green River and Montezuma Canyon deposits of Utah, to the deposits near San Ysidro, and to the Gallina-Coyote district of New Mexico. The Mo, As, and Se relationships of the uranium deposits of Poison Buttes and Gas Hills areas in Wyoming were investigated and tests for these metals were run in the field on selected samples. All three tracer metals are closely associated with uranium in these areas and plants rooted in the deposits were found to be accumulating large amounts of both Se and Mo. A brief study was made of the Blackhawk and White Signal districts of New Mexico where uranium occurs in Co-Ni, Cu, and Ag vein deposits. Preliminary samples were collected and plans were made for a geochemical study in the spring directed toward the use of Co, Ni, and As as tracer elements in plants and soils in the detection of buried ore deposits.

Prospecting

by

F. J. Kleinhampl and Carl Koteff

The major objective of the botanical prospecting program shifted in 1955 from prospecting for uranium deposits to evaluating botanical prospecting methods and results.

Both the indicator plant and the plant analysis methods have been used to locate uraniferous ground. Indicator plants require large amounts of particular elements such as selenium, calcium, and/or sulfur to grow, and where these elements are associated with uranium deposits, concentrations of indicator plants may occur and define mineralized areas. The plant analysis prospecting method depends on plants absorbing larger than normal amounts of uranium if they grow in the proximity of mineralized rock, and on the detection by chemical analysis of the anomalous amounts of uranium in the plants.

On South Elk Ridge, San Juan County, Utah, plant analysis prospecting in 1954 located about 60 localities apparently containing anomalously large amounts of uranium (fig. 19). A drilling program tested four of the localities to provide data for evaluating the plant analysis prospecting method. Drilling also tested three favorable localities which were located by plant analysis prospecting on adjacent Deer Flat in 1953.

All of the localities tested contain some mineralized rock; it appears, however, that this prospecting method cannot determine the grade of mineralized ground and the utility of the method as an indicator of ore is therefore decreased in an area containing much spotty, low-grade mineralized rock. Some lack of spatial correlation between the positions of mineralized drill holes and plants containing anomalously large amounts of uranium indicates that the method is useful in determining the general, but not everywhere the exact, location of mineralized ground. Tentatively, the drilling program suggests that on South Elk Ridge many of the 60 apparently anomalous localities are underlain by mineralized ground. However, geologic appraisal of the localities indicates that only about 21 have any real chance of containing minable quantities of uranium.

Plant analysis prospecting conducted near Meeker, Rio Blanco County, Colorado, had as objectives the determination of ore trends and favorable areas in the Salt Wash sandstone member of the Morrison formation away from known deposits, and the acquisition of botanical prospecting data from preliminary studies of Triassic rocks. Juxtaposed aspen and conifers were sampled to

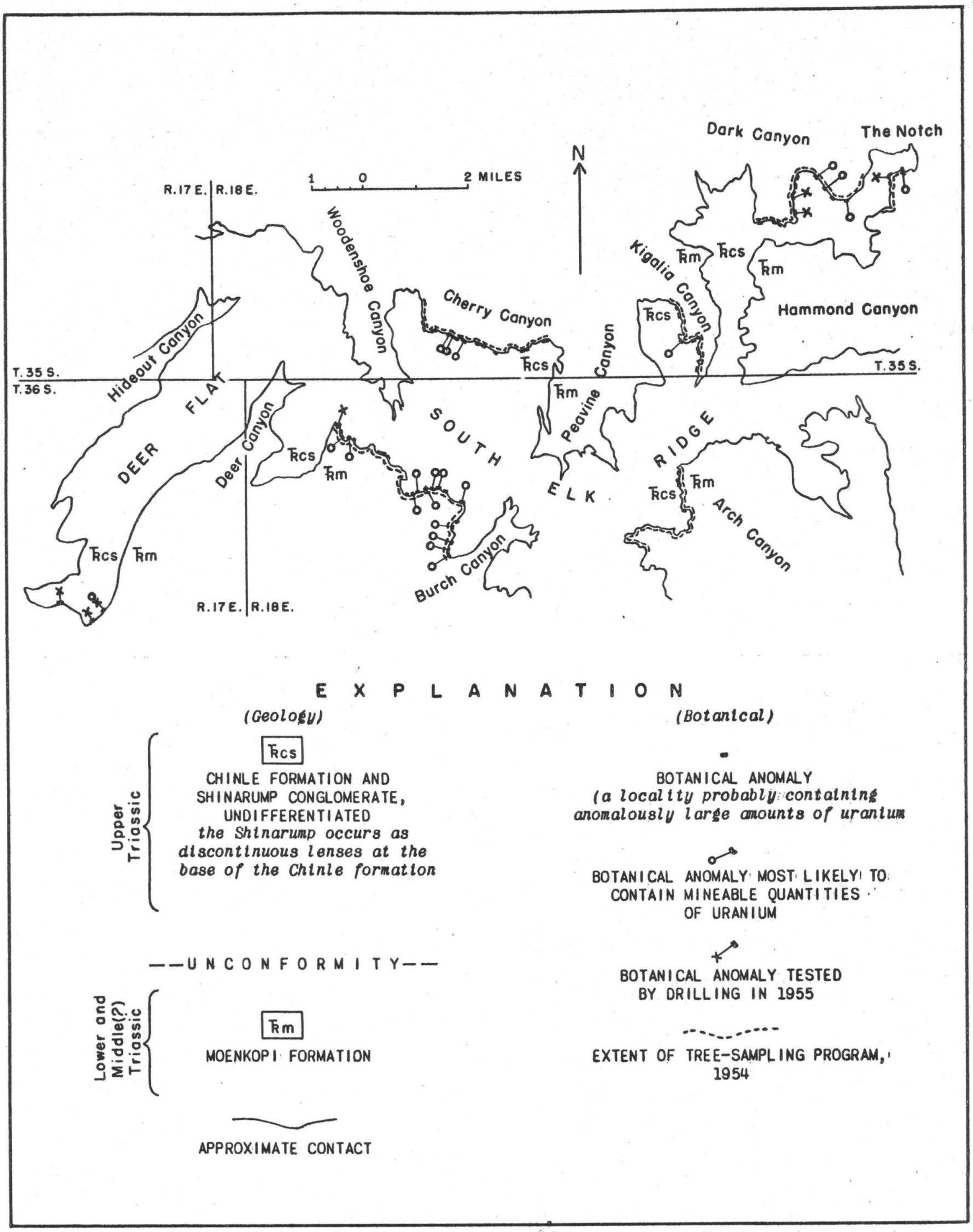


FIGURE 19. BOTANICAL ANOMALY MAP, SOUTH ELK RIDGE AND DEER FLAT, SAN JUAN COUNTY, UTAH.

evaluate the use of aspen in botanical prospecting.

Although botanical anomalies were obtained over the Salt Wash, no significant trend was found; the data evaluated indicate only a spotty uranium distribution. Almost all trees sampled over Triassic rocks near a known uranium deposit gave anomalous results. It is thought that these results probably reflect contamination from surface dust, rather than mineralized ground.

A brief study in 1954 of the utility of botanical prospecting on the Triassic Shinarump conglomerate of the Circle Cliffs area, Garfield County, Utah, indicated that tree sampling can detect deposits that are from 1 to 70 feet beneath the trees. As the Shinarump conglomerate in much of the area, particularly in the southern part, generally exceeds 70 feet in thickness where the unit fills channels in the Moenkopi formation, and as the channel bottoms are the loci of most of the uranium deposits of the area, further tree sampling appears to be unwarranted. Indicator plant studies show that only *Stanleya pinnata*, a weak selenium and sulfur indicator, and *Astragalus pattersoni*, a selenium indicator, are helpful in defining approximately the favorable area within which ore deposits may occur, provided the ore horizon is exposed or only thinly covered.

Mineralogic studies

Ore mineralogy

by

Theodore Botinelly

Detailed studies of the mineralogy of the J.J. mine, Jo Dandy group, Bull Canyon district, have been completed; a report on this mine is in preparation.

The mineralogic studies have been extended to the other mines of the Jo Dandy group, and a report on the geology and mineralogy of the group is in preparation.

The J.J. mine, Jo Dandy group, Montrose County, Colorado, contains vanadium-uranium ore which above the water table is oxidized or partly oxidized and below the water table is unoxidized. The oxidized ore, which makes up the greater part of the mined ore, contains carnotite and vanadium silicates. Partly oxidized ore, which is quantitatively unimportant, contains hydrous vanadium oxides with intermediate valences. Unoxidized ore contains montroseite, uraninite, and coffinite, and is the ore presently being mined.

The mineralogy of the other mines of the group is similar to that of the J.J. mine. The ore in the other mines is more oxidized, and low valent minerals are quantitatively less important. Unoxidized and partly oxidized ore is preserved as remnants where the ore has been protected from oxidizing solutions by mechanical (or possibly chemical) barriers. Typically, these unoxidized or partly oxidized remnants are associated with claystone lenses or large masses of carbonized wood. The distribution of these remnants is irregular and not related to depth from surface.

The ore associated with carbonized wood contains montroseite or paramontroseite, corvusite-type minerals, and pascoite, indicating, according to Garrels' pH-Eh diagrams, that the oxidizing solutions were acid. Some of the ore associated with the claystone seams shows sherwoodite and melanovanadite, indicating the oxidizing solutions were alkaline or only slightly aicd. Pyrite in these seams is usually unoxidized. The presence of pascoite in some of these clay seams indicates the solutions became more acid as oxidation progressed, probably because of the oxidation of sulfide minerals associated with vanadium minerals.

Silicate minerals containing vanadium are present in all stages of oxidation. These minerals seem to be quantitatively more important in oxidized than in unoxidized ore. They are extremely fine-grained and difficult to identify in thin section. Vanadium-bearing chlorites seem to be the most important, but confirmation of this will require detailed X-ray analyses.

The ore at the Rifle vanadium mine, Garfield County, Colorado, is high in vanadium, low in uranium, and differs in mineralogy from the uranium-vanadium mines of the Plateau. Vanadium silicates (probably roscoelite) are predominant; montroseite is rare in primary ores, and oxidation has little effect on the ore.

Clay studies

by

L. G. Schultz

About 400 samples of rocks from the Triassic formation in southeastern Utah have been analyzed by X-ray spectrometer supplemented with X-ray powder patterns.

The dominant clay mineral of the Moenkopi formation is illite with very little associated mixed layered clay. Either kaolinite or chlorite is present in small amounts (between 5 and 10 percent). The chloritic Moenkopi occurs in the eastern part, and the kaolinitic Moenkopi in the western part of the area so far investigated.

Upper Triassic beds are divided into six units; in ascending order, the Shinarump conglomerate and the Monitor Butte, the so-called Moss Back, the Petrified Forest, the Owl Rock, and the Church Rock members of the Chinle formation. The Shinarump conglomerate, and in places the lower part of the

Monitor Butte member of the Chinle are the most kaolinitic of the Triassic rocks and are also the most variable mineralogically. Both the type and amount of kaolinite vary. The so-called Moss Back member is like the upper sandstones of the Monitor Butte member; it contains less kaolinite and a better organized type of clay than is characteristic of the Shinarump. The characteristic clay mineral of the Petrified Forest member is a mixed layered illite-montmorillonite in the fine-grained rocks and montmorillonite in the sandstones. In the Owl Rock member the dominant clay mineral is illite with very little mixed-layer or other types of clays. A zone near the base of the Owl Rock and the top of the Petrified Forest contains abundant illite and mixed layer clay. Clays of the Church Rock member contain small amounts of kaolinite or chlorite-vermiculite and mixed layer illite-montmorillonite.

In the White Canyon area no mineralogical differences were found which could be attributed to near-surface weathering.

Samples of purple, red and greenish rocks of the Monitor Butte member showed no clay mineral variation related to color. The cause of the color variation seems to be related to the presence or absence of hematite and its crystal size. There seems to be very little mineralogical difference in clays in calcareous and noncalcareous rocks.

Montmorillonite and kaolinite seem to be more abundant in the coarser-grained sediments. Illite, chlorite, and some other clay minerals seem to be more abundant in the finer-grained sediments.

General mineralogic studies

by

Alice D. Weeks and Robert Coleman

Most of the summer's field work was in the Colorado Plateau region; collections of comparative material were taken from the Tertiary uranium deposits in Wyoming. The oxidation sequence of the Plateau uranium deposits has been established through mineralogical and chemical work, and the field collections were taken primarily to establish the character of the primary unoxidized ore as related to the site of deposition. A suite of samples collected from the Grants district, New Mexico completes the planned reconnaissance collection of minerals from the major uranium districts of the Colorado Plateau. Preliminary study indicates that the Tertiary uranium deposits of Wyoming differ from the Plateau uranium deposits in mineralogy and form, although the lithology and depositional history of the host rocks are similar. Differences in oxidation-reduction conditions in the two regions are being considered in light of different post-depositional histories. A detailed collection, representative of the various types of vanadium silicates, was taken in order to establish the mechanism by which roscoelite, vanadium hydromica, and vanadium chlorite have been formed.

A comprehensive study of the sulfide species and their minor and trace element content is being carried out in order to establish the nature of the ore solutions responsible for the uranium deposits. From this study it can be shown that selenium is concentrated in the sulfides from the Morrison and Entrada formations of Jurassic age and is extremely low in the sulfides from the Chinle and Shinarump formations of Triassic age; therefore it would seem that sulfides forming within these seleniferous stratigraphic zones contain selenium derived from those rocks. Cobalt apparently has been introduced by the ore solutions, as the sulfides intimately associated with uranium show a strong enrichment in cobalt when compared with the earlier diagenetic sulfides within the same stratigraphic zone.

The problem of secondary enrichment during oxidation has been illuminated in part. The vanadiferous uranium ores show no field or mineralogic evidence of enrichment although there may have been a loss of uranium during oxidation where these deposits were flushed by oxidizing ground waters. The non-vanadiferous copper-uranium deposits show secondary enrichment where they are situated in favorable structures.

A paper, "Oxidation of Colorado Plateau ores and its relation to recent geologic history", by A. D. Weeks, was presented at the annual GSA meeting in New Orleans and an abstract published in the 1955 Program of the Annual meeting of the Geological Society of America.

Chemical analyses were completed on synthetic voglite, a hydrated copper uranyl carbonate, and on three samples of synthetic phosphuranylite, a hydrated calcium uranyl phosphate. Up to now, both of these minerals were poorly defined species with inaccurate and incomplete descriptions; chemical analyses are in progress on a new tetragonal mineral containing Ca, V(IV), and V(V), and on another new mineral containing Fe, V(IV) and V(V) from three different mines in Colorado.

Distribution of elements

by

A. T. Miesch

I.B.M. methods have proved satisfactory in compilation of statistical data on element distribution and will be used almost exclusively in future computations. Using these methods, a correlation chart showing the correlation coefficients and scatter diagrams of 25 pairs of elements can be constructed in two to three man-weeks. Other statistical estimates such as means and standard deviations can also be calculated at a rapid rate.

Oxidation-reduction measurements are being made by a titration method suggested by Garrels to determine variations in oxidation states of ore; such data will be used to determine how oxidation changes the chemical composition of the ore. The ratios of oxidizable constituents (with $KMnO_4$) to total reducible constituents (with SO_2 after oxidation with $KMnO_4$) in five selected samples are as follows:

1. Sample of carnotite from Jo Dandy mine mixed with unmineralized Salt Wash sandstone (average of 2 tests)........ 0.34
2. Sample of corvusite from Jo Dandy mine mixed with unmineralized Salt Wash sandstone (average of 2 tests)........ 0.76
3. Mill pulp sample from Cactus Rat mine, Thompson district, Utah.. 0.89
4. Mill pulp sample from Frenchie Incline mine, Slick Rock district, Colorado (average of 7 tests).................. 0.83
5. Mill pulp sample from Wyoming mine, Gypsum Valley district, Colorado (average of 3 tests)...................... 0.94

Sample numbers 4 and 5 are reportedly from carnotite ore bodies and contain higher proportions of oxidizable or reducible constituents than anticipated. The results obtained may be due to organic carbon which can be oxidized by $KMnO_4$ but not reduced by SO_2. Three tests made on sample no. 4 after magnetic material had been removed did not give significantly different results.

Average chemical compositions of mineralized sandstones from uranium deposits in the Morrison formation and in Upper Triassic rocks and of unmineralized sandstones from the Morrison formation and from Upper Triassic formations are shown in table 8. The figures are based on more samples than

Table [illegible] Average composition of uranium ores and unmineralized sandstones of the principal uranium ore-bearing formations on the Colorado Plateau.

Element	Uranium ores from the Morrison formation (chiefly the Salt Wash member)			Unmineralized sandstones from the Salt Wash member of the Morrison formation			Uranium ores from Upper Triassic rocks (chiefly the Shinarump conglomerate) and Moss Back member of the Chinle formation			Unmineralized sandstones from the Shinarump conglomerate and Moss Back member of the Chinle formation		
	GM[1]		GD[2]	GM[1]		GD[2]	GM[1]		GD[2]	GM[1]		GD[2]
Al[3]	2.48	×÷ 1.14	2.03	1.19	×÷ 1.18	1.89	2.2	×÷ 1.42	2.21	3.3	×÷ 1.66	2.85
Fe[3]	0.90	×÷ 1.12	1.89	0.24	×÷ 1.19	1.91	1.5	×÷ 1.33	1.90	1.2	×÷ 1.81	3.40
Mg[3]	0.68	×÷ 1.19	2.60	0.23	×÷ 1.33	2.85	0.17	×÷ 1.61	2.99	0.13	×÷ 2.12	4.72
Ca[3]	1.97	×÷ 1.22	3.07	3.3	×÷ 1.40	3.47	0.7	×÷ 1.87	4.14	0.25	×÷ 2.60	7.19
Na[3]	0.091	×÷ 1.23	3.19	0.089	×÷ 1.42	3.73	0.08	×÷ 1.63	3.04	~0.1		--
K[3]	~0.27		--	<0.37 ~0.3[6]		--	~0.48		--	<0.15 ~0.2[6]		--
Ti[3]	0.104	×÷ 1.13	1.95	0.051	×÷ 1.20	1.96	0.13	×÷ 1.43	2.26	0.18	×÷ 1.56	2.50
Zr[3]	0.0237	×÷ 1.14	2.11	0.0103	×÷ 1.27	2.40	0.018	×÷ 1.36	2.03	0.025	×÷ 1.81	3.39
Mn[3]	0.031	×÷ 1.15	2.17	0.022	×÷ 1.33	2.89	0.024	×÷ 1.58	2.85	0.012	×÷ 3.05	10.00
Ba[3]	0.084	×÷ 1.16	2.32	0.034	×÷ 1.34	3.00	0.07	×÷ 1.67	3.22	0.05	×÷ 1.97	4.06
Sr[3]	0.0122	×÷ 1.13	2.00	0.0049	×÷ 1.28	2.50	0.014	×÷ 1.52	2.59	0.006	×÷ 2.21	5.13
Be[3]	<0.0001		--	<0.0001		--	~0.00007[6]		--	<0.0001		--
B[3]	~0.0015		--	<0.001 ~0.0008[6]		--	0.0014		--	~0.0016		--
Sc[3]	<0.001		--	<0.001		--	<0.001 ~0.0005[6]		--	<0.001 ~0.0004[6]		--
V[3]	0.49	×÷ 1.15	2.14	0.0010	×÷ 1.32	2.81	0.063	×÷ 1.92	4.40	0.0030	×÷ 2.08	4.52
Cr[3]	0.00169	×÷ 1.14	2.03	0.00066	×÷ 1.25	2.27	0.0030	×÷ 1.56	2.74	0.0014	×÷ 1.54	2.44
Co[3]	0.00104	×÷ 1.27	3.77	<0.0002 ~0.0005[6]		--	0.0025	×÷ 2.00	4.16	~0.0005		--
Ni[3]	0.00084	×÷ 1.28	4.02	<0.0002 ~0.00005[6]		--	0.0025	×÷ 1.67	3.22	~0.0009		--
Cu[3]	0.0086	×÷ 1.30	4.34	0.0013	×÷ 1.28	2.49	0.030	×÷ 2.76	10.10	0.010	×÷ 1.79	3.33
Zn[4]	0.0116	×÷ 1.44	2.58	0.0053	×÷ 1.53	2.09	0.031	×÷ 3.11	4.16	--		--
Ga[3]	<0.0005		--	<0.0005		--	<0.0005 ~0.0002[6]		--	<0.0005 ~0.0001[6]		--
As[4]	0.0168	×÷ 1.42	2.48	<0.001		--	0.020	×÷ 1.85	2.16	--		--
Se[5]	0.00118	×÷ 1.48	4.45	<0.0002		--	~0.0006		--	~0.0003		--
Y	0.00129	×÷ 1.21	2.86	<0.0005 ~0.0002[6]		--	0.0017	×÷ 1.76	3.61	0.0016	×÷ 1.50	2.31
Mo[3]	~0.0013		--	<0.0005		--	~0.0017		--	<0.0005 ~0.0002[6]		--
Ag[3]	<0.0001 ~0.00005[6]		--	<0.0001 ~0.00003[6]		--	<0.0001 ~0.00004[6]		--	<0.0001		--
Sb[4]	~0.0001		--	~0.0002		--	~0.0002		--	--		--
La[3]	<0.002		--	<0.002		--	<0.002 ~0.001[6]		--	<0.002 ~0.0008[6]		--
Yb[3]	--		--	<0.0001 ~0.00003[6]		--	--		--	0.00024	×÷ 1.68	2.42
Pb[3]	0.0088	×÷ 1.29	4.10	<0.0001		--	0.0064	×÷ 1.66	3.16	~0.001[6]		--

Footnotes for Table 8. Average composition of uranium ores and unmineralized sandstones of the principal uranium ore-bearing formations on the Colorado Plateau

1/ Geometric mean (percent) showing the 99 percent confidence interval for the population geometric mean: the limits of the confidence interval are determined from Student's t distribution (Fisher and Yates, 1953, p. 1 and 40) where t is the deviation (or range of the population mean), in units of estimated standard error, for a normal distribution:

$$\text{Confidence interval of the mean} = \pm t \frac{s}{\sqrt{n-1}}$$

or for a lognormal distribution

$$\text{Confidence interval of GM} = \times\!\!\div \text{ antilog} \left[t \frac{(\log GD)}{\sqrt{n-1}} \right]$$

The most efficient estimate of the arithmetic mean of a lognormal population may be obtained from the following equation if n is large:

$$\log_{10} \text{ estimated arithmetic mean} = \log_{10} GM + 1.1513 (\log_{10} GD)^2$$

2/ Geometric deviation or antilog of the log standard deviation.

3/ Semiquantitative spectrographic analyses: Column 1 - 211 deposits, Column 2 - 96 samples, Column 3 - 38 deposits, Column 4 - 32 samples.

4/ Colorimetric analyses: Column 1 - 49 deposits, Column 2 - 23 samples, Column 3 - 14 deposits.

5/ Colorimetric analyses: Column 1 - 102 deposits, Column 2 - 8 samples, Column 3 - 30 deposits, Column 4 - 30 samples.

6/ Estimated geometric mean. Estimated by assuming the part of the frequency distribution below the limit of sensitivity conforms to part of a log-normal distribution. Where a majority of analyses are below the limit of sensitivity the geometric mean is estimated from the frequency above the limit of sensitivity by assuming a lognormal distribution for the total frequency and by assuming for the element in question an average log-standard deviation computed for elements in the type of rock or ore analysed.

those given in a previous report (Newman, 1954, TEI-440, p. 43), and where possible, are qualified by confidence limits for a 99 percent level of probability. Geometric deviations (antilogs of a log standard deviations) of each of the elements in the four rock types are given where data were sufficient.

Studies of the distribution of elements in and adjacent to individual uranium deposits were made during the report period. Colorimetric analyses of samples of mineralized and unmineralized Salt Wash sandstone from the Jim Dandy mine east of the Henry Mountains show that cobalt is dispersed in barren sandstone above the ore for a distance of at least 2 feet; one sample from an outcrop 28 feet above the ore body contained 8 ppm cobalt. Barren Salt Wash sandstone normally contains less than 2 ppm cobalt. Vanadium appears to be dispersed into barren sandstone at least 4 feet above ore. The tabulated results of the Jim Dandy study are given below:

Sample No.	Distance above ore layer	Composition Co (ppm)	V (ppm)	CaCO (%) 1/
26	0-2"	37	1,200	0.75
27	34"	12	250	0.77
28	1'	6	60	0.50
29	2'	3.5	<60	0.84
30	4'	<2.5	400	0.41
31	8'	<2.5	<60	0.45
34	12'	<2.5	<60	0.25
32	28'	8	<60	0.48

1/ Estimated by loss of CO_2 with 1N HCL

Additional samples from the same area are currently being analyzed for cobalt, vanadium, and other trace elements.

Geophysical investigations

District studies

by

R. A. Black

Geophysical measurements were made during the report period in Lisbon Valley, Utah, and Monument Valley, Arizona.

Lisbon Valley, Utah

Measurements were made to assist in mapping the trace of the Lisbon Valley fault in parts of Lisbon Valley where the fault trace is hidden by alluvium. A total of 30 traverses were laid out across the valley at intervals ranging from one-quarter mile to one mile. These traverses were shot using air shooting techniques and the method of continuous profiling with reversed shots. The trace of the Lisbon Valley fault was readily determined from the seismic data, although the throw of the fault could not be determined. The seismic data indicate that the Lisbon Valley fault is not a single fault, but is a zone consisting of two or more essentially parallel faults.

In addition to seismic work, experimental electromagnetic and electrical measurements were made in the Lisbon Valley area. The experimental electromagnetic measurements were made with 3,600 cycle Boliden and 400 cycle Turam equipment. The Boliden equipment was tested over an ore body in Section 36 mine in the hope that the pyrite, known to be associated with the ore, would produce detectable electromagnetic anomalies. The results of the electromagnetic survey were contoured on the basis of the quadrature field component and compared with the ore extent and grade as determined by drilling and mining operations. Small anomalies, apparently due to resistivity contrasts in the country rock, were observed but no correlation exists between the electromagnetic results and the ore body.

The Boliden equipment was tested over the Lisbon Valley fault, and in the northwestern part of the valley the fault trace delineated by the electromagnetic profiles correlated well with the seismic results. The Turam equipment, utilizing a single 1,500 foot grounded cable, energized by a 100 milliamp, 400 cycle current, was also tested over the Lisbon Valley fault. The gradients of the in-phase and quadrature components of the vertical were measured using two coils 50 to 100 feet apart along profiles perpendicular to the grounded cable, which was laid out parallel to the fault. Both components showed definite anomalies corresponding in position to the fault trace.

Electric logging and measurements of electrical transients were made in Lisbon Valley. The electric logging was done to establish control information for interpretation of the electromagnetic and electrical transient measurements. Electrical transient measurements were made over the ore body in the Section 36 mine, and although fairly large transients were measured, they seemed to have no relation to the ore occurrence. Electrical transient measurements were also made over the Lisbon Valley fault, where Dakota sandstone was brought against Wingate sandstone, and where Dakota sandstone was brought against Hermosa limestone. In each of these cases the electrical transients recorded were too small to be measured accurately. Earlier work on electrical transients in mudstones has shown large transients to exist, but there was a possibility that they resulted from electrode polarization. Considering that the high resistivity sandstones in Lisbon Valley produce very small transients, it is believed that the possibility of the large mudstone transients being produced by electrode polarization may now be discounted.

Monument Valley, Arizona

Geophysical measurements were continued in the Oljeto Wash area of Monument Valley from June to December 1955. As a result of the previous reconnaissance and detailed seismic work done in this area, (TEI-540, pp. 90-91) a test drilling program was initiated by the Survey to provide geologic control for interpretation of the seismic data, and to test seismic anomalies. (See pp. 71-77 for results of drilling.) The drilling was conducted from June to August 1955. A total of 41 holes were drilled. The drilling was conducted in two phases; (1) drilling of wide spaced holes in the southern part of the Oljeto Wash, 150 to 400 feet deep, to determine thickness and character of the overburden above the Shinarump, and (2) drilling of closely or moderately spaced holes in the northern and central part of Oljeto Wash, generally less than 100 feet deep, to test specific geophysical anomalies. The original seismic reconnaissance lines, areas of detailed seismic coverage, and location of the test drill holes are shown in figure 20.

In connection with the drilling program, electric, gamma-ray, and velocity logs were obtained in the drill holes. Additional seismic profiles were run in a few parts of the Oljeto Wash area in connection with the drill tests of seismic anomalies.

The geologic data obtained in the wide spaced holes in the southern part of Oljeto Wash, together with the geophysical logging data obtained in these holes, will be invaluable in the interpretation of the seismic data in the area. As a result of the close-spaced drilling several small seismic anomalies that had been interpreted as small channels were discovered to be due to the presence of small remnants of Chinle capping the Shinarump. Near section corner D-3, however, a large seismic anomaly proved, on drilling, to

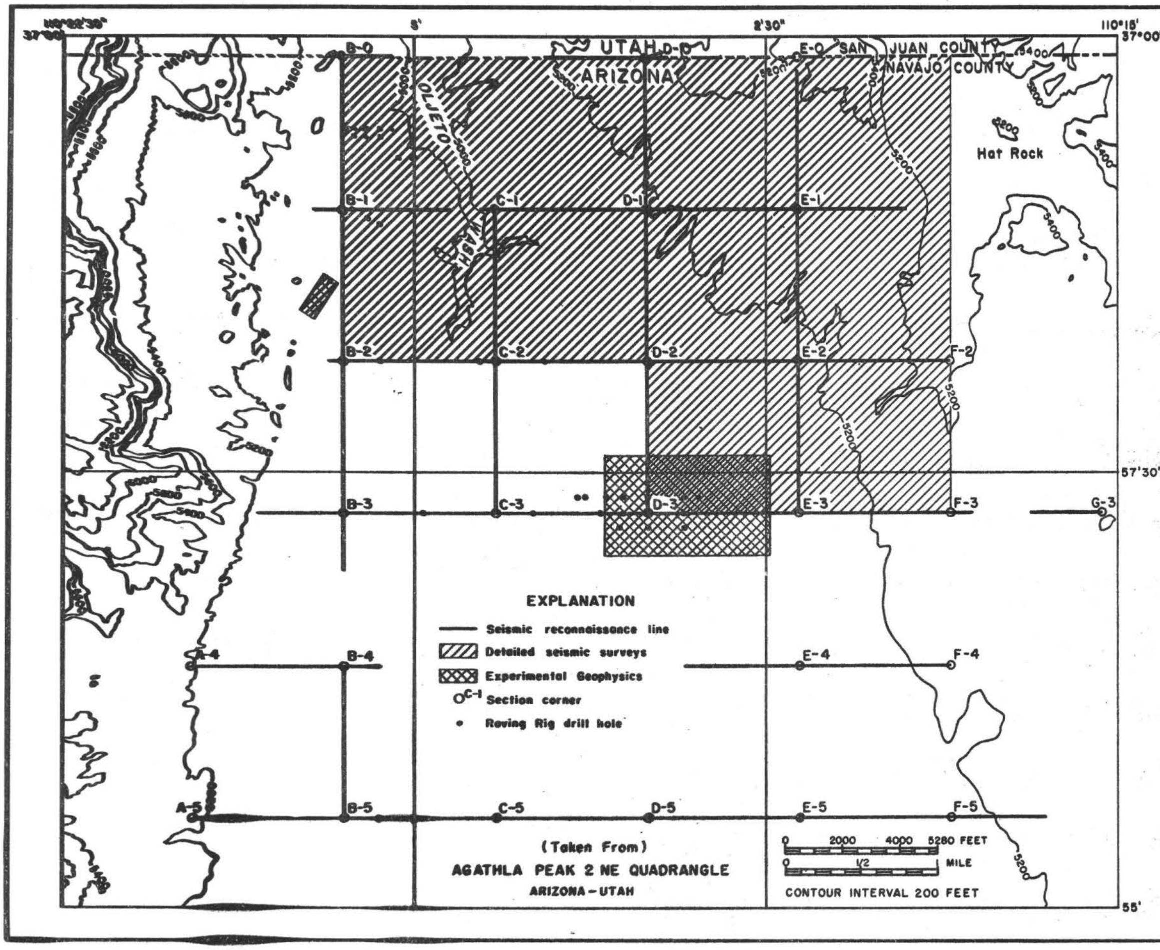


FIGURE 20 INDEX MAP OF PART OF MONUMENT VALLEY, ARIZONA, SHOWING THE OLJETO WASH AREA AND THE LOCATION OF THE GEOPHYSICAL SURVEYS.

be caused by a large buried channel with a differential scour of more than 100 feet. Additional drilling and seismic work was done to extend the channel, and for the most part the drilling and seismic results compared favorably, although the eastern extension of the channel is not clearly defined by either the drilling or the seismic work.

The large amount of geologic and geophysical data available in the Oljeto Wash area as a result of government and private drilling, and previous geophysical work makes this area an excellent one for testing and development of geophysical methods. Three areas, two of which are shown in figure 20 and one which is off the map to the southeast, were chosen as excellent areas for experimental geophysical work. The work done in these areas includes electromagnetics, electrical resistivity, magnetics, and measurements of electrical transients.

Electromagnetic measurements have been carried out in each of the three experimental areas mentioned above. Preliminary examination of the data indicates that low readings in the quadrature are observed over the buried Shinarump channels. In one of the experimental areas, a total change, from low to high in the quadrature field, of more than 70 percent was noted. This feature, which has been traced for more than one mile, may be due to an erosional remnant of a mudstone phase of the Chinle and the Shinarump, left near the center of the Oljeto syncline.

Electrical resistivity horizontal profiles have been made in each of the three experimental areas. These measurements were made with D.C. equipment, utilizing the Lee Partitioning configuration, at electrode separations of 100 to 200 feet. It appears that this method may be quite useful in tracing buried channels. It is important to note that resistivity horizontal profiles detected buried channels in places where the Shinarump was covered by 50 to

80 feet of Chinle shales and mudstone. Where remnants of the Chinle formation overlie the Shinarump the seismic refraction method has not proved very successful in differentiating between anomalies caused by channeling and those caused by the Chinle cover; therefore the success of the resistivity method under these conditons is notable. Preliminary comparisons between the electromagnetic data and the resistivity data have indicated a considerable degree of correlation. Detailed comparisons of these two methods will be made, looking to the development of a cheap and efficient combined method of exploration for subsurface structures.

Although there is no evidence that appreciable quantities of magnetic materials are associated with either the buried Shinarump channels, or the uranium deposits in Oljeto Wash, a few detailed magnetic traverses were run across known channels in two of the experimental areas. Preliminary examination of the data shows no magnetic anomalies to be associated with either the channels or the ore bodies.

Experimental shallow reflection measurements were made in Oljeto Wash with multiple seismometers in an attempt to improve the quality of the reflections obtained during previous work. The records were a distinct improvement over the previous results, but still leave much to be desired. It is interesting to note, however, that several deeper reflections of good character were recorded, which may be of interest in mapping deeper structures in the Monument Valley area.

Regional studies

by

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

Compilation of aeromagnetic data covering about 20,000 square miles of the Colorado Plateau is roughly three-quarters finished. Magnetic contour maps covering about 9,000 square miles of the southern part of the area are being edited, and compilation of data covering the remainder of the area is in various stages of completion (fig. 21).

Small-scale magnetic surveys were flown over several areas during the past summer to obtain more detailed information than was available from existing surveys. These surveys covered a 100 square mile area of the Uncompahgre Plateau to determine the magnetic pattern of the near-surface basement rocks; the Upheaval Dome structure in Utah to obtain information on the depth and configuration of the underlying igneous intrusion; and the Ute and La Sal Mountains to learn more of the form and structural relations of these laccolithic mountains.

Regional gravity surveys were started in the Elk Ridge and Orange Cliffs areas in Utah, and others were carried to completion in the La Sal-Lisbon Valley area in Utah and the Carrizo Mountains area in Arizona. A total of 825 gravity stations were established in these areas during the past season. The present status of regional gravity surveys is shown in table 9 and figure 21.

Determinations of densities and magnetic properties were made of several hundred specimens of Colorado Plateau rocks to aid in the interpretation of gravity and magnetic data. The specimens include crystalline basement rocks, Tertiary intrusive rocks, and Paleozoic and Mesozoic sedimentary rocks. Only

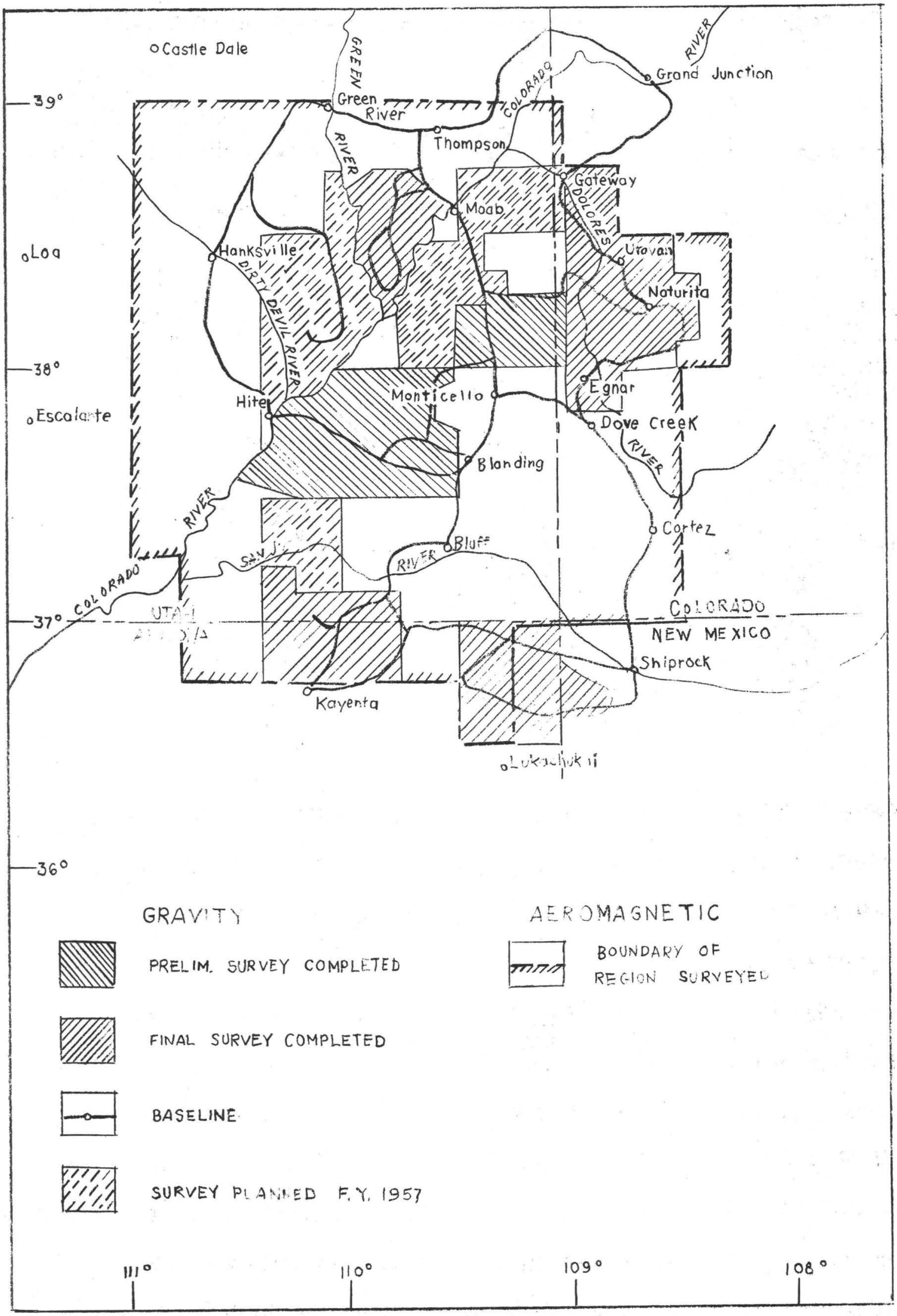


Figure 21.--Regional geophysical surveys, Colorado Plateau

Table 9. Regional gravity field work completed through October, 1955

Area	No. of 7-1/2" Quads	Approx. Area Sq. mi.	Stations			Station Density	
			Base	Other	Total	Sta. Sq. mi.	Sq. mi. Sta.
Uravan	23	1,380	21	659	680	.49	2.02
Inter-River	9	500	48	218	266	.53	1.90
Monument Valley	19	1,000	62	430	492	.49	2.03
Carrizo	18	900	43	494	537	.60	1.68
Lisbon Valley (Mt. Peale quadrangles)	10	580	47	354	401	.69	1.45
Elk-Ridge-White Canyon	25	1,450	26	333	359	.25	4.04
Orange Cliffs	20	1,200	10	60	70	----	----
Other stations*			60		60		
	124	7,010	317	2,548	2,865		

* Includes stations in main base nets as follows:

Crescent Junction - Hite, Utah	14
Inter-River - Hite Canyon	11
Dove Creek - Shiprock	10
Carrizo - Monument Valley	1
Blanding - Mexican Hat	9
Grand Junction - Gateway	8
Others	7
	60

the basement and intrusive rocks are important megnetically, whereas the sandstones, shales, limestones, evaporites and other sedimentary rocks encountered on the Plateau show significant density contrasts, as do the crystalline rocks.

Bore hole temperature measurements were made in the Temple Mountain and Lisbon Valley areas in Utah; the northern part of the Lukachukai Mountains in Arizona; and Disappointment Valley in Colorado. Thermal gradients were found to vary rather widely: from about 0.5°C per 100 feet in Temple Mountain to more than 1°C per 100 feet near the Lukachukai Mountains. These variations could be due either to variations in the flow of heat from the earth, or to variations in the thermal conductivity of the rocks in which the measurements were made. Cores have been collected to permit measuring thermal conductivities so that heat flow may be computed in the localities where temperature data are available. It was found that about three months was required after drilling for the holes at Temple Mountain to regain practical thermal equilibrium. Complete information on the holes in other areas is not yet available.

Original-state core studies

by

G. E. Manger

During the past half year two experimental holes were core-drilled with oil-base mud in Lisbon Valley, San Juan County, Utah in uraninite terrane in basal Chinle formation of Triassic age. Approximately 1 foot of 1.5 U_3O_8 percent ore was penetrated and recovered in one drill hole; the other drill hole about 50 feet away was essentially barren.

The gamma-ray and electrical logs of the holes show relationships between the occurrence of uranium and indications of physical properties derivable from the electric logs significantly similar to such relationships previously found in carnotite and "blue-black" ore terrane in Long Park and Bitter Creek, Montrose County, Colorado. These relations are: (1) decrease in resistivity in the radioactive (and ore) zones; (2) relatively high resistivity in the sandstones overlying the ore, or in the sandstones above the stratigraphic equivalent of the ore in barren drill holes; (3) the appearance of maximum resistivity in the sandstone below the ore in drill holes penetrating ore; and (4) the appearance of lower resistivity in sandstone below the correlated position of the ore zone in barren drill holes than in sandstone above this level. Graphs illustrating these

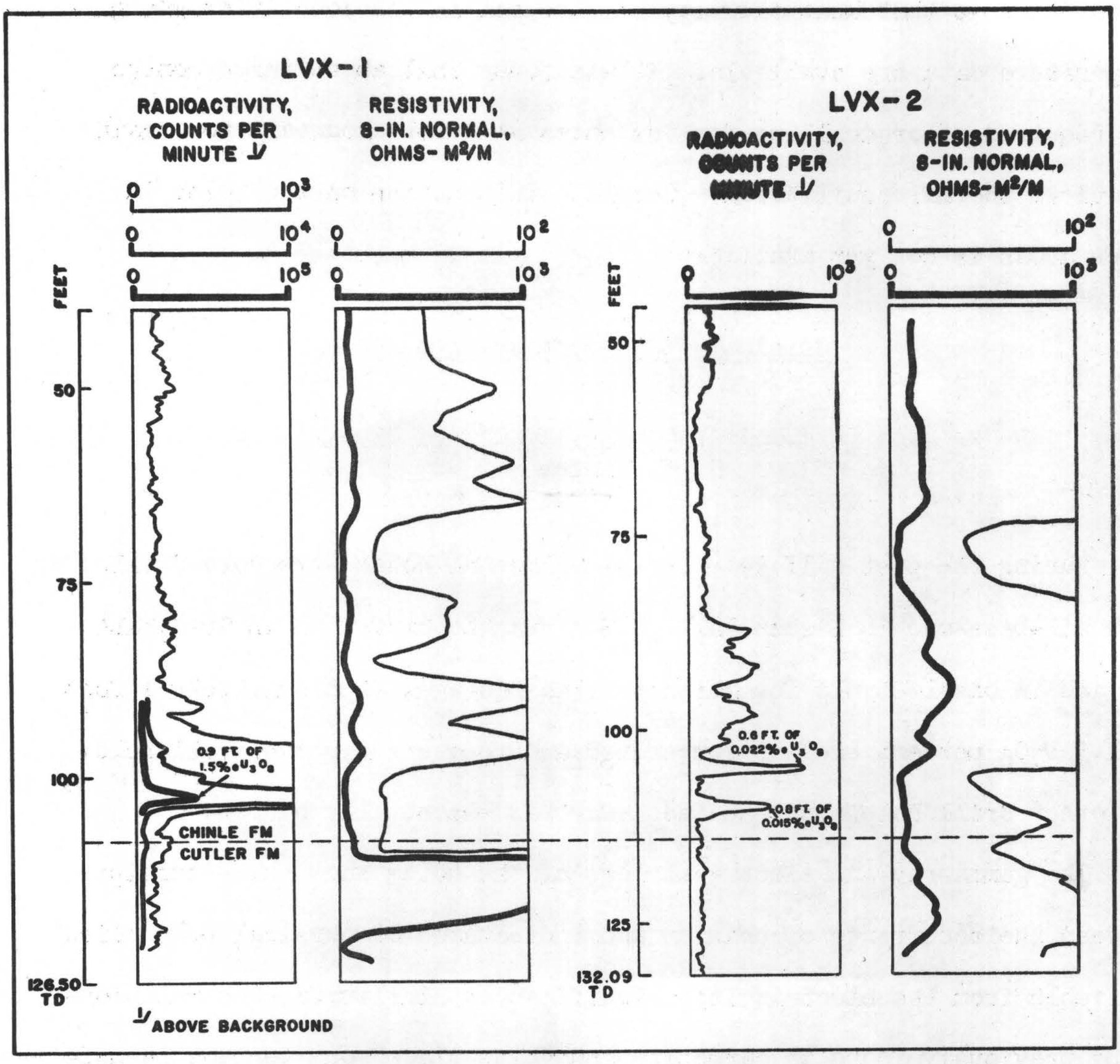


FIGURE 22--DRILL HOLE PROPERTIES IN URANINITE TERRANE, LISBON VALLEY AREA, SAN JUAN COUNTY, UTAH.

relationships for the Long Park and Bitter Creek drill holes were presented in TEI-540, figures 15 and 16. The graph (fig. 22) shows the same relationships for the Lisbon Valley experimental drill holes. The Long Park and Bitter Creek bore holes were drilled on a mesa and on a valley rim. The Lisbon Valley holes are in a valley floor. Thus the electric log relationships hold for all the experimental bore holes, which are in diverse topography and in sedimentary rocks of different ages containing both oxidized and unoxidized ore. Electric logs of a number of exploration drill holes midway between Long Park and Bitter Creek show identical relationships of electrical log resistivity in ore-bearing and barren ground.

In permeable sandstones variations in electrical log resistivity are dependent almost solely upon the amount and salinity of the interstitial (pore) water. The original equations of Archie, Leverett, Martin and others are modified according to the formula:

$R_W = S_W^m \phi^n R_t$ where

R_W = resistivity of formation water

S_W = fraction of pore space occupied by water

ϕ = fractional porosity

R_t = true formation resistivity

Values of the exponents m and n were taken both as 1.8 and 1.7, after Wyllie, and 2.0 and 1.9, after Keller. By means of appropriate graphs, the resistivity of the formation (pore) water, R_W, was converted to salinity values in terms of sodium chloride concentration.

Table 10 compares salinity so obtained with a number of core properties. Objection may be made that the original pore water saturation in sandstone units A-1 and A-2, averaging 3.1 and 7.7 percent, is too low to permit the use of the mentioned equation, especially because in these units the original

Table 10. Average values of core properties of sandstone units in carnotite terrane referred to salinity derived from electric logs and core data, drill holes LP-530 and LP-530A, Uravan district, Montrose County, Colorado

Unit	From analyses of cores						From electric log and core data
	Water saturation, fraction of pore space		Porosity, fraction of bulk volume	Soluble[3] solids assigned to pore water, mg/l	Permeability, dry air, millidarcies	Uranium content, chemical det., percent	Salinity, NaCl equivalent, mg/l
	Original[1] S_w	Capillary[2]					
Sandstone unit O. 231-240 ft. Electric log, 231-241 ft. Basal Brushy Basin member of Morrison formation	.138	n.d.[4]	.185	592,000	224	.0010	33,000
Partly impermeable unit. 240-252 ft.	.292	n.d.	.133	485,000	3.20	.0023	n.d.
Sandstone unit A-1. 252-261 ft. Electric log, 251-259 ft. Ore-bearing sandstone, Salt Wash member of Morrison fm.	.031	.151	.161	886,000	136	.0009	At least 75,000
Sandstone unit A-2. 261-273 ft. Electric log, 261-272 ft. Salt Wash member of Morrison fm.	.077	.122	.205	790,000	469	.0013	10,000 - 13,000
Permeable unit. 273-275.56 ft.	.185	n.d.	.200	96,200	452	.0006	n.d.
Carnotite ore zone 275.56-278.46 ft. Ore 276.73-277.66 ft.							
a) 275.56-276.73 ft. (each sample.)	.410	n.d.	.202	43,300	189	.0015	n.d.
	.454	.428	.183	43,000	29.2	.0014	n.d.
b) 276.73-277.66 ft. (each sample.)	.341	n.d.	.155	72,300	30.4	.046	n.d.
	.781	n.d.	.153	29,800	3.27	.26	n.d.
	.866	.713	.219	35,900	44.5	.96	n.d.

Table 10. Continued

Carnotite ore zone 275.56-278.46 ft. Ore 276.73-277.66 ft. (Con't)							
c) 277.66-278.46 ft. (each sample.)	.374	.327	.208	31,400	660	.0024	n.d.
	.239	n.d.	.194	68,500	174	.0024	n.d.
	.246	n.d.	.161	75,700	265	.0010	n.d.
Sandstone unit D-1. 281-311 ft. Ore-bearing sandstone, Salt Wash member of Morrison fm.							
a) 281-290 ft. Electric log, 281-290 ft.	.290	.180	.204	62,800	425	.0008	580-700
b) 281-311 ft. Electric log, 281-290 ft.	.296	.154	.210	82,700	520	.0008	580-700

1/ Samples obtained by oil-base-mud coring.
2/ Core saturated with 3% sodium chloride solution, then desaturated through a semi-permeable membrane under 100 psi air pressure.
3/ Soluble solids derived by water leaching of cores and assigned to available pore water.
4/ n.d. = not determined.

pore water saturation is less than the so-called irreducible minimum values of capillary water saturation, 15.1 and 12.2 percent. The empirical relationships of Archie, Leverett and others were developed for porous media where pore water occupied 10 percent or more of pore space and electrolytic continuity was assured, and where variations in resistivity were found to be proportional to the reciprocal of the square of the fraction of the pore space occupied by water. Sandstone units A-1 and A-2 may be identified in figure 17 of TEI-540 by appropriate depth. This figure shows that small changes in pore water saturation in the region of the very low saturation of sandstone units A-1 and A-2 are correlative with variations in resistivity. Use of the mentioned formula is therefore justified.

The table shows that the original (residual) water saturation in the sandstone unit from 281 to 311 feet averages 29.6 percent of pore space and exceeds the capillary amount of 15.4 percent. This condition indicates that some gravity flow of ground water exists. If so the pore water should be relatively fresh and should contain about the same proportion of soluble solids as is found in spring water in the area. Phoenix reports 666 mg/l dissolved solids in spring water issuing from the base of the ore-bearing sandstone, at the approximate stratigraphic level of the sandstone unit D-1, where the most likely value of pore water salinity is calculated to lie between 580 and 700 mg/l equivalent sodium chloride salinity.

The data of table 10 are persuasive that dilute water solutions have moved upwards from sandstone unit D-1 through the ore into the overlying sandstone units A-1 and A-2 where the solutions became much more concentrated. The mechanism of actively circulating relatively fresh ground water moving upward through the ore and becoming more concentrated and depositing soluble salts in the overlying sandstone provides an attractive explanation for the oxidation of uranium into carnotite. However, serious objection may be made to this explanation. As the electric log resistivity profiles in the Long Park carnotite drill holes are demonstrably a response to the varying amount and salinity of water in the pore spaces, similar profiles in drill holes in "blue-black" ore in Bitter Creek and in uraninite in Lisbon Valley indicate similar distribution of the amount and salinity of pore water and similar movement of ground or pore water upward through the ore. The question is why such movement should result in complete oxidation of uranium dioxide in Long Park but no oxidation in Lisbon Valley. A more serious objection may be based on the measured high desaturation in the sandstone cores in the barren drill holes below the correlated position of the ore in carnotite and blue-black terrane to the extent that gravity flow of ground water is not likely, even though sandstone above the correlated position of the ore is highly desaturated (TEI-540). Thus it is by no means certain that the present distribution of the amount and salinity of pore water with reference to the occurrence of uranium has resulted from ground water flow now in progress.

URANIUM IN SANDSTONE-TYPE DEPOSITS OUTSIDE THE COLORADO PLATEAU

Powder River Basin, Wyoming

Southern Powder River Basin

by

W. N. Sharp and A. M. White

Reconnaissance mapping during the report period covered most of the northern half of Converse County, Wyoming. The data were compiled on 1:24,000 quadrangle sheets where available and on aerial photographs where topography was not available. During mapping, particular note was made of the contact of the Wasatch formation of Eocene age and the Fort Union formation of Paleocene age, mappable coal beds, facies changes in the Wasatch, and occurrences of uranium minerals. (See fig. 23.)

The only two prominent areas where uranium occurs in the southern basin--the Monument Hill area on the Dry Fork of the Cheyenne River and the Box Creek area--where most of the exploration and mining activity is centered, were studied in detail; the mine areas were mapped by plane-table methods.

The Wasatch formation is of fluvial origin composed of fine-grained clastic sediments, clay and siltstone. Irregularly spaced throughout most of the formation are numerous small and large lenses of coarse-grained to conglomeratic sandstone. At places, particularly toward the eastern edge of the Basin, the Wasatch consists predominantly of fine-grained clastic sediments with numerous coal or carbonaceous shale bands.

In general the rocks of Wasatch age dip 30 to 60 feet per mile to the northwest along the axis of the basin and away from the Laramie Range,

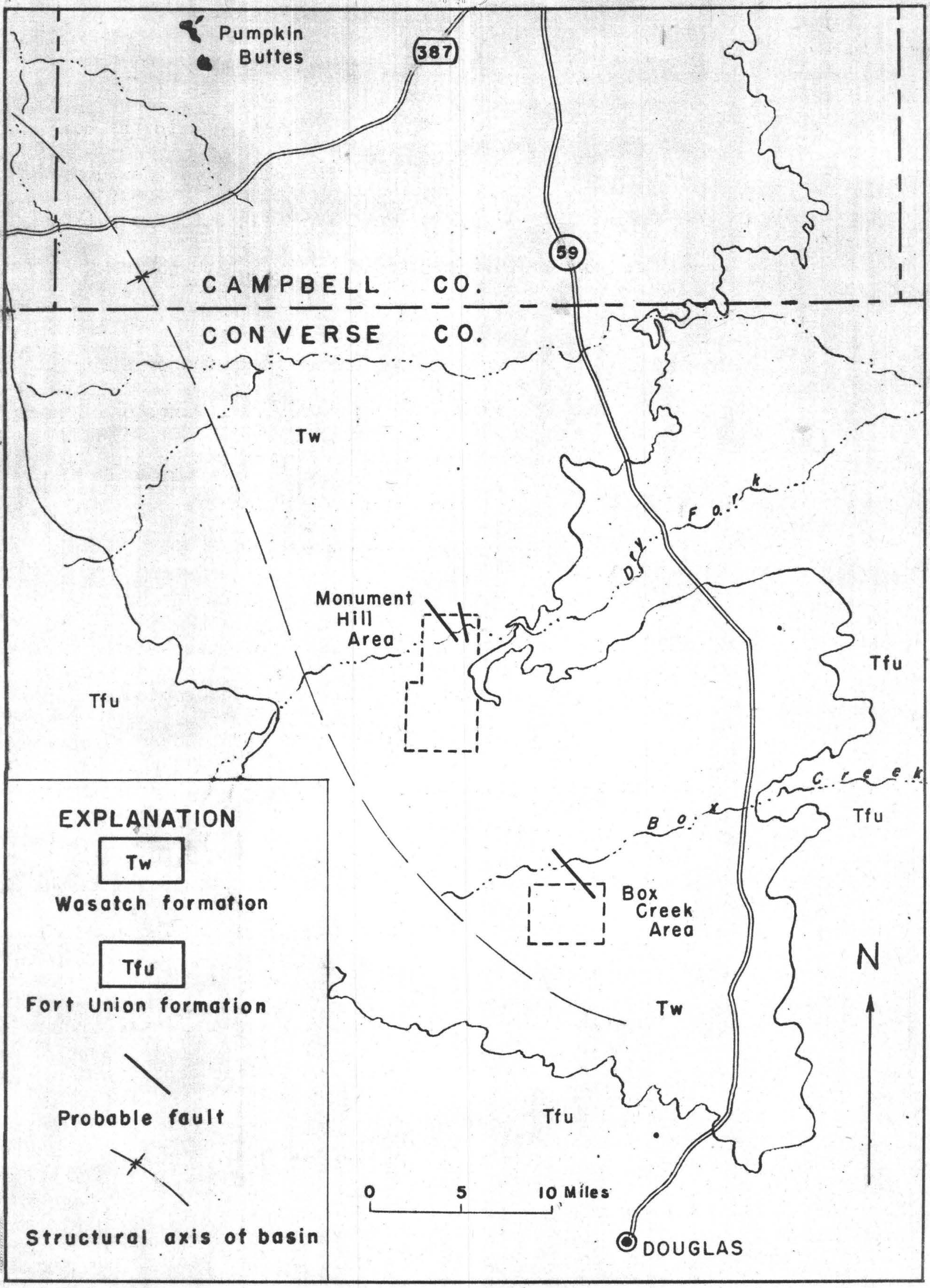


FIGURE 23.—GEOLOGIC MAP OF SOUTHERN POWDER RIVER BASIN, WYOMING, SHOWING AREAS MAPPED

the principal source of the composing materials.

Several probable faults have been mapped. A fault zone in the Box Creek area trends N. 30° to 40° W. In the Monument Hill area, features that are apparently faults trend N. 10° W and N. 45° W. Specific relationships between these fault zones and uranium occurrences have not been determined.

The uranium occurrences and deposits in the southern Powder River Basin are in a zone of randomly spaced, red or partly red, sandstone lenses about 8 miles wide that extends northward to the Pumpkin Buttes area along the center of the Wasatch exposure. Most of the sandstone lenses in the Wasatch formation of the basin are gray to tan or buff in color.

The exposures of uranium appear to be grouped at places along this zone. This may be the result of erosion along the strong east-west drainage trend and in part may be dependent upon the presence of favorable lithology.

At places along the western side of this zone of red-colored sandstone lenses, white clay is particularly abundant in the sandstone. Preliminary examination indicates that montmorillonite is the predominant clay and that it is associated with small fragments of volcanic glass. At places in the basin some sandstone lenses contain abundant volcanic ash. The alteration of this ash to clay gives the sandstone a white color.

Detailed study shows that these uranium deposits are characterized by many of the features previously found in the Pumpkin Buttes deposits to the north. The deposits mined to date have been at the color contact between the red sandstone and the buff-gray sandstone. At the color change concretions of uranium minerals tend to concentrate in a zone peripheral to calcite. Coalified wood fragments are abundant in the deposits, and yellow uranium minerals are abundant on these fragments in some places.

The uranium minerals are predominantly carnotite-tyuyamunite; uranophane is less common and when found is generally with manganese-oxide nodules in the deposits. The manganese-oxides generally enclose, or are mixed with the uranium minerals and are found in the red sandstone.

Areas most favorable for prospecting in this area appear to be in the red sandstone near the boundary of the red and gray sandstones.

Black Hills uplift, Wyoming-South Dakota

Southern Black Hills, South Dakota

by

E. V. Post, R. W. Schnabel, Garland B. Gott, and Henry Bell, III

Investigations during the past six months consisted of mapping at a scale of 1:7,200 of approximately 98 square miles in the Flint Hill, Cascade Springs, Burdock, Dewey, Minnekahta and Harney Peak 3 SW quadrangles; field-checking of approximately 213 square miles previously mapped in the Edgemont, Edgemont NE, and Flint Hill quadrangles (fig. 24); and detailed geologic mapping of the Gould mine and K claims in the Flint Hill quadrangle.

Revision of Inyan Kara terminology

The principal uranium ore-bearing formations in the southern Black Hills are the Fall River and Lakota sandstones. These, with the Fuson formation and the Minnewaste limestone, comprise the Inyan Kara group. Geologic mapping has shown that it is not possible to define consistently a contact between the Lakota sandstone and the Fuson formation throughout the area mapped. Work by the Geological Survey in the northern Black Hills has shown that there, also, the Fuson-Lakota contact cannot be defined. It has therefore been suggested that the nomenclature of the Inyan Kara group

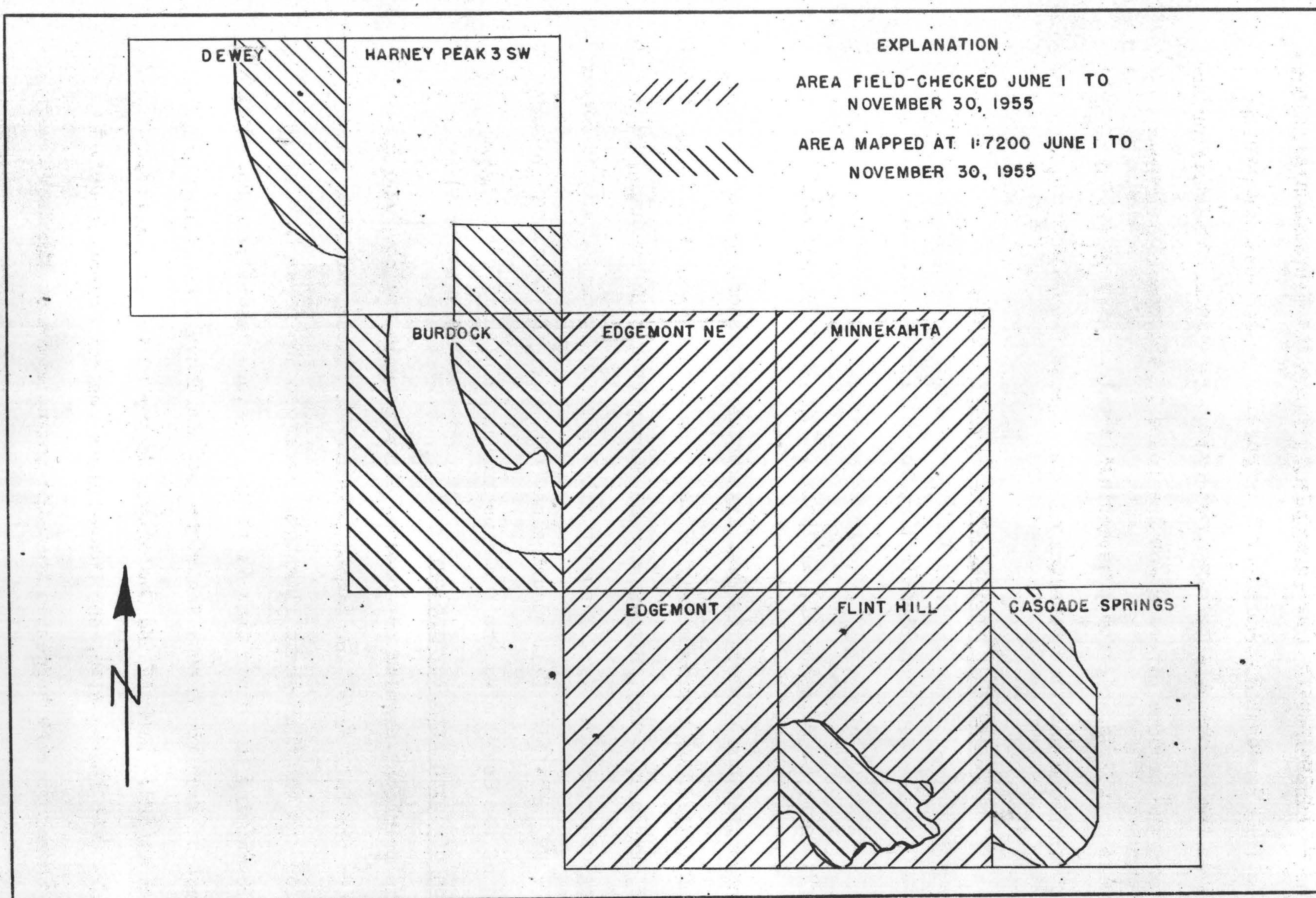


FIGURE 24.—INDEX MAP SHOWING AREAS FIELD-CHECKED AND MAPPED JUNE 1 TO NOVEMBER 30, 1955, SOUTHERN BLACK HILLS, SOUTH DAKOTA AND WYOMING.

should be changed to a two-fold division, with Fall River formation above and Lakota formation below. A consistent lithogenetic break has been traced from the northern to the southern Black Hills, and it is proposed that this break be used as a basis for the separation of the Inyan Kara group into these two units.

Ore-bearing units

In the southern Black Hills, most of the uranium ore is found in three lithologies: (1) in a conglomeratic channel sandstone; (2) near the edges of a thick (30 to 70 feet) lower Lakota sandstone and in adjacent thin (10 to 15 feet) sandstones and mudstones; and (3) in thin-bedded sandstones and mudstones in the lower part of the Fall River formation. As a result of this year's field work, the distribution of these lithologies is better known. Figures 25, 26, and 27 show the distribution of these lithologies with the locations of the significant uranium deposits in each.

Channel sandstone.--Geologic mapping and field-checking during the 1955 field season resulted in the delineation of a prominent channel sandstone extending from the Cheyenne River in the Flint Hill quadrangle to the southeast part of the Harney Peak 3 SW quadrangle. (See fig. 25.) The age of this sandstone is uncertain, but is thought to be pre-Fall River, because of the occurrence in Red and Coal Canyons of mudstones believed to be characteristic of the upper part of the undivided Fuson and Lakota formations above the channel sandstone. The channel sandstone commonly overlies gray to variegated claystones and mudstones, but locally it fills a channel scoured through these mudstones into underlying sandstones. Except between Red and Coal Canyons, where mudstones are present, the unit is commonly overlain by a laminated carbonaceous siltstone and interbedded

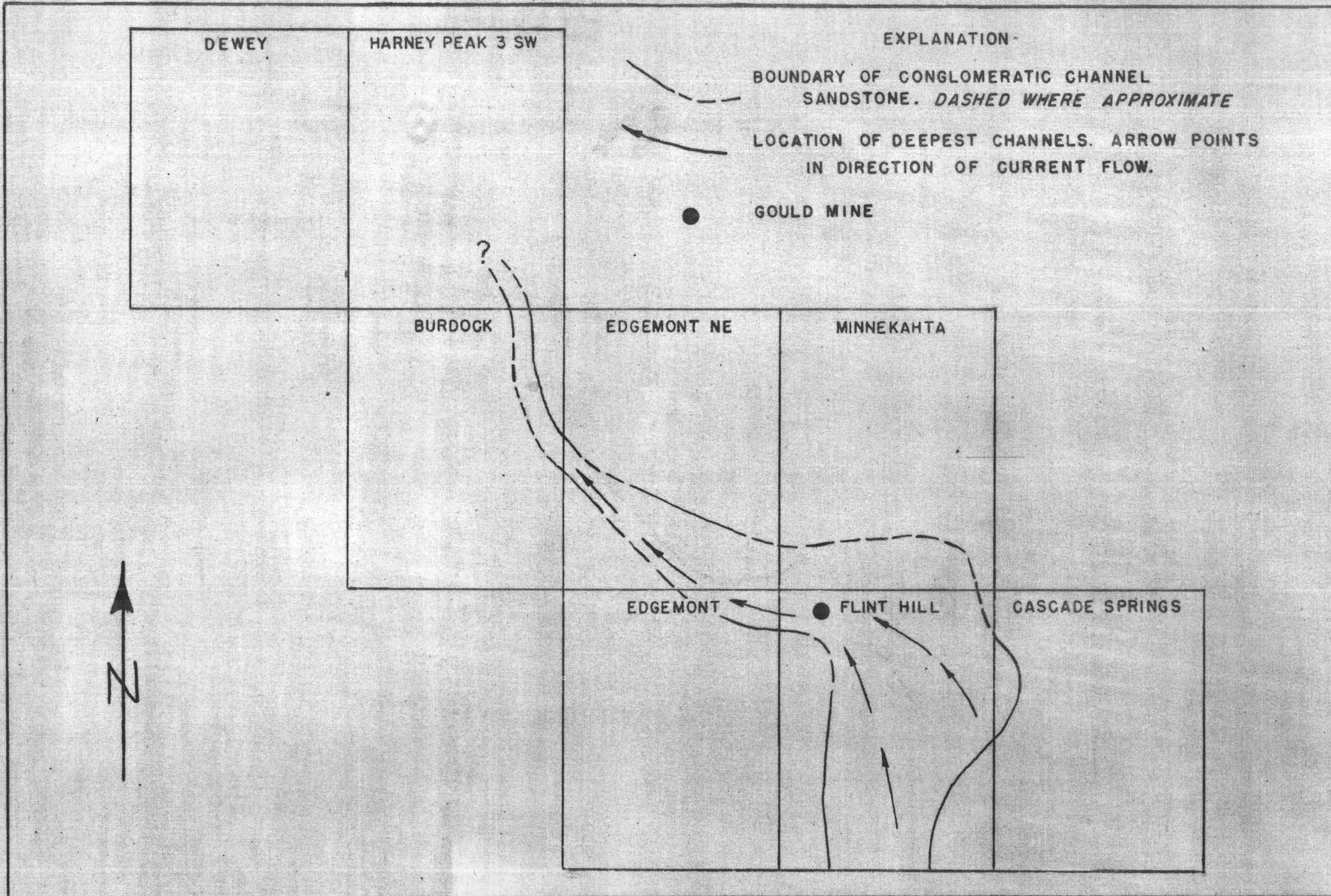


FIGURE 25.—MAP SHOWING DISTRIBUTION OF CONGLOMERATIC CHANNEL SANDSTONE

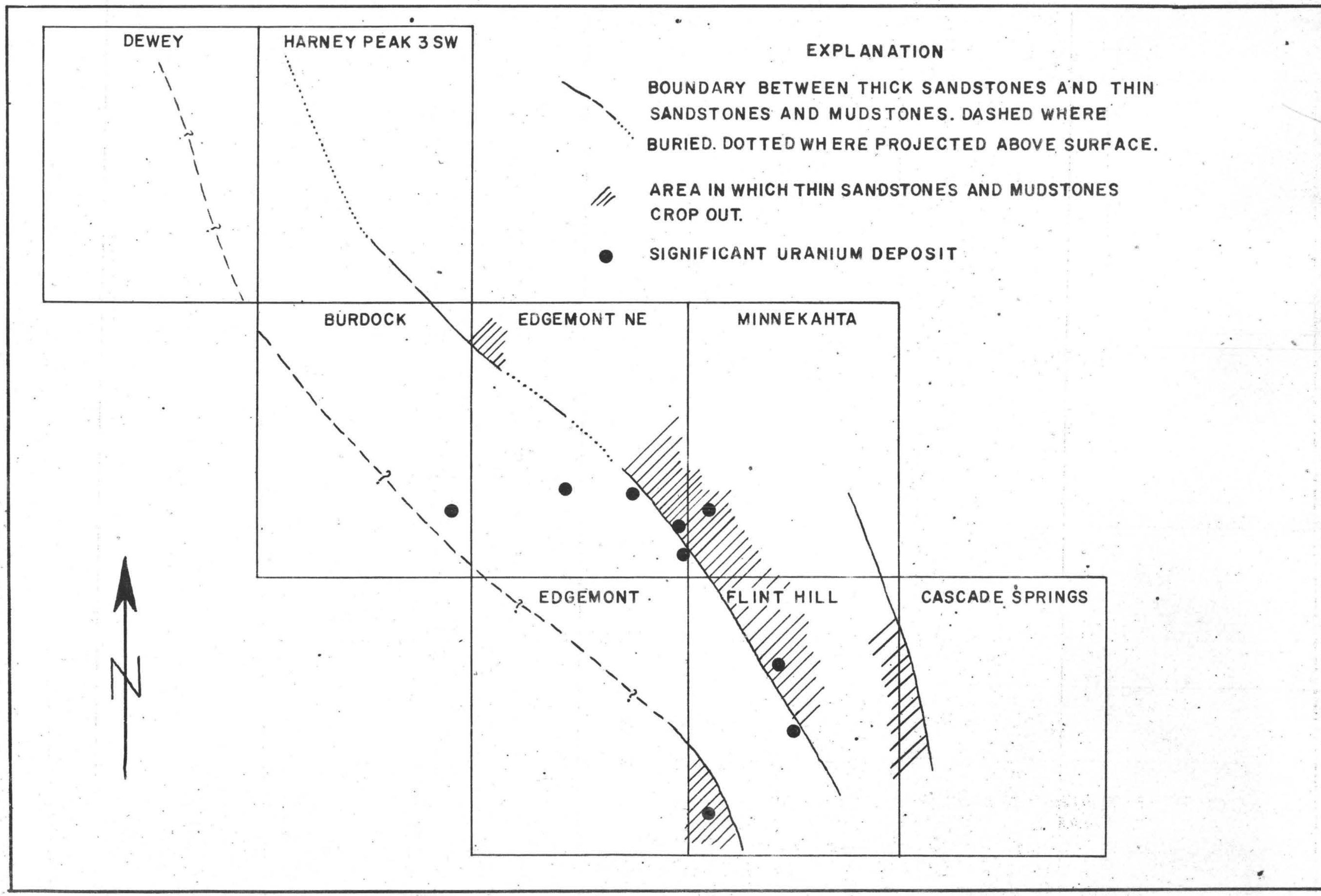


FIGURE 26.—MAP SHOWING RELATION OF URANIUM DEPOSITS TO THICK LAKOTA SANDSTONES AND MARGINAL THIN SANDSTONES AND MUDSTONES

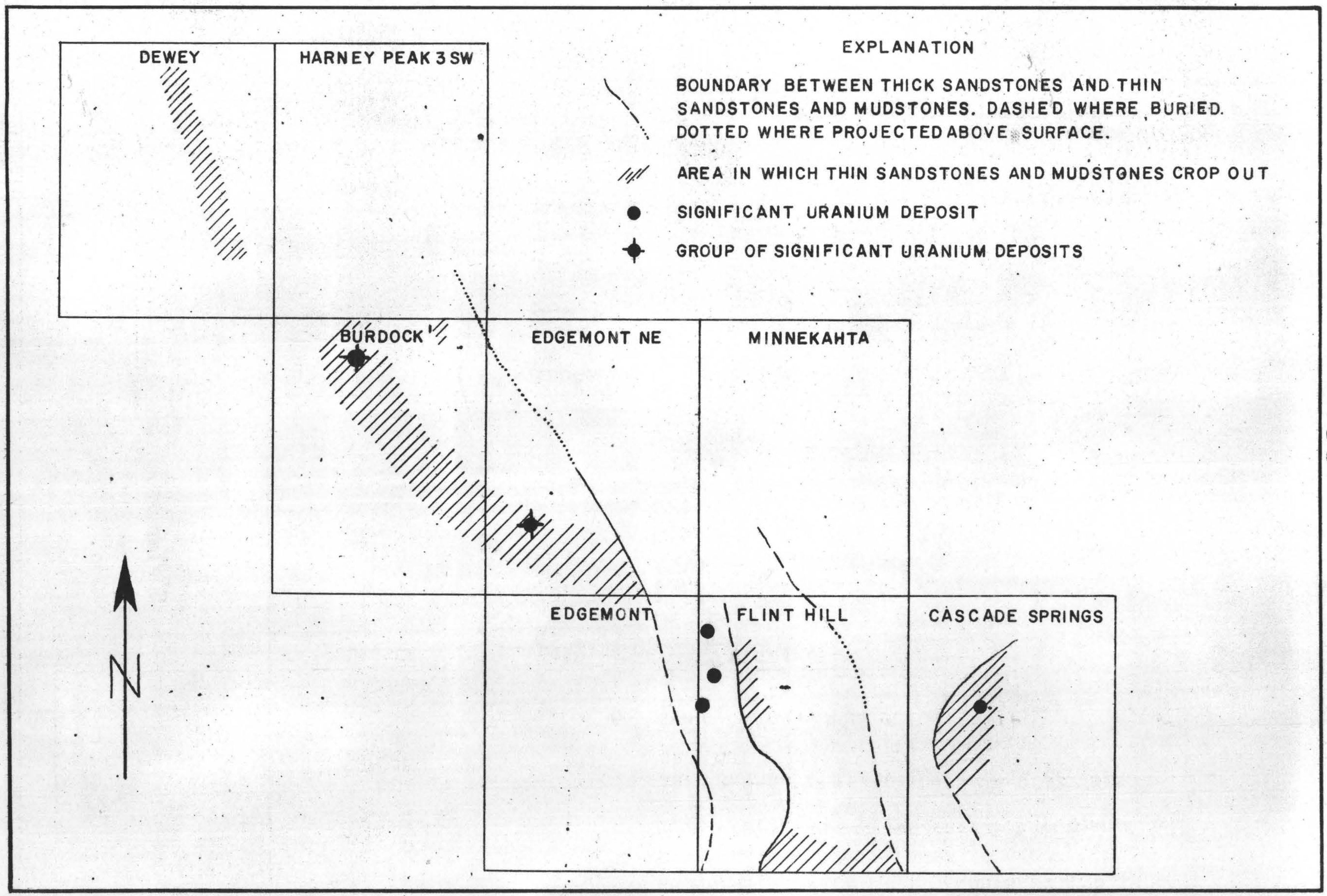


FIGURE 27.—MAP SHOWING RELATION OF URANIUM DEPOSITS TO THICK FALL RIVER SANDSTONES AND MARGINAL THIN SANDSTONES AND MUDSTONES

sandstone and siltstone, the aggregate thickness of which ranges from 10 to 50 feet.

The sandstone of this channel unit is predominantly medium- to coarse-grained. It is very coarse grained to gritty near the base, and much of it in the Flint Hill, Minnekahta, and Cascade Springs quadrangles is conglomeratic. The pebbles of the conglomeratic sandstone range from about one-quarter inch up to two inches in maximum diameter and consist of 98 percent chert and minor quantities of pink to red quartzite, sandstone, and vein quartz. The lower few feet of the unit locally includes fragments of underlying mudstone and blocks of underlying sandstone up to two feet in diameter.

Two distinctive types of cross-stratification are characteristic of this sandstone. One of these types consists of tabular sets of very thinly bedded cross-strata from a few inches to two or three feet thick separated by thin sets of horizontal strata. The cross-strata dip generally to the northwest. The other type is a variety of the first, in which the upper parts of the cross-strata are overturned in the direction of current flow.

The definition and correlation of this channel sandstone are important because the unit contains the deposits of the Gould mine, one of the larger uranium deposits in the southern Black Hills. Unsystematic surface prospecting to date has disclosed no other uranium deposits in this sandstone, although further prospecting may show that some do exist.

Red sandstone marker bed.--In the northwestern part of the Cascade Springs quadrangle a prominent red sandstone was found to be an excellent marker bed within the Inyan Kara group. This bed has been traced discontinuously from Lindsley Canyon in the Cascade Springs quadrangle westward as far as Chilson Canyon in the Flint Hill quadrangle where it is exposed north of the county road from Highway 18-85A to Flint Hill just west of the Chicago, Burlington and Quincy railroad tracks. It is well exposed in Wolf Canyon north of the Accidental mine, in Dick Canyon, Wildcat Canyon, Cedar Canyon, Falls Canyon, and along the canyon of the Cheyenne River in the western part of the Cascade Springs quadrangle and the eastern part of the Flint Hill quadrangle.

This red sandstone ranges in thickness from 5 to 10 feet; it is generally fine-grained and moderately calcareous. It shows little bedding, weathers somewhat cavernously, and is locally brecciated as in Wolf Canyon.

Where the Minnewaste limestone is present, it immediately overlies this red sandstone. Where the Minnewaste limestone is absent, gray to red claystones of the upper part of the undivided Fuson and Lakota formations rest on the red sandstone. Below the red sandstone are approximately 25 feet of massive gray sandstone or poorly exposed interbedded friable sandstone and variegated mudstone.

Thermoluminescence

A photograph of the thermoluminescence of a piece of carbonate-cemented sandstone from the Lion No. 1 claim reveals thin concentric thermoluminescent bands within calcium carbonate nodules. Although this piece of sandstone contains no uranium-bearing minerals, similar sandstone from the same locality contains carnotite interstitial to the carbonate cement. The areas of greatest thermoluminescence correspond to the areas in which carnotite is concentrated in the carnotite-bearing sandstones. The thermoluminescent bands within the carnotite cement suggest that uranium has been deposited contemporaneously with the calcium carbonate cement. Other sandstones show the same type of carbonate cement, but uranium has been found in this type of sandstone only at the Lion claims. Samples of the other sandstones have been collected for thermoluminescence investigations.

A paper by Henry Bell, III, G. B. Gott, E. V. Post and R. W. Schnabel, titled "Lithologic and structural controls of uranium deposition in the southern Black Hills, South Dakota", was published in the Proceedings of the United Nations International Conference on the Peaceful Uses of Atomic Energy.

Carlile quadrangle, Wyoming

by

M. H. Bergendahl and R. E. Davis

The Carlile quadrangle occupies approximately 50 square miles in southwestern Crook County, Wyoming (fig. 28). The quadrangle contains several areas of radioactivity anomalies and, in the northeastern part, the Homestake Mining Company's Carlile mine, to date the largest single producer of uranium in the Northern Black Hills. Previous work by the Atomic Energy Commission and private industry has disclosed many occurrences of uranium-bearing material.

The quadrangle is being mapped by the Geological Survey in order to (1) provide a geologic map as an aid to further exploration, (2) study in detail the uranium deposits, (3) determine relations among structure, stratigraphy, lithology, and uranium deposits, (4) find geologic guides to uranium deposits, and (5) outline areas favorable for more detailed exploration for uranium.

Geologic mapping at a scale of 1:12,000 was begun during the summer of 1955, and mapping of approximately 12 square miles in the northeastern quarter of the quadrangle was completed. An area covering about three-quarters

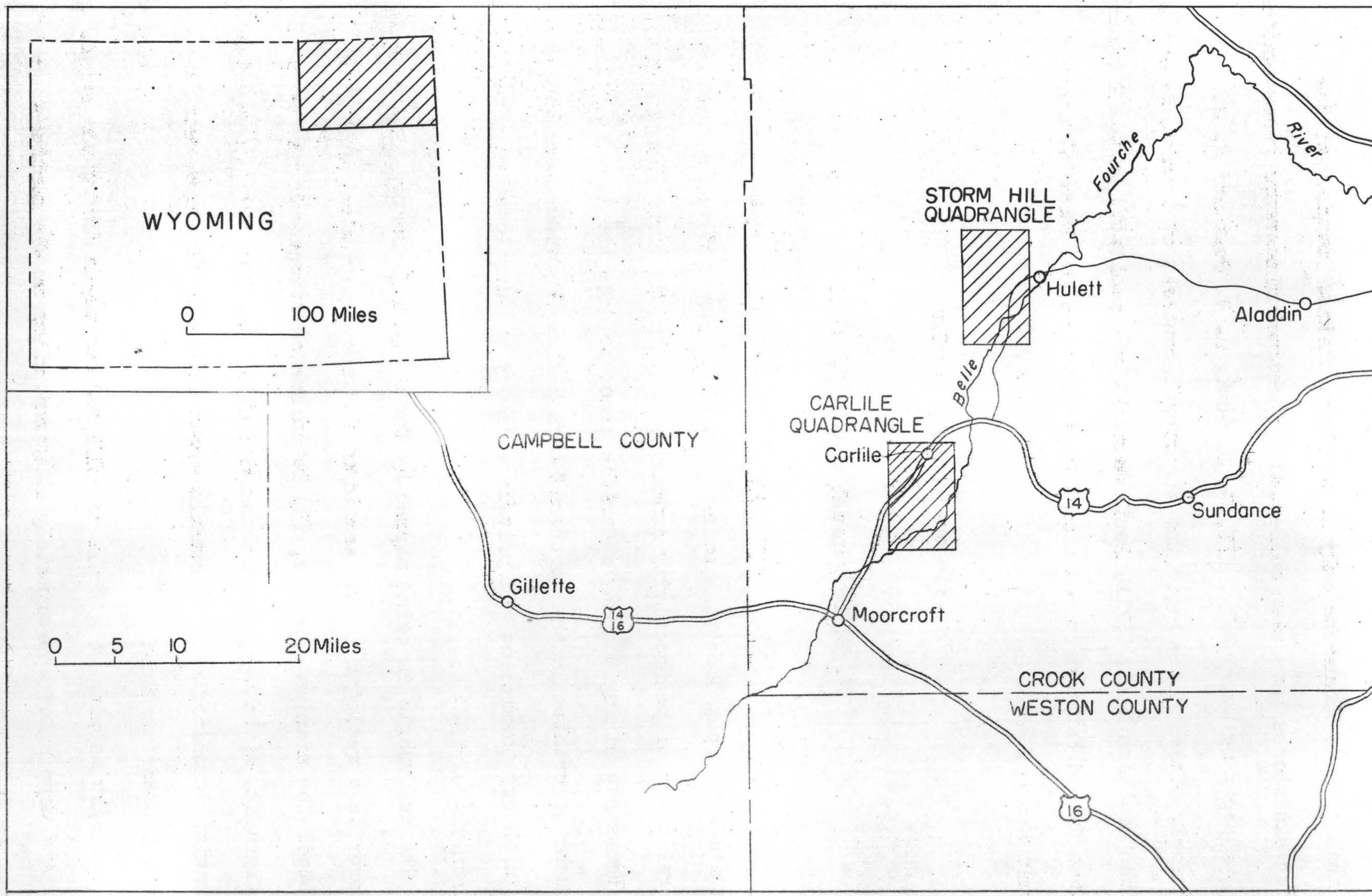


FIGURE 28-INDEX MAP SHOWING LOCATION OF CARLILE AND STORM HILL QUADRANGLES, WYOMING.

of a square mile surrounding the Carlile mine was mapped by plane-table methods, at a scale of 1:2,400. A more detailed plane-table map, scale 1:1,000, was made of the surface mine workings and areas immediately adjacent. The underground workings were mapped at a scale of 1:240. Six stratigraphic sections were measured in detail.

Large-scale mapping of the mine area was necessary to provide close control on minor tectonic and sedimentary structures and to obtain detailed information on facies changes and character of the mineralized rock. Scintillation-meter traverses were carried on in conjunction with the detailed mapping of the mine area. A local, high anomaly (1.0 mr/hr.), previously unreported, was found in the lower massive sandstone of the Lakota formation.

General geology

The area mapped comprises a nearly structureless sequence of sedimentary rocks that rises steeply from the valley of the Belle Fourche River on the east and forms a deeply dissected plateau. The exposed rocks, in ascending order, include the Redwater shale member of the Sundance formation, and the Morrison formation of Jurassic age, and the Lakota-Fuson sequence, the Fall River sandstone, and the Skull Creek shale of Cretaceous age (fig. 29). The beds dip very gently to the west and northwest to the western margin of the area mapped, where the dip steepens along the edge of what apparently is a shallow syncline.

Sandstones, siltstones, claystones, and shales comprising the Morrison, Lakota-Fuson, Fall River, and Skull Creek sequence, are exposed along the walls of canyons cut into the plateau by streams flowing to the east and southeast into the Belle Fourche River. The Redwater shale is exposed only along the more deeply cut valley of the Belle Fourche. The flat, high,

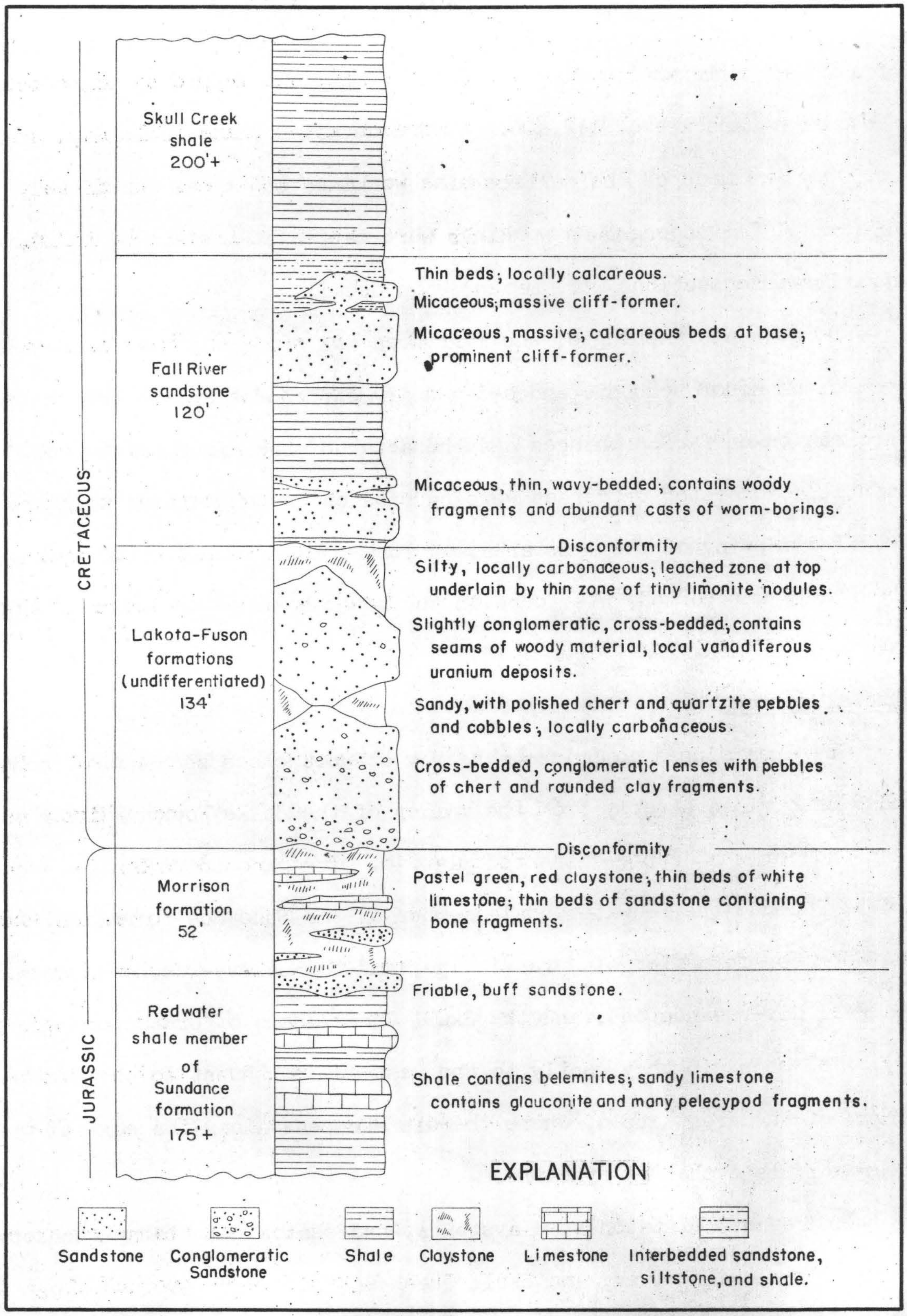


FIGURE 29 COMPOSITE SECTION OF ROCKS EXPOSED IN THE NORTH-EASTERN PART OF THE CARLILE QUADRANGLE, WYOMING.

intercanyon areas generally are capped with thin-bedded sandstones and silty shales that, in this area, characterize the upper part of the Fall River sandstone. Isolated patches of Skull Creek shale are exposed where the dip of the beds steepens to the west.

Uranium deposits

The ore deposits at the Carlile mine consist of carnotite-type minerals in sandstone. Two ore bodies have been mined. The upper body, mined both by stripping and by underground workings, is in a flat-lying Lakota sandstone bed that caps the southern end of a long promontory in the W 1/2 sec. 26, T. 52 N., R. 66 W. The lower body, several hundred feet east and about 150 feet lower in elevation, is in the same horizon of the Lakota but is part of a large landslide block that has dropped from the edge of the promontory down into the Belle Fourche Valley. The beds in this block dip from 32° to 57° west. This lower ore body has been worked through an open cut.

The host rock for the ore deposits is a sandstone bed or lens in the upper part of the Lakota sandstone. In some areas this bed merges with the massive lower sandstone that comprises the bulk of the formation, but at and adjacent to the mine it is a distinct unit separated from the massive sandstone by about 25 feet of bluish-gray claystone. The upper sandstone is from 17 to 20 feet in thickness, and the top of the bed is from 35 to 40 feet below the base of the Fall River sandstone.

The ore-bearing unit consists of thin-bedded, cross-bedded, gray to buff, medium- to coarse-grained sandstone with intercalated seams and partings of shaly siltstone and sandy or silty carbonaceous shale. Carnotite-type minerals occur as disseminations in the carbonaceous seams and in the adjacent sandstone. Concentration of the minerals occurs where several of the thin carbonaceous seams coalesce to form a thicker zone or layer of sandy and silty carbonaceous material. Ore controls other than these local accumulations of carbonaceous material have not been determined.

Storm Hill quadrangle, Wyoming

by

R. C. Vickers and G. A. Izett

Mapping of the Storm Hill 7-1/2 minute quadrangle began in July 1955. The quadrangle occupies approximately 53 square miles in central Crook County, Wyoming, and is on the northwest flank of the Black Hills uplift (fig. 28, p. 160). Previous work in the quadrangle by the Atomic Energy Commission and prospectors disclosed many radioactivity anomalies and two occurrences of uranium minerals. To date, no uranium deposits of economic tonnage and grade have been discovered.

The exposed sedimentary rocks range in age from Triassic to Tertiary, and the average aggregate thickness is 1,200 feet. In ascending order the stratigraphic sequence is: Spearfish formation of Triassic age; Gypsum Spring, Sundance, and Morrison formations of Jurassic age; Lakota-Fuson undivided, Fall River sandstone, Skull Creek shale, and Newcastle sandstone of Early Cretaceous age; and White River group (?) of Oligocene age. A small sill of phonolite porphyry crops out near the western edge of the quadrangle.

Minor structural features are superimposed on a regional dip of 60 feet to the mile in the northwest. A dome in sec. 13, T. 54 N., R. 65 W., with dips up to 10°, is the most prominent structure in the quadrangle; on the eastern flank of this dome, in the N 1/2 of sec. 19, visible uranium minerals occur in the lower part of the Fall River sandstone. The Survey's mapping shows that radioactivity anomalies and uranium mineral occurrences are restricted to well-bedded sandstone units, generally less than 4 feet thick, in the lower part of the Fall River sandstone.

Mapping of the southern half of the quadrangle, at a scale of 1:12,000, has been completed, and the information is being compiled.

Wind River Basin, Wyoming

Gas Hills area, Fremont County

by

H. D. Zeller and P. E. Soister

Detailed mapping of the Wind River formation of Eocene age was completed during the report period in the Rongis Reservoir SE, Ervay Basin, and Ervay Basin SW quadrangles and in parts of the Gas Hills, Puddle Springs, Coyote Springs, and Muskrat Basin quadrangles. Plane-table maps showing geology and topography were prepared for the Lucky Mc, Phil No. 3, Phil No. 4, Bull Rush, and Aljob mines.

A 5-to 30-foot granite cobble- and boulder-conglomerate and its possible equivalents were mapped on topographic sheets at a scale of 1:24,000 over an area of about 12 square miles in the southeast and south-central parts of the Puddle Springs quadrangle and in the north-central and northwestern parts of the Coyote Springs quadrangle. This conglomerate apparently pinches out to the east in coarse-grained arkosic sandstone just inside the Gas Hills quadrangle. Almost all of the known uranium deposits in the western part of the Gas Hills area occur in or stratigraphically near this conglomerate.

A total of 145 rock samples were collected for mineralogical study, uranium analyses, and spectrographic analyses. Fifty-eight water samples were collected for uranium analyses. A seep near the center of sec. 22,

T. 33 N., R. 90 W. contains 4,300 ppb uranium and has a Ph of 3.7. This seep is about a mile from the nearest known uranium mineral occurrence.

Eight core holes ranging in depth from 348 to 810 feet were drilled by the AEC and all but the deepest one reached the base of the Wind River formation. The results of this drilling show that in the general area bounded by Puddle Springs, Coyote Springs, the Lucky Mc and Vitro mines and Cameron Springs, the base of the Wind River formation averages about 340 feet topographically lower than was indicated by pre-existing evidence. One of the holes drilled one-half mile southwest of the Aljob mine (sec. 15, T. 33 N., R. 89 W.) revealed the same anomalous situation.

A geophysical field party of the Geological Survey worked in the area during the later part of the field season. Good results were obtained by employing shallow refraction seismic methods to trace faults and check possible faults. (See pp. 168-170.)

Irregularities of the base of the Wind River formation are due to (1) deep pre-Wind River erosion and (2) post Miocene normal faulting. Field relationships and data obtained from the core drilling and geophysical work indicate that the principal mineralized area is underlain by a complex basin or series of basins. Figure 30 shows the configuration of the pre-Wind River erosion surface.

All recently discovered uranium deposits and occurrences are in, and all ore production is from, the Wind River formation.

Both oxidized and unoxidized uranium ore is being mined at the Lucky Mc, Vitro, Aljob, and Bull Rush mines. Oxidized ore is being mined at the Phil Nos. 3 and 4 and the Upetco mines. Some shipments, mostly of oxidized ore, have been made from the McAlester Fuel Company, Sage Brush, and Blarco mines. At the Lucky Mc mine the top of the ground water table coincides with the top

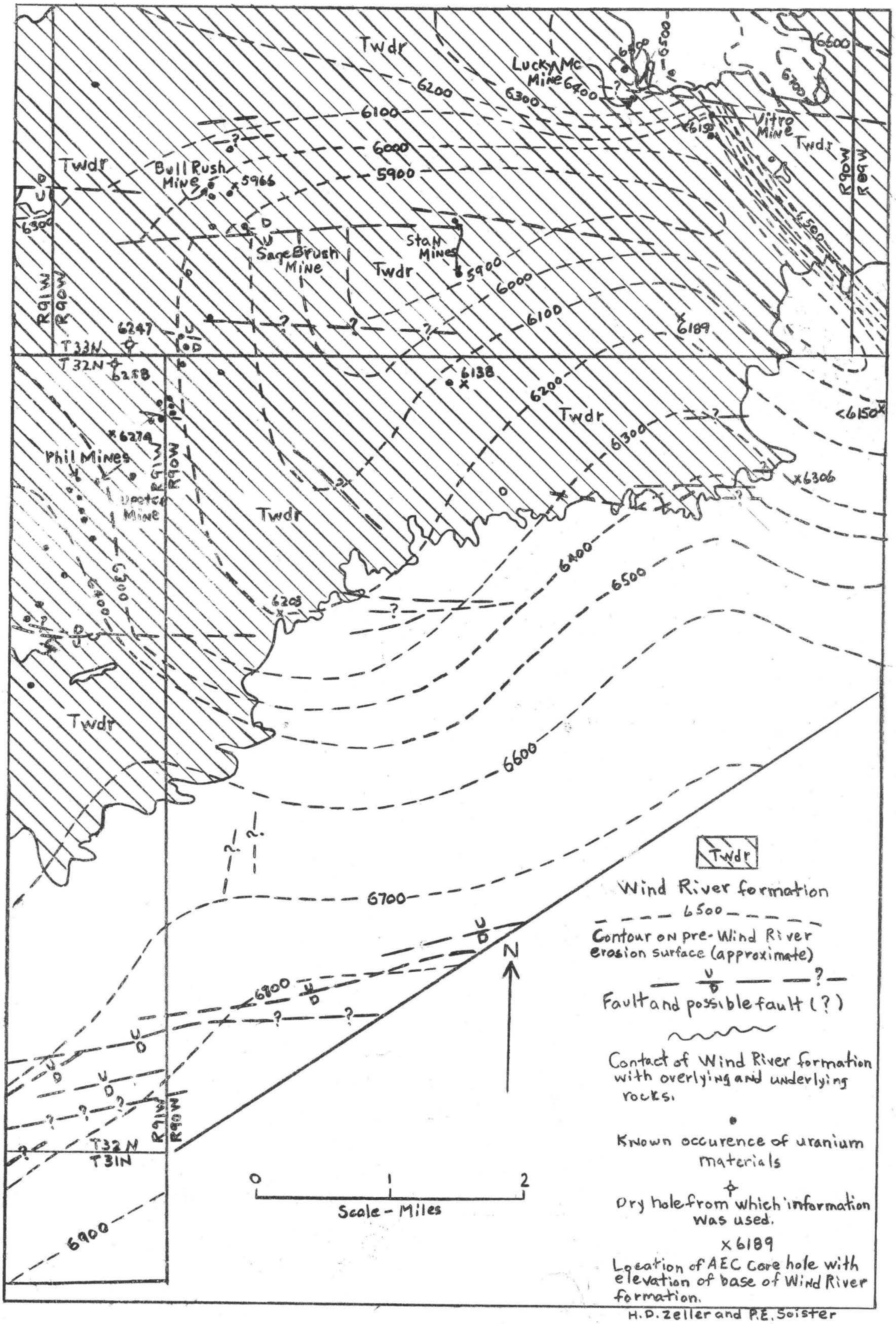


Figure 30. Revised map showing configuration of the Pre-Wind River erosion surface in a part of the Gas Hills area, Wyoming

of the unoxidized zone; at the Vitro mine, the unoxidized ore zone lies partly above and partly below the water table. The oxidized ore in all the mines and occurrences is mainly autunite in yellowish-gray arkosic sandstone, and the unoxidized ore is mostly grayish-blue siltstone with minor clay and sandstone.

Several new uranium minerals have been found within the past year. These include ianthinite, para-schoepite, umohoite, tyuyamunite and coffinite. Ilsemannite (a hydrous molybdenum oxide ?) occurs in both the oxidized and unoxidized uranium ore at the Lucky Mc mine and in the unoxidized zone at the Vitro mine. Native selenium occurs as interstitial material in irregular pink, orange, and pale brown lenses in the arkosic sandstone in the oxidized ore zone at the Lucky Mc mine. These lenses lie above, below, and adjacent to lenses of uranium ore; two channel samples from a two-foot lens of pink arkosic sandstone contain 0.24 to 2.73 percent selenium. Selenium also occurs in the oxidized ore zone at the Vitro and Upetco mines.

A few miles west of the Gas Hills area near the axis of the Conant Creek anticline (sec. 3, T. 32 N., R. 94 W.), uranium occurs in coarse-grained asphaltic sandstone near the top of a sequence of unnamed Middle and Upper Eocene rocks. The deposit is now being mined.

Seismic studies, by R. A. Black

Seismic refraction measurements were made in the Gas Hills area (fig. 31) from September 1 to October 26, 1955. The seismic work was done in connection with the geologic mapping program in this area. It has been suggested that the localization of the uranium deposits in the Wind River formation may be localized by faults cutting the Wind River sandstone. The initial seismic tests indicated that a small but favorable velocity contrast existed between the Wind River sandstone and the underlying Cody or Mowrie shales. Subsequent

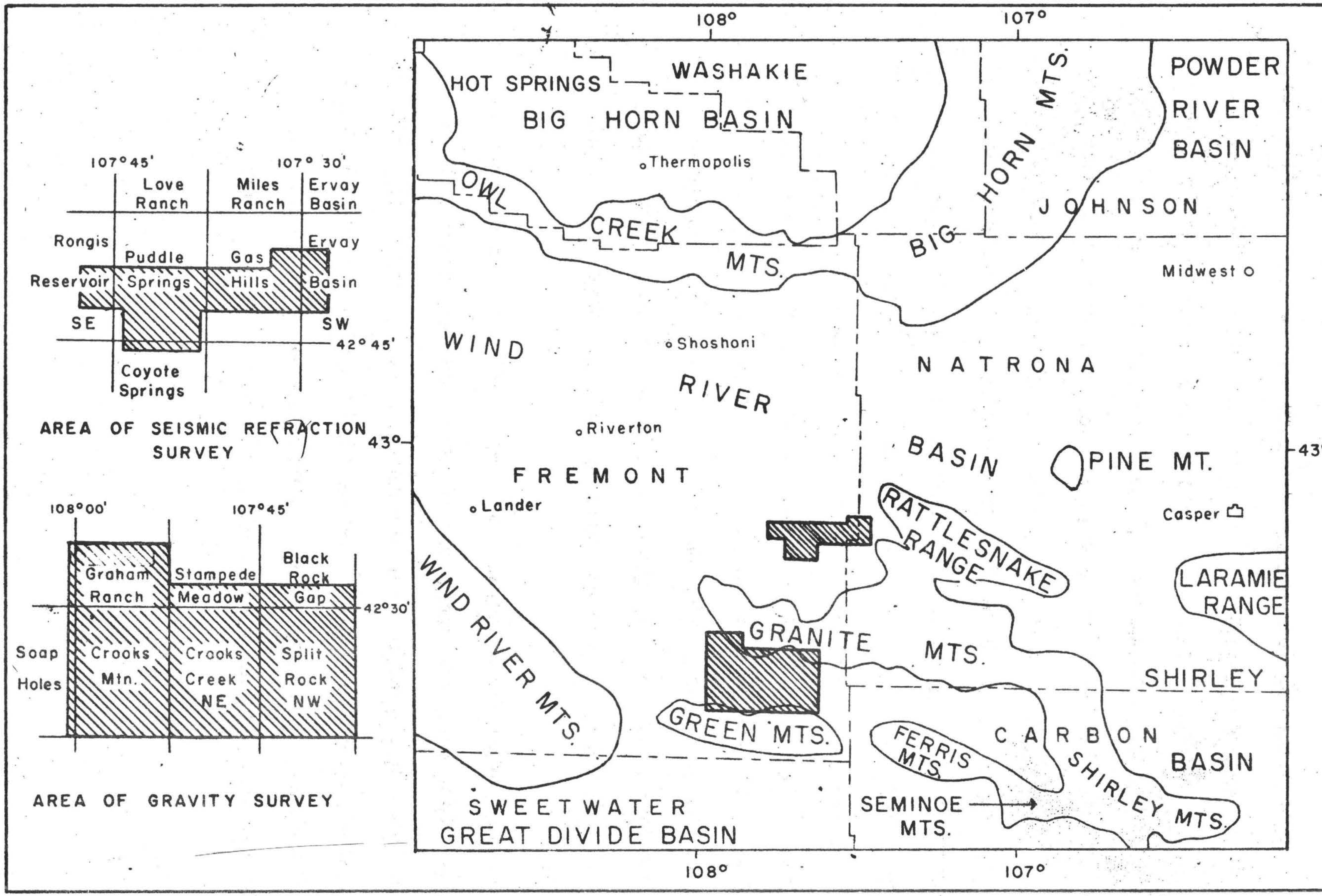


FIGURE . INDEX MAP SHOWING SEISMIC REFRACTION AND GRAVITY SURVEY AREAS, FREMONT AND NATRONA COUNTIES, WYOMING.

0 10 20 30 40 MILES

work was quite successful in delineating both major and minor fault trends. A large fault exposed approximately one half mine south of Puddle Springs, and extended 4 miles by lineation on aerial photos, was traced for more than 6 miles by seismic measurements. Near the Bull Rush mine a fault suspected from lineations on aerial photos was verified by seismic means, and traced for about 4 miles to the east, where it split into five small faults before dying out. A fault exposed at Coyote Springs was extended for 3 miles to the east and 1 1/2 miles to the west by seismic measurements. Four other lineation patterns indicated on aerial photos were checked by seismic means and three of the lineations proved to be due to faulting.

In two places where drill hole control was available, the thickness of the Wind River sandstone was calculated from the seismic data. The calculated thicknesses checked closely with the drill hole determinations; however, the small velocity contrast between the Wind River formation and the underlying Cretaceous shales necessitates very long spreads for purposes of depth computation.

Both the method of continuous profiling at right angles to suspected fault traces with reversed shots, and the fan shooting method with the geophones laid out on a straight line perpendicular to the suspected fault trace were employed. Either of the two methods can be used to locate the fault trace. Fan shooting is quicker and cheaper than continuous profiling, but lacks the vertical control possible with the continuous profiling method.

Hiland-Clarkson Hill area, Natrona County

by

E. I. Rich

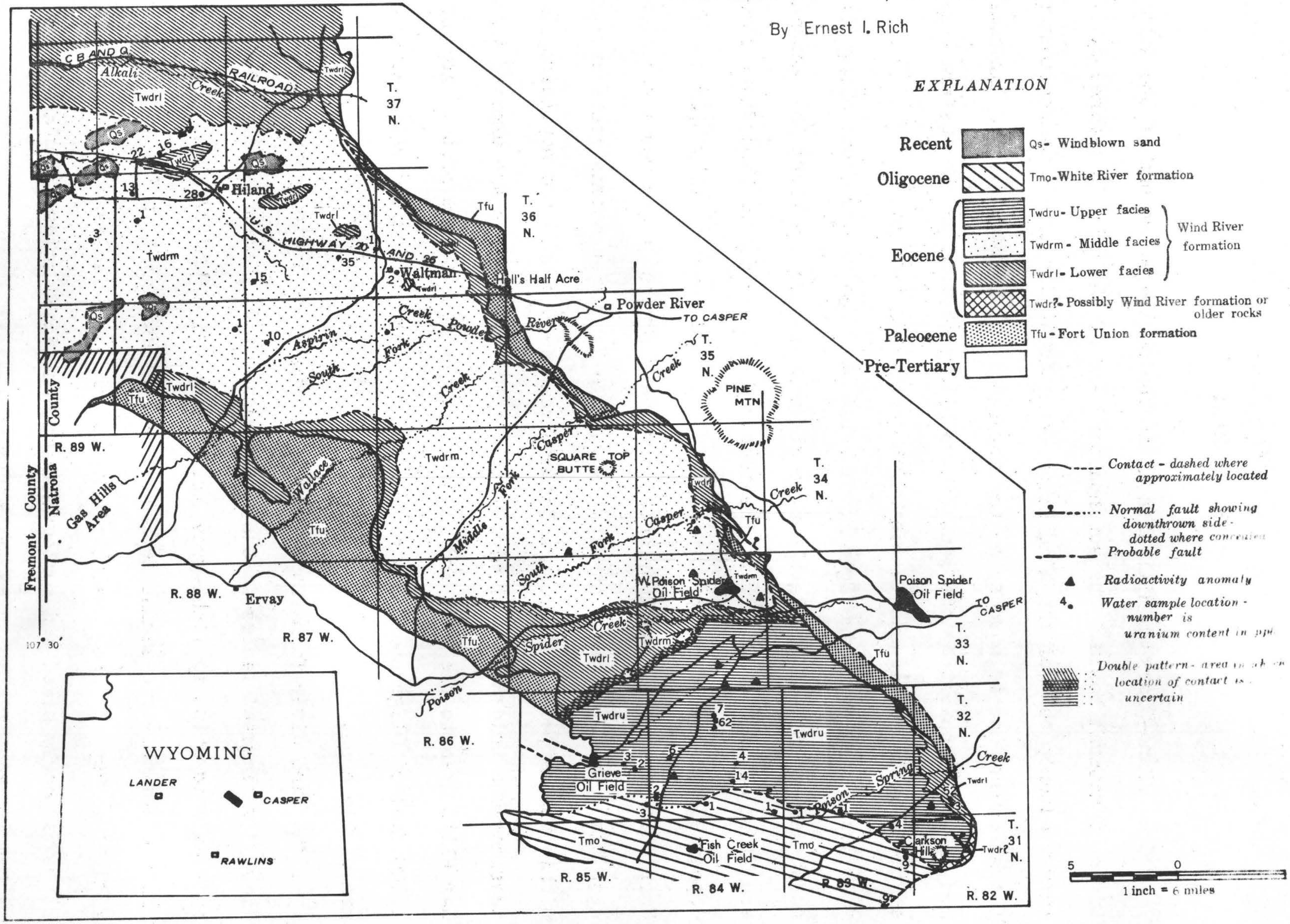
The Hiland-Clarkson Hill area is in the southeastern end of the Wind River structural basin. The southeastern end of the area is defined by the narrow outcrop belt of the Wind River formation. The area broadens toward the northwest and is bounded on the northeast by the Powder River lineament and on the southwest by the Rattlesnake Hills anticline. The western edge of the area is contiguous in part with the Gas Hills area.

Rocks ranging in age from Precambrian to Paleocene crop out along the northeastern limb of the Rattlesnake Hills anticline and along the southwestern flank of the Powder River lineament. The lower Eocene Wind River formation, deposited in the central part of the basin, laps unconformably upon the Paleocene Fort Union formation and in places completely covers it and rests unconformably upon the upper Cretaceous strata. No middle and upper Eocene rocks are present within the mapped area nor in adjacent areas to the east and northeast; however, considerable thicknesses of middle and upper Eocene rocks are exposed in the Gas Hills area to the west and in the Badwater area to the north. Approximately 1,000 feet of Oligocene and Miocene rocks crop out along the southeastern margin of the area.

The Wind River formation is divided into three facies consisting of (1) a "lower" variegated facies at the base composed of siltstones, claystones, and intercalated white to light-gray sandstones; (2) a "middle" drab claystone and arkosic channel-type sandstone facies derived chiefly from Precambrian rocks; and (3) an "upper" conglomeratic arkosic sandstone facies that is much coarser and more poorly sized and sorted than the "middle" facies. The areal distribution of these facies is shown in figure 32.

32. GENERALIZED GEOLOGIC MAP OF HILAND—CLARKSON HILL AREA
NATRONA COUNTY, WYOMING

By Ernest I. Rich



A uranium-bearing stratigraphic sequence that may be older than the Wind River formation but that rests unconformably on the Fort Union formation crops out on Clarkson Hill. A section of these rocks was measured north of the major fault on the east-facing cliff of Clarkson Hill, sec. 16, T. 31 N., R. 82 W. The sequence tentatively has been assigned to the Wind River formation until more complete information regarding its age relationships can be obtained.

It appears from preliminary fossil identification and from reconnaissance study of a relatively complete stratigraphic section that no middle and upper Eocene rocks are present along the southeastern margin of the basin. The middle and upper Eocene rocks that may have been present in this area were removed by pre-Oligocene erosion, so that the White River strata fill a channel cut deeply into rocks of pre-Wind River age. A post-Oligocene east-west normal fault has brought the White River formation into contact with the "upper" facies of the Wind River formation. The history of post-Wind River--pre-Oligocene erosion, subsequent channel filling by the White River formation, and later normal faulting is similar in the part of the Gas Hills area, about 25 miles to the west, where the best uranium deposits occur.

An area of high radioactivity occurs about 35 feet above the base of the Wind River (?) formation in an area about 500 feet long and 300 feet wide near the base of Clarkson Hill. The zone of highest radioactivity is in a carbonaceous siltstone lens within a thick unit of coarse to conglomeratic arkosic sandstone. Chemical analyses have been received for three samples collected at this locality; however, these indicate that the uranium is strongly out of equilibrium with the equivalent uranium. The following are data on these three analyses:

Sample No.	Type of Sample	eU%	U%
ER-55-12	Selected sample from siltstone layer	0.14	0.080
ER-55-14	2' channel sample of sandstone above siltstone	0.027	0.021
ER-55-15	1' channel sample of sandstone below siltstone	0.015	0.003

Uranium occurs in an east-northeast trending channel in the "middle" facies of the Wind River formation, about 2.5 miles northwest of Hiland, Wyoming. The channel is about 2,200 feet long and 30 feet wide with the highest radioactivity occuring in a zone of carbonaceous material and poorly indurated sandstone about 10 feet wide and 1 to 5 feet thick. Although one selected sample contains 0.14 percent uranium and 0.11 percent equivalent uranium, the average of six channel samples representing 3 feet of average stratigraphic thickness from the zone of highest radioactivity is 0.024 percent uranium and 0.055 percent equivalent uranium. If occurrences of ore grade uranium deposits are found in the "middle" facies, the recognition that localization can occur in a continuous carbonaceous sandstone channel may be important in prospecting.

No radioactivity anomalies were found in the "lower" facies of the Wind River formation.

Washakie Basin, Wyoming and Colorado

Baggs area, Carbon and Sweetwater Counties, Wyoming and Moffat County, Colorado

by

G. E. Prichard

The Browns Park formation of Miocene age and the immediately underlying rocks west of Poison Basin were mapped geologically at a scale of 1:20,000 in an area of about 200 square miles in southern Sweetwater County, Wyoming, and northern Moffat County, Colorado. The mapped area consists of Tps. 12 and 13 N., Rs. 95, 96, and 97 W., Wyoming, and the two northern tiers of sections in T. 12 N., Rs. 96 and 97 W., Colorado. In the Baggs (Poison Basin) area the Browns Park formation was mapped and studied to determine possible relationships between uranium occurrences and the lithology and structure of the host rocks.

All presently known occurrences of uranium minerals in the Browns Park formation are in fine- to medium-grained, cross-bedded sandstone except one minor occurrence which is in the uppermost 2 feet of the basal conglomerate. Anomalous radioactivity was detected at scattered localities in rocks of the Green River and Wasatch formations of Eocene age, but no visible uranium minerals were found. Recent exploratory drilling by private companies in Tps. 12 and 13 N., Rs. 92 and 93 W. has disclosed uranium mineralization, reported to be as much as 0.1 percent, in the unoxidized zone, the so-called "blue" sandstone. The depth to the unoxidized or "blue" zone is from 20 to 70 feet, but the depth has no apparent relationship to the present land surface. The mineralized zones are variable as to thickness and stratigraphic position in the sandstone. The operator reportedly shipped ore from the strip mine in sec. 4, T. 12 N., R. 92 W. that averaged about 0.3 percent U_3O_8, the maximum being about 0.6 percent. The mine and several groups of drill holes in the area were mapped in detail showing the spatial distribution of the uranium-bearing zones. Drill cuttings, cores, and water samples from selected drill holes were collected for detailed chemical and lithologic studies.

Selenium in the Browns Park formation of Poison Basin has been known for many years because vegetation growing on or near the sandstone is toxic to livestock. Recent increased industrial demands for selenium have led to extensive prospecting in the Baggs area. Qualitative field tests indicate greater concentrations of selenium in unoxidized than in oxidized zones. The association of uranium and selenium probably is due not to chemical combination but to a common origin.

Maybell-Lay area, Moffet County, Colorado

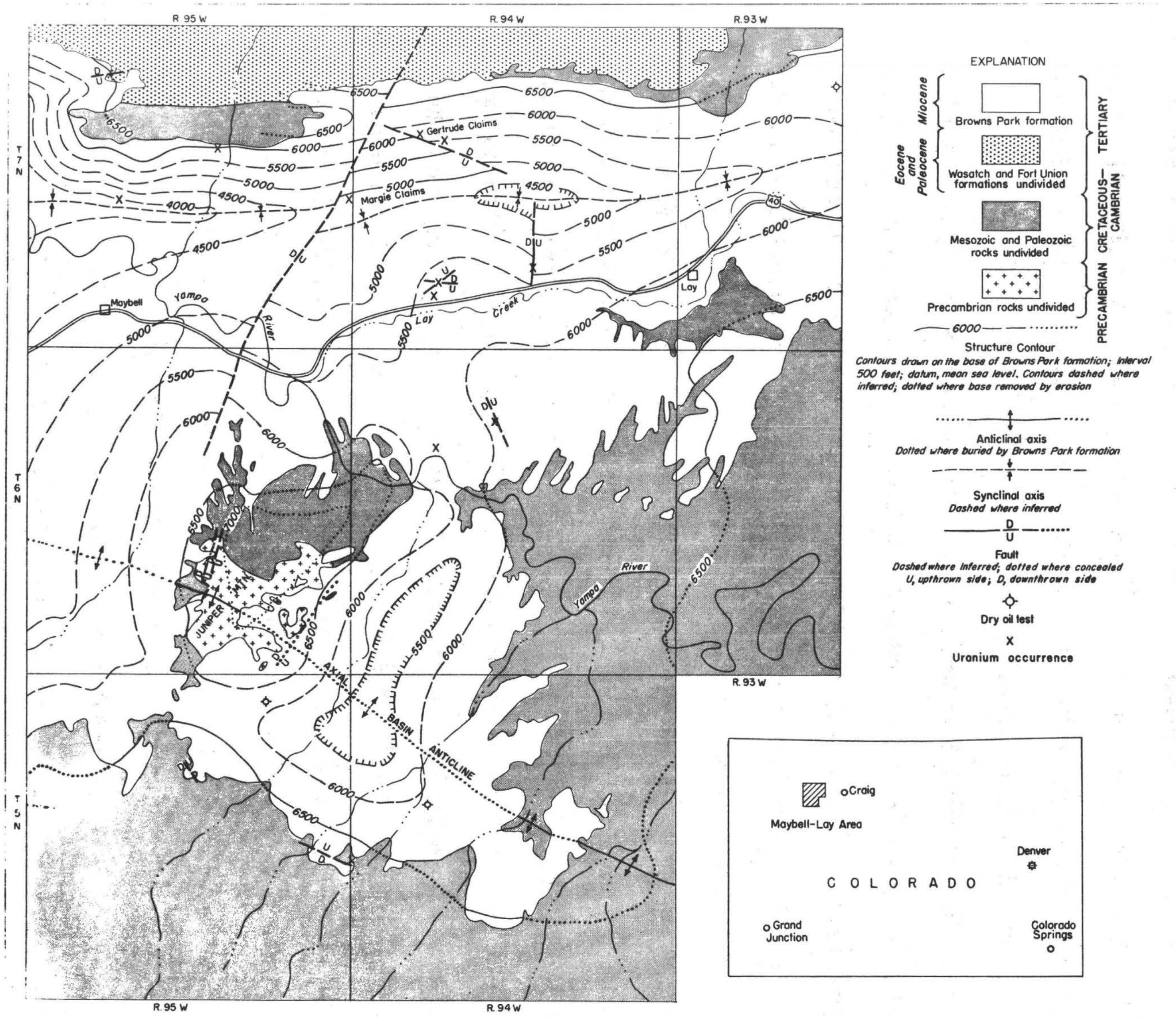
by

M. J. Bergin

Extensive exploration for uranium has been done by private companies in the Maybell-Lay area about 25 miles west of Craig in southeastern Moffat County, Colorado (fig. 33, index map). Ore-grade deposits occur in the Browns Park formation of Miocene age both at the surface and at depths of as much as 200 feet (Gertrude claims, sec. 8, 17, and 18, T. 7 N., R. 94 W., and Margie claims, sec. 24, T. 7 N., R. 95 W.; fig. 33). At the present time ore averaging between 0.20 and 0.22 percent uranium is being shipped from the Margie claims.

Geologic investigations consisted of geologic mapping on aerial photographs at a scale of 1:20,000 in approximately 220 square miles in Tps. 5, 6, and 7 N., Rs. 93, 94, and 95 W. Detailed mapping and sampling was undertaken only where ore-grade deposits have been located (Gertrude and Margie claims, fig. 33).

The Browns Park formation which may be as much as 2,500 feet thick rests with angular discordance on rocks ranging in age from Precambrian to Eocene. The formation consists principally of fine- to medium-grained sandstone made up of quartz grains cemented by clay and calcium carbonate. At most localities the base of the formation is marked by a conglomerate ranging from 1 to 120 feet in thickness. The Browns Park formation was deposited on an erosional surface cut on older rocks which were folded into the Axial Basin anticline during



Geology modified from Sears, J.D., USGS Bull. 751 pt.II, 1924

FIGURE 23 GENERALIZED GEOLOGIC MAP SHOWING CONFIGURATION OF THE BASE OF THE BROWNS PARK FORMATION IN THE MAYBELL-LAY AREA, MOFFAT COUNTY, COLORADO

0 1 2 3 4 5 6 7 8 9 10 Miles

1955

post-Eocene-pre-Miocene time (fig. 33). A synclinal structure in the Browns Park formation superposed on the north flank of the older anticline was formed by post-Miocene deformation (fig. 33). Several normal faults of post-Miocene age cut the Browns Park formation.

Uranium occurs in both the basal conglomerate and the overlying sandstone of the Browns Park formation, but commercial deposits have not been found in the basal conglomerate. Slight radioactivity is present in a coal bed one foot in thickness in the Lance formation of Cretaceous age in sec. 4, T. 7 N., R. 93 W., but no abnormal radioactivity was detected in the older rocks.

Company drilling indicates that on the Gertrude claims from one to five overlapping mineralized zones are present at depths ranging from 5 to 200 feet and on the Margie claims one to three mineralized zones are present at depths ranging from 10 to 180 feet. These zones in drill holes are reported to range from 1 to 19 feet in thickness. The operator reports that samples from the zones contain as much as 1.25 percent uranium. The largest mineralized zone outlined to date is approximately 1,000 feet long and 200 to 300 feet wide. These zones are believed to be circular to elongate bodies of irregular thickness lying near normal faults which have displacements of about 250 feet (fig. 33). Uranium occurs in gouge zones along faults, as coating material on fracture planes, and as disseminated material in soft sandstone at several localities (sec. 27, T. 7 N., R. 94 W., sec. 29, T. 7 N., R. 94 W., and sec. 9, T. 6 N., R. 94 W.; fig. 33). Uranium also occurs in association with iron oxide staining around hard calcareous cemented sandstone masses in sec. 29, T. 7 N., R. 94 W. and sec. 20, T. 7 N., R. 95 W. (fig. 33).

Uranium minerals occurring at the surface and in shallow prospect pits include meta-autunite, uranophane, and zeunerite or torbernite. Uranium minerals have not, as yet, been identified from deposits at depth in the unoxidized sandstone.

Megascopic examination of mineralized and barren sandstone samples show no significant difference in grain size, sorting, mineral assemblage, or cementing material, except for the presence of uranium minerals. Since the known uranium occurrences are on the steep north flank of a syncline and adjacent or in proximity to normal faults, it is believed that localization of uranium from solutions moving through the Browns Park formation may have been controlled by the presence of these structures (fig. 33). The occurrences of uranium along faults, near diastems, and adjacent to some calcareous cemented sandstone masses indicates that changes in permeability and porosity of the host rocks may also have influenced the localization of uranium.

Crooks Gap area, Fremont County, Wyoming

by

J. G. Stephens

Approximately 200 square miles have been mapped during the 1954 and 1955 field seasons in the Crooks Gap area of southeastern Fremont County, Wyoming (fig. 34 and 35). The mapped area includes part of the boundary between the Sweetwater Arch to the north and the Great Divide Basin to the south. The boundary is marked by reverse faults and later normal faults, both of large displacement. South of the boundary, northwest-trending folds of Laramide age intercept the fault zone to the north. Only in the Crooks Gap area and in other places breached by erosion may the older structures be seen. At most places the older rocks are covered by a thick sequence of Eocene(?) sediments derived from weathering of the Sweetwater granite to the north. The Tertiary rocks are folded, apparently along trends determined by the earlier Laramide folds. All significant uranium deposits found to date in the gap are located in the folded Tertiary rocks.

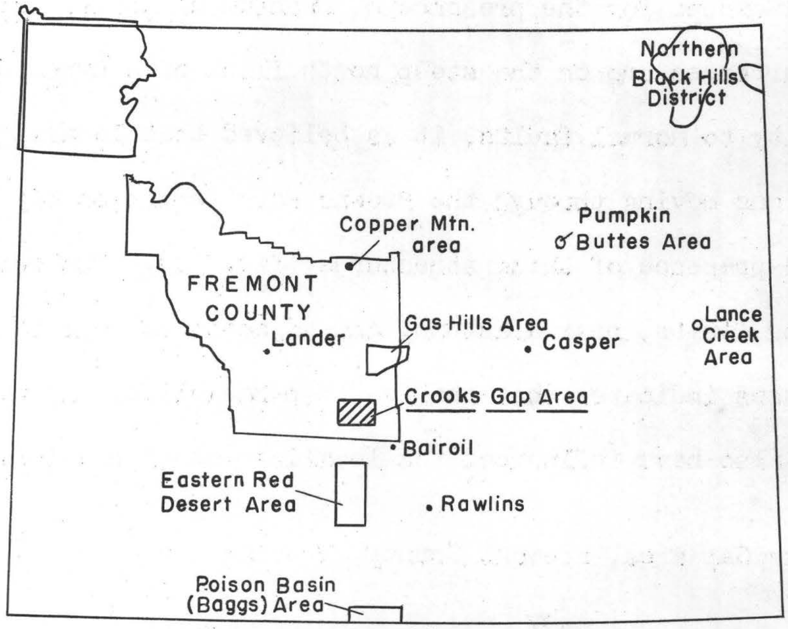


FIGURE 34—INDEX MAP OF WYOMING SHOWING LOCATIONS OF CROOKS GAP AND OTHER URANIUM AREAS.

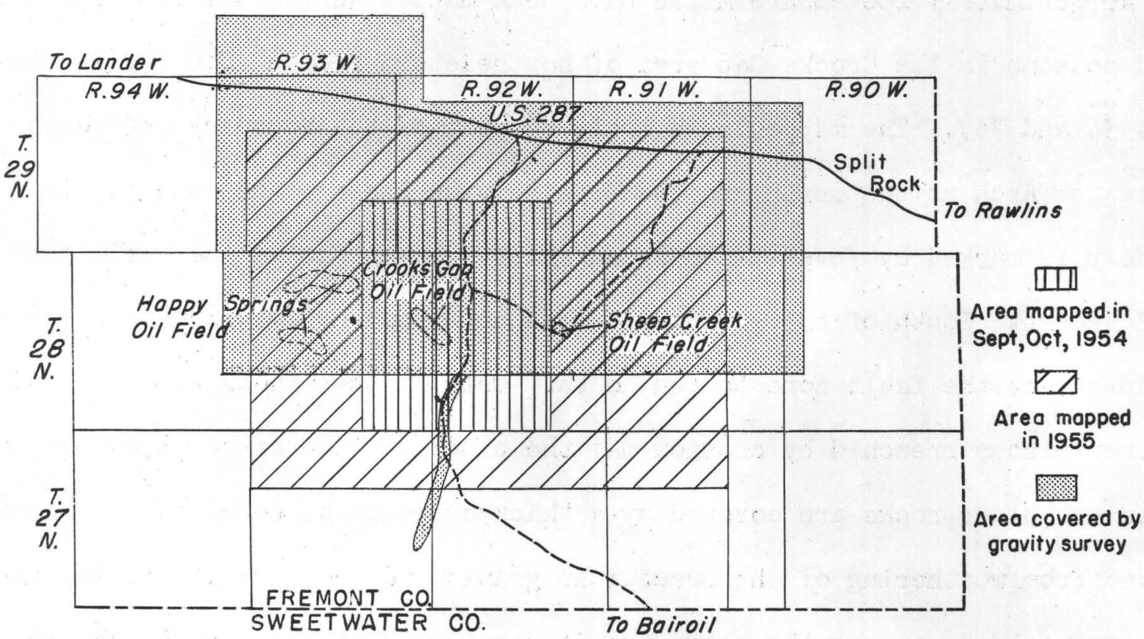


FIGURE 35—INDEX MAP SHOWING AREAS COVERED BY GEOLOGIC MAPPING (1954 AND 1955) AND GRAVITY SURVEYING.

The only uranium mines in the area are on the east side of the gap in secs. 9, 16, 20, 28, and 29 of T. 28 N., R. 92 W. in a north-trending belt three miles long and about two miles wide (fig. 36). All deposits occur in the conglomeratic arkose of the Eocene Wasatch(?) formation except at the Hazel mine (sec. 9, T. 28 N., R. 92 W.) where the ore mined was along the plane of a high angle reverse fault, which places the Triassic Chugwater formation on the Cretaceous Cody shale. The Wasatch(?) formation east of the gap appears to be folded into two synclines separated by an anticline, all of which plunge to the southeast (fig. 36). Along their southern parts these structures are covered by a very coarse conglomerate which appears to be the same as that capping Sheep Mountain.

Recent deep drilling has disclosed mineralized zones at depth near the Sno-ball mine and in the topographic basin of secs. 16 and 21 (fig. 36). Deep drilling on the Sundog claims of sec. 28 penetrated, at approximately 470 feet, material tentatively identified as uraninite. A preliminary study of the drill data suggests that the mineralization is controlled by local structures, the deposits being found along the axes of shallow synclinal troughs. The delimiting of ore bodies by drilling has not yet been completed.

Two water samples with anomalously high uranium contents (one of 148 ppb and another of 460 ppb, both from sec. 24, T. 28 N., R. 93 W.) have been collected from the west side of the gap and may indicate the presence of uranium at depth. Uranium minerals also have been found in the vicinity of Willow Creek (sec. 27, T. 28 N., R. 90 W.) fifteen miles to the east of Crooks Gap. Although extensive cover prohibits detailed work at present, the similarity of the geologic setting to that of Crooks Gap indicates that the area is worthy of further extensive prospecting.

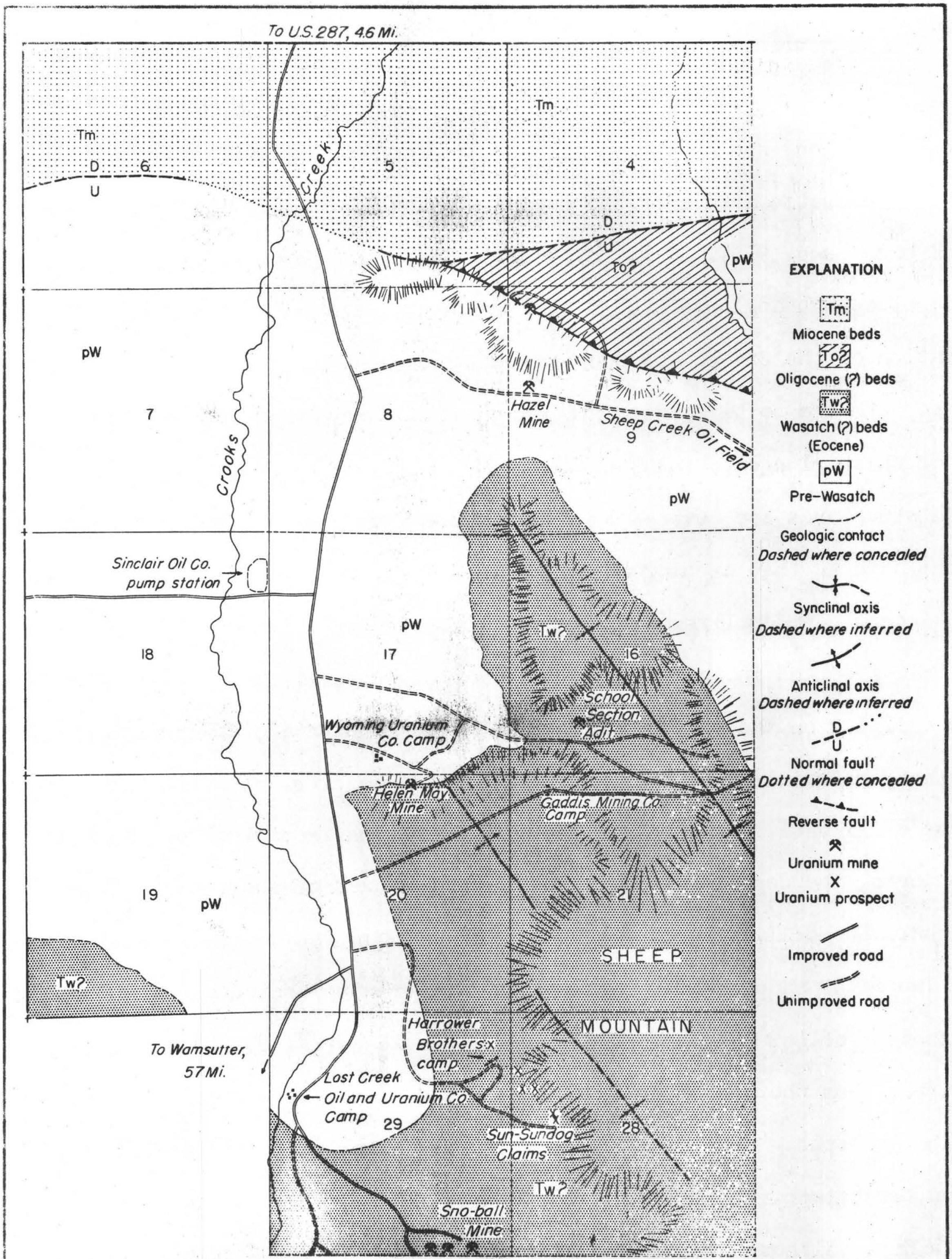


FIGURE 36 SKETCH MAP OF URANIUM PRODUCING AREA OF THE CROOKS GAP AREA, T. 28N, R 92 W., FREMONT COUNTY, WYOMING.

1/2 1 Miles

The ore controls in the area as indicated by recent drilling and mining are: (1) presence of carbonaceous material: deposits occur in and adjacent to carbonaceous siltstone beds in the arkose; (2) changes in permeability: an ore body may be located at the boundary between rocks of different permeability. The largest ore body mined is at the base of the Wasatch(?) formation where it rests on less permeable rocks; (3) structural controls: a fault may produce an impermeable barrier as at the Sno-ball mine where faults bound blocks, only some of which are mineralized. Drilling results suggest that the Tertiary folds may also be important in localizing ore bodies.

All of the controls suggest that deposition of the uranium minerals was from ground water and that features controlling the movement of ground water are important in searching for new deposits. Local features that concentrate the flow of uranium-bearing ground water, such as synclinal structures, impermeable layers, and faults are likely to cause deposits. In stratigraphic zones rich in carbonaceous material, and where the movement of ground water is impeded, a reducing environment is formed which favors the deposition of uranium.

Gravity studies, by R. A. Black

Gravity measurements were conducted in the Crooks Gap area of Wyoming during the period of September 1 to October 28, 1955. The gravity measurements were made in conjunction with geologic mapping of the Crooks Gap uranium deposits. The gravity measurements were intended to provide information on postulated subsurface structures buried beneath unconsolidated Miocene sediments. Such structural information may be quite useful in eventually formulating a theory for the origin of the Crooks Gap uranium deposits. The area covered by the gravity survey of the Crooks Gap area is shown in figure 35, p. 180. The area surveyed includes the Crooks Mountain, Crooks Creek NE, and Split Rock NW 7-1/2 minute quadrangles and parts of the Soap Holes, Black Rock Gap, Graham

Ranch and Stampede Meadow 7-1/2 minute quadrangles.

Gravity stations were occupied on approximately one mile spacings to cover an area of approximately 220 square miles. Most of the stations occupied have been at section corners, benchmarks, or spot elevations where the elevations are known to within one foot. Plane table traverses were run in areas of little vertical control.

The gravity values have been reduced and a Bouguer contour map has been prepared from the data. Although elevation corrections must be made at some of the stations before the gravity contour map can be used for interpretation, it is interesting to note the following features which are revealed on the present map: (1) the Happy Springs oil field is marked by a gravity high trending NW - SE; (2) the granitic overthrust block in the area is marked by a prominent gravity high; and (3) the northern boundary of the Green Mountains is paralleled by a long E-W trending gravity low.

Interpretation of the gravity data will begin when the final corrections have been made to the data.

Laramie Basin, Wyoming

Uranium in carbonaceous sandstone near Laramie, Wyoming

by

J. D. Love

Metatyuyamunite occurs in carbonaceous sandstone in the Lower Cretaceous Cloverly formation 22 miles southwest of Laramie, southeastern Wyoming. Uranium has not previously been reported from the region, except for some radioactive titaniferous sandstones in the Mesaverde formation 10 miles to the north. Mineralization was observed in three localities along an outcrop distance of

1 1/2 miles, and many spots of radioactivity showing from 0.5 to 1 mr/hr. were noted in the area extending 1/2 mile beyond the farthest west mineral occurrence.

The Cloverly formation is about 150 feet thick and consists of a basal white and carbonaceous buff sandstone, a middle variegated claystone, and an upper carbonaceous buff ferruginous sandstone. Metatyuyamunite occurs in both the upper and lower sandstones. The underlying Morrison formation is chiefly variegated claystone with little sandstone. Some siliceous limestone nodules are moderately radioactive. Overlying the Cloverly formation is the Thermopolis shale, about 60 feet thick, consisting of nonradioactive soft, fissile, black shale. Above the Thermopolis shale is the Muddy sandstone, about 40 feet thick, and resembling the sandstones in the Cloverly formation, except that it contains less carbonaceous material. Only one radioactive spot was observed in the Muddy sandstone. The rocks are gently folded and both the Cloverly formation and the Muddy sandstone crop out in broad dip slopes that could easily be stripped.

Fifteen samples of carbonaceous sandstone from various parts of the Cloverly formation were analyzed for uranium. Surface samples contain much higher eU than U. Samples one foot or more below the surface contain much more U than eU. Selected samples from the lower sandstone contain as much as 0.8 percent U, and random samples from an adjacent handpicked stockpile contain 0.33 percent U and 0.18 percent eU. Random samples from three nearby stockpiles of handpicked material from the same sandstone contain 0.1 to 0.14 percent U and from 0.069 to 0.097 percent eU. A pit eight feet deep shows at the base two feet of plastic variegated claystone, overlain by six feet of highly carbonaceous ferruginous fine-grained thin-bedded sandstone with mineralization both in the sandstone and along fractures and bedding planes.

One and one-half miles farther southwest, numerous radioactive spots were sampled on surface outcrops of the uppermost sandstone in the Cloverly formation. Six-inch to 1-foot channel samples contain from 0.011 to 0.064 percent eU and from 0.003 to 0.010 percent U. Metatyuyamunite was identified from one pit in this locality.

The origin of the uranium in this area is of considerable interest because there are broad outcrops of the Cloverly formation around the southern margin of the Laramie Basin. No evidence of hydrothermal activity was observed. No Tertiary tuffaceous rocks are now present in the vicinity of mineralization. However, four miles to the southwest, approximately 500 feet of tuff, claystone, and tuffaceous limestone comprising the North Park (?) formation of Miocene or Pliocene age is present. The top of this sequence is approximately 500 feet above the uranium occurrences, and it is likely that the North Park (?) formation was stripped off the area of mineralization during Pleistocene time. One of the limestones in this formation is moderately radioactive and shows abundant yellow fluorescence. Analyses of this limestone are not yet available. The North Park (?) formation locally contains uranium minerals in the Saratoga area 50 miles to the west and along the northern margin of the Hanna Basin, 75 miles to the northwest.

Nine water samples collected from springs in the general area of the uranium occurrences, contain from 2 to 29 parts per billion, and average 12 ppb uranium.

Arizona

Dripping Spring quartzite

by

H. C. Granger

The following data are believed to be of importance in understanding the origin and localization of the uranium deposits in the Dripping Spring quartzite.

The abnormally high radioactivity of the upper member of the Dripping Spring quartzite is due to the unusually high potassium content of the siltstones. Six samples of the uranium-favorable rocks contain an average of 10 percent K which is equivalent in radioactivity to about 0.005 percent uranium. These favorable siltstones also contain as much as 2 percent disseminated organic carbon, some of which is in the form of graphite.

The most promising uranium deposits have been found within a few feet of discordant contacts between the host rock and diabase intrusive bodies. The heat and emanations from diabase have, in some places, converted the favorable siltstone host rock to a crystalline, feldspar-rich rock which will be referred to as feldspathized siltstone. Where the deposits occur in feldspathized siltstone they commonly follow the margins of narrow rheomorphic breccia zones and dikes. This rheomorphic material is believed to have been derived by a mobilization of the feldspathized siltstone and represents the ultimate degree of metamorphism of the siltstone near diabase.

Where the deposits occur in unmetamorphosed siltstone the ore minerals are disseminated in the walls of tight joints. Subsequent opening and deposition of carbonate and pyrite in these joints have resulted in limonite-filled fractures in near-surface parts of the deposits.

In some localities the deposits do not appear to follow fractures, and have no particular trend. These deposits are invariably of very low grade. The uranium is very finely disseminated in the host rock in a form not yet identified.

Another type of deposit occurs at the base of the upper member of the Dripping Spring quartzite. These deposits, as far as is known, contain only secondary minerals and were probably derived from leaching of uranium in overlying rocks.

The mineralogy of deposits in or near feldspathized siltstones differs from the mineralogy of those in unmetamorphosed siltstones. In and near feldspathized siltstone visible blebs and discontinuous veinlets of fine-grained uraninite are associated with disseminated pyrrhotite and molybdenite. Uraninite has been identified in only one deposit in unmetamorphosed siltstone,and there it was near a thick diabase dike. In most deposits in unmetamorphosed siltstone the primary uranium mineral is finely disseminated in the host rock but has not been identified. Much of the uranium may be adsorbed on clay minerals. Pyrite is common in most of the deposits in unmetamorphosed siltstones but no pyrrhotite or molybdenite has been identified.

The diabases that are spatially associated with some of the deposits have differentiated to local bodies of sodic syenite. These differentiates range from pegmatoid bodies rich in albite to aplitic textured dikes that are, in some instances, almost pure albite. Similar diabase bodies known to intrude the Dripping Spring quartzite elsewhere are believed to have differentiated into potassium-rich facies or to have formed coarse-grained pegmatoid rocks with calcic plagioclase.

A series of samples taken in the chilled border of a diabase sill contains nearly twice as much uranium as a similar series taken about 30 feet from the contact in coarser-grained diabase. Very little of this uranium is removed from a ground sample in a dilute acid leach, which suggests that it may be held within the crystal lattice of constituent minerals in the diabase.

Hypothesis on origin

The data presented herein and that given in previous semiannual reports relates the origin of the uranium deposits in the Dripping Sping quartzite to diabase. Whether the uranium was derived from the diabase, or was concentrated by redistribution of syngenetic uranium in the siltstone by factors related to the diabase, probably cannot be proved. It is here suggested, however, that the uranium was derived from the diabase.

Metamorphism of the sedimentary rocks during the period of intrusion and cooling of diabase magma was widespread and varied. Much of the intruded rock was unaffected, but locally asbestos and serpentine were developed in siliceous limestone and dolomite; magnetic iron ores were formed in limy siltstones; actinolite and other amphiboles were developed in mudstones; and potassium-rich siltstones were converted to crystalline feldspar-rich rocks. Locally, in the feldspar-rich rocks (feldspathized siltstone) fissures and breccia were healed by a medium-grained crystalline rock similar in composition to the feldspathized siltstone but containing more quartz.

During this period the diabase was undergoing differentiation. Soda-rich components of the magma were concentrated in pegmatoid syenite facies and in later aplitic dikes that locally intruded the enclosing rocks. The uranium originally contained in the magma was sealed into the rock along the quickly chilled borders but was expelled from those central parts of the magma undergoing differentiation. None of the facies produced by differentiation contained any minerals with which the uranium could combine; therefore, much of it was expelled along with sulfur and other elements in a fluid emanation.

The fluid emanations permeated the surrounding sedimentary rocks, mainly following tight joints, bedding planes, permeable beds, and the margins of rheomorphic dikes and breccias. Where the heat and other conditions were favorable uraninite was deposited. Farther from the source the uranium was adsorbed by clay minerals and fine-grained carbon. In some deposits near diabase much of the iron in the rocks was converted to pyrrhotite and the molybdenum to molybedenite; in deposits farther from the diabase pyrite and marcasite were formed.

An essential factor in deposition of uranium was a strongly reducing condition brought about by finely divided carbon and the original pyrite content in the rocks.

At a late stage in the process and during the Tertiary and Quaternary periods more pyrite and marcasite, chalcopyrite, galena and sphalerite were deposited. Generally they were localized along the same structures that controlled uranium deposition.

There is apparently a coincidence between the positions of uranium deposits and of diabase bodies that differentiate to sodic facies. The present study has not thoroughly tested this thesis, but it is suggested that the uranium is more closely related genetically to diabases differentiating to sodic facies than to diabases differentiating to potassic or calcic facies.

The foregoing hypothesis may be of application regarding the origin of other uranium deposits. The persistent tendency has been to relate most uranium deposits of hydrothermal origin to acid igneous rocks. Acid igneous rocks, however, generally contain accessory minerals such as zircon which may serve to capture the uranium ions from the magma into their crystal lattices. Basic rocks such as diabase have few of these minerals. If their differentiates also contain few of these minerals, there is an excellent possibility that the uranium will be expelled at a late stage in the crystallization history.

New Mexico

Tucumcari-Sabinoso area

by

R. L. Griggs

The Tucumcari-Sabinoso area lies mainly in San Miguel and Quay Counties in northeastern New Mexico. It embraces the southeastern part of the Canadian Plateau and an adjacent plains area which is surmounted by remnants of this plateau.

The rocks of the area are relatively flat-lying and range in age from Upper Triassic to Pliocene. The Upper Triassic Dockum group crops out in the plains area, and Jurassic and Cretaceous rocks crop out on the Canadian Plateau and its outlying remnants. Deposits of uranium minerals were discovered in the area in 1954 in both the Upper Triassic Dockum group and the Upper Jurassic Morrison formation. The deposits in the Dockum group are in conglomeratic sandstone beds that are present in the lower half of the group. These sandstone beds are similar to and occupy approximately the same place in the stratigraphic column as the Shinarump conglomerate. They are exposed along stream valleys and one bed locally forms cuestas in the plains area. The same beds are present under shallow cover over large areas. In one place in southern Quay County, about 15 miles south of Tucumcari, the uppermost of these sandstone beds probably is present under very shallow cover over an area of about 100 square miles. The known uranium mineralization is associated with carbonaceous and ferruginous material at the base of the sandstone beds, where the beds channel into underlying shale.

The known uranium mineralization in the Morrison formation is near the middle of the formation and in the upper part of a member in which light gray sandstone beds are predominant. For the most part this member is poorly exposed along the edges of the Canadian Plateau or along the edges of outlying remnants of this plateau. The mineralization is associated with plant and dinosaur remains in channel sandstone.

During the field season of 1955 an area of about 2,000 square miles was mapped on a scale of 1:60,000, and two prospects were mapped on a scale of 100 feet per inch.

At the Lucky group prospect in sec. 6, T. 7 N., R. 32 E. in southeastern Quay County a mineralized lens is present at the base of a channel of gray conglomeratic sandstone in the Dockum group (figs. 37 and 38). This lens, about 60 feet long and ranging from a knife edge to 2 feet thick, contains a yellow uranium mineral impregnating the sandstone, but some of the uranium is apparently held by abundant carbon trash. The estimated eU content of the lens ranges from about 0.10 to 0.15 percent for a distance of about 30 feet along the lens.

At the Bel-Aro prospect in sec. 24, T. 11 N., R. 28 E. in western Quay County a yellow uranium mineral occurs in a channel sandstone in the Morrison formation. The uranium mineral fills cracks in petrified wood and impregnates dinosaur bones present in the channel. Mapping indicates that the mineralization is located in the channel sandstone near the axis of a shallow syncline (fig. 39).

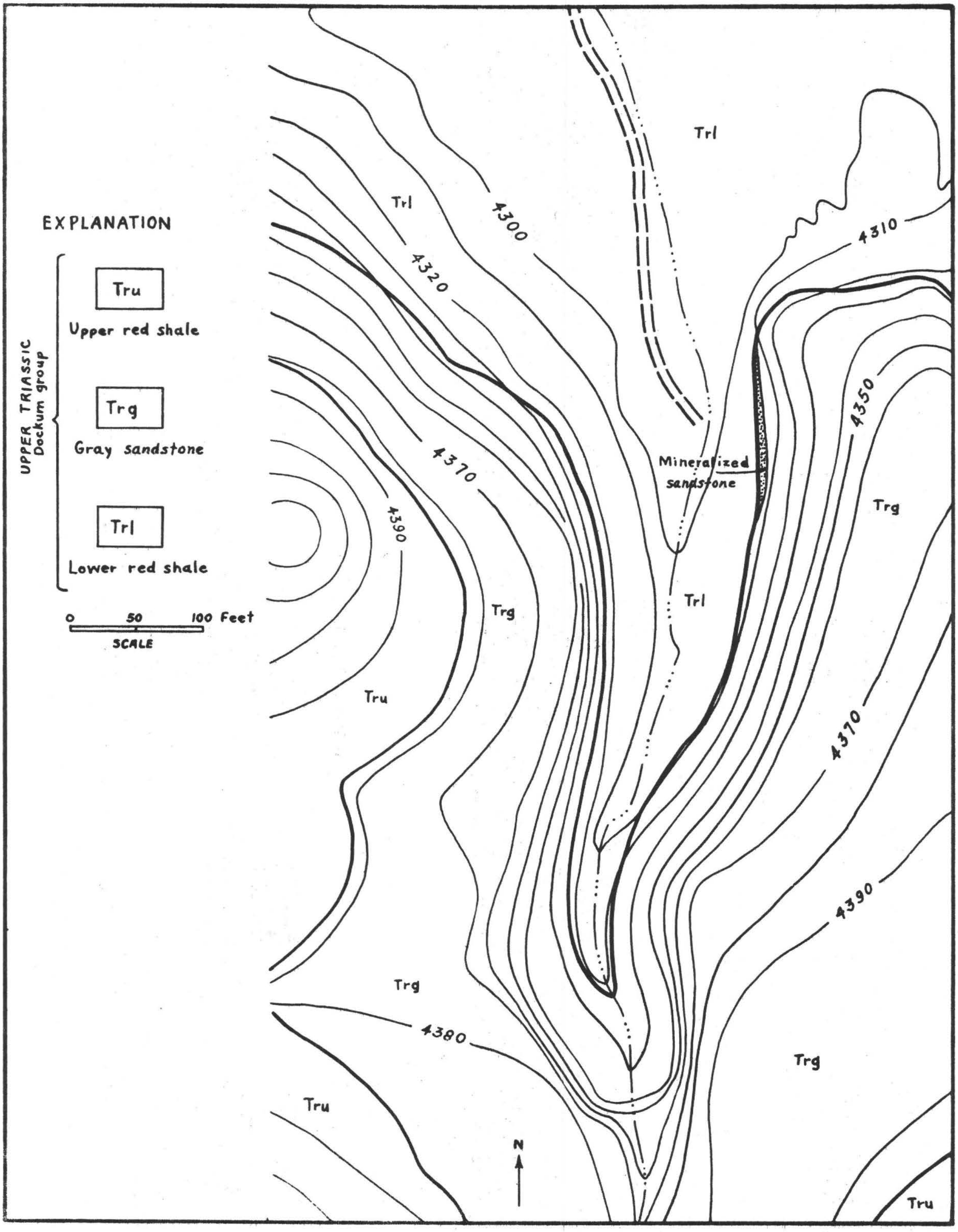


FIGURE 37 LUCKY GROUP PROSPECT, SEC. 6, T. 7N., R. 32 E.
QUAY COUNTY, NEW MEXICO

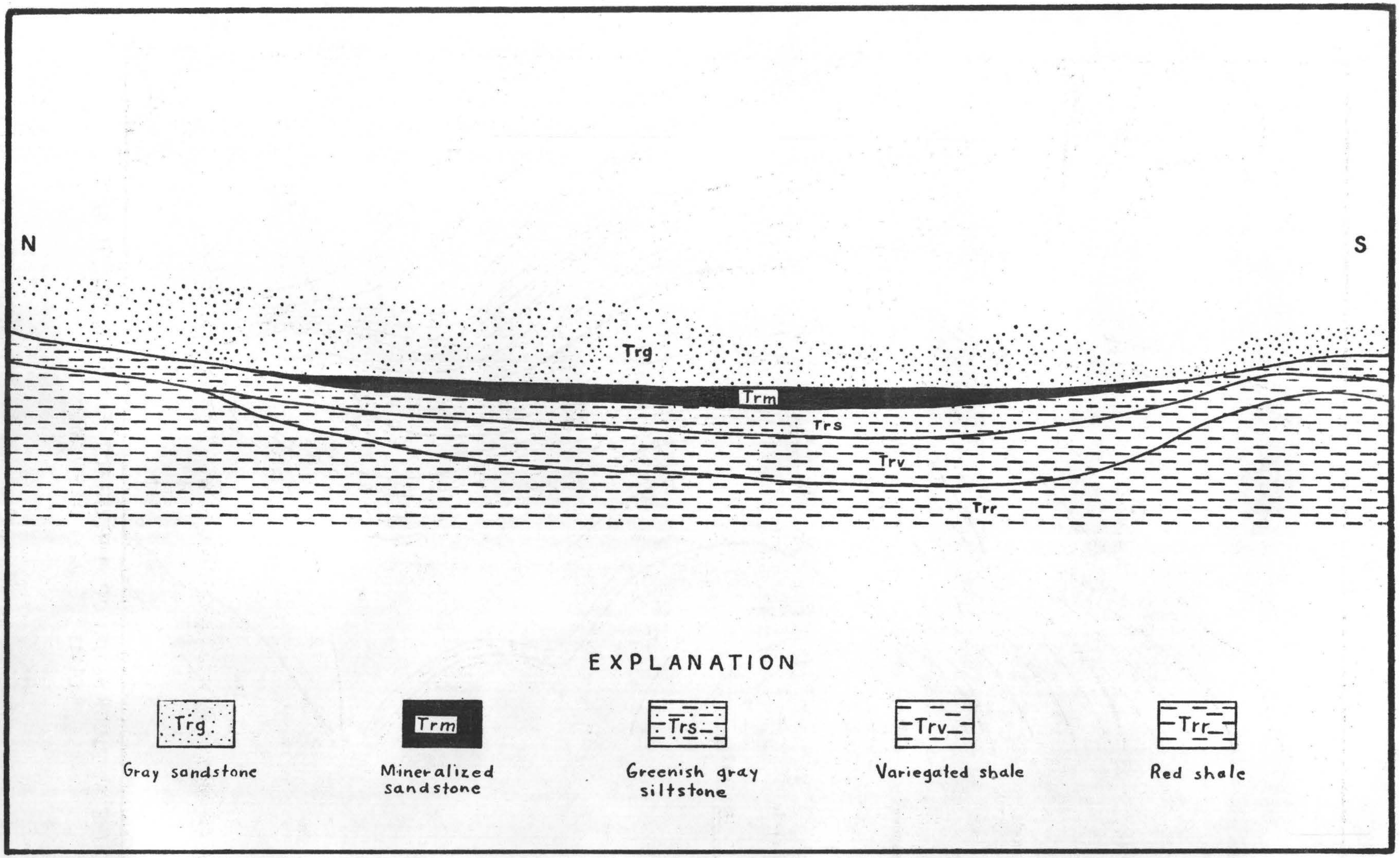


Figure 38 Sketch of mineralized lens and enclosing rocks along outcrop at Lucky Group prospect, Sec. 6, T. 7 N., R. 32 E., Quay County, New Mexico.

0 10 20 Feet

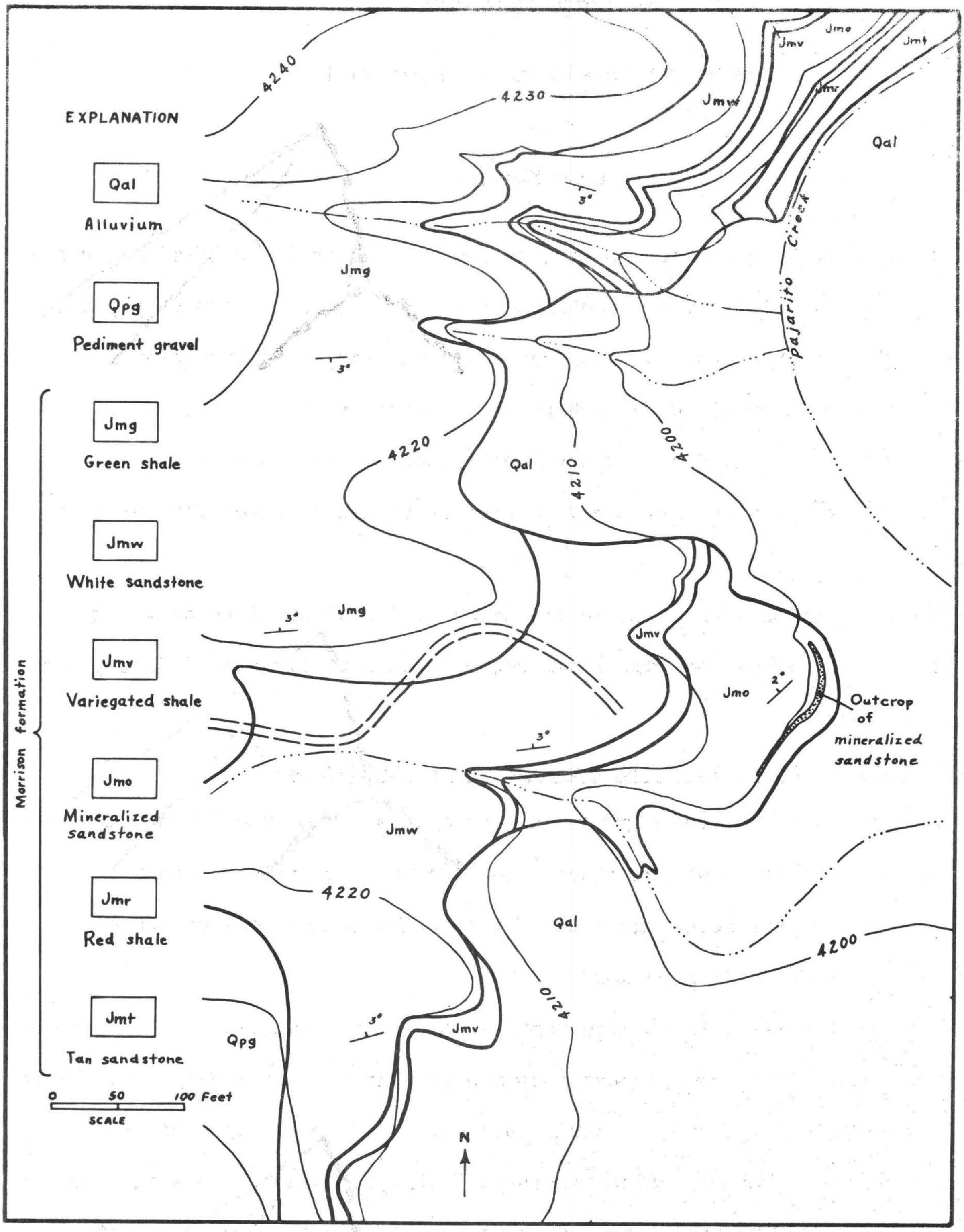


FIGURE 39 BEL ARO PROSPECT, SEC. 24, T. 11 N., R. 28 E.
QUAY COUNTY, NEW MEXICO

Appalachian region

Mauch Chunk quadrangle, Pennsylvania

by

Harry Klemic

Geologic mapping in the northern half of the Mauch Chunk 15-minute quadrangle was started in July and continued until October 1. About 60 percent of the northwestern quarter of the quadrangle was mapped. Stratigraphic sections were studied along the Lehigh River, along some of the streams tributary to the river, and in excavations along the northeastern extension of the Pennsylvania Turnpike. Many samples of rock were taken for petrographic study.

Two occurrences of uranium in the Catskill formation of Devonian age are known in the area. No additional occurrences were discovered during the investigations.

Occurrences of uranium in Paleozoic rocks of Pennsylvania

In connection with the mapping and geologic study of the Mauch Chunk quadrangle, occurrences of uraniferous rock found by prospectors during the past three years have been examined. The distribution of some of these localities is shown in figure 40.

Although too small to be important as sources of uranium, the occurrences may be of general interest because they are similar and are widely distributed in the same part of the stratigraphic section. All are in rocks of Upper Devonian age that probably belong to the Catskill formation. Beds of uraniferous dark gray to light greenish gray and brown to pale tan sandstone, siltstone, and shale are interbedded with barren red sandstone and shale. They range from a few inches to a few feet in thickness. At several localities the uraniferous

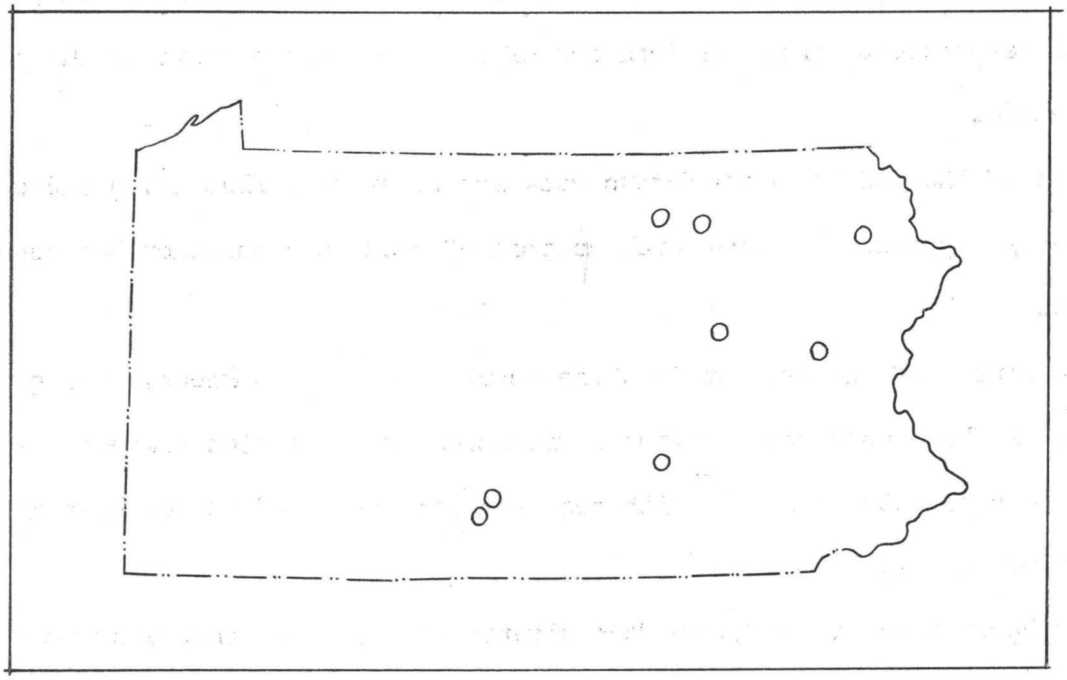


FIG. 40 Map of Pennsylvania showing distribution of localities where uranium has been found by prospectors in Paleozoic sedimentary rocks.

beds occur in two or three stratigraphic zones with intervening barren beds of both red and nonred sandstone.

Within the uraniferous beds the radioactive rock is discontinuously distributed. Zones in which carbonaceous plant fossils are abundant or where the rock is stained brown with iron oxides generally contain the most uranium. Torbernite, meta-torbernite or meta-zeunerite, and tyuyamunite have been found in trace amounts at some of the localities.

Secondary copper minerals are common in the uraniferous rock. At two of the occurrences in northern Pennsylvania, uranium is in beds which were once prospected for copper. Samples from these localities contain 0.008 to 2.0 percent copper. No uranium minerals were identified at these prospects.

The uranium content of rock samples from the localities shown in figure 40 ranges from 0.02 to 0.29 percent. In general, the higher grade samples are from the localities where uranium minerals have been found. A few grams of black carbonaceous material from one of the occurrences contains 0.7 percent uranium.

Some of the beds of uraniferous rock are relatively flat lying and others are steeply dipping. No structural control of uranium deposition has been observed.

The source of the uranium in these occurrences is not known. The general features of the occurrences and their widespread distribution suggest a source within the sediments, possibly with some redistribution of the uranium by percolating waters.

The Upper Devonian rocks in Pennsylvania contain beds that are favorable hosts for uranium. Areas underlain by these rocks may be favorable ground for further uranium prospecting. Background radioactivity in large areas of Upper Devonian rocks in Pennsylvania is generally between 0.01 and 0.03 milliroentgens per hour. The known occurrences of uranium have been found in outcrop and in old prospect pits. Many are small or poorly exposed and their radioactivity can only be detected in the immediate vicinity of the outcrop of bedrock. The mantle of soil and rocks may shield radioactivity in unexposed areas of favorable host rocks.

<u>Uraniferous rocks in New Jersey</u>

An occurrence of coarse-grained magnetite ore containing a few percent of rare earth minerals was examined and sampled in the Scrub Oaks mine near Dover, Morris County, New Jersey. Analyses of five samples show uranium ranging from 0.002 to 0.013 percent, ThO_2 ranging from 0.020 to 0.11 percent, and total rare earths, calculated as oxides, ranging from 0.53 to 2.30 percent. The thorium, uranium, and rare earth elements are in doverite (a recently described yttrium fluocarbonate mineral), bastnaesite, xenotime, zircon, allanite, apatite, and sphene, and possibly in some other radioactive minerals in material that is still being studied.

URANIUM IN VEINS, IGNEOUS ROCKS AND RELATED DEPOSITS

Colorado Front Range

by

P. K. Sims

Field investigations of five mining districts--Central City, Idaho Springs, Lawson-Dumont-Fall River, Freeland-Lamartine, and Chicago Creek--in a fifty-square mile area between Central City and Georgetown were essentially completed in 1954; during 1955 a few weeks were spent in the field to complete the study of active mines. A summary of the general geology of the region and an economic evaluation of the deposits were given in the previous semi-annual reports--TEI-390 and TEI-490. In this report the distribution, mineralogy and paragenesis, structure, and genesis of the uranium deposits are discussed.

Distribution of uranium deposits

Abnormally radioactive veins are widely scattered in the Central City-Georgetown area, but only a few veins contain deposits of commercial importance. One hundred forty-one abnormally radioactive localities are known in the Central City district and adjoining mining areas; 53 of these localities contain selected material that assays 0.10 percent eU or better; 13 mines are known to have produced uranium ore, some of which is high-grade.

Many of the uranium deposits occur in clusters, the largest of which, in the Quartz Hill area, occupies an area of a square mile. Other clusters of deposits are considerably smaller.

Mineralogy and paragenesis

The uranium-bearing ores consist of pitchblende and rarely yellow-green secondary minerals. The pitchblende occurs in precious-metal-bearing sulfide veins.

The pitchblende typically is hard and botryoidal; locally it is soft and sooty. X-ray studies of the mineral indicate that the A_o spacing (cubic cell dimension) varies considerably, and it is concluded that the variation is a linear function of the state of oxidation.

The pitchblende at Central City contains unusual quantities of Zr and Y and at places contains high Mo and W. The pitchblende at the Joe Reynolds mine, in the Lawson district, contains a similar trace-element suite. The pitchblende from Fall River, however, contains a notably different suite of trace elements; it is high in Mn and Ni and low in Zr and W.

Structure of deposits

The pitchblende, and its alteration products, occur in several fracture sets, and commonly within an area containing uranium deposits it is in two or more different sets, some of which may intersect. It rarely is present in the faults that belong to the breccia-reef system; also it is not known to occur in the youngest fracture set.

The pitchblende is not regularly distributed throughout the veins, but occurs in discrete shoots or small lenses and pods. The shoots rarely exceed 50 feet in height, 50 feet in stope length, and a foot in width. The ore shoots were localized by structural features that provided open spaces for the deposition of uranium. In the Fall River area, the known deposits occur where a quartz- and garnet-rich lime silicate gneiss forms the wall rock; possibly these deposits owe their location to a chemical control.

Genesis of the uranium

The uranium at Central City is believed to have been derived from local, relatively shallow sources; the pyritic and base-metal mineralization, on the other hand, is thought to have been derived from a common deep-seated source, the apex of which was beneath the pyritic core of the zoned district. The most probable source for the uranium was quartz bostonite magma. Because the sources of the uranium ore were asymmetrically located relative to the concentric zonal arrangement of the pyritic base-metal ores, the uranium deposits are not spatially related to the district-wide mineral zoning pattern. The deposits south of Lawson, as the Joe Reynolds and perhaps other mines, are thought to have been derived also from a quartz bontonite source, for the suite of trace elements in these pitchblendes closely resembles that from the Central City pitchblende. Possibly the deposits in Fall River, characterized by a different trace-element suite, were derived from a different source magma.

A paper, "Pitchblende deposits of the Central City and adjoining areas, Gilpin and Clear Creek Counties, Colorado", by P. K. Sims and E. W. Tooker, was published in the Proceedings of the United Nations International Conference on the Peaceful Uses of Atomic Energy.

A radioactive copper-bearing shear zone in the vicinity of the F. M. D. mine, Jefferson County, Colorado

by

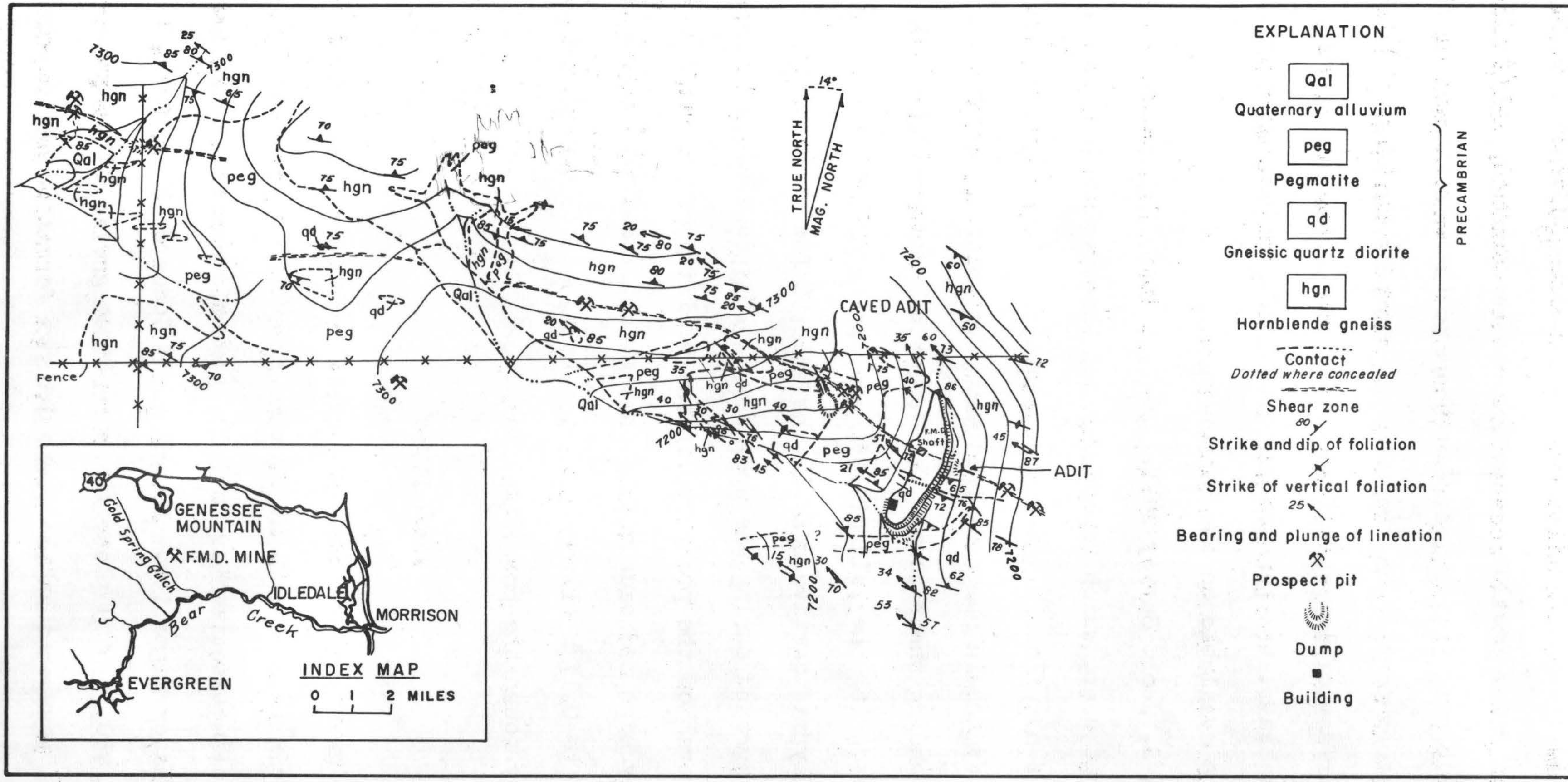
P. K. Theobald and R. R. Guilinger

The F. M. D. mine is at an altitude of 7,200 feet on the east flank of the Front Range in the NW 1/4 sec. 25, T. 4 S., R. 71 W., Jefferson County, Colorado. The mine is on a tributary to Cold Spring Gulch, which joins Bear Creek 1 mile southeast of the mine and 4-1/2 miles west of Morrison, Colorado. U. S. Highway 40 and graded dirt roads provide access to Genessee Mountain, 1-1/2 miles north of the mine, and logging trails lead from there to the western part of the mapped area. In the western part of and north of the mapped area (fig. 41) the streams originate on a surface of low relief where outcrops are poor. Within a short distance of their heads, the streams are intrenched, and nearly continuous bed-rock exposures are available on the canyon walls.

Lindgren (U. S. Geol. Survey Bull. 340-B, p. 168-169), describes the mine as a shaft 350 feet deep, which reportedly cut three veins of copper-bearing ore. The shaft is now flooded and inaccessible, but copper minerals are abundant in two nearby adits and in numerous prospect pits which follow the trace of a west-northwest-trending shear zone. The Geological Survey's plane-table mapping of the shear zone during the fall of 1954 and spring of 1955 was prompted by reports of a highly radioactive zone in the adit 90 feet east of the shaft. Radioactivity background during the spring was 0.015 to 0.025 milliroentgens per hour, and several of the prospects in the vicinity of the shaft were found to have abnormally high radioactivity. In the fall, however, background had increased to 0.07 to 0.17 milliroentgens per hour, effectively masking abnormally high radioactivity found the preceding year.

Rock types

Precambrian igneous and metamorphic rocks underlie most of the Front Range. In the vicinity of the F. M. D. mine these are represented by hornblende gneiss, probably of metasedimentary origin, gneissic quartz diorite and related pegmatite, and a later pegmatite. Lovering and Goddard (U. S. Geol. Survey Prof. Paper 223, 1950, p. 67) place the hornblende gneiss in the younger part of their sequence, younger than the Idaho Springs formation and possibly in the



Geology and topography by P.K. Theobald, 1955

FIGURE 41.-GEOLOGIC MAP OF A COPPER-BEARING SHEAR ZONE, JEFFERSON COUNTY, COLORADO

0 500 1000 Feet

Contour interval 20 feet
Datum is approximate mean sea level

Swandyke hornblende gneiss. Boos (Geol. Soc. America Bull., 1954, v. 65, no. 2, p. 168-170) maps the quartz diorite as Mount Morrison orthogneiss, migmatite, and injection gneiss. Following Boos' classification the pegmatites would be related to the Mount Morrison gneiss and the Silver Plume granite.

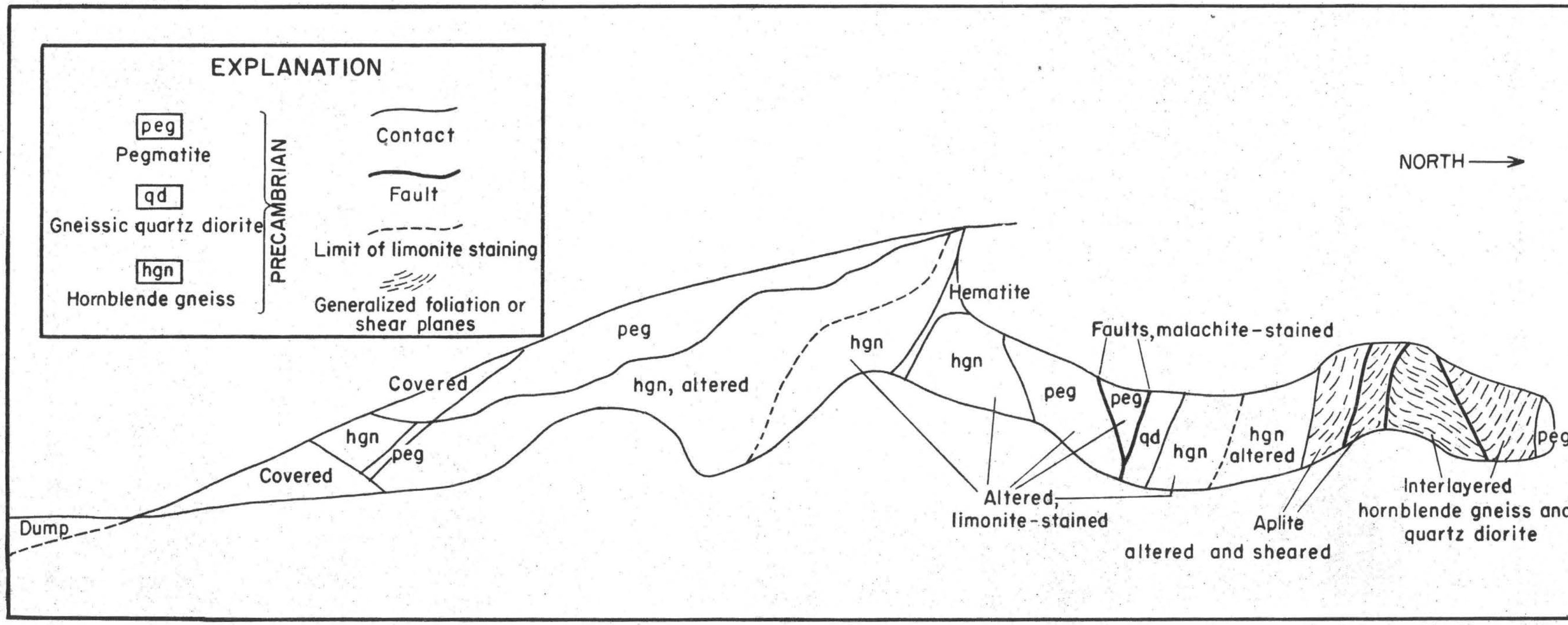
Most of the area north of the copper-bearing shear zone of figure 41 is underlain by fine-grained, granular, well-foliated to massive hornblende gneiss. The hornblende gneiss is composed of about 65 percent hornblende and 35 percent andesine with accessory magnetite, apatite, biotite, calcite, and allanite. Gneissic banding is common, formed by alternate hornblende- and andesite-rich layers 2 to 10 millimeters thick. Numerous oriented hornblende metacrysts occur in the hornblende-rich layers. Near contacts with biotite gneiss, quartz and biotite become more common, and hornblende appears to be replaced by plagioclase. Coarse biotite clusters separate the hornblende gneiss from pegmatite. Adjacent to the shear zone, the hornblende gneiss is altered to a limonitic chlorite-sericite-clay rock; most of the copper minerals occur in this rock.

In the southeast corner of the mapped area gneissic quartz diorite is the most common rock. The general aspect of the rock here is that of a migmatite, with interlayered fine-grained biotite schist, medium- to coarse-grained pegmatite, and scattered layers of hornblende gneiss. A thin section of mixed schist and pegmatite contains 52 percent quartz, 35 percent oligoclase, 7 percent microcline, 6 percent biotite, and accessory zircon, apatite, albite, and orthoclase. This, however, is not the average composition of the biotite gneiss, which in the central part of the mapped area is more uniform, less well foliated, and in tabular crosscutting bodies. The weak foliation is parallel to the contacts of these bodies, and distinctly different from that in the enclosing hornblende gneiss. The caracteristics of the rock are those of an igneous, quartz-rich diorite containing 39 percent oligoclase, 22 percent quartz, 13 percent microcline, 13 percent biotite, 10 percent hornblende, 2 percent monazite, 1 percent apatite, and a trace of zircon.

Both the hornblende gneiss and quartz diorite are intruded by pegmatites. A white quartz-albite-microcline pegmatite is mixed with the quartz diorite to form a migmatite in the southeast part of the mapped area and is probably genetically related to the quartz diorite. This pegmatite is parallel to the foliation of the quartz diorite and grades into the quartz diorite. A pegmatite of similar composition--though coarser, commonly with perthitic and graphic feldspar, and well foliated--occurs along the shear zone and as the west-trending dike that passes through the caved adit shown on figure 42. This dike and the others shown on the map are principally of a later, coarse-grained pink quartz-microcline pegmatite. This pegmatite intrudes all of the other rocks, but is most common in the well-jointed hornblende gneiss. Most of the pegmatites follow joints or faults, and the large mass of pegmatite in the western part of the area is apparently at the junction of the copper-bearing shear zone with a northerly-trending fault that offsets the shear zone. Reactivation of the copper-bearing shear zone is evident in the sheared and kaolinized pegmatites that cross or were emplaced along it.

Structure

Foliation and linear trends are shown on figure 41. The dip of the foliation is steep, ranging from 65° N. to 65° S., and the strike is generally N. 55° to 70° W. Just east of the large pegmatite in the western part of the mapped area, the foliation has a more westerly trend, N. 75° to 85° W., and in the dike-like bodies of quartz diorite the foliation has a more northerly trend, N 35° to 50° W. The linear features--minor fold axes, crenulations on foliation



Geology by P. K. Theobald, 1955

FIGURE 42—GEOLOGIC SECTION OF WEST WALL OF CAVED ADIT SHOWING COPPER-BEARING SHEAR ZONE, F.M.D. MINE, JEFFERSON COUNTY, COLORADO

0 10 20 Feet

planes, and aligned hornblende metacrysts--have consistent northwesterly bearings with a gentle plunge to the northwest.

Except for the major copper-bearing shear zone, faults are difficult to recognize. The large pegmatite in the western part of the area probably follows a major north-trending fault that offsets the copper-bearing shear zone. The more westerly trend of the foliation east of the pegmatite could then be explained as caused by a reverse drag fold. At least two faults with northerly trends can be recognized immediately west of the mapped area, and it is likely that the northerly-trending pegmatites east of the large pegmatite body were emplaced along minor, north-trending faults. The pegmatite that trends westerly from the north end of the dump of the F. M. D. shaft through the caved adit is sheared through most of its length, and the copper-bearing shear zone is slightly offset where it crosses this pegmatite. Several faults are evident along this trend in the caved adit (fig. 42), though these may be a part of the copper-bearing shear zone.

Results of 200 measurements of joint planes are summarized on figure 43. Although insufficient data are available for a precise joint analysis, it is worth noting that the north-northwest-trending, west-dipping joints and the west-northwest-trending, south-dipping joints commonly are lined by white albite-microcline-quartz pegmatite. The latter joints are parallel to a group of faults that cut this pegmatite. Pink microcline-quartz pegmatite is common along northeasterly-trending, south-dipping joints and west-northwest-trending, south-dipping joints.

Copper-bearing shear zone

The feature of major interest in the area is the west-northwest-trending shear zone with its associated alteration, copper minerals, and radioactivity. The zone is shown on figure 41 and in more detail on figure 42. It probably

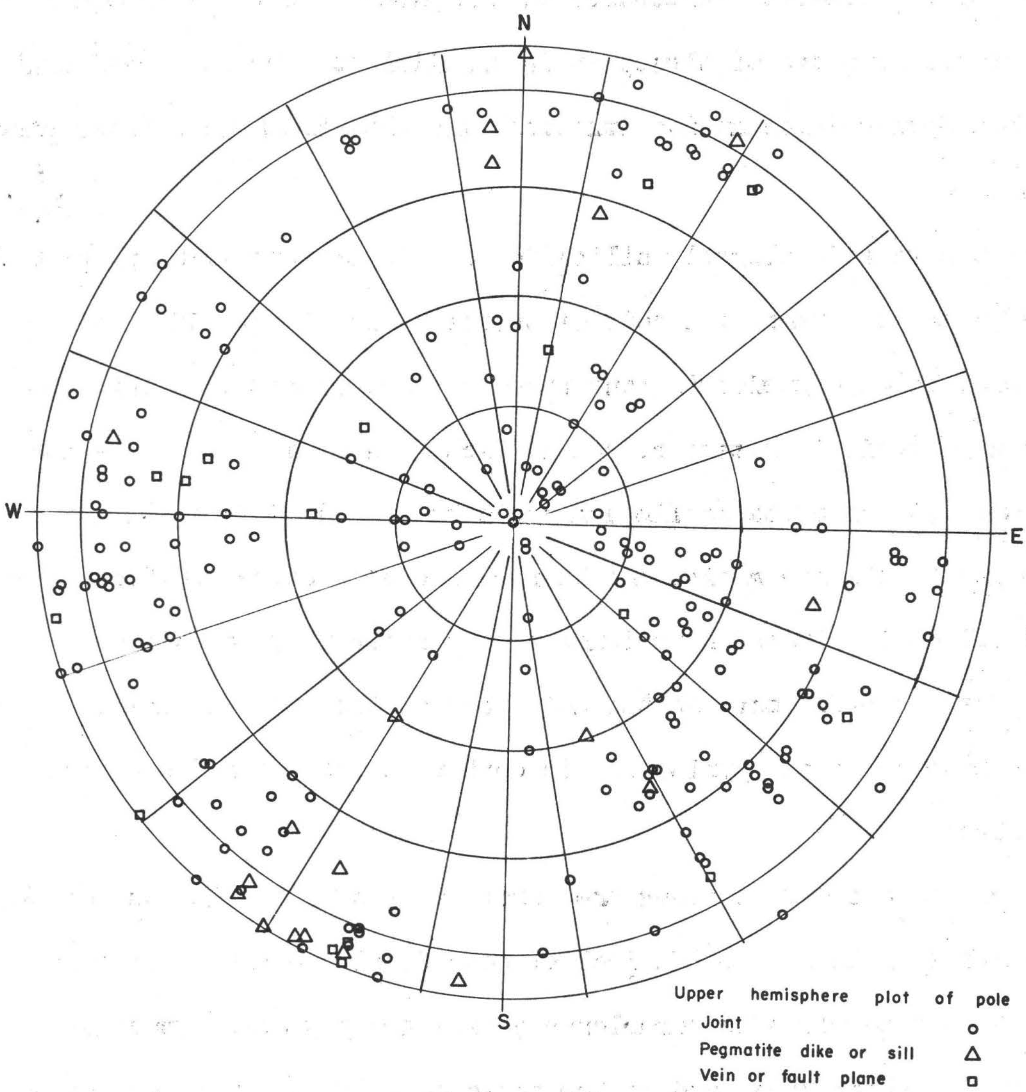


FIGURE 43

SCHMIDT NET PLOT OF JOINTS, PEGMATITES, VEINS, AND FAULT PLANES NEAR THE F. M. D. MINE, JEFFERSON COUNTY, COLORADO is one of the breccia-reef structures in the mineral belt. Although it has not been traced into one of these, it is parallel to a breccia reef that crosses Cold Spring Gulch at its junction with the stream that flows past the mine.

The shear zone is slightly silicified and in the west-central part of the mapped area is marked by a vein of quartz-garnet rock. Adjacent to the shear zone, hornblende gneiss is converted to clay, chlorite, biotite, and sericite; and within it masses of coarse biotite are common. Pegmatite minerals were converted to kaolin and sericite in and adjacent to the zone. In places the hornblende gneiss has been replaced by copper sulfides, pyrite, and biotite. (This altered hornblende gneiss apparently was the chief source of ore.) One cross-fracture in the adit east of the shaft is filled with manganese oxide and chalcopyrite and is coated on the exposed surface with copper sulfate.

Iron oxides are common along the zone; walls of the adit east of the shaft are coated with 1/8 to 1/4 inch of botryoidal limonite. Limonite staining is most abundant in hornblende gneiss and pegmatite immediately adjacent to the shear zone, and in the caved adit (fig. 42) a hard hematite vein crosses the altered hornblende gneiss.

Most of these limonite-rich zones are radioactive, generally 3 to 10 times background, but reaching a maximum of 100 times background in the back of the adit east of the shaft. Three samples of radioactive, limonite-stained, altered pegmatite from the shear zone, analyzed by the Survey's Denver laboratory, contained the following:

Sample location	Equivalent uranium (percent)	Uranium (percent)	Copper (percent)
Caved adit	0.019	0.007	0.32
Prospect 250 feet east of caved adit	.021	.019	1.79
Adit east of F. M. D. mine	.21	.028	.27

Radiochemical analysis by J. N. Rosholt, Denver Laboratories, U. S. Geological Survey, of the sample from the adit east of the shaft shows:

Isotope	Percent equivalent
Th^{230}	0.14
Pa^{231}	.30
Ra^{226}	.30
Rn^{226}	.33
Pb^{210}	.29

The disequilibrium of uranium with its daughter products probably indicates leaching of uranium from these shallow exposures.

Relative ages

The oldest rock in the vicinity of the F. M. D. mine is the hornblende gneiss. This rock probably was metamorphosed and had well developed joints before intrusion of the quartz diorite, because the quartz diorite is generally less well foliated than the hornblende gneiss, is in places quite poorly foliated or has a foliation that cuts across the foliation of the hornblende gneiss, and is emplaced in regular, dike-like masses in the hornblende gneiss. The copper-bearing shear zone developed shortly after or during the later stages of intrusion of the quartz diorite, and pegmatite related to the quartz diorite was emplaced along the shear zone and along a west-trending fracture. The shear zone and west-trending fracture were active after emplacement of this pegmatite, shearing and foliating the pegmatite before intrusion of the pink microcline-quartz pegmatite along these and other fractures. A third period of activity along the shear zone was associated with the introduction of copper and possibly uranium minerals along fractures opened in hornblende gneiss and in both generations of pegmatite. This last activity may have occurred during the Laramide orogeny; earlier activity was probably during the Precambrian. This suggests that some of the breccia reef structures, generally considered to be Laramide, may have originated in the Precambrian and were reactivated during the Laramide orogeny.

Economic potential

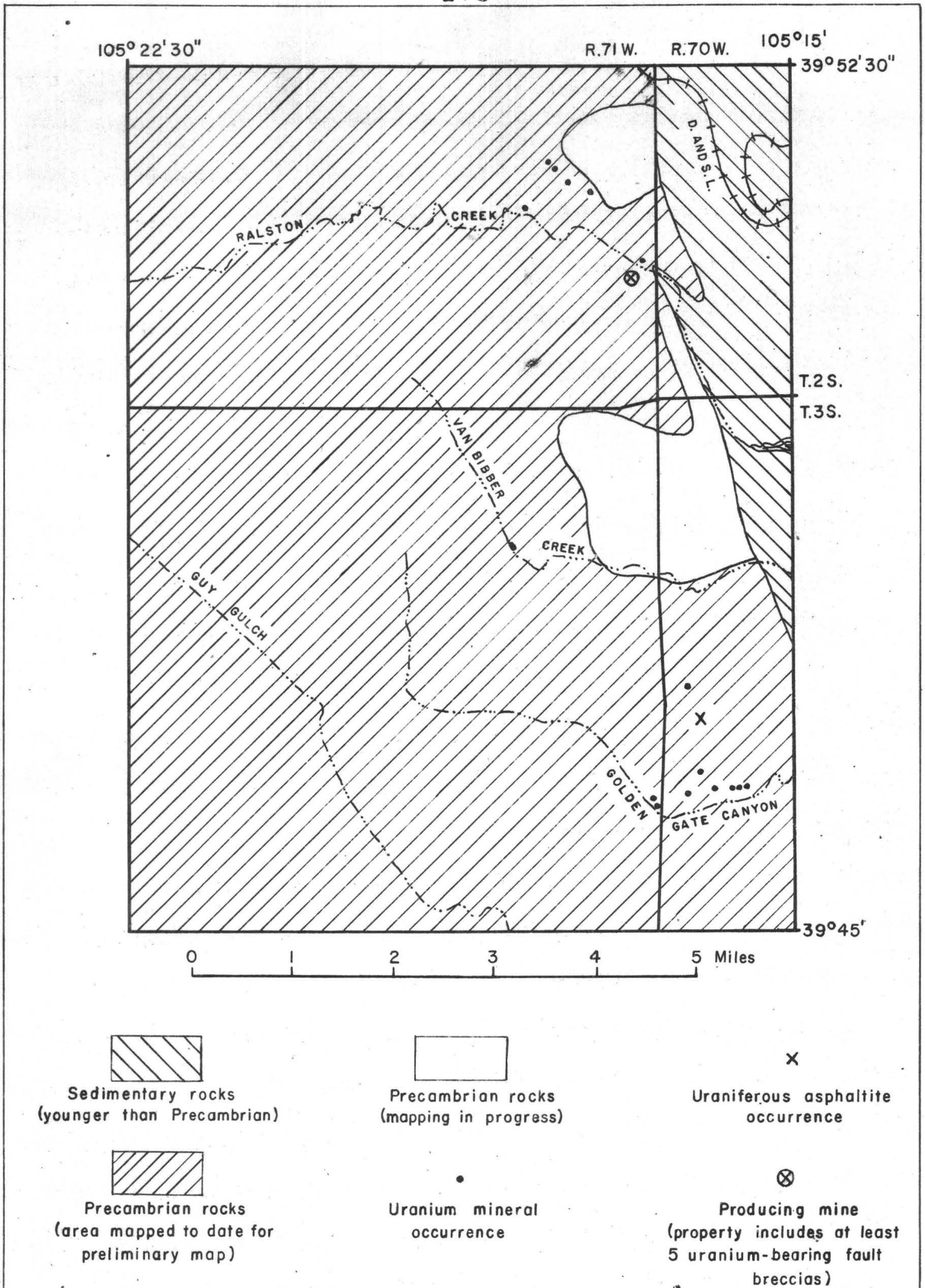
The F. M. D. mine is significant as another uranium-bearing locality along a northwesterly-trending, copper-bearing fault zone cutting hornblende gneiss in the Front Range area of Colorado. Uranium distribution along the shear zone is spotty, and the radioactive zones are generally low in grade. Although the grade probably increases where equilibrium conditions are reached below the zone of weathering, it is not likely that commercial deposits of large size will be found.

Ralston Buttes district, Colorado

by

D. M. Sheridan

Significant deposits of uranium occur in the Ralston Buttes district, Jefferson County, Colorado. Most of the deposits are pitchblende-bearing fault breccias of probable Tertiary age. The Ralston Creek mine in the northeastern part of the district (fig. 44) is continuing to produce pitchblende



November 1955

FIGURE 44 — INDEX MAP OF RALSTON BUTTES QUADRANGLE, JEFFERSON COUNTY, COLORADO

ore and is the major uranium producer on the eastern slope of the Colorado Front Range. Mining activity at the Ralston Creek mine has been conducted along three major ore shoots, but at least two other ore structures, as yet undeveloped, are known in the mine area. Elsewhere in the district geologic exploration has been conducted by at least seven private individuals and companies. This work includes systematic surveys with scintillation detectors, bulldozer trenching along numerous anomalies, core-drilling, and exploratory mining.

During the report period the following work was done by the Survey:

(1) Areal mapping:--Thirty square miles of the Precambrian portion of the quadrangle were mapped at a scale of 1:20,000. The mapping included tracing of Tertiary fault breccias and branching fault structures over a total length of 176,000 feet. A total of 95 percent of the Precambrian terrain has been mapped as a scale of 1:20,000, and mapping of the remaining 5 percent of the Precambrian area is in progress. The mapping emphasizes major structural, lithologic, and economic features.

The area of sedimentary rocks younger than the Precambrian in the northeastern part of the quadrangle is being mapped as part of the Geological Survey's Engineering Geology program.

(2) Detailed mapping:--Triangulation has been completed in the vicinity of the producing mine - the Ralston Creek (Schwartzwalder) mine. Plane-table mapping of 0.15 square mile in this mine area at a scale of 1:1,200 is in progress. Detailed studies have also been started in several areas of recent exploratory activity, including detailed logging and lithologic sampling of a private company's diamond drill-hole, 1,963 feet in depth, and mineralogic studies at several uraniferous exposures.

(3) Radioactivity surveys:--Systematic radioactivity surveys have been completed in about 85 percent of the Precambrian part of the quadrangle. The data are being correlated with major geologic features on enlarged base maps (scale 1:7,200). During the report period a total of 1,047 radioactivity readings were taken on traverses along most of the Tertiary fault structures and on traverses across Precambrian country rock between known faults. Whereas the normal background reading ranges from 0.010 to 0.025 mr/hr, a total of 110 anomalous readings along Tertiary faults ranged from 0.030 to over 1.0 mr/hr. Presumably this radioactivity is caused by the presence of uranium or its daughter products. Sampling of some of these radioactive areas along faults is now in progress. A total of 59 anomalies in the country rock had readings ranging from 0.030 to 0.1 mr/hr. Most of these anomalies are caused by Precambrian pegmatites containing monazite, zircon, or rare-earth minerals, but some are caused by radioactive Tertiary dike rocks.

As mapping and exploration have progressed in the district is has become increasingly evident that the localization of most of the pitchblende deposits has been controlled by structure and favorable host rocks. Most of the significant pitchblende deposits in the district are in or near carbonate-bearing fault-breccias of probable Tertiary age. Furthermore, most of these known deposits are located where the faults cut Precambrian rock units rich in hornblende, biotite, or lime silicate minerals. For example, the only producing mine (Schwartzwalder) is located where a group of faults cuts a zone of garnetiferous biotite-rich gneiss. The zone of garnetiferous rock marks the gradational contact between two major Precambrian rock units--a unit of schist and a unit of lime silicate gneiss and amphibolite. Two of the more promising recent discoveries in the Golden Gate Canyon area are also located along faults or fractures that cut this same type of lithologic contact.

Other pitchblende deposits in the district are localized where faults cut Precambrian layers of amphibolite or biotite-rich gneiss. One deposit of secondary uranium minerals is located in fractures in Precambrian pegmatite.

On the index map (fig. 44) two major groups of uranium deposits are indicated--one group along Ralston Creek and the other in the Golden Gate Canyon area. Trending northwest from each of these uraniferous areas are prominent fault systems which extend for miles across the Front Range Mineral Belt. Whereas the patterns formed by these faults appear to be relatively simple in areas barren of uranium deposits, in the two uraniferous areas the southeastward extensions of these fault systems seem to have split into wider and more complex zones containing numerous small faults.

Detailed study by C. H. Maxwell of one of the mineralized fault breccias, exposed by recent exploration in the Golden Gate Canyon area, disclosed an occurrence of uraniferous asphaltite. Other minerals in this deposit include pitchblende, rhodochrosite, galena, sphalerite, chalcopyrite, pyrite, marcasite, and thucholite(?). Spectrographic analyses also disclosed the presence of anomalous amounts of cobalt and molybdenum. The asphaltite occurrence is interesting from a genetic standpoint because an oil seep from Precambrian rocks also occurs in the Golden Gate Canyon area. A westward-dipping thrust fault crops out to the east of the quadrangle. Presumably, Pennsylvanian and younger sedimentary formations have been thrust under Precambrian rocks. The oil seep and the asphaltic material in the mineralized breccia may have a common origin in petroliferous material coming from the underlying sedimentary thrust block.

A paper, "Wall-rock control of certain pitchblende deposits in the Golden Gate Canyon, Jefferson County, Colorado", by J. W. Adams and Frederick Stugard, Jr., was published in the Proceedings of the United Nations International Conference on the Peaceful Uses of Atomic Energy.

Thomas and Dugway Ranges, Utah

by

M. H. Staatz

The Thomas and Dugway Ranges are in central Juab and Tooele Counties, Utah, in the Basin and Range Province. The Thomas Range consists of three distinct geologic units: (1) the main eastern part consisting almost entirely of Tertiary rhyolites and tuffs, (2) a western part (Spor Mountain) consisting of highly faulted Ordovician to Devonian quartzite, dolomite, and limestone, and (3) a northwestern part consisting of upper Devonian sediments and basic volcanics. The Dugway Range, which adjoins the Thomas Range on the north, is a distinct topographic unit formed by Paleozoic sediments ranging in age from Cambrian to Mississippian, which in the southern part are overlain by Tertiary volcanics. The topography of the Thomas and Dugway Ranges is shown on the Dugway Range and the northern one-third of the Topaz Mountain 15-minute quadrangles.

Uranium has been found in fluorspar pipes and veins on Spor Mountain and at several places in the volcanic rocks. The Spor Mountain area has been previously described in Geological Survey Bulletin 1005, "Fluorspar deposits of Utah", by W. R. Thurston and others (1954). The aims of the present work are (1) study of the known uranium deposits in the sedimentary and volcanic rocks, (2) study of the volcanic rocks themselves, as all the uranium is believed to have been derived from the magma which formed these rocks, and (3) study of carbonate rocks adjacent to the volcanic rocks, in order to evaluate the possibility of finding other uraniferous fluorspar deposits.

During the report period about 70 square miles were mapped on a scale of 1:24,000, to complete the mapping of the Thomas Range, and 8.5 square miles of Tertiary volcanics in the Dugway Range were mapped. A detailed plane-table map on the scale of one inch to 100 feet was made of the Goodwill uranium property.

Areal mapping shows that the volcanic rocks are divided into an older sequence consisting of porphyritic rhyolite, welded tuff, crystal tuff, and latite, and a younger series consisting of tuff or agglomerate, obsidian, and a topaz-bearing rhyolite. These two series are separated by a pronounced unconformity. The rocks of the younger series were formed by a number of extrusions, which repeated the same sequence of tuff, obsidian, and rhyolite. All the volcanic rocks have a high background count on a Geiger counter. Several analyses have been made of the rhyolite; the highest shows a uranium content of 0.009 percent.

Several areas of abnormal radioactivity have been found in the younger volcanics. These areas are found along hyalite-coated shear zones, with or without the presence of small amounts of fluorite and calcite. The low counter readings and the narrowness of the shear zones suggest that these deposits are of little economic value.

The largest uranium deposit associated with the volcanic rocks is the Goodwill, which is located along a wide shallow valley on the west side of the main volcanic mass. This deposit is a replacement in a lens of friable sandstone and conglomerate lying between two tuffs in the older series of volcanic rocks. Exposures are extremely poor, and it was not until extensive bulldozing began in October that it was possible to determine some of the geologic relationships. Economically significant deposits are found in two places on the Goodwill claims. The best known one is on the west side of the valley where a series of clastic rocks unconformably overlies a compacted crystal tuff. Starting at the base of the section on the valley bottom, these rocks are sandstone, conglomerate, and tuff. The sandstone is a friable rock with coarse rounded grains of clear quartz and dark volcanic material. In some places a matrix of fine-grained white ashy material is present. This unit has a minimum thickness of 40 feet and is overlain by a coarse 1- to 6-foot-thick conglomerate, which lies on an irregular erosion surface on the sandstone. The conglomerate has pebbles, cobbles, and boulders of rounded pink limestone and latite in a matrix of green fine-grained and commonly ashy clay. Overlying the conglomerate is a white fine-grained tuff which commonly weathers to a clay.

The first uranium found occurs as a replacement of the limestone cobbles by an unnamed uranium silicate similar in composition to uranophane. Pebbles from this conglomerate were found scattered along a strike length of 950 feet. The uranium in the conglomerate, however, is spotty and of little economic significance. The major uranium minerals occur in the underlying sandstone. The chief uranium mineral appears to be beta-uranophane; some schroeckingerite has also been found. Small amounts of uranium occur scattered at various places in the sandstone, but the chief deposit is in an area of about 70 feet long by at least 50 feet wide. The owners report finding ore in a drill hole 60 feet below the surface. The outline of the ore body is not readily visible and must be determined by counter measurements. A yellowish clay, interstitial to the sand grains, is present in some places, and gives the appearance of rich uranium ores. Four samples taken from this deposit contains from 0.021 to 0.65 percent uranium. A 30-foot channel sample across the center of the deposit contains 0.51 percent uranium.

The second area of economic significance at the Goodwill lies 1,000 feet south of the first on the opposite side of the valley. The stratigraphic sequence here is similar to that at the first deposit. The sandstone here, however, is only about 20 feet thick. It is underlain by a friable crystal tuff similar to the sandstone but having a dense matrix of fine white ashy material. It is believed that the tuff is a relatively unfavorable host rock for economically significant uranium deposits because of its low porosity. The beds at this deposit strike at an angle of 83 degrees from those on the west side of the valley. This change in strike most likely results from folding or initial dip, although the possibility of faulting cannot be ruled out. Here too the uranium occurs in the sandstone underlying the conglomerate. Exposures are poor but suggest that the strongly mineralized area does not exceed 50 feet in length and 15 feet in width. Geiger counter readings suggest that the grade of ore will be three-quarters to one-half of that found at the deposit on the opposite side of the valley.

A paper entitled "Uranium in the fluorspar deposits of the Thomas Range, Utah", by M. H. Staatz and F. W. Osterwald, was published in the Proceedings of the United Nations International Conference on the Peaceful Uses of Atomic Energy.

Jarbidge, Nevada-Idaho

by

R. R. Coats

During the report period, work on the Jarbidge project, Nevada-Idaho, was principally geologic mapping of the Jarbidge 15-minute quadrangle, but including some field study of the distribution of radioactivity in the rhyolitic rocks, and collecting of samples for laboratory study.

Approximately two-thirds of the quadrangle is now mapped. About 70 square miles was completed in the summer. About 9 square miles were mapped on a scale of 1:24,000; the rest, on a scale of 1:48,000. Mapping has found two formations unconformably underlying the oldest rhyolite in the area and has permitted the subdivision of this rhyolite.

Field study has shown only minor variations in the radioactivity of the younger rhyolite, but laboratory study has shown variations as great as five-fold in the amount of uranium present in the glassy phases of successive welded tuff flows. The uranium content of spherulites developed in these glassy phases seems to be much more consistent.

The amount of uranium in the glassy rocks ranges from 0.0005 to 0.0025 percent and the amount of fluorine from 0.066 to 0.105 percent. This is three to nine times as much fluorine as the spherulites that have crystallized out from the glasses contain. No spherulites in the younger rhyolite seem to have more than about 0.001 percent uranium and 0.029 percent fluorine. This tends to support the good correlation between uranium and fluorine found in many parts of the west.

The apparent loss of uranium from the spherulites, or its exclusion from them during their crystallization, suggests that the uranium is, to a considerable extent, contained in the glass rather than in the accessories, such as zircon, that are found in both glassy phase and spherulitic phase.

In the older rhyolite, the maximum amounts of fluorine are comparable to those in the younger rhyolite, but the amounts of uranium seem to be lower. This conclusion is quite tentative, because rocks suitable for sampling and analysis are hard to find.

Results of spectrographic analysis for other trace elements have not been received.

A summary of the work done through fiscal year 1955 is included in "Distribution of uranium and certain other trace elements in felsic volcanic rocks of Cenozoic age of the western United States", by R. R. Coats, published in the Proceedings of the United Nations International Conference on the Peaceful Uses of Atomic Energy.

Boulder Batholith, Montana

by

G. E. Becraft

In and adjacent to the Boulder batholith geologic mapping of about three 7-1/2 minute quadrangles at a scale of 1:24,000 was completed during the report period. A radioactivity anomaly was detected along a silicified fault zone in remnants of pre-batholithic volcanic rocks less than 100 feet above the roof of the batholith, at the top of Iron Mountain in sec. 5, T. 6 N., R. 6 W. Though more than 100 anomalies have been detected in veins and fault zones in the batholith, only two have been found in veins and fault zones in pre-batholithic rocks. The strong preponderance of concentrations of uranium in structures that cut batholithic rocks suggests that these rocks are more favorable hosts than pre-batholithic rocks. If this is true, there is a good possibility that the Iron Mountain vein may be considerably higher in grade where it cuts the batholithic rocks below the contact. This vein is well suited to test this hypothesis, for it is a strong structure that almost certainly cuts batholithic rocks at shallow depth.

A field study of the uranium deposits in tuffaceous Tertiary sedimentary rocks in the Townsend and Helena Valleys, Montana, shows that uranium-bearing carbonaceous shale and lignite beds are exposed in several areas in the two valleys. The greatest number of exposures are in an area of several square miles northeast of Winston in the Townsend Valley. The uranium-bearing beds are in the lower part of a thick sequence of Oligocene sedimentary rocks (Tertiary unit 2 of Mertie, Fischer, and Hobbs, 1951, U. S. Geol. Survey Bull. 972) consisting largely of thin-bedded, white to buff, pure and impure tuffs, parts of which are altered to bentonite.

The uranium deposits, none of which appears to be of commercial size and grade, have several features in common: (1) they are in or adjacent to carbonaceous shale or lignite; (2) the shale is interbedded with light-gray or white, fine-grained tuffs and lapilli tuffs; (3) the stratigraphic section in the vicinity of the deposits includes bentonite and partly bentonized tuff; (4) the distribution of the uranium in the deposits is erratic. Many of the major valleys in western Montana contain similar Tertiary rocks and might profitably be prospected for uranium.

"Uranium deposits of the Boulder Batholith, Montana", by G. E. Becraft, was published in the Proceedings of the United Nations International Conference on the Peaceful Uses of Atomic Energy.

Stevens County, Washington

by

P. L. Weis

Field work during the report period included geologic mapping of approximately 30 square miles in the Turtle Lake quadrangle, which includes the Midnight mine on the Spokane Indian Reservation. Geologic reconnaissance has also been carried out in other parts of the quadrangle.

The work done to date shows that two phases of granite are present, which can be distinguished on the basis of texture, mineralogy, and radioactivity. Five of the six uranium deposits now known in the quadrangle occur at least in part in the granite with the higher radioactivity. The sixth is in sediments that are clearly younger than the granite. Faulting is associated with all of the uranium deposits, and may have been a factor in localizing the uranium. Reconnaissance suggests the possibility of a major fault trending approximately N. 45° W. along the Spokane River.

Three groups of soil samples taken across the ore body at the Midnight mine have been analyzed spectrographically. Interpretation of the analyses is incomplete, but a significant association of molybdenum and uranium can be recognized. Molybdenite is associated with uranium at the Midnight mine and also at the Spokane Molybdenum mine to the south.

Minerals thus far identified at the Midnight mine include autunite, uranophane, liebigite, phosphuranylite, metatorbernite, chalcopyrite, pyrite, molybdenite, and pitchblende. Pitchblende was found in one drill core from the property.

Reconnaissance along the north boundary of the Turtle Lake quadrangle shows that the metasedimentary rocks there are less metamorphosed than those farther south, where they are in closer proximity to the granites of the Loon Lake batholith. Structure can be worked out with assurance in these less metamorphosed sediments, and it appears likely that once structures are worked out to the north, they can be traced southward into more highly metamorphosed rocks. Inspection of the less metamorphosed facies of the sediments also shows that they bear a striking resemblance to Belt sediments known in the Coeur d'Alene district, Idaho, about 100 miles to the east.

Results of the work in Stevens County during the report period suggest that additional detailed mapping may contribute significant information on the origin and distribution of uranium and the geologic history of the area.

Spokane County, Washington

In connection with the mapping program in Stevens County, investigations have been made in the Mount Spokane area, Spokane County. The work included mineralogical and geochemical studies of selected samples of uranium minerals, drill cores, and surface waters. A comparison of radiometric and chemical analyses suggests that meta-autunite from the Daybreak mine in the Mount Spokane area is too old to be related to recent ground-water circulation. Analyses of surface waters show that unusual amounts of uranium can be found in surface water over an area of approximately 20 square miles. Some springs show very high percentages of uranium in solution. However, it has not yet been demonstrated that abnormal amounts of uranium in surface water are necessarily coincident with the occurrence of minable ore.

Kern River area, California

by

E. M. MacKevett

Field work in the Kern River uranium area consisted of geologic mapping of 30 square miles in the southern Sierra Nevada, Kern County, California, and detailed mapping of the Miracle and Kergon mines (fig. 45), the most promising uranium deposits within the area.

The area is underlain by Cretaceous (?) granitic rocks and pegmatites, except for a small septum of Late Paleozoic (?) Kernville series metasedimentary rocks in the southeast part. The granitic rocks megascopically appear to be mainly quartz diorite and granodiorite which intrude the Kernville series rocks. The granitic rocks were subdivided during field mapping into three units. Contacts between the units are gradational. Pegmatite dikes ranging from

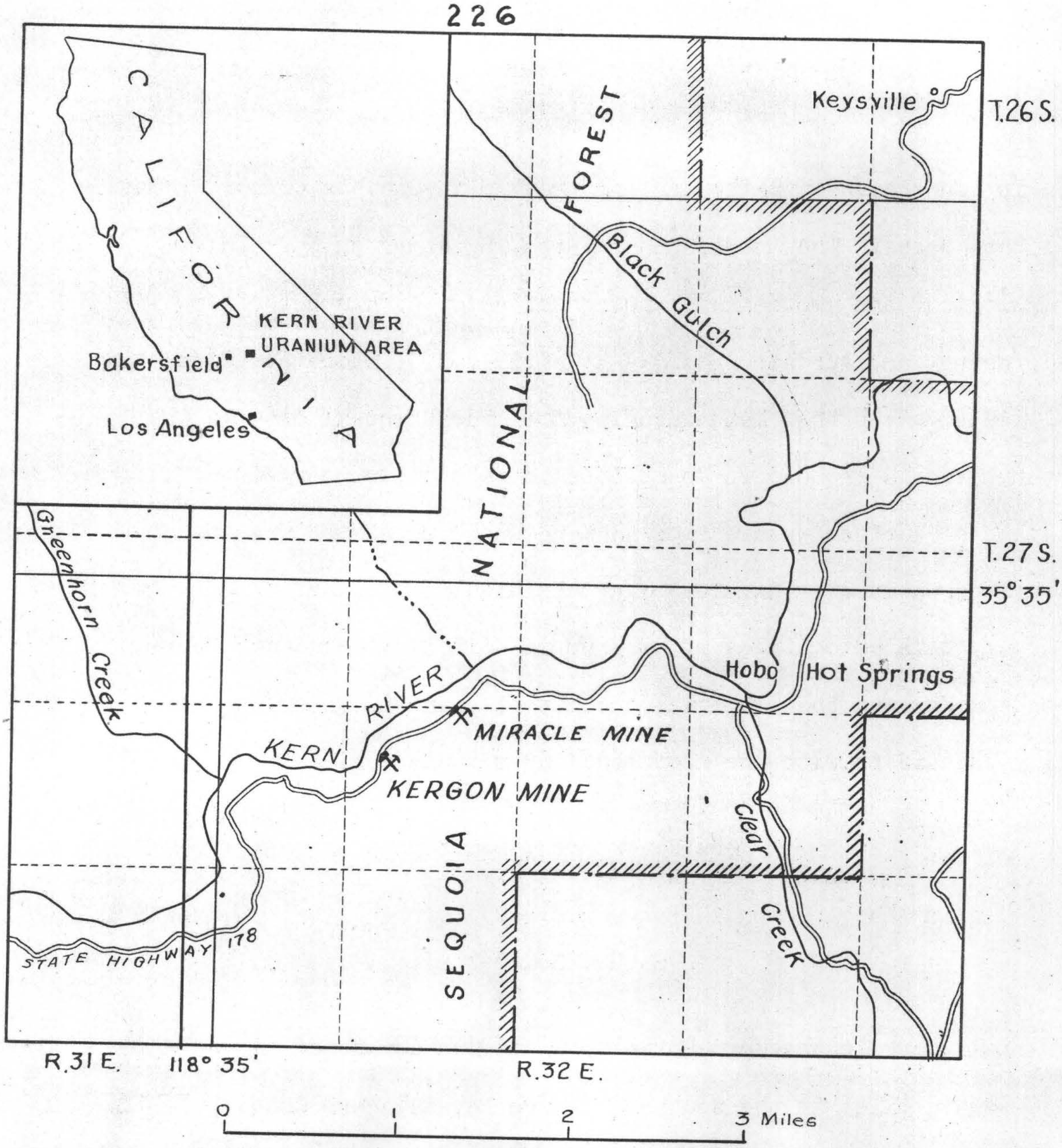


FIGURE 45.- INDEX MAP OF THE KERN RIVER URANIUM AREA, CALIFORNIA

a few inches to about 150 feet in thickness and from a few tens of feet to over a mile in strike length cut all the other rocks.

No major faults were found in the area although the northerly-trending Kern Canyon fault is a few miles to the east. Two sets of secondary fractures are well developed. One set strikes N. 50° to 80° E. and dips vertically or steeply southeast. The other set strikes N. 15° to 45° W. and dips nearly vertically. The fractures are mainly joints but regional tectonic forces caused movements on many of them as evidenced by slickensides, mullion structures, and offset dikes. Displacements appear to be mainly strike-slip; the largest measured component is right-lateral for 12 feet on the northwest-striking Miracle shear. Most of the discrete fractures cannot be definitely traced on the surface for more than a few hundred feet. Many of them apparently give way to en echelon fractures, or project into areas of poor outcrop.

Most of the known uranium occurrences are along the conjugate fractures, particularly along the northwest-striking set. Autunite, the dominant uranium mineral, is sporadically distributed in the iron-stained fractures as coating on gouge, altered granitic rock and pegmatite, and as veinlets cutting argillic material and altered granitic rock. Where the fractures cut pegmatites they commonly are tight and poor in uranium minerals. To date, exploration has not penetrated unoxidized parts of the fractures. Notable features of the deposits, with the exception of those at the Kergon mine, are the lack of common gangue minerals and the paucity of wall-rock alteration both in extent and intensity.

The Kergon deposits are, in several respects, unique for the area. They are on a 2-12 foot thick N. 26° E.-trending shear that dips 50° to 60° SE.--- a structure difficult to reconcile in the regional pattern. Limonitic and argillic alteration are locally conspicuous. The minerals associated with autunite include sooty pitchblende (Bowes, W. A., oral communication), fluorite, ilsemannite, and black carbonaceous (?) material, that have not been recognized in other uranium deposits in the district.

Numerous minor radioactivity anomalies were found throughout the area. These commonly emanate gamma rays at a rate 2 or 3 times that of the background count. Most anomalies are irregularly distributed along the conjugate fractures and probably manifest small, scattered, low-grade autunite deposits. One anomaly is probably due to thorium minerals in a biotite-rich inclusion within granitic rock. Other anomalies are caused by sparsely disseminated radioactive minerals in pegmatites.

Occurrence of uranium in veins and igneous rocks

by

G. J. Neuerburg

Studies primarily intended to explore the relation between petrographic character and the leachability of uranium from igneous rocks, were essentially completed. To date, 202 rocks have been analyzed in the fashion described in TEI-540. These rocks were chosen at random, as especially radioactive, and to determine the uranium contents of a variety of rocks not recorded in the literature. The distribution is: 22 Magnet Cove, Arkansas alkaline plutonic rocks; 68 anorthosites, noritic anorthosites, and titaniferous magnetite ores; 37 granitic rocks, including syenites, granites, granodiorites, pegmatites, aplites, migmatites and other gneissic granitic rocks; "igneous" and "metamorphic" charnockites; 2 cordierite gneisses; 17 amphibolites of diverse character and origin; 6 rhyolite flows and ashes; 1 basalt; 1 troctolite; 6 diabases; 1 calcalkaline diorite; 7 alkaline diorites; 9 spessaritite plutonic lamprophyres; and 16 "volcanic lamprophyres", including analcite basalt, monchiquite, minette, and trachybasalt.

Although not yet completely evaluated, the data accumulated on these specimens, with few exceptions, show no evidence of clear-cut relations of uranium content, uranium leachability, and/or rock solubility to petrographic character. In general, the sympathetic relation of uranium to silicon and potassium noted within many groups of genetically related igneous rocks does not prevail on comparisons of genetically unrelated and geographically widely separated rocks. The uranium content of each rock type, for which several samples were analyzed, varies appreciably, but is most commonly less than 3 to 4 grams per ton. The rhyolitic volcanics and the "volcanic lamprophyres" are the only two groups which show evidence of having most frequent values in excess of 4 grams per ton. Appraisal of the uranium contents of all samples according to freshness and extent of alteration **indicates** the possibility that metamorphosed and hydrothermally or deuterically altered rocks generally contain less uranium than their fresh, unaltered equivalents; the uranium content of weathered specimens varies widely and shows no consistent behavior. Chilled borders of otherwise undifferentiated spessartite (the rock type, not the garnet of the same name) and diabase intrusives contain slightly more uranium than their coarser equivalents from the central parts of the intrusives (see Dripping Spring quartzite, this volume).

With the possible exception of the rhyolitic rocks, which contain very little leachable uranium, the percent of uranium leached in laboratory procedures from all rocks appears to be of similar magnitude; amounts in excess of 40 percent leachable uranium are uncommon and the greatest number of samples yields 5 to 15 percent leachable uranium. Very few of the samples yield more than a few tenths of a gram per ton of uranium to the leach solution. Most samples yielding in excess of 40 percent leachable uranium are included among those rocks considered to be hydrothermally or deuterically altered.

There is slight indication that less uranium is leachable from the generally more weathered anorthosites of the San Gabriel Mountains, California, than from the less weathered anorthosites of the Laramie Range, Wyoming. Fifteen samples of granites and amphibolites from a drill core from the Front Range, ranging in depth from 34 to 1,135 feet, were analyzed and the results indicate that the percent of leachable uranium increases with depth, although no systematic relation between uranium and depth was noted. Suspicions of variable uranium content and uranium leachability in otherwise similar rocks were confirmed by analyses of several pairs of samples collected a few feet apart in uniform outcrops in the Laramie Range, Wyoming.

Thorium analyses were made of 48 samples. The results are of much the same character as the uranium results. The thorium-uranium ratios of rock, leached residue, and leachate (dissolved rock) proved to be random, ranging from less than 1 to more than 40, with a slight concentration of values below 3.0. Despite the remarkable spread and the presence of only ten Th/U ratios (out of 144) between 3 and 4, the average (mean) ratios for the total rock, the leached residue, and the leachate were all between 3 and 4.

Commonly, the leachate has a higher concentration (enrichment) of uranium and thorium than the leached residue and the rock as a whole. Except for the strongly alkaline rocks, where more commonly the leachate has a lower concentration (depletion) of uranium and thorium than the leached residue and total rock, the enrichment of uranium and thorium in the leachate shows no compelling correlation with the mineralogic composition of the rock. The proportion of total rock dissolved during leaching shows only crude relation to mineralogy, with two notable exceptions. Alkaline rocks yield 10 to 15 percent substance to solution in most cases, presumably due to the solution of nepheline, pyrite, and calcite. Granitic rocks yield uniformly less than 1.0 percent of their substance to solution. The other rocks yield from less than 1 percent to 7 percent in a random pattern. In view of the fair proportion of rock dissolved in all but one rock (syenite - 0.0025 percent), it is most unlikely that even large enrichments of uranium in the leachate can be defensibly construed as evidence for the occurrence of interstitial uranium. In one rock it is possible to assign all leached uranium to the proportion of dissolved apatite, the uranium content of which had been determined.

From the results so far obtained and evaluated, it is evident that the solubility of uranium in an igneous rock is a function of a complex series of geologic processes and events as well as of petrographic character, variables which require exploration before the possibility of using leachable uranium as a guide to ore can be intelligently assessed. Accordingly, these studies are now being oriented toward investigations of the effects of geologic processes on uranium solubility. For this purpose, samples to explore relations with depth and thus indirectly with weathering were obtained from Butte, Montana, and from the Laramie Range, Wyoming; samples to explore the effects of hydrothermal alteration of igneous rocks with and without accompanying sulfide mineralization were obtained from Montana and California; samples to study the effects of assimilation and to cast some light on the high uranium contents of "volcanic lamprophyres" were collected from Montana; and samples to further elucidate the chilled border effect on uranium contents will be collected shortly from Arizona. These studies and the analysis of a group of zeolites from near Golden, Colorado, collected to test the possibility of using zeolites to trace the movements of uraniferous solutions, are scheduled for completion during the next six months.

Continued testing of analytical procedures resulted in methods for completely dissolving 4- to 5-gram samples of rock crushed only to pass 20 mesh, thus obviating chances for error in splitting and pulverizing the residue from leaching. Attempts are now being made to increase the proportion of sample taken into the phosphor for fluorimetric determination in order to increase the fluorimetric readings and thus the sensitivity and accuracy of the analyses, especially in those rocks containing less than 1 gram per ton of uranium. As an analytical sidelight of these studies, the commonly appreciable enrichment of uranium in leachates provides a means for detecting uranium in rocks which themselves contain too small a concentration of uranium for direct determination. That this approach could be extended to other minor elements is indicated by the results of leaching studies made by Harrison Brown and his associates at California Institute of Technology.

Because sample splitting at the "coarse" grinds necessary for leaching experiments proved unreproducible, studies are currently being made to test the advisability and meaning of analyzing entire samples of rock weighing 4-5 grams (blocks approximately 1 cm^3), neglecting crushing and splitting, and relating the results only to the volume of rock actually analyzed.

A paper by G. J. Neuerburg titled "Uranium in igneous rocks of the United States of America", was published in the Proceedings of the United Nations International Conference on the Peaceful Uses of Atomic Energy.

URANIUM IN CARBONACEOUS ROCKS

Lignite investigations

Regional synthesis, eastern Montana and North and South Dakota

by

J. R. Gill and N. M. Denson

During the reporting period vertical controls were obtained on the pre-Oligocene erosion surface in southwestern North Dakota, northwestern South Dakota, and eastern Montana. The generalized map showing the present configuration of this surface (fig. 46), based on more than a thousand control points, relates the location and altitudes of the higher grade uranium occurrences to the pre-Oligocene erosion surface. All known occurrences are near this surface, which, therefore, is believed to have had a marked influence on the concentration of uranium.

The gently folded pre-Oligocene erosion surface in the area studied has a regional relief of about 2,000 feet and is characterized by an average slope of about 12 feet to the mile to the northeast. The erosion surface had a relief of about 100 feet locally. At many places the rocks beneath this surface are deeply or highly oxidized, and are readily recognizable by their pastel shades of red, yellow, and brown. Hard, dense quartzite, chert, ironstone, and other resistant rock debris are common lag constituents developed on the surface prior to deposition of the White River group. These features, inasmuch as they appear to indicate proximity to the pre-Oligocene erosion surface, are useful guides to uranium mineralization.

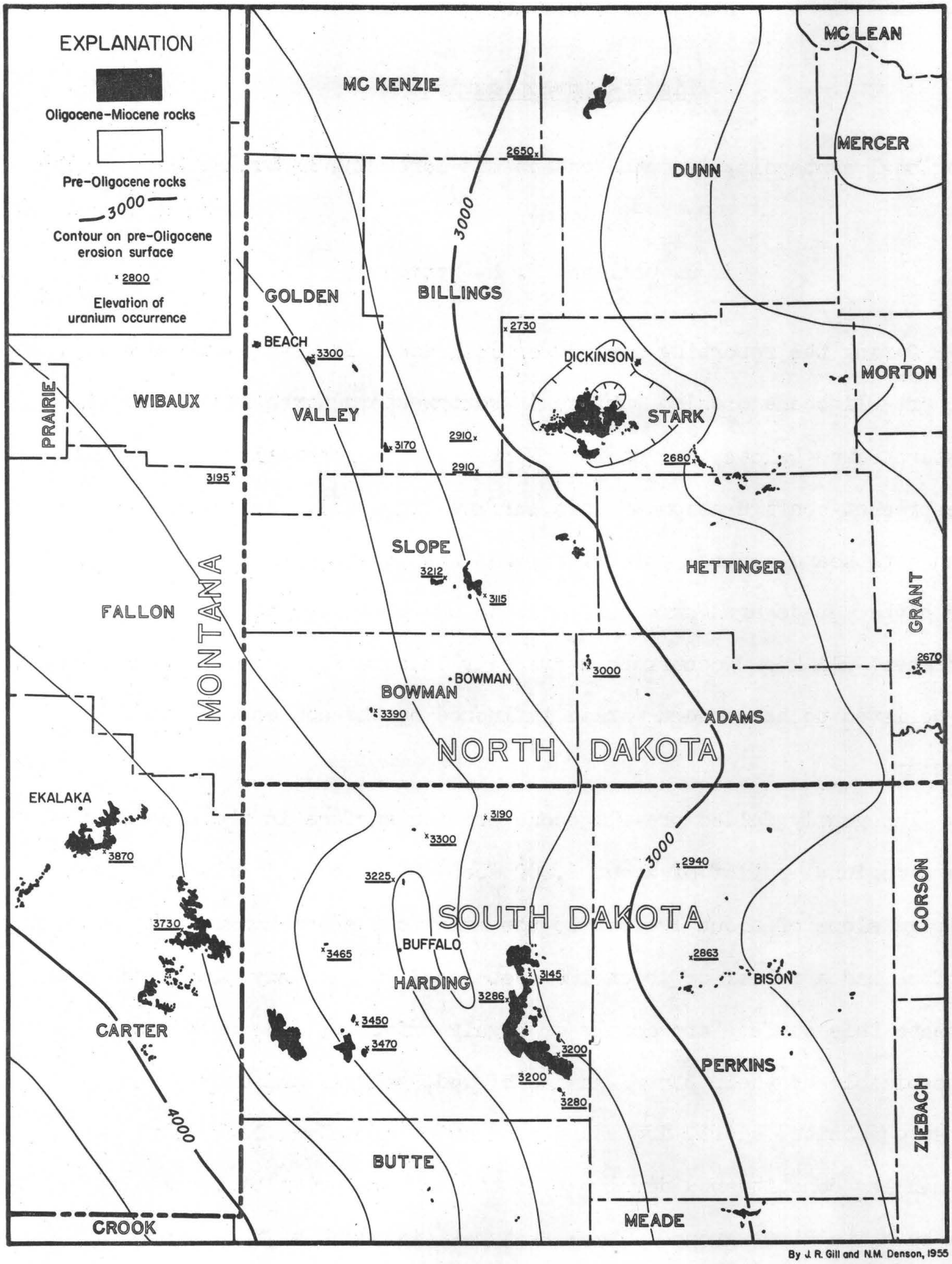


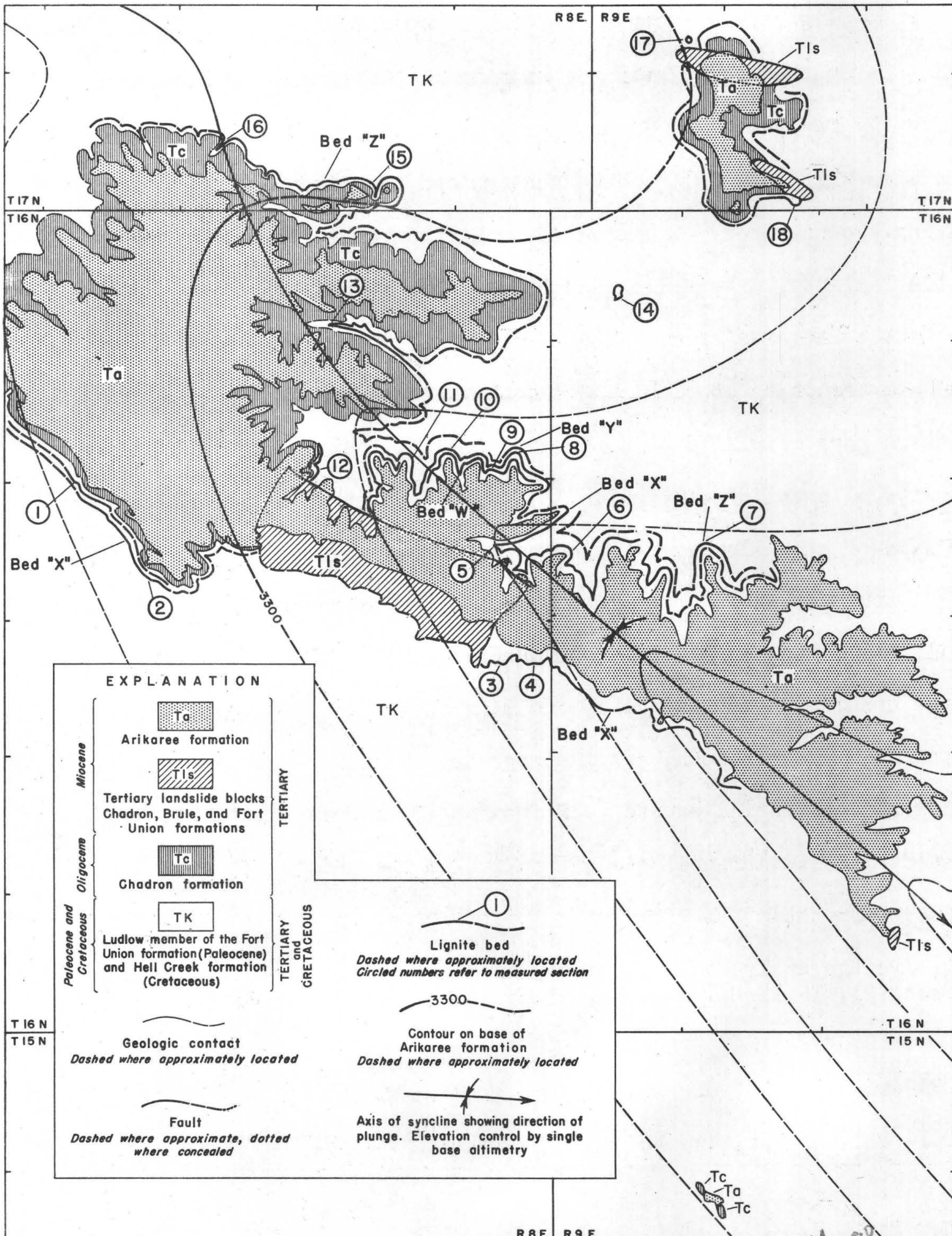
FIGURE 46 PRELIMINARY MAP SHOWING CONFIGURATION OF THE PRE-OLIGOCENE EROSION SURFACE IN EASTERN MONTANA AND THE DAKOTAS

Post-Oligocene structural features appear to have had a significant influence on the accumulation of uranium of ore grade. Structures apparently favorable for such concentration are flanks or troughs of synclines which are believed to have guided the circulation of mineralizing ground water. Examples of such structures are found in the Little Badlands, Cave Hills, and Slim Buttes areas. Along the axis of the Little Badlands syncline in Stark County, North Dakota uraniferous opal and carnotite in clay occur in the Chadron formation, while in the southern part of Slim Buttes, Harding County, South Dakota, significant deposits of uraniferous lignite in the Fort Union formation occur along the axis of a shallow post-Oligocene syncline (fig. 47).

A study of known uranium occurrences in the region reveals striking similarities and variations. Semiquantitative spectrographic analyses of the uranium-bearing lignite, and mineralogic and petrographic studies of potential source rock, are in progress. Results of rapid rock analysis of potential source rock from the Slim Buttes area are contrasted with similar analysis of rocks from the underlying Fort Union formation in table 11.

Table 11.--Average analyses, in percent, of samples from core hole SD-24, NW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 31, T. 18 N., R. 8 E., Slim Buttes, Harding County, S. Dak.

Constituent	Tuffaceous sandstone, Arikaree formation (10 samples)	Sandstone from Fort Union formation (3 samples)	Constituent	Tuffaceous sandstone Arikaree formation (10 samples)	Sandstone from Fort Union formation (3 samples)
SiO_2	61.3	77.5	K_2O	3.2	2.9
Al_2O_3	12.4	11.2	TiO_2	0.39	0.32
Fe_2O_3	2.7	2.1	P_2O_5	0.10	0.10
FeO	0.15	0.16	MnO	0.07	0.02
MgO	1.7	0.74	H_2O	8.4	3.1
CaO	4.7	0.45	CO_2	2.9	<0.05
Na_2O	2.0	1.4			



Geology modified after G.W. Moore and J. R. Gill, 1955

FIGURE 47-GEOLOGIC MAP OF THE SOUTHERN PART OF THE SLIM BUTTES AREA, HARDING COUNTY, SOUTH DAKOTA

0 1 2 3 Miles

Contour interval 20 feet
Datum is mean sea level

74K

Semiquantitative spectrographic analyses of selected samples of ore-grade uranium-bearing lignite from the Dakotas are shown in table 12. The samples contain appreciable amounts of vanadium, molybdenum, arsenic, and the rare earths as well as uranium.

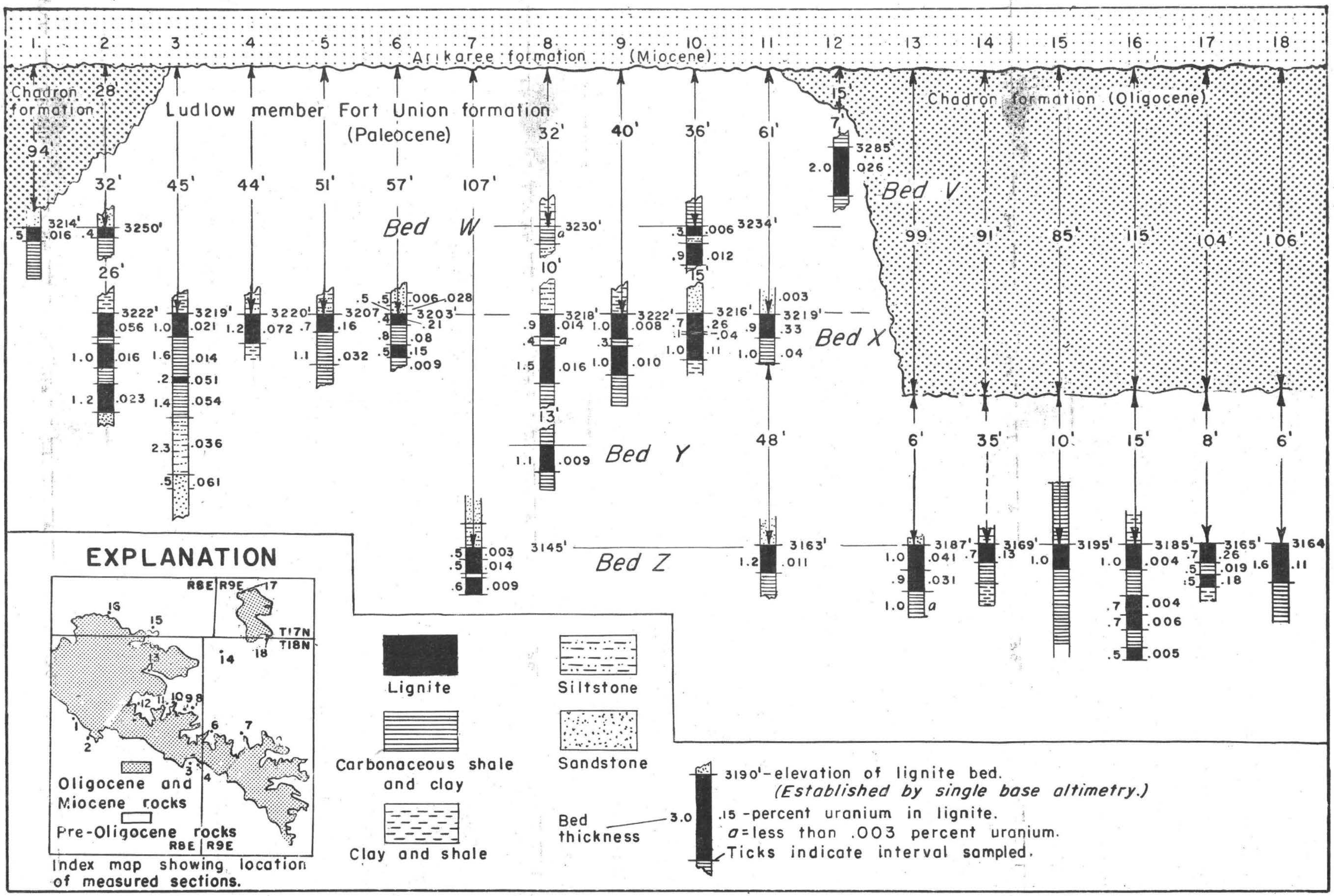
Table 12.--Comparison of semiquantitative spectrographic analyses of ash from uranium-bearing lignite deposits in North and South Dakota

Sample from:	North Cave Hills Harding County South Dakota	Rocky Ridge area Billings County North Dakota	Killdeer Mt. area McKenzie County North Dakota
Uranium in ash (percent)	1.6	1.3	4.2
Range (percent)			
10	Si	-	Si, Al
5-10	Al, Na, Fe, Ca	Si	Fe
1-5	Mg	Al, P, Ca, Fe, Mo	Ca
.5-1	Mo, K	Ba	K, Mg, Ti
.1-.5	Ba, Sr, As, Ti	Na, K, As, Mg, B	Ba, Y, Na, Nd, Ce, La
.05-.1	Zr, B	Sr, Ti	Zr
.01-.05	V, Ni, Y, Ca, Cu, Pb	Li, Zr, Co, Ni, Pb, Y, M	B, Sr, Pr, Ni, Yb, Gd, Mo, Sm, V, Ca, Dy
.005-.01	Mn, Ca, Ge, Sr, La	V, Mn, Cr, Cu, La	Sn, Cr
.001-.005	Sr, Yb, Sn	Sn, Ga, Sc, Yb	Co, Mn, Sc, Ge, Pb, Ho
.0005-.001	Be	-	Be
.0001-.0005	Ag	Be, Ag	Ag

A detailed study was made of uraniferous lignite in the Ludlow member of the Fort Union formation in the southern part of the Slim Buttes area (fig. 47), Harding County, South Dakota. Stratigraphic and sample data were collected and a structure map was compiled on the base of the Miocene rocks to determine the relation of local structure to uranium mineralization. The study indicates that the more intensely mineralized beds have several stratigraphic and structural features in common. This is particularly striking at localities 1-13 inclusive, 15 and 16 (fig. 48).

Structural features present in this area which may effect concentration of uranium are broad gentle synclines of post-Miocene age which may have concentrated the flow of the mineralizing solutions. The fault blocks shown in figure 47 are the result of landsliding which took place along topographic highs on the pre-Oligocene erosion surface prior to the deposition of the Arikaree formation. These blocks are composed chiefly of Oligocene strata and appear to bear no relation to uranium mineralization other than forming possible barriers to ground-water circulation.

At localities 5, 6, 10, and 11 (fig. 48) lignite and carbonaceous shale contain 0.10 percent or more uranium. These deposits differ from lower grade occurrences at nearby localities because of their structural and stratigraphic settings. The highly mineralized deposits lie along the axis of a gentle syncline, are overlain by soft permeable sandstone, and are underlain by clay or shale. They also are closely overlain by the Chadron or Arikaree formations. Evidently no single factor such as structure entirely controls mineralization as can be



By J. R. Gill and N. M. Denson 1955

FIGURE 48 CHART SHOWING URANIUM CONTENT AND CORRELATION OF LIGNITE BEDS IN THE SOUTHERN PART OF THE SLIM BUTTES AREA, HARDING COUNTY SOUTH DAKOTA

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seen at locality 16 where a weakly mineralized lignite lies at the axis of the syncline, but there the bed is enclosed in impervious clay. Probably the most important single control is the permeability of the rocks directly overlying the receptor beds (lignite).

A paper, "Uranium-bearing lignite and its relation to volcanic tuffs in eastern Montana and the Dakotas", by N. M. Denson and J. R. Gill, was published in the Proceedings of the United Nations International Conference on the Peaceful Uses of Atomic Energy.

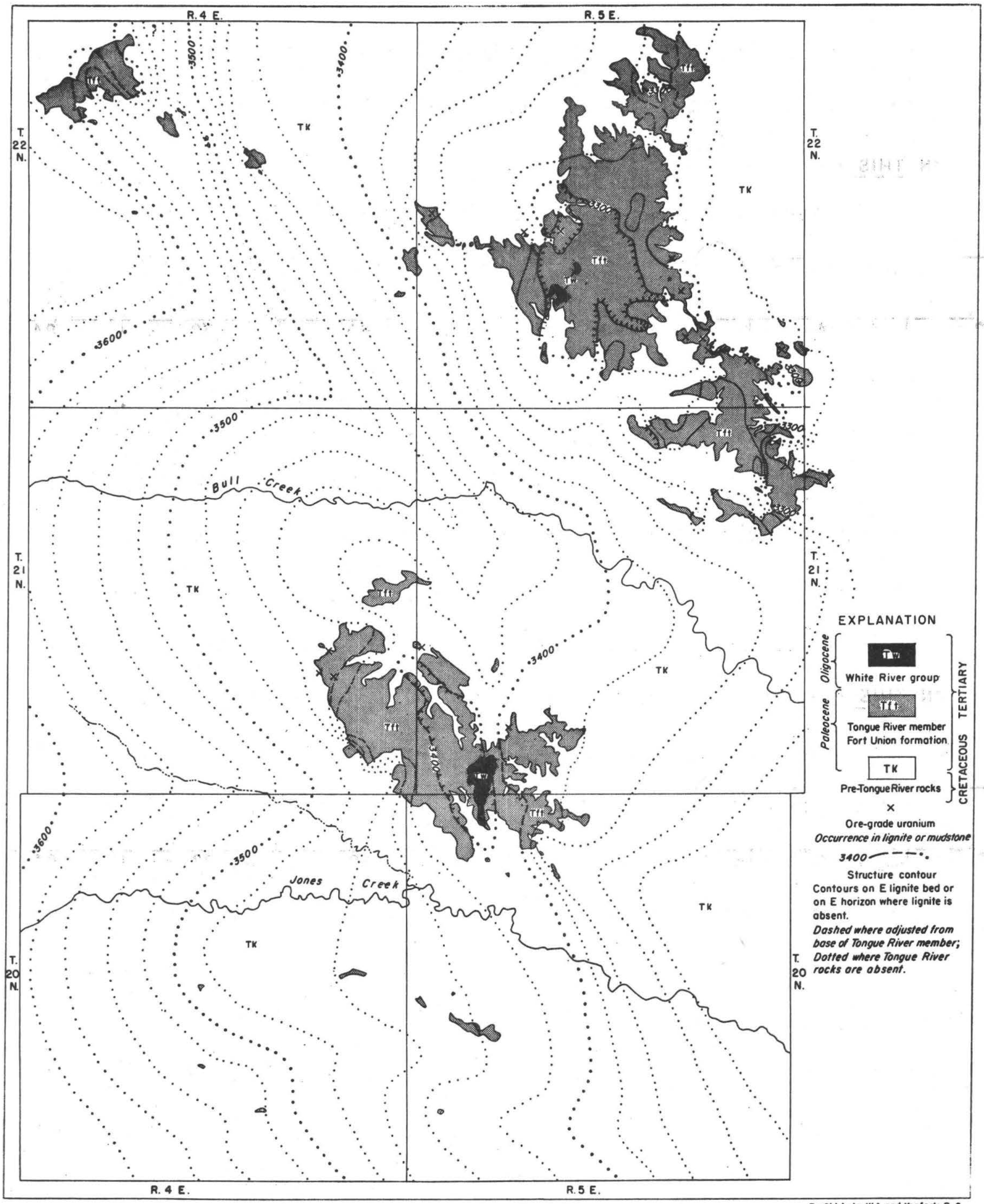
Cave Hills, Harding County, South Dakota

by

R. C. Kepferle and W. A. Chisholm

Since the discovery of ore-grade lignite in the North Cave Hills in 1954, reasons for its occurrence have been sought to facilitate the detection of additional deposits. In the search for indicators or guides to ore deposition a structure map was made of the Cave Hills area and the principal types of deposits were mapped in detail by plane table at a scale of about 1:3600.

Less than 400 feet of structural relief is present in the area mapped (fig. 49) and the dips range from 10 to 100 feet per mile; the average is about 30 feet per mile. The regional dip is 40 to 80 feet per mile to the northeast into the Williston Basin off the east flank of the Cedar Creek anticline, the axis of which lies about 5 miles west of the Cave Hills (fig. 49). Most of the known ore-grade deposits are in minor structural irregularities superimposed on the regional dip of the Fort Union formation.



By Chisholm, W.A., and Kepferle, R. C

FIGURE 49 STRUCTURE MAP OF THE CAVE HILLS AREA, HARDING COUNTY, SOUTH DAKOTA.

0 1 2 3 4 5 Miles

Contour interval 20 feet.
Datum is mean sea level.
1955

The principal types of deposits studied include the strongly mineralized areas in the E lignite bed in the Riley Pass area of the North Cave Hills, in the phosphatic mudstone at the Lonesome Pete prospect, and in the carbonaceous mudstone at the Carbonate prospect, in the South Cave Hills (fig. 50).

All three occurrences are in the Fort Union formation of Paleocene age, which is locally overlain by tuffaceous rocks of Oligocene age. The uraniferous lignite deposits of the "E" bed are approximately 100 feet above the base of the Tongue River member. The two mudstone deposits are in the upper part of the Ludlow member.

Channel samples were taken on 25- to 50-foot centers in all of the deposits studied to determine the variation in uranium content with lithology. About 500 lignite and mudstone samples were taken.

Detailed water sampling in the area shows that the more uraniferous waters are adjacent to the ore-grade deposits (fig. 51). The water with the most uranium (2250 parts per billion) was from a small pond in an exploration pit where meta-autunite occurs as a secondary coating along bedding planes and cleats in lignite. The waters sampled have a pH ranging from 7.4 to 9.6; the average is about 8.2.

Ground water is believed to be the vehicle of emplacement of the uranium in the lignite and mudstone deposits. The ground water conditions, that is the zones of saturation and aeration, at the time of emplacement appear to have been largely controlled by the distance below the pre-Oligocene erosion surface, and the porosity, permeability, and structure of the rocks directly below this surface. The position of this erosion surface over much of the area must be left largely to inference because most of the late Tertiary rocks in the Cave Hills area have been removed by erosion.

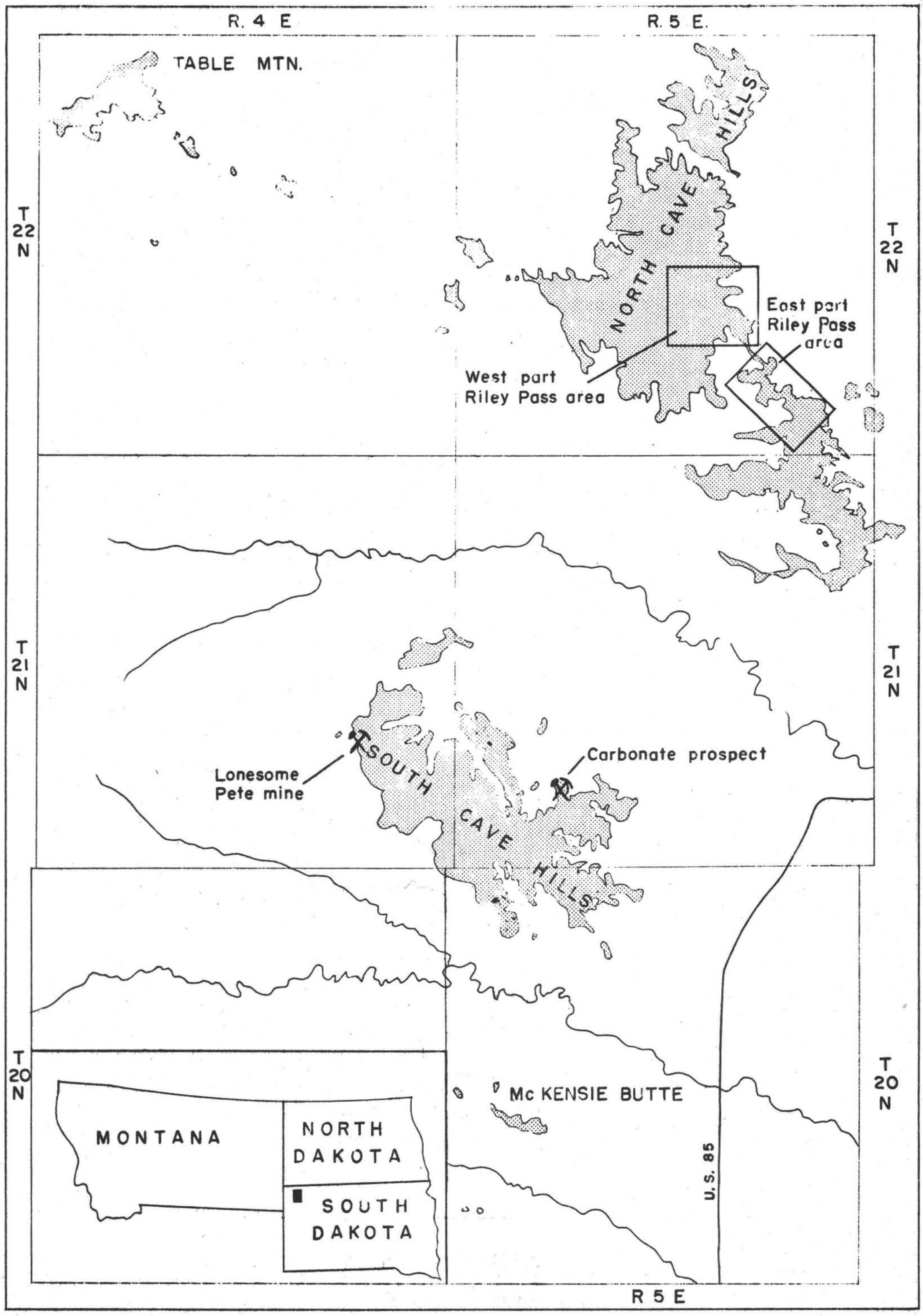


FIGURE 50-INDEX MAP SHOWING URANIUM DEPOSITS STUDIED IN DETAIL, CAVE HILLS AREA HARDING COUNTY, SOUTH DAKOTA

1 0 1 2 3 4 5 Miles

1955

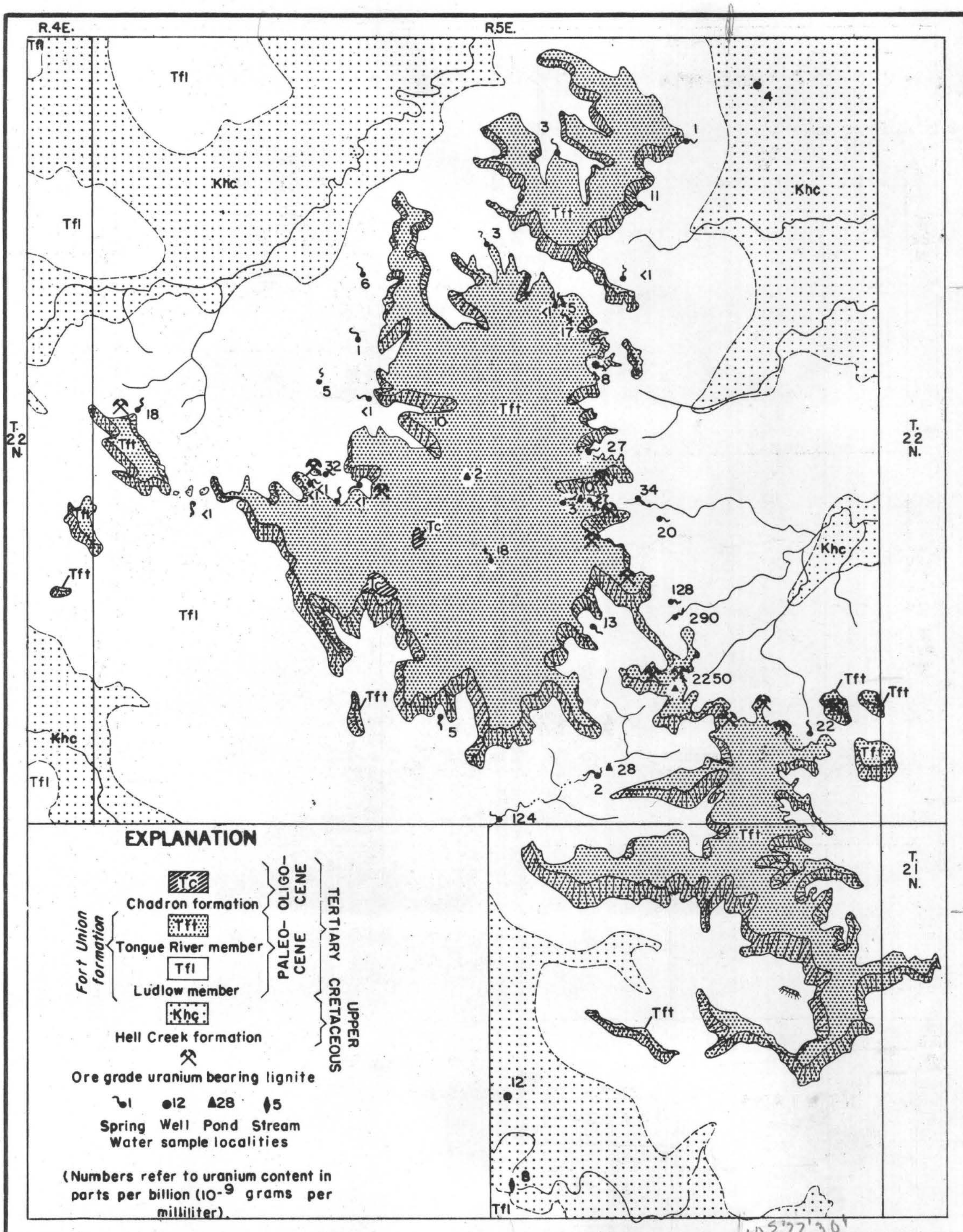


FIGURE 51 GEOLOGIC MAP SHOWING URANIUM CONTENT OF WATER IN THE NORTH CAVE HILLS, HARDING COUNTY, SOUTH DAKOTA.

1 0 1 2 Miles

The high-grade deposits of uranium in lignite have not proved to be as extensive as first surmised because of the lenticularity of the beds and the spotty character of mineralization. The mineralized "E" lignite bed is generally less than 2 feet thick and may pinch out to a mere carbonaceous streak within half a mile. Throughout most of the area examined in detail the "E" bed appears to consist mainly of detrital coal with an admixture of silty sand and clay, and even where under as much as 80 feet of cover, appears to be highly weathered. The ore bodies within the "E" bed are irregularly elongate with a maximum known length of about 1,000 feet and a width of as much as 700 feet. Uranium minerals reported in the lignite include autunite, torbernite, and zeunerite (Gill, TEI-540). In the higher grade parts of deposits, those containing 4 ± percent uranium, the uranium may occur in the lignite in the form of uraninite. Much of the uranium, however, is in an unidentifiable form. The grade of a 1.3-foot channel sample containing as much as 3.8 percent uranium was increased to 14.7 percent by ashing. The ash content of surface samples of the "E" bed generally ranges from 20 to 45 percent and averages about 33 percent. Nearly all the samples are out of equilibrium in favor of chemical uranium, generally by a factor of 200 to 300 percent. As much as 0.5 percent molybdenum and 0.9 percent arsenic have been reported from the Riley Pass area.

The uranium in the mildly uraniferous carbonaceous mudstone at the Carbonate prospect appears to have been concentrated locally by ground water passing through vertical sandstone dikes. Because of the lack of permeability of the mudstone, high-grade material does not extend laterally more than a foot from the dikes. A secondary uranium mineral, tentatively identified as autunite, appears as a fracture coating on some of the more uraniferous mudstone.

Preliminary analyses indicate that much of the uranium in the phosphatic mudstone ore at the Lonesome Pete prospect is closely associated with abundant analcite and apatite (Virgin, W. and Stone, J., written communication). A marine origin for the phosphate is suggested by fossil remains tentatively identified as marine sharks in an overlying sandstone. The phosphate and the sandstone with shark remains could easily be tongues of the marine Cannonball member of the Fort Union formation which has been mapped within 15 miles of the eastern boundary of the area (Winchester, U. S. G. S. Bulletin 627).

Features that may control the localization of uranium in the Cave Hills area are: (1) structural irregularities imposed on a low regional dip; (2) high porosity in rocks overlying receptor beds (lignite, phosphatic mudstone, or carbonaceous mudstone); (3) areas of higher porosity of receptor beds to uranium resulting from weathering prior to or during mineralization; and (4) impermeable clays, siltstone, and sandstone directly below receptor beds that might impede downward migration and introduce lateral migration of mineralizing solutions.

Features which are thought to indicate the presence of uranium occurrences are: (1) orthoquartzite in beds and as surface debris — common in the vicinity of ore deposits. The importance of this feature is thought to lie chiefly in the fact that it supports some of the higher hills, thereby preserving the mineralized beds from erosion; (2) the various hues of red staining in the topographically high rocks;

and (3) the presence of analcite. The last two features are thought to be directly related to the pre-Oligocene unconformity.

Coal petrology

by

J. M. Schopf, R. J. Gray and B. D. Middleton

Two sets of high-grade uranium-bearing lignite samples from Harding County, S. Dakota, were studied in the laboratory. About 8 feet of core, including highly uraniferous coal and associated strata, from a uranium deposit in the North Cave Hills (sec. 26, T. 22 N., R. 5 E.), and two large blocks, representing a nearly complete column sample of unweathered uraniferous coal from an open pit in the southern Slim Buttes (sec. 2, T. 16 N., R. 8 E.), were examined. Lithologic sections of this material are illustrated in figure 52 . The results of radioactivity determinations (pulses per minute per gram) from samples of this material are shown graphically in the same illustration.

Noteworthy irregularity is evident in the distribution of radioactivity, and chemical analyses of the core samples show that a good general correlation exists between total radioactivity and the amount of uranium present. Chemical analyses have not yet been received for samples from the column specimen. The three high peaks of radioactivity from the core samples correspond, respectively, with 0.11 percent, 0.11 percent, and 0.17 percent uranium in the coal. The intermediate peaks correspond, on the average, with about 0.023 percent uranium; the samples showing lowest radioactivity average about 0.005 percent uranium. All values given are for samples of coal in dry condition.

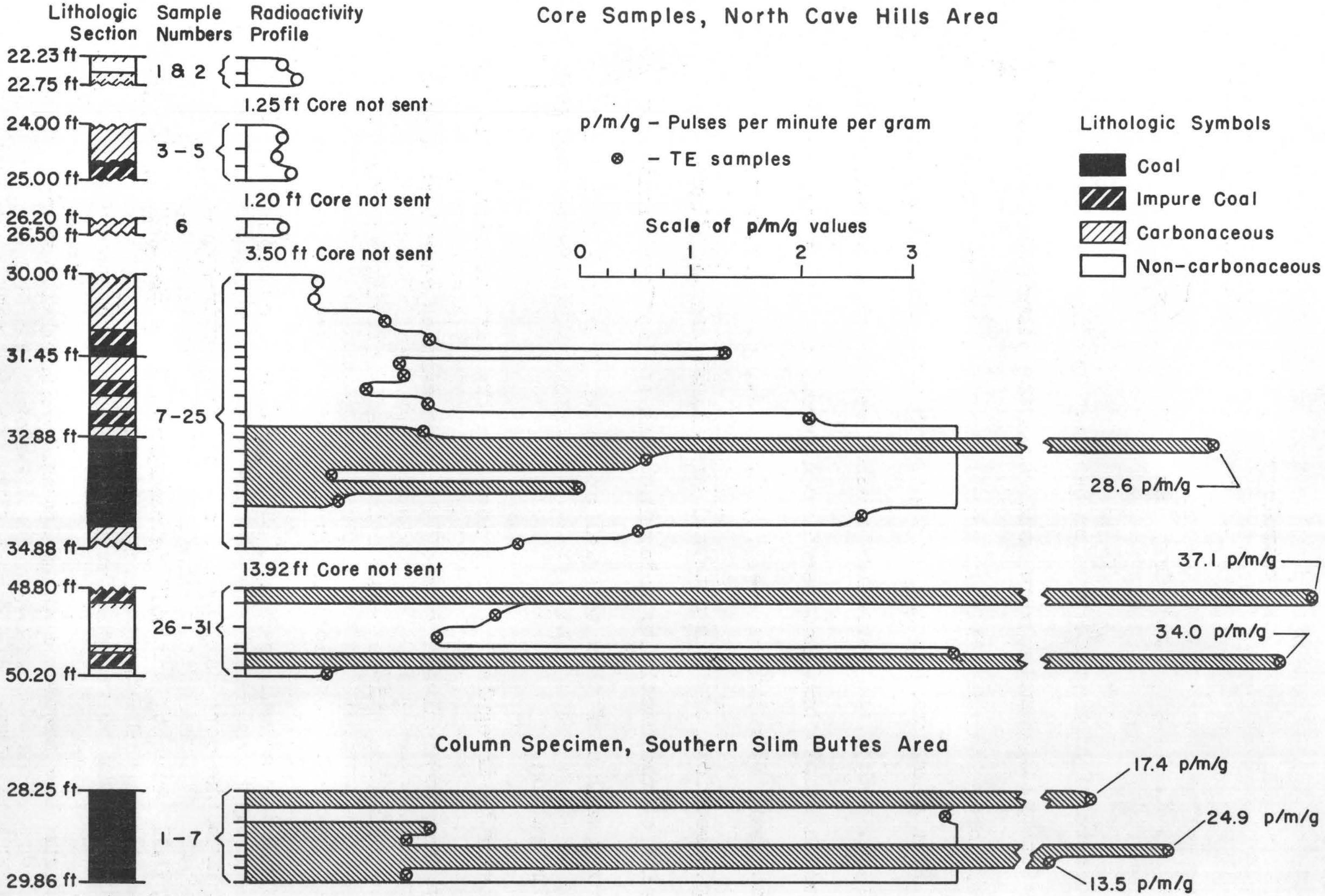


FIG. 52. SUMMARY P/M/G RESULTS OF TWO COALS FROM HARDING COUNTY, SOUTH DAKOTA.

Spectrographic results on the suite of core samples show unusually large amounts of potassium, ranging up to about 3 percent (dry basis) in samples 9, 12, 29 and 31. Samples including this much potassium do not seem to show any greater variation in radioactivity than those low in potassium, when the measurements are made on coarsely crushed samples in a cup-mounted Geiger tube.

Preliminary microscopic studies of thin sections prepared from the core and column samples show that analcite spherulites are present in the coal and some of the associated clays. These do not seem to be direct (*in situ*) alteration products of volcanic ash, but appear to have been introduced secondarily in solution during late diagenesis when compaction of plant material and clay was nearly complete.

Carbonaceous rock investigations

Midcontinent Devonian shale

by

E. R. Landis

During the report period a study of the Chattanooga shale in Kansas was made, using chiefly radioactivity logs. The Chattanooga shale does not crop out in the state, but is exposed to the southeast in Oklahoma, Arkansas and Missouri. In the subsurface in Kansas the formation ranges from a knife edge to 250 feet in thickness. In the southern part of the state it consists chiefly of dark-gray and black bituminous shale that changes progressively to the north to light-gray and light-green shale; in the northern part of Kansas it consists almost wholly of non-bituminous, light-colored shale.

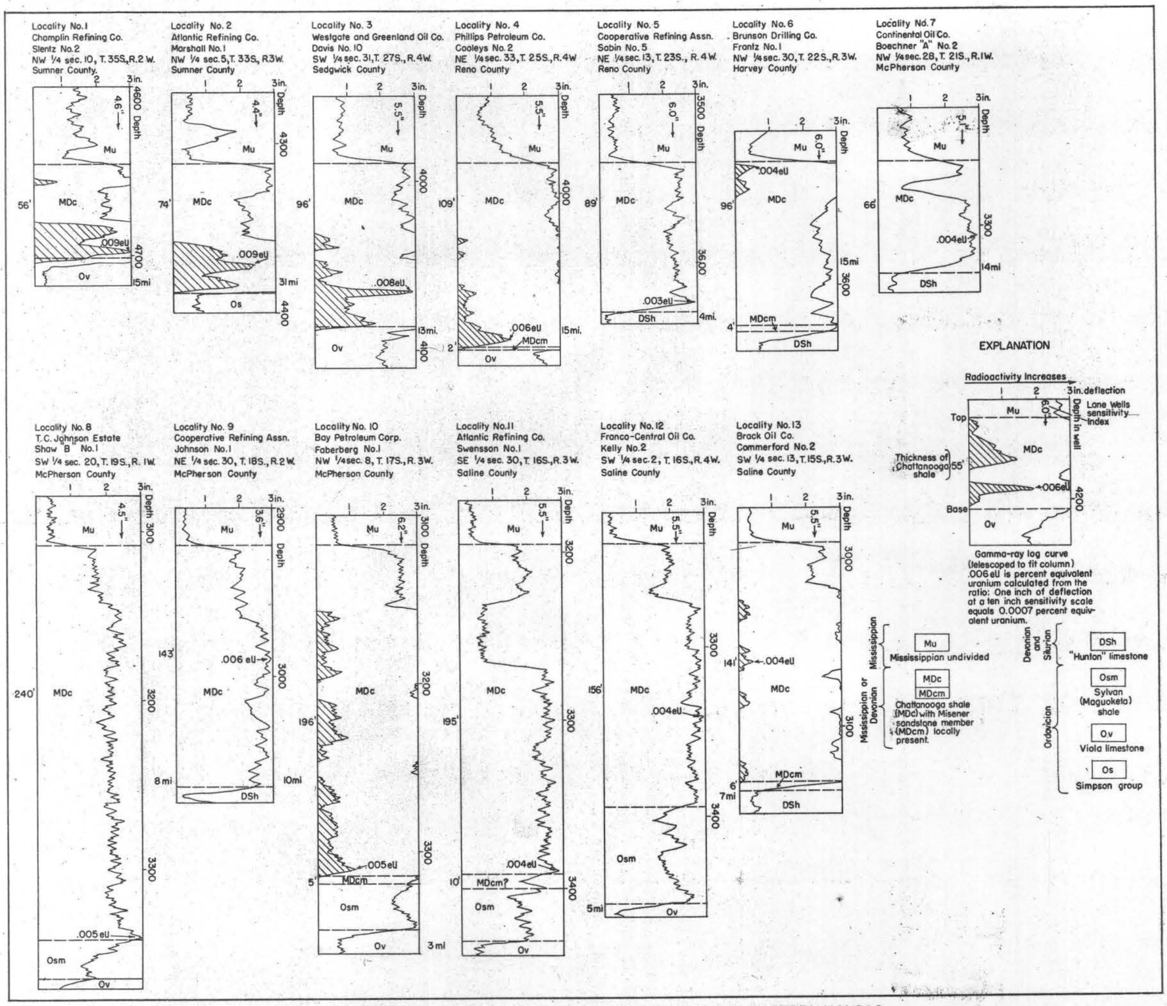


FIGURE 53 GAMMA-RAY LOGS OF CHATTANOOGA SHALE IN EASTERN KANSAS

In Kansas the Chattanooga shale, which is of late Devonian or early Mississippian age, lies unconformably on rocks ranging in age from Ordovician to Devonian. In most of the state the Chattanooga shale is overlain by rocks of Mississippian age; but due to post-Mississippian pre-Pennsylvanian erosion, it is overlain by rocks of Pennsylvanian age in several small areas near the center and along the western margin of the state.

Figure 54 shows the locations of wells in Kansas that have been used in the gamma-ray log study, and also shows the approximate thickness of the Chattanooga shale prior to subsequent erosion. In general the Chattanooga in Kansas exhibits a radioactivity in the gamma-ray logs of from 0.004 to 0.005 percent eU up to a maximum of 0.014 percent eU. The equivalent uranium values were calculated by use of the ratio: a one-inch deflection on a ten-inch sensitivity index on Lane Wells gamma-ray logs is equal to about 0.0007 percent equivalent uranium. Chemical uranium analyses of subsurface samples will be made to verify this ratio as applied to the Chattanooga shale.

The Chattanooga in Kansas generally is most radioactive in areas where the original thickness of the formation was less than 100 feet. This suggests that the rate of deposition exerted some control over the amount of radioactive material present.

Figure 54 shows significant portions of selected gamma-ray logs in the south-central part of the area of investigation. These logs show that the basal part of the Chattanooga shale near the state boundary of south-central Kansas is much more radioactive than the upper part and that the peak radioactivity is consistently located near the base of the formation. To the north the difference in radioactivity of individual parts of the Chattanooga shale is greatly lessened and the peak radioactivity shown on the log is inconsistent in its stratigraphic location in the formation. In this area the Chattanooga shale is reported to comprise a basal sequence of black shale that thins northward, overlain by a dark-gray shale and gray shale sequence that thickens northward.

In eastern and southeastern Kansas the lowermost part of the Chattanooga shale is also consistently the most radioactive. Some black shale is reportedly present at the base of the formation in southeastern Kansas, but to the north it is reported to consist largely of dark-gray and gray shale with no black shale present. The Chattanooga shale of Kansas seems to increase in radioactivity, and presumably uranium content, in a south and southeastward direction.

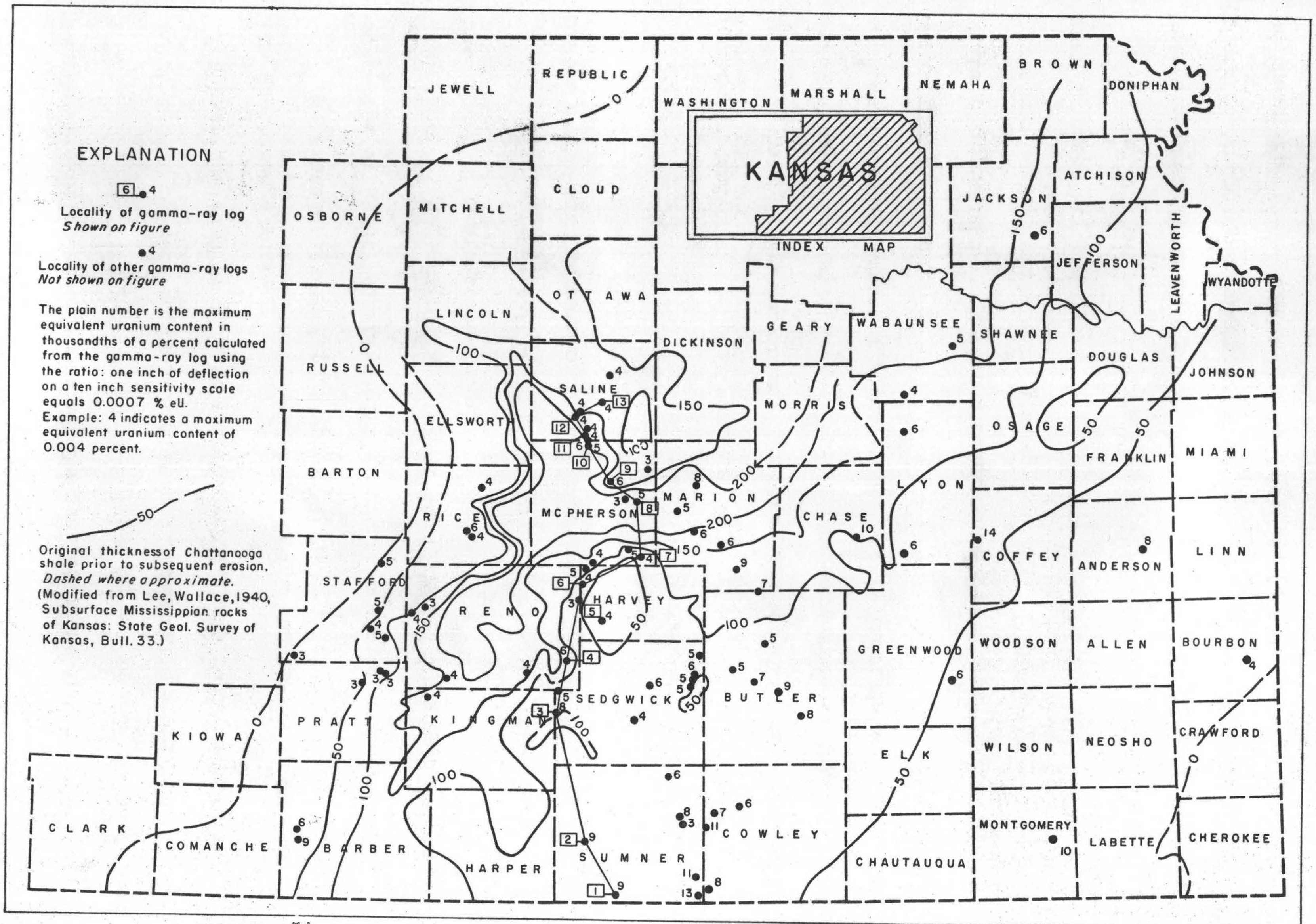


FIGURE 54—MAP OF EASTERN KANSAS SHOWING THE LOCATION OF WELLS USED IN THE RADIOACTIVITY LOG STUDY OF THE CHATTANOOGA SHALE.

10 0 10 20 30 40 Miles

Midcontinent Pennsylvanian shales

by

H. J. Hyden and Walter Danilchik

An investigation of the distribution of uranium and other metals in Pennsylvanian rocks of the Midcontinent was initiated in July 1955. As a first step, reports of uranium concentrations and other radioactive anomalies (including gamma-ray logs) in Pennsylvanian rocks were gathered and catalogued. These included reports on uraniferous black shales; on abnormally high uranium contents in asphalts; and on the high radioactivity of the oils and waters produced from the Nowata and other fields in Oklahoma. The ultimate objective to be gained from the synthesis of data from previous reports and field work of this project is to discover geological and geochemical controls for the stratigraphic and geographic distribution of uranium in the area investigated.

Area of investigation

Rocks of Pennsylvanian age in the Midcontinent crop out in a belt bordering the Ozark dome that trends from central Arkansas into eastern Oklahoma and north-northeast through eastern Kansas and western Missouri into Nebraska and Iowa.

Rocks of the Des Moines series, which includes the Marmaton and Cherokee groups in northeastern Oklahoma and southeastern Kansas, were selected for initial field investigations (fig. 55). These rocks strike generally north-northeast, and the regional dip is westward 25 to 50 feet per mile. The area has a rolling, low relief, with gentle north-northeast trending cuestas capped by sandstone or limestone and separated

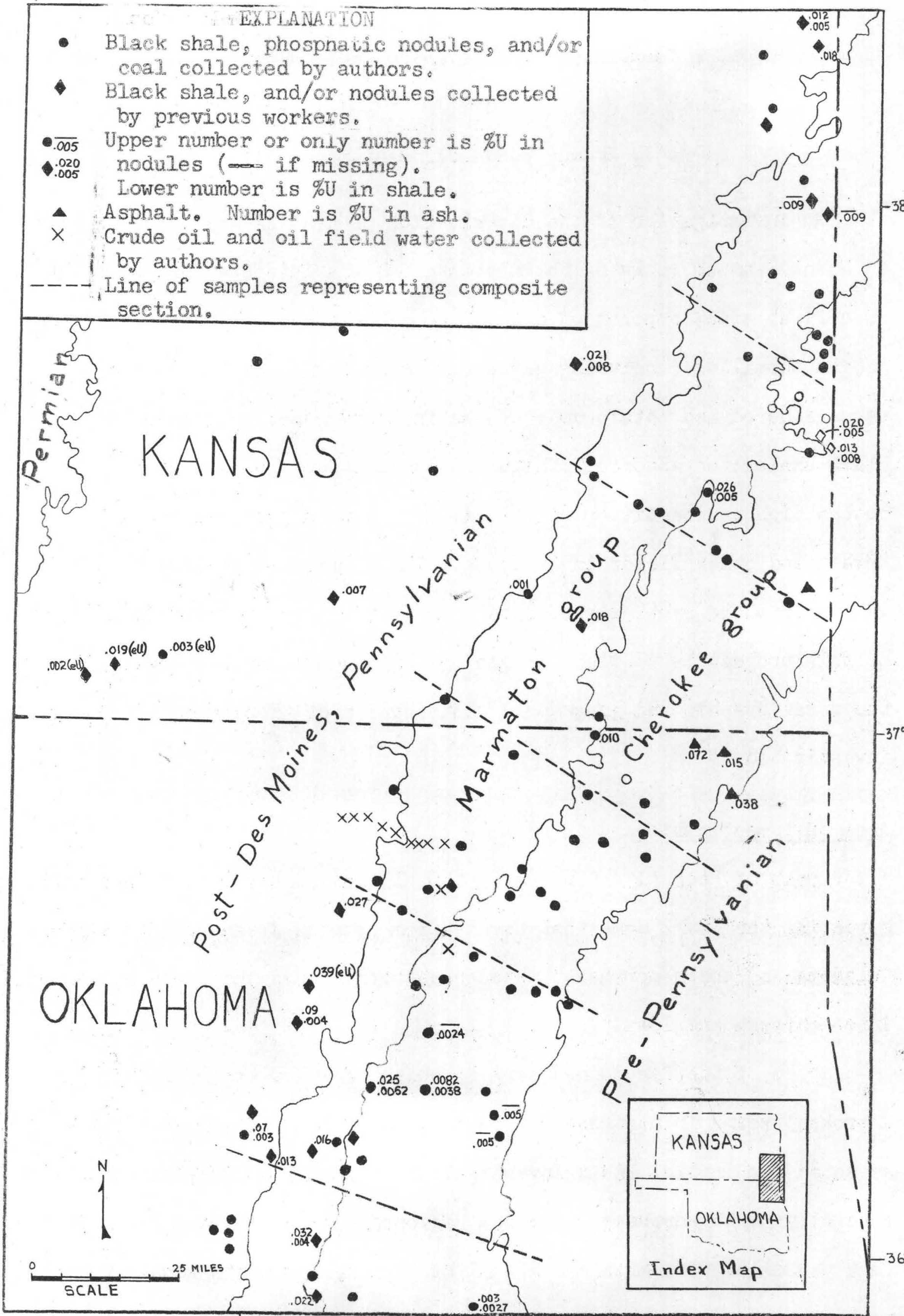


Figure 55. Map of northeastern Oklahoma and southeastern Kansas showing localities where samples from Pennsylvanian rocks have been collected.

by shale lowlands. Exposures of shale are generally confined to stream and road cuts.

This area is considered to have been a shelf area for the Pennsylvanian sediments which thicken toward the McAlester Basin to the south and toward the Forrest City Basin on the north. The Bourbon arch which trends west-northwest across southeastern Kansas is the approximate line of minimum thickness of these sediments.

The dominant lithology of the Pennsylvanian sediments of this area is a dark gray clay shale with abundant siderite concretions. Also present are thin, persistent fossiliferous marine limestones; hard fissile bituminous black shales with phosphatic nodules; fresh water limestones; sandstones which in places occupy channels into the underlying rocks; soft fossiliferous black shales; and coals. These different lithologies generally are repeated in a cyclical manner in vertical sequence. A complete set of these repeating units represents a pulsation of sea level, and includes both marine and continental sediments.

Pennsylvanian rocks of all lithologic types were field checked radiometrically; however, with the exception of a few coals, only black bituminous shales were found to be appreciably radioactive. Numerous black shales, many containing phosphatic nodules, are present in the Des Moines series; those in and immediately below the Marmaton group, the upper group of the Des Moines, are mildly radioactive and most persistent.

Samples were collected for laboratory study and analysis from most of the black shale units in the Des Moines series near five different lines of section about 35 miles apart (fig. 55). Because the

Excello shale, the uppermost unit of the Cherokee group, is the most persistent of the more highly radioactive black shales, it was sampled at 14 localities. The Lake Neosho and Little Osage shales of the Marmaton group, and the shale underlying the Verdigris (or Ardmore) limestone of the upper part of the Cherokee group were also sampled at many localities. A small number of shale samples from Pennsylvanian rocks younger than Des Moines, as well as a few coal samples, and one sample of asphaltic sandstone, were also collected for analysis.

Table 13 shows analytical data available at this time for a group of samples, which constitute a part of the southernmost composite section. These data confirm previous reports that the uranium in black shale is concentrated in the phosphate nodules. However, the presence of uranium in the shales themselves should be noted. Sample no. 4, a channel sample including both shale and phosphate, contains an interestingly high uranium content. Table 13 also shows that for the given group of samples the black shales capped by limestones are generally slightly more uraniferous than the black shales capped by sandstones; and that the uranium in the black shales capped by limestones is closer to equilibrium than the uranium in the black shales capped by sandstones.

Nowata oil field

In order to investigate the origin and distribution of uranium and radium in the Nowata oil field, samples of oil, brine, injection water and produced water were collected at different localities in the field (fig. 55). In all, 11 samples of crude oil, 20 samples of water and four samples of detergent additives for the injection water were taken for chemical and spectrographic analyses. Several drill cores were also collected for field and laboratory study. Asphaltic material and black shale lying immediately below the oil-producing sandstone are being investigated as possible sources of the radium in the brine.

Table 13. Uranium and equivalent uranium content of black shales and associated phosphate nodules, southeastern Kansas and northeastern Oklahoma (Lithologic units in order of natural superposition)

Name of unit	Series	Group	Lithologic Association	Uranium in shale %eU	Uranium in shale %U	Phosphate Nodules %eU	Phosphate Nodules %U
(Unnamed sh.)	Missouri	Pleasant	Overlies Checker-board ss.	.004	.003	.108 1/	.05 1/
Little Osage	Des Moines	Marmaton	Lies between two ls.	.004	.0025	----	----
Excello sh.	"	Cherokee	Capped by a ls.	.006	.0052	.048 1/	.025 1/
(Unnamed sh.)	"	"	Capped by Verdigis ls.	.009 2/	.010 2/	----	----
"	"	"	Capped by Taft ss.	.002	.0005	----	----
"	"	"	Capped by Tiawah ls.	.004	.003	.009	.0082
"	"	"	Capped by ss.	.004	.002	----	----
"	"	"	Capped by Little Cabin ss.	.002	.0005	----	----

1/ Data from previous investigation.
2/ Channel sample included both shale and phosphate nodules.

Permian and Triassic sediments of Northern Texas and Southern Oklahoma

by

D. Hoyle Eargle and E. J. McKay

The uranium localities of the Red River region of northern Texas and southern Oklahoma are in Permian and Triassic red-bed sedimentary rocks that are generally thick and distinguishable only as groups. Correlative groups to the north in Oklahoma and to the south in Texas are divisible into formations chiefly because of fossiliferous limestone units in the section, and because of other lithologic distinctions that are not present in the Red River region. Units having uraniferous rocks in the Red River region are being mapped in reconnaissance and correlated with known stratigraphic units to the south and with the groups and formations shown on the geologic map of Oklahoma (Miser, 1954). The present work includes field checking of reported uranium finds and determining their stratigraphic positions, as well as the gamma-ray logging of selected oil and water wells and test holes, and correlation of radioactive beds shown on commercial gamma-ray logs.

The general geology of the area and the position of known uranium localities are shown on figure 56. The principal stratigraphic divisions of the region, as recognized in Texas and Oklahoma, and the general type of uranium occurrences in each of the divisions are shown in table 14.

The Wichita formation in northern Texas and southwestern Oklahoma consists chiefly of red shale containing lenticular beds of sandstone. Near the Wichita Mountains, which consist chiefly of Precambrian red granite and are believed to have been a major source of the sediments, the greater part of the Wichita formation is arkosic conglomerate. Farther from the mountains tongues of arkosic coarse sand extend outward into red shale, and the sand becomes finer grained and the beds more sheetlike in character with increasing distance from the mountains. In the vicinity of Red River, the sandstone beds average 10 to 15 feet in thickness and may be traced for several miles, but some are channel sands 50 to 60 feet thick and a few hundred feet wide. One sandstone bed, or sequence of channel-filling lenses, near the top of the Wichita formation, has been termed, in Oklahoma, the "t" bed, or the Ryan sandstone, and consists of strongly crossbedded to thinly laminated carbonaceous arkosic sandstone. It is abnormally radioactive near its base in many places, chiefly

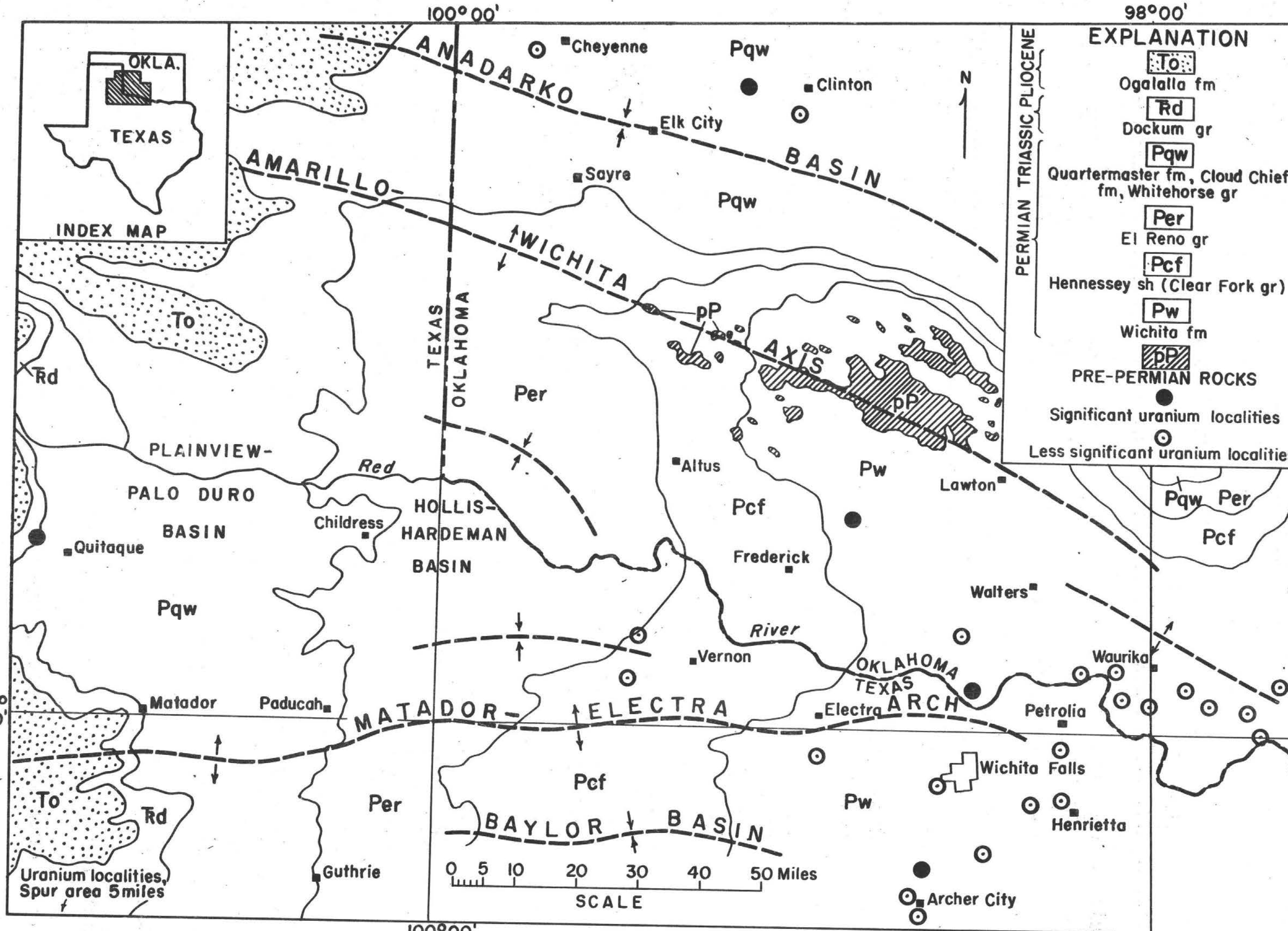


FIGURE 56 GENERALIZED GEOLOGIC MAP OF SOUTHWESTERN OKLAHOMA AND NORTHERN TEXAS SHOWING URANIUM LOCALITIES.

Table 14. Types of uranium occurrences in northern Texas and southern Oklahoma

Age	Southwestern Oklahoma (Miser, 1954)	Northern Texas (Darton and others, 1937)	Type of occurrence
Post-Triassic	Ogallala formation (Tertiary) and Pleistocene deposits	Ogallala formation (Tertiary) and Pleistocene deposits	A few reported occurrences of uranium minerals in caliche.
Triassic	(Not present)	Dockum group, undifferentiated	Radioactive crossbedded carbonaceous conglomerate and sandstone.
Permian	Quartermaster formation	Quartermaster formation	Thin beds of radioactive carbonaceous sandstone.
	Cloud Chief formation	Cloud Chief gypsum	Uranium minerals in thin beds of sandstone and siltstone.
	Whitehorse group	Whitehorse group	None reported
	(Dog Creek shale	Dog Creek shale	" "
	(Blaine gypsum	Blaine gypsum	" "
	(Flower Pot shale		
	(Duncan sandstone	San Angelo sandstone	" "
	Hennessey shale	Clear Fork group, undifferentiated	Uranium minerals in bituminous(?) nodules in olive-gray claystone.
	Wichita formation, includes, near top, "t" bed, and at base, Post Oak conglomerate	Wichita formation (group divisible into formations to the south, and includes limestone, shale, and sandstone members)	Channel deposits of crossbedded carbonaceous sandstone containing uranium and copper minerals near base.
Pennsylvanian	Vanoss formation	Cisco group	None reported.

in the vicinity of Red River, and locally contains copper and uranium minerals, abundant plant fragments, and clay pebbles. The correlative position of this sandstone in Texas is approximately the Coleman Junction limestone, and in central and northern Oklahoma, the Garber sandstone.

The Wichita formation is underlain by the Pennsylvanian Vanoss formation in Oklahoma, and by the Cisco group in north-central Texas, but rocks of this age do not crop out in the Red River area. The thickness of the Wichita is about 2,000 feet in wells down the dip, but is slightly less toward the outcrop, and considerably less over the higher buried structures such as the Electra arch. The Wichita formation in northern Texas and southwestern Oklahoma is correlative with the Garber sandstone, Wellington formation, and the upper part of the Pontotoc group of central and northern Oklahoma.

The Clear Fork group, undifferentiated, of Texas, and its correlative, the Hennessey shale of Oklahoma, consist chiefly of red shale and thin beds of light-gray to olive shale. Near the top of this unit in a few places, soft dark bituminous(?) nodules an inch or less in diameter containing yellow uranium minerals are sparsely distributed through a thin bed of pale-olive claystone. The maximum thickness of the Clear Fork group is about 1,200 feet. Down dip to the west, this group, as well as the underlying Wichita formation, consists of evaporites, red shales, and dolomite.

The San Angelo sandstone lies unconformably on, and partly overlaps, the sedimentary rocks of the Clear Fork group and its correlative in Oklahoma, the Hennessey shale. It is a pale-gray crossbedded sandstone that averages less than 100 feet in thickness near Red River. The correlative of the San Angelo in Oklahoma is the Duncan sandstone. Numerous deposits of sedimentary copper have been found in this and the immediately overlying formations, but none of them have been found to be radioactive. The San Angelo-Duncan sandstone is overlain by the Flower Pot shale, the Blaine gypsum, and the Dog Creek shale, in which no radioactive deposits have been reported. These formations constitute the El Reno group of Oklahoma.

No uranium localities have been reported from the Whitehorse group of Oklahoma and the Whitehorse sandstone of Texas. This unit consists chiefly of red sandstone and gypsiferous red shale.

In the Cloud Chief formation, consisting chiefly of gypsiferous red shale and thin beds of sandstone, high radioactivity and yellow uranium minerals have been reported from several localities in western Oklahoma near Clinton and Elk City. The minerals are disseminated in thinly laminated olive-gray clayey very fine sandstone and siltstone, enclosed by reddish-brown gypsiferous shale.

Near the base of the Quartermaster formation in western Oklahoma, especially west of Cheyenne, high radioactivity is found in thin beds of yellow to gray sandstone, enclosed by red shale. In these regions, local caving-in of surface rocks, associated with leaching-out of gypsum at depth, has produced high dips and false structures, and makes tracing and correlation of the beds difficult. Structure in sandstone beds that are aquifers may provide local controls of uranium concentration in this region.

Extensive exploration of highly radioactive zones near the base of the Triassic Dockum group in the Quitaque area, Briscoe County, Texas, is being carried on by private operators. Here, crossbedded pale-red to gray micaceous sandstone contains abundant radioactive fragments of plant matter and clay pellets. The basal conglomerate of the Triassic is here about 50 feet thick and grades upward into red and variegated shale lying beneath the "Cap rock" caliche of the Ogallala formation of the High Plains.

Uraniferous zones in the Green River formation, southwestern Wyoming

by

J. D. Love

Four low-grade uraniferous zones in the Laney shale tongue (including at the base the lateral vestiges of the Cathedral Bluffs tongue) of the Green River formation were identified and sampled during October and November 1955, along the west side of the Rock Springs uplift, southwestern Wyoming. The lowest stratigraphically and most radioactive of these zones is a slabby slightly calcareous gray shale interbedded with ferruginous sandstones and siltstones between 10 and 25 feet above the top of the Tipton tongue. The maximum analysis obtained to date is 0.15 percent U for a 3-inch bed, and 0.041 percent U for 21.5 inches of shale within the center of the zone. The zone was recognized along an outcrop distance of more than 90 miles.

A second radioactive zone is a dark green blocky claystone between 60 and 65 feet above the Tipton tongue. Samples from one foot of section contain from 0.009 to 0.020 percent eU. A 3-inch brown oil shale 44 to 55 feet above the second zone contains from 0.003 to 0.020 percent eU. A fourth zone is a dark green claystone about 185 feet above the thin radioactive oil shale, and contains 0.007 to 0.008 percent eU in a one-foot interval.

At depths of 1 to 3 feet, the uranium content of the lowest zone is moderately close to being in equilibrium. Erratic surface radioactivity is thought to be, in part, at least, the result of surface leaching. No uranium mineral was observed megascopically, even in the layers containing 0.15 percent U. The uraniferous zones and the rocks both above and below them have very little porosity or permeability so it is possible that the uranium may have been deposited along with the Laney sediments.

Geochemistry of uranium-bearing shales

by

Maurice Deul and I. A. Breger

Experiments to determine the mode of occurrence of uranium in the Chattanooga shale were completed. Some of these data were reported in previous semiannual reports but a more positive interpretation can be made at this time. It can now be definitely stated that regardless of the manner or degree of mechanical reduction in size, the finest sized fraction of shale separated contains the greatest concentration of uranium. This is illustrated in figure 57 where the data are plotted for the carbon and uranium content of subsieve fractions obtained by air elutriation from the pulverized shale.

In figure 57 the lower curves, A, are for subsieve size fractions from a head sample of original shale ground to pass a 44 micron screen and which assays 13.7 percent carbon and 0.009 percent U. The upper curves, B, are for subsieve size fractions from a shale separate previously concentrated by separation of an extremely fine size collected from an air jet pulverized as a "smoke"; this sample, which was composed of particles of about 0.1 micron in size, contained 19.4 percent carbon and 0.0129 percent U. From these curves it is evident that the finest sized fractions are enriched in uranium as well as in carbon. Although a rough correlation of uranium and carbon exists, from these data it does not appear that the uranium content is a simple function of the carbon content.

Figure 58 shows the composition of the mineral, organic, and intermediate fractions from three different experiments in the fractionation of Chattanooga shale to obtain separation and concentration of shale components.

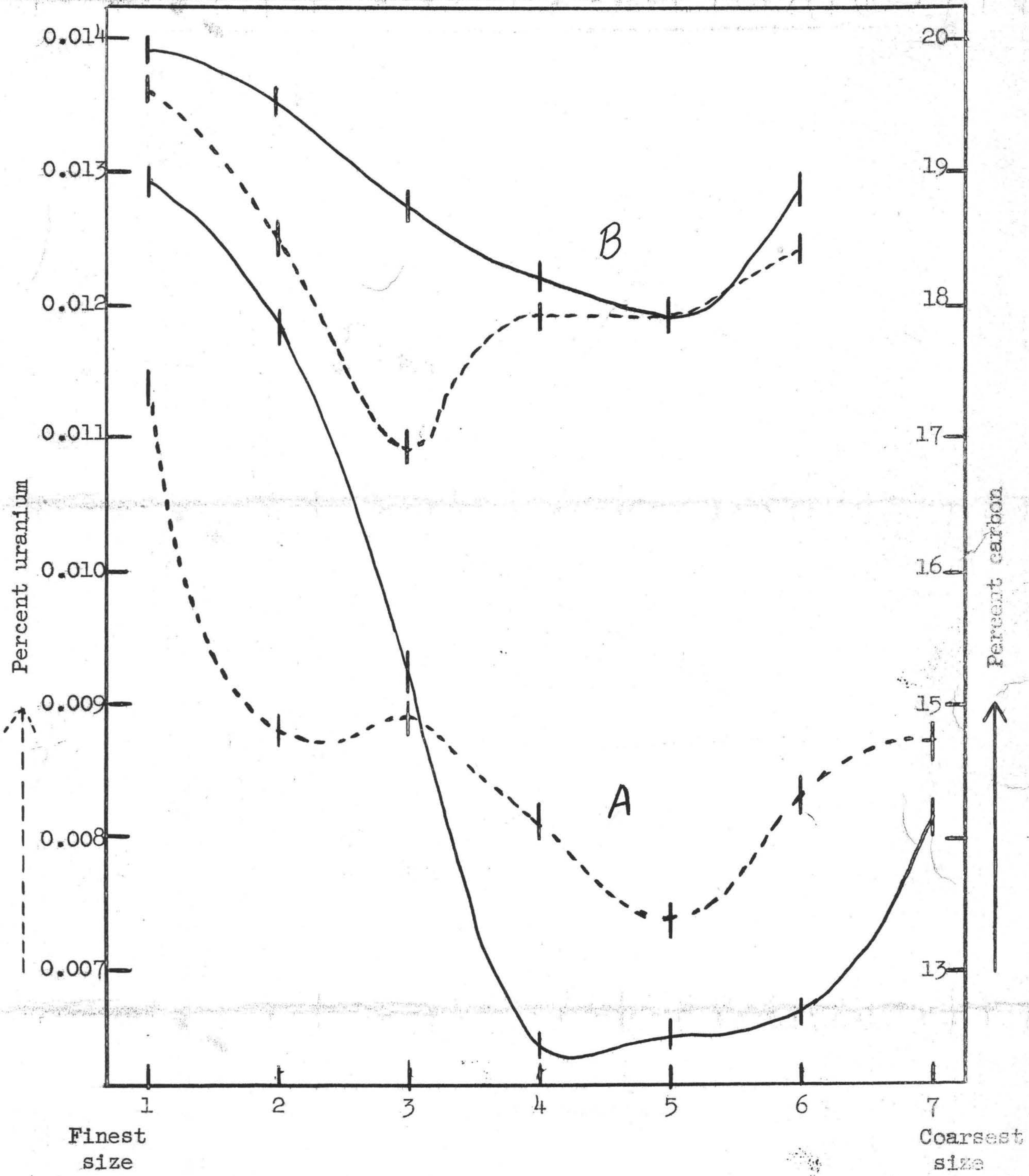


Figure 57 Plot of uranium and carbon vs sub-sieve-size fractions of pulverized dry Chattanooga shale. A. Curves for -325 mesh shale; B. Curves for fine-grained concentrate of about 0.1 micron size.

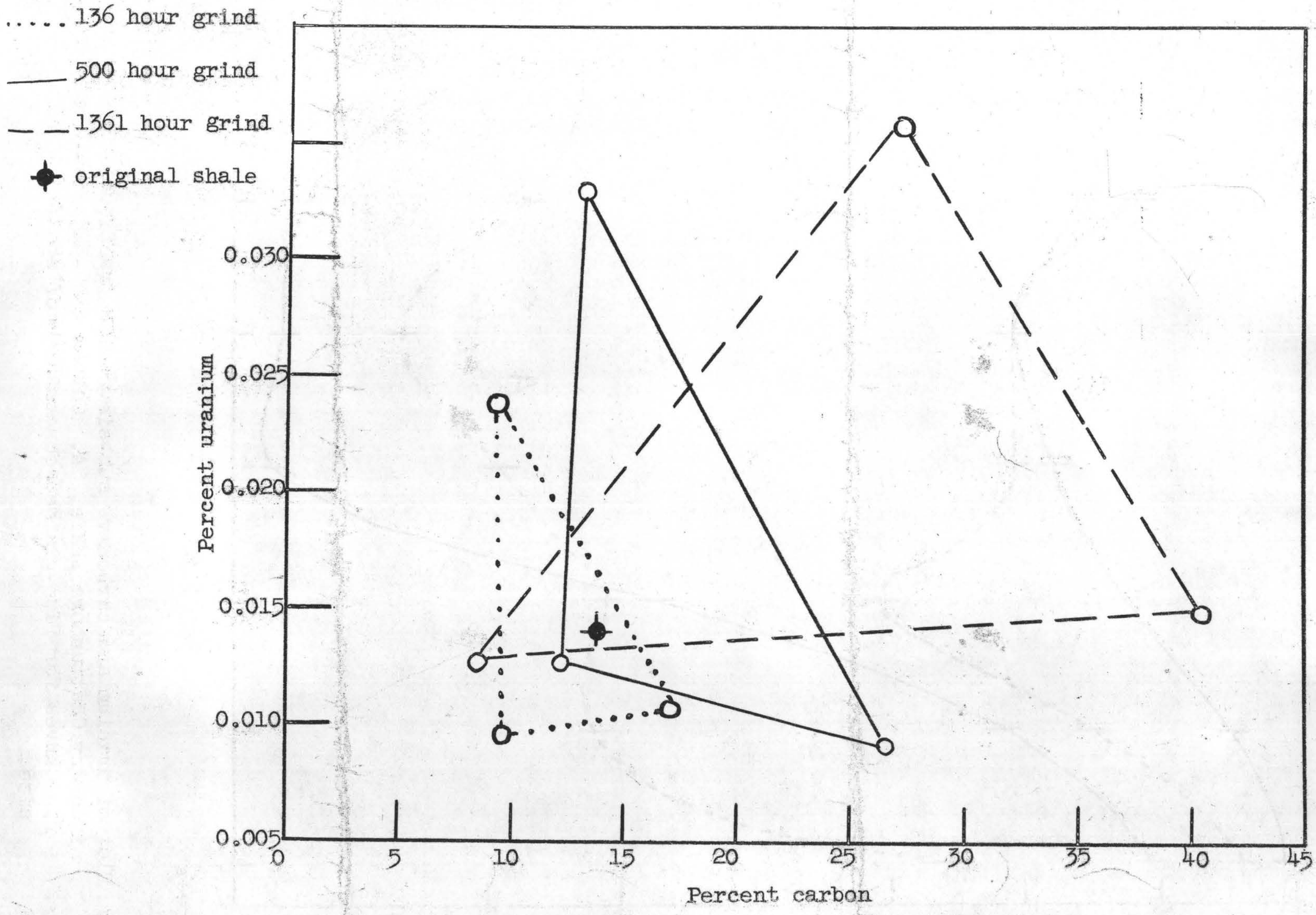


Figure 58. Carbon and uranium contents of mineral-rich, organic-rich, and intermediate fractions separated from shale.

All three experiments were performed on splits of the original shale which contains 0.009 percent U and 13.7 percent carbon. The mineral fractions from all these separations are represented by the lower left points of the triangles, the organic fractions by the lower right points of the triangles, and the intermediate or middlings fractions are represented by the apices of the triangles.

Analysis of these data leads to certain conclusions of fundamental importance. There are:

1) The mineral-rich and organic-rich end members from each experiment are not enriched in uranium.

2) Uranium is concentrated in the middlings fraction.

3) The greatest concentration of uranium is in the middlings fraction of the shale ground for the longest period of time.

The increase in carbon content of the middlings fraction is believed to be a function of the grinding time with consequent reduction of the organic material to colloidal sizes which are not readily separable. Other experiments demonstrated that for a given organic-rich or mineral-rich concentrate a second fractionation yields cleaner end fractions each of which is lower in uranium content than the preliminary concentrate. Thus a fraction containing 48.8 percent carbon contained only 0.0045 percent U.

Uranium in asphaltite and petroleum

by

A. T. Myers

In the last six months, 270 chemical determinations were completed on 166 samples. In addition, 6,060 semiquantitative and 111 quantitative spectrographic determinations were completed on 138 samples. Distribution of chemical determinations by sample type and constituent is shown in table 15.

Table 15 Distribution of asphaltite and petroleum samples by sample type and constitutent

Sample Type		No. of Samples
Crude oil		120
Petroliferous rocks		10
Asphaltite		11
Other 1/		25
	Total	166

Constituent		No. of Determinations
Oil 1/		10
Ash (of oil)		100
U in ash		142
U 3/		16
Carbon		1
eU		1
	Total	270

1/ Includes oil well brine, filter sands, marine organisms.
2/ Refers to material extracted by a hot solvent mixture composed of 75 percent benzene, 15 percent acetone, 10 percent methanol.
3/ U in water and unashed material.

The study of dry ashing losses on crude petroleum is nearly completed. Results so far obtained show excellent agreement between duplicates for the amounts of Cu, Ni, V, Pb, Co, Ca, Mo, and Mn, and acceptable agreement for the percent ash. The amount of uranium lost by ashing varied somewhat, depending upon the amount of uranium present. The largest amount of loss noted was about 1 part uranium in 70,000 which may be considered analytically insignificant for the samples studied.

An experiment was designed to determine if various types of crude oil could leach uranium and other metals from uraniferous ores. The ore types included carnotite, phosphate, carbonate, autunite, and a highly vanadiferous ore. Paraffinic, aromatic, asphaltic, and mixed base oils were used. Both ores and oils were carefully analyzed prior to mixing and at the end of 9, 12 and 15 months small samples will be removed for analysis.

Spectrographic data from 148 samples of asphalt deposits from western states were correlated. Of interest was the concentration of the following 16 elements with relation to uranium: Zn, B, Fe, Al, Cu, Ni, Zr, Ba, Cr, Co, V, Pb, Sr, Mg, Ti, and Mn. Positive correlation of the uranium content was found to be probably significant with Zn, B, Fe, Al, Cu, Ni, and Zr.

Preliminary study on petroliferous sediments
from Carlsbad, New Mexico

Oil extracted from a petroliferous asphaltite-bearing dolomite and from a sandstone of Permian age, in an exclusively marine environment, contained 154 ppm and 30 ppm of uranium respectively. Before analysis both extracted oils were passed through a filter of 0.5 micron pore size, to avoid contamination from asphaltite or host rock particles. Therefore, the uranium must be present in colloidal or true solution. The asphaltite pellets associated with the dolomite and sandstone contained 2.7 percent and 1.0 percent uranium respectively.

A thermal diffusion experiment was conducted on the extracted oil from the dolomite (containing 154 ppm uranium) in a stainless steel diffusion column. The thermally diffused fractions were analyzed chemically for uranium and spectrographically for other trace metals.

Analysis of 9 fractions obtained from the thermal diffusion column showed uranium to be concentrated by a factor of 6 in the ninth fraction, by 1.5 in another fraction and by 3 in a third fraction. The concentration of uranium in the remaining fractions was one-half or less the concentration of uranium in the original oil. As, B, Cd, Co, Mo, Pb, Sn, V, and Zn and possibly Cu seem to be selectively concentrated in two fractions. This experiment will be repeated on a fresh sample of the same oil using a glass diffusion column to eliminate the possibility of contamination.

A paper, "Uranium in asphalt-bearing rocks", by W. J. Hail, Jr., A. T. Myers and C. A. Horr, was published in the Proceedings of the United Nations International Conference on the Peaceful Uses of Atomic Energy.

Uranium in petroleum in the western United States

by

H. J. Hyden and N. W. Bass

Uranium in different crude oils

A routine distillation analysis was made by the U. S. Bureau of Mines of most of the samples of crude oil collected for this investigation. On the basis of these analyses the crude oils were separated into 13 types. The oils of higher uranium content, however, appear to be randomly distributed among these 13 oil types. No preferential distribution of oils either relatively rich or poor in uranium was discerned. Furthermore, the uranium content of the oils seems to vary independently of the age, lithology, and geographic province of the reservoir rocks.

Uranium, vanadium, nickel and nitrogen in crude oils

The ratios of vanadium to nickel and of vanadium to uranium in the crude oils investigated (see TEI-540, p. 182-183) are shown in table 16. The oils are grouped chronologically by the geologic age of the reservoir rocks, beginning with the oldest. The data for table 16 were obtained from quantitative spectrographic analyses by the Geological Survey laboratory for vanadium and nickel in the oils, and from chemical analysis for uranium in the oils.

Table 16. V/Ni & V/U ratios in ash of crude oils grouped by geologic age of reservoir rock

Age of Reservoir Rock	V/Ni	V/U
Cambrian	3.55	7,330
Ordovician	1.32	176
	2.17	22,200
	1.55	610
	3.66	22,000
	4.52	956
	3.20	13,300
Mississippian	3.44	10,000
	4.00	7,000
Pennsylvanian	4.47	42,500
	3.81	2,640
	1.55	7,650
	2.63	4,440
	1.74	6,000
	1.85	133,000
	4.13	3,800
	220.00	73,300
	4.88	5,330
	1.24	1,030
Permian	3.50	56,000
	5.26	9,300
	6.05	167,000
Triassic	4.38	7,570
	3.63	175,000
Jurassic	1.21	---
	.679	---
	1.48	6,170
Cretaceous	0.422	45,900
	.970	24,800
	.779	2,330
	.550	---
	.077	2
	.816	3,670
Tertiary	.054	4,100
	.041	778
	3.44	---

It is commonly known that porphyrins (metallo-organic complexes) are present in crude oils. Furthermore, previous investigators have identified vanadium and nickel porphyrins in crude oils. It is noteworthy in table 16 that the vanadium to nickel ratio has relatively small variation and, on the other hand, the vanadium to uranium ratio has very large variation. These data suggest that most of the vanadium and nickel in crude oils is present in organic complexes, and the major part of the uranium in crude oil is not present in organic complexes. This suggests that vanadium and nickel are probably present mostly as porphyrin complexes.

It is noteworthy that the V/Ni ratio varies from 1.21 to 6.05 (with one exception of 220.0) in oils from rocks of Cambrian to Jurassic age, and is (with one exception of 3.44) less than one in oils from rocks of Cretaceous and Tertiary age. The inference may be drawn that the vanadium porphyrin is more stable than the nickel porphyrin.

Linear correlation coefficients were determined for 21 samples of crude oil on which quantitative spectrographic determinations had been made and nitrogen percentages determined. The linear correlation coefficients are: (1) V content of ash to N content of oil is .6985, (2) V content to N content of oil is .8407, (3) Ni content of ash to N content of oil is .2019, (4) Ni content to N content of oil is .70871, (5) U content of ash to N content of oil is -.11733, and (6) U content of oil to N content of oil is .25664.

These data show that in crude oil the vanadium, and to a lesser extent the nickel, are associated with nitrogen and that uranium bears little direct relation to the nitrogen. Hence, most of the vanadium and nickel in crude oil may be present as nitrogenous compounds. A much smaller amount of uranium may be present as a nitrogenous compound. Inasmuch as porphyrins are nitrogenous compounds, it is inferred from these coefficients that a greater percentage of vanadium, a smaller amount of nickel, and an even smaller amount of uranium are present as porphyrin complexes.

The possibility of differential losses of metals during the ashing process is of major concern; hence, these data and inferences are tentatively offered until reliability of analytical data for each metal is determined.

A paper, "Uranium and other trace elements in crude oils of the western United States", by H. J. Hyden, was published in the Proceedings of the United Nations International Conference on the Peaceful Uses of Atomic Energy.

Geochemistry of uranium-bearing carbonaceous rocks

by

I. A. Breger and Maurice Deul

Studies of the carbonaceous sandstone ore from the AEC No. 9 mine, Temple Mountain, Emery County, Utah, were completed. Infrared analysis of the extract (0.09 percent) isolated from the ore shows it to be unrelated to petroleum. Ultimate analyses, studies of the yield of tar acids on distillation, infrared absorption analysis, and vacuum differential thermal analysis all provide evidence for the conclusion that the carbonaceous material is related to coal and not to petroleum.

A composite of carbonaceous pellets from the AEC No. 8 mine (Temple Mountain area) was ground in a ball mill with a mixture of kerosene and water to decrease the mineral content. In this manner the ash content of the material was reduced from 24.15 to 12.77 percent. Analysis of the organic concentrate, computed on a moisture- and ash-free basis, shows it to contain 74.7 percent carbon, 5.1 percent hydrogen, and by difference 20.2 percent oxygen, nitrogen, and sulfur. This composition is essentially the same as that of the carbonaceous material isolated from the sandstone ore (carbon, 76.5 percent; hydrogen, 4.9

percent; oxygen, nitrogen, and sulfur, 18.6 percent). This is not surprising inasmuch as the pelletal material merges or coalesces with the carbonaceous sandstone in many places.

The movement of coal extracts or colloids on a micro scale has long been recognized by coal petrographers; the carbonaceous material from the sandstone or pellets, however, is believed to be the first reported occurrence of such material on a macro scale. To confirm these conclusions, a number of samples of similar occurrences in the Colorado Plateau region were collected during the past field season and are now being studied. Information regarding the association of the carbonaceous material with the quartz grains and clay balls of the sediments in which it occurs may permit deductions regarding the nature of the ore-bearing fluid that deposited uranium and vanadium in the region.

The insolubility in common solvents for coal of carbonaceous matter associated with the sandstone ore is thought to result from cross-linkage of coal molecules by the alpha particles from the dispersed uranium and its daughter products. There is evidence that under certain conditions coalified wood of the Plateau can be increased in rank from lignite to bituminous depending on the nature of the uranium-coalified wood association and/or the concentration of the uranium. To investigate this matter, samples of coals and other carbonaceous substances were exposed in the Brookhaven pile for periods up to 10 days. Although significant increases in carbon content were noted as a result of the exposure, the changes in rank were small. New experiments of much longer duration are now being planned. Use of pile radiation as a source of low-temperature energy may be useful in simultaneous studies of the origin of coal.

Autoradiographic studies are being carried out on microtome sections of degraded wood that have been immersed in circulating solutions of uranium at

75° C. Observations are being made of changes in the cellular and chemical structure of the wood, and the areas of the wood where uranium concentrates. Similar experiments at 100° C are also underway. When degraded wood or sub-bituminous coal was treated with a solution of uranyl sulfate or chloride at 200° C for three days, the uranyl ion was reduced to uraninite. Although the coal was found to contain 33 percent U, most if not all of which was uraninite, the mineral had formed on the external edges of the coal fragments and not within the cell lumens or walls (Schopf, personal communication). Placing the experimental system under a pressure of about 2,000 psi prior to heating did not alter the results. New experiments have been designed in an attempt to obtain a product similar to the uraninite-bearing coalified wood of the Plateau. Such experiments will yield durther information on geologic conditions at the time the uranium was deposited.

Continued studies of a coalified log from the Maury glauconitic member of the Ridgetop shale shows that the contained rare earths are associated with carbonaceous matter.

During the report period a paper entitled "The organic geochemistry of uranium", by I. A. Breger and M. Deul, was published in the Proceedings of the United Nations International Conference on the Peaceful Uses of Atomic Energy. A paper by I. A. Breger, M. Deul, and R. Meyrowitz, "Geochemistry and mineralogy of a uraniferous subbituminous coal", was published in Economic Geology, v. 50, pp. 610-624; and a paper by I. A. Breger, "Radioactive equilibrium in ancient marine sediments", was published in Geochimica et cosmochimica acta, v. 8, pp. 73-83.

URANIUM IN PHOSPHATE

Northwest phosphate

Phosphate investigations in northwest Utah, northeast Nevada, and south-central Idaho

by

T. M. Cheney, W. C. Gere, C. E. Dobbin, D. VanSickle, and E. Richardson

Investigations during the summer and fall of 1955 resulted in the discovery of about 75 miles of outcrop of phosphate-bearing formations (fig. 59) in northwestern Utah, south-central Idaho, and northeastern Nevada.

The thickest and most phosphatic of these deposits appear to be those in the Leach Mountains (locality 3, fig. 59) near Montello, Nevada. There the phosphatic shale member, which was exposed by trenching with a bulldozer, is about 680 feet thick. Overlying the phosphatic shale are 2,520 feet of beds roughly equivalent to the Rex chert member of the Phosphoria in southeastern Idaho. These beds in turn are overlain conformably by shales of Triassic age. A cherty phosphate rock at the base of the phosphatic shale member averages 28 percent P_2O_5 and is 2.8 to 3.2 feet in thickness. About 80 feet above the base of the shale is a zone of interbedded calcareous phosphate rock and mudstone that is 10.3 feet thick and averages 17 percent P_2O_5. The lower 3.7 feet of this unit averages 22 percent P_2O_5 and the lower 5.5 feet averages 20.5 percent P_2O_5. Other phosphatic beds are present but are thinner and lower in grade. The uranium content of the highest grade phosphate rocks ranges from 0.002 to 0.004 percent and is thus conspicuously

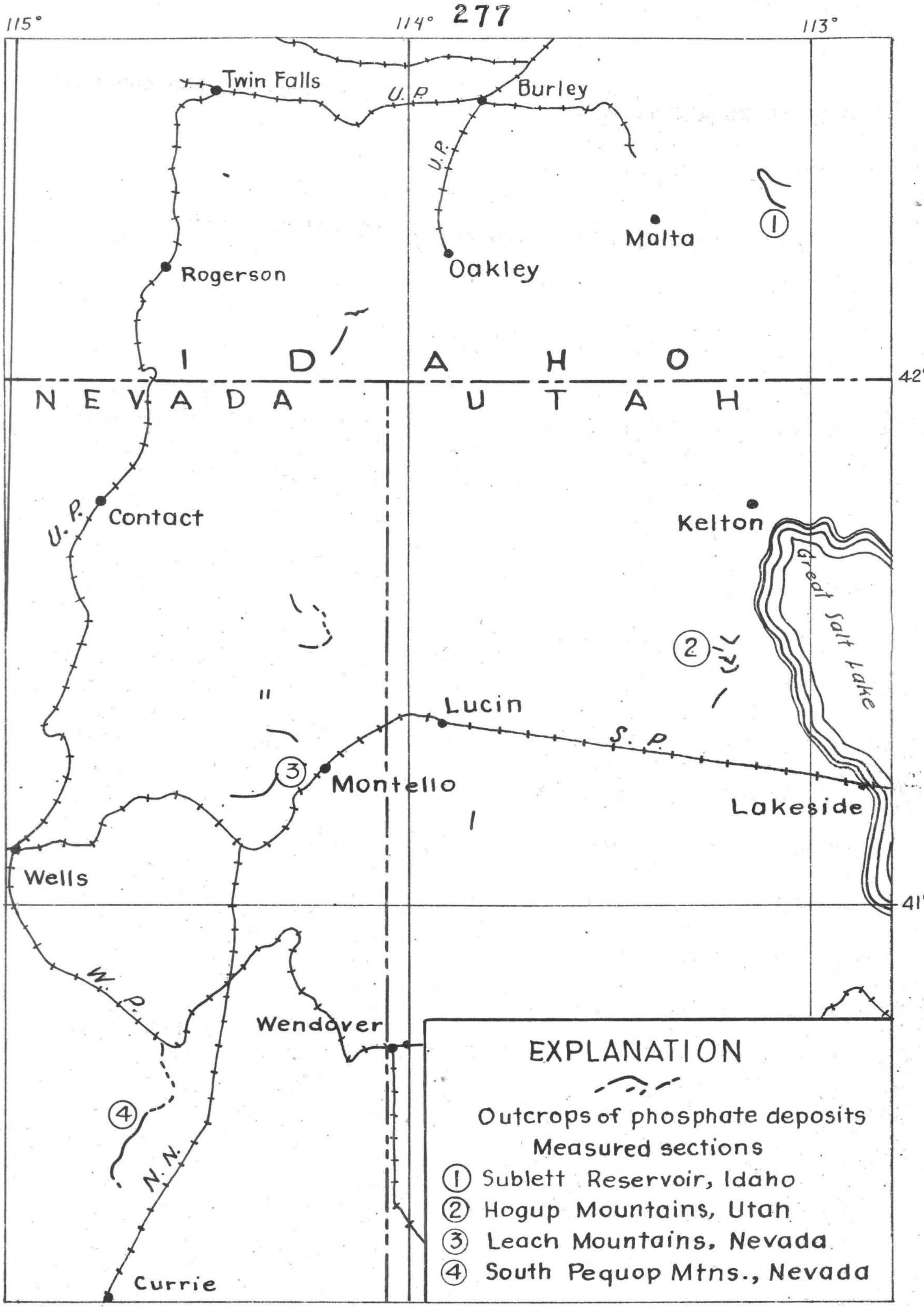


FIGURE 59.—OUTCROPS OF PERMIAN PHOSPHATE DEPOSITS IN NORTHWEST UTAH, NORTHEAST NEVADA, AND SOUTH-CENTRAL IDAHO

0 10 20 30 40 50 Miles

lower than that of rocks of equivalent phosphate content in the phosphatic shale to the east.

Geology of the Snowdrift Mountain quadrangle, Idaho

by

E. R. Cressman

Mapping in the Snowdrift Mountain 7½-minute quadrangle of southeastern Idaho was essentially completed during the 1955 field season, and about 15 square miles were mapped in the adjacent 7½-minute quadrangle to the west. The area was mapped by Mansfield (U.S.G.S. Prof. Paper 152, pls. 6, 7) as part of the Brannock overthrust sheet.

The pre-Tertiary sedimentary rocks exposed in the Snowdrift Mountain quadrangle range in age from Mississippian to Early Cretaceous and total 8,500 feet in thickness. The Paleozoic rocks consist in general of competent limestone and sandstone whereas the Mesozoic section consists of incompetent shale and shaly limestone alternating with competent limestone and sandstone.

The structure consists of several north-northeast trending folds in the lower Triassic and older rocks and a north-northeast trending zone of thrusts near the eastern margin of the quadrangle that have brought the older formations in contact with Jurassic and lower Cretaceous rocks to the east. Axial planes generally dip steeply west, and a few of the folds are overturned to the east. The thrusts dip west at angles of from 45 to 80 degrees. Several transverse faults extend from the thrust belt 2 or 3 miles westward into the thrust block where they die out in the upper Paleozoic strata. Although the thrust belt was mapped previously as part of the Brannock overthrust, relations within the quadrangle can be adequately explained by high-angle thrusting on the east limb of a large overturned anticline.

Cenozoic sedimentary deposits in the quadrangle probably range in age from Late Tertiary to Recent and together with the associated physiographic features record a complex history of erosion, valley filling, and re-excavation.

Spectrographic analyses of samples of the phosphatic members of the Phosphoria formation

by

Bond Tabor and R. A. Gulbrandsen

During the past several years approximately 1,200 samples of the phosphatic members of the Phosphoria formation have been semiquantitatively spectrographically analyzed by the U. S. Geological Survey laboratory in Washington, D. C., and by the U. S. Bureau of Mines laboratory in Albany, Oregon. Preliminary study of these analyses shows that the concentrations of minor elements in the phosphatic shale members of the Phosphoria formation are typical of shales as a whole, with some noteworthy exceptions. Cd occurs in modal concentration 1000 fold greater, Ag 100 fold, and Cr, Ni, Sc, and Y 10 fold greater than their respective average values in shale as given by Rankama and Sahama (Geochemistry, 1950, p. 226). Ti occurs in concentration about 10 fold less than that in shales generally.

The phosphatic shale members are composed of three principal compositional rock types--phosphorite, carbonate rock, and quartz-silicate rock. Of these, quartz-silicate rock contains Be, B, Ti, Zr, and Sn in greater concentration than in other types; phosphorite contains Cd and Sr in greater concentration than in other rocks; and carbonate rock contains no abnormal concentration of minor metals.

The content of organic matter in all rocks shows a positive correlation with Cr, V, Mo, Zn, and Ag.

Southeast phosphate

Exploration

by

W. L. Emerick

Radioactivity logging of drill holes

A total of 57 holes aggregating 5,402.4 feet were logged by the gamma-ray unit during the period. Fourteen of the 57 holes were drainage or observation wells in Orange, Orlando, Polk and Hillsborough Counties logged for geologic information on the phosphate-bearing Hawthorn formation. The cumulative total for the gamma-ray unit is 3,650 holes totalling 133,575 feet. Calibration work on the gamma-ray unit was resumed in October after a summer recess.

Geologic studies

Report work on the aluminum phosphate zone in the Clarke James-South Ridgewood tract of the Davison Chemical Company was suspended during the period pending additional studies of the zone in other parts of the district. Final field work depends upon the drilling of additional holes in the southern part of the tract for gamma-ray data.

Field and laboratory studies on drill core from the Lakeland Highlands area of the land-pebble phosphate district were made during the period; gamma-ray logs and chemical assays indicate an aluminum phosphate zone of minable thicknesses with average to above-average uranium and aluminum content. The aluminum phosphate zone in the area is a clayey phosphatic sand with only minor fragments or thin layers of vesicular sandstone.

Economic geology of the land-pebble phosphate district

by

J. B. Cathcart

Compilation of data on the uranium and phosphate content of the land-pebble phosphate deposits of Florida is continuing, and all of the data on the uranium and phosphate content, thickness, and tonnage for the aluminum phosphate zone has been compiled in rough draft form. Data on the uranium content of the pebble and concentrate fractions (the phosphate products) of the calcium phosphate zone are being compiled on base maps with a scale of one inch to one mile, and will be assembled finally on 15-minute quadrangle sheets. For each quadrangle there will be a geologic map, a subsurface structure contour map drawn on the contact of the matrix with the top of the Hawthorn formation, an isograde map of the uranium content of the pebble and of the concentrate fractions of the matrix, an isopach map of the aluminum phosphate zone, and an isograde map of the uranium content of the aluminum phosphate zone.

A study of the relation of size distribution, phosphate and uranium contents in the aluminum and calcium phosphate zones is shown in figure 60. This bar chart shows the weight percent distribution of the size products, and the phosphate and uranium distribution, in percent, in the size products.

In the calcium phosphate zone, or matrix, although 30 percent of the material mined is recovered as merchantable products, the coarse fraction contains 61 percent of the total phosphate and 60 percent of the total uranium. In the aluminum phosphate zone, however, the finest fraction, or slime, is about 33 percent by weight of the total, but contains 68 percent of the total phosphate, and 72 percent of the total uranium. The coarsest (pebble) fraction of the aluminum phosphate zone contains only about 5 percent of the total uranium and phosphate.

Two papers on the phosphate deposits of Florida were published in the Proceedings of the United Nations International Conference on the Peaceful Uses of Atomic Energy: "Distribution and occurrence of uranium in the calcium phosphate zone of the Land-pebble district of Florida", by J. B. Cathcart, and "The aluminum phosphate zone of the Bone Valley formation and its uranium deposits", by Z. S. Altschuler, E. R. Jaffe and Frank Cuttitta.

Phosphate deposits and their "leached zones" in the northern part of Florida

by

G. H. Espenshade

Area of abnormal radioactivity south of Ocala

Analytical work was completed on the surface and auger drill samples from an area of abnormal radioactivity associated with phosphatic Miocene outliers south of Ocala. The radioactivity anomalies are associated both with pellet phosphorite composed of apatite pellets, sand, and clay, and with very porous, leached phosphatic sandstone consisting of aluminum phosphate minerals and

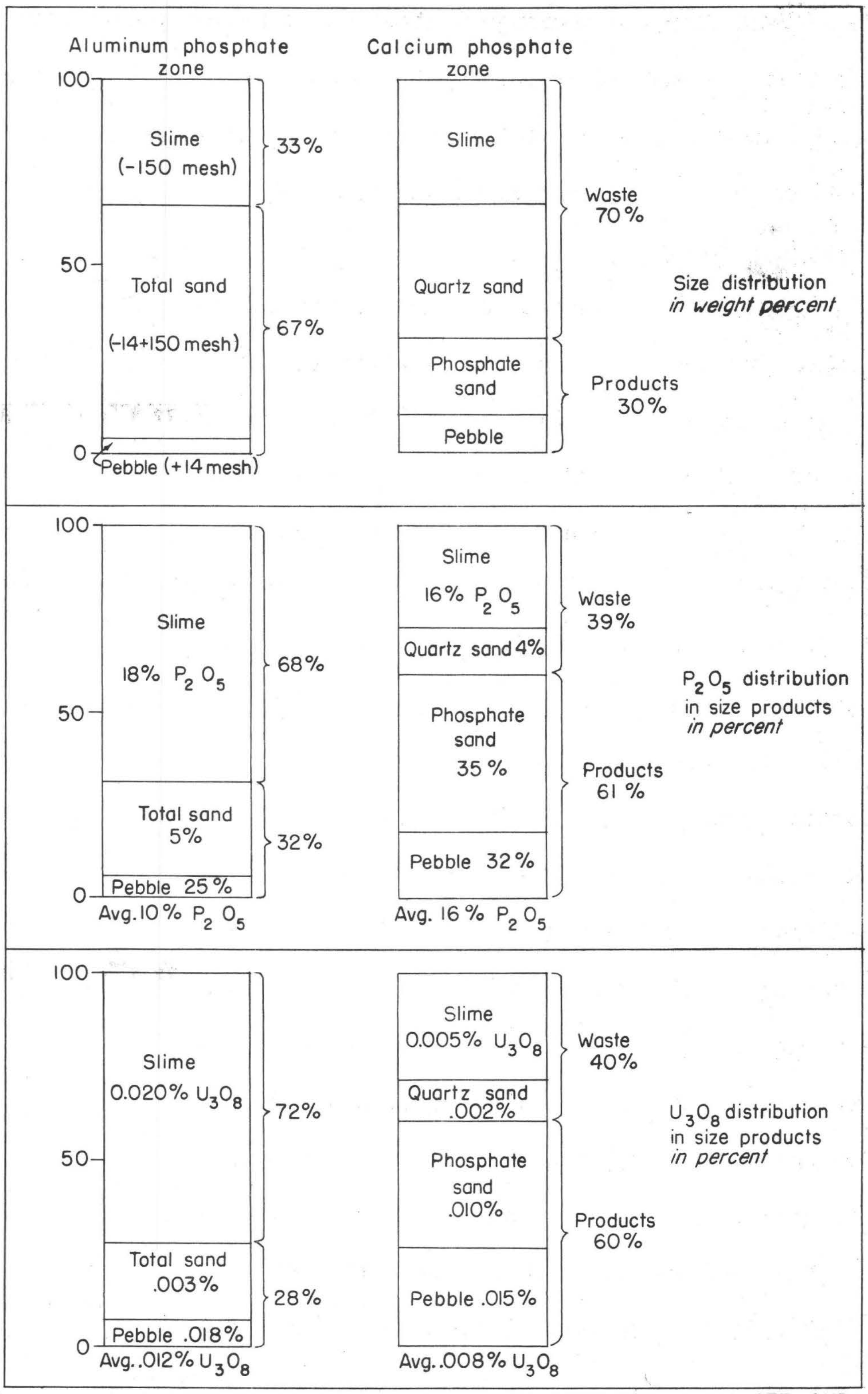


FIGURE 60 COMPARISON OF DISTRIBUTION OF SIZE PRODUCTS, PHOSPHATE, AND URANIUM IN THE ALUMINUM AND CALCIUM PHOSPHATE ZONES, LAND – PEBBLE PHOSPHATE DISTRICT, FLORIDA.

quartz, and derived from the thorough weathering of pellet phosphorite. Samples of pellet phosphorite contain up to about 20 percent P_2O_5, and from .004 to .022 percent U; samples of the leached phosphatic sandstone contain from 12.7 percent to 16.8 percent P_2O_5, and from .019 to .023 percent U.

Hardrock phosphate district

Investigation of the hardrock phosphate deposits was continued by means of petrographic studies, compilation of analytical data, review of drilling records and geologic interpretation of aerial photographs.

Samples of phosphatic sand overburden contain from 50 to 95 percent quartz (average about 80 percent), 0.3 to 9.5 percent P_2O_5, and .001 to .005 percent U. The calculated uranium content of the non-quartz portion ranges from .005 to .035 percent. X-ray analyses of the minus 250-mesh fractions of several samples of phosphatic sands show kaolinite, millisite, crandallite (pseudowavellite), and wavellite.

The common occurrence of phosphate pellets in these deposits, and other field evidence, supports the conclusion that these secondary deposits were derived from the weathering of Miocene phosphorite, perhaps very similar to the Bone Valley phosphorite, that formerly extended over the area. The hardrock deposits were evidently formed by very thorough leaching of phosphate, and its reprecipitation in limestone by descending ground waters, combined with the mechanical mixture of phosphatic material that slumped into solution cavities. The phosphatic sands overlying these deposits are probably the residuum of a widespread sandy bed that may have been very similar to the upper, sandy part of the Bone Valley formation.

URANIUM IN NATURAL WATERS

by

P. F. Fix

Recent investigations by the AEC, private groups and individual prospectors confirmed the suggestion in TEI-540 that the Karnes County area of Texas was anomalously uraniferous and merited careful consideration. Laboratory analysis of waters collected from these areas continued, followed by correlation of the resultant data as it became available. Although the results are not complete enough for quantitative evaluation, they show clearly that, qualitatively, natural waters can be used most advantageously in geochemical prospecting for uranium.

Preliminary investigations suggested that the autunite type deposits in the vicinity of Spokane, Washington are suitable for checking the relationships of uranium in natural water to associated deposits. Sufficient field studies of this type have now been completed to permit summary results and evaluation. No further field work is contemplated beyond that required to obtain minor details that may be needed to fill in the final report to be completed during the ensuing fiscal year.

A paper, "Geochemical prospecting for uranium by sampling ground and surface waters", by P. F. Fix was published in the Proceedings of the United Nations International Conference on the Peaceful Uses of Atomic Energy.

URANIUM IN PLACER DEPOSITS

Central Idaho placers

by

D. L. Schmidt

The petrographic study of the bedrock of the Cascade-Bear Valley placer area was completed during the report period, and one month was spent in field study of petrogenetic problems in the Hailey uranothorite placer area.

The Cascade-Bear Valley placer area includes the western border of the Idaho batholith. Part of the border zone consists of hornblende-biotite gneiss with relatively abundant allanite and sphene. Monazite and ilmenite are rare or absent. The gneisses grade eastward into an ill-defined belt of structureless leucocratic granite rock without allanite and sphene but with monazite and ilmenite as common accessories. This granitic rock is the source of the placer monazite. Several lines of evidence indicate that the structureless granitic rock was produced by replacement of rock similar to the border zone gneisses, and that the monazite and ilmenite were formed by crystallization of substances released by the destruction, during replacement, of the sphene and mafics of the gneisses. Other hypotheses for the origin of the monazite cannot be eleminated, however, and many of the broad petrogenetic problems are still unsolved.

The source rock of the Hailey placers is a body of intrusive quartz monzonite in which the uranothorite is a pyrogenic accessory. The quartz monzonite is cut by a system of faults and fractures which in the Hailey Gold Belt carry quartz veins with gold, silver, uraninite, and base metals.

The veins are characteristically bordered by broad zones of wall-rock alteration. The uranothorite in these zones is altered and is somewhat lower radiometrically than the uranothorite in the quartz monzonite outside of the zone of alteration. This and other lines of evidence suggest that the uraninite of the veins was derived from alteration of the pyrogenic uranothorite.

A paper, "Uranium and thorium-bearing minerals in placer deposits of Idaho", by J. H. Mackin and D. L. Schmidt, was published in the Proceedings of the United Nations International Conference on the Peaceful Uses of Atomic Energy.

AIRBORNE RADIOACTIVITY SURVEYING

by

W. J. Dempsey

Approximately 22,500 traverse miles were flown in the study of the correlation between airborne radioactivity data and areal geology in Alaska, Maine, Michigan, Montana, Wyoming, Nebraska, Kansas, and Texas.

In conducting these surveys considerable care was taken to measure instrument and cosmic background drift. The background at flight elevation along a test line was measured at the start, during, and at the completion of each day's flight. Response of the equipment to a radium source and a cesium source was measured at the start, during, and at the completion of each day's surveying. Results of these measurements have not been completely analyzed, but in the Findlay, Ohio, area an average drift of 20 c/p/s per hour downward was determined from test line flying. The average background from all sources along this test line was about 400 c/p/s. Insufficient evidence is at hand to indicate that this drift is linear. All of the flights were from approximately 7:30 A.M. to 1 P.M. and it is conceivable that this is not an instrumental drift but represents a diurnal variation, possibly associated with early morning inversion layers. Evidence contradictory to this is found in the cesiumm source measurements, which also show a progressive lesser counting rate during the day. Results from the radium source indicate either that there is no drift or that the results are inconclusive. Studies of the drift problem will be continued.

Preliminary analysis of the airborne radioactivity results indicates that significant background differences of approximately 50 c/p/s are sustained along large segments of the records and that these background differences continue across several flight traverses. Contouring of the airborne radioactivity results is being done for surveys in Kansas, Wyoming, and Texas in order to study measured radioactivity background variations with respect to the surface geology.

The most significant background changes were observed in Karnes County, Texas where a sharp change of from 220 to 400 c/p/s across several miles was seen at 500 feet. This same background difference appeared as a change of from 200 c/p/s to 300 c/p/s at 750 feet. Magnetic intensity was measured but no significant anomalies were observed in the Texas survey.

The following is a summary of radioactivity surveys completed from June 1 to November 30:

State	No. on map	Area	County	Traverse miles
Ohio	1	Findlay	Wood	175
"		"	Hancock	1,765
"		"	Seneca	200
"		"	Wyandot	90
"		"	Allen	450
"		"	Putnam	120
"		"	Hardin	140
California	2	Taft-McKittrick	San Luis Obispo	220
"		"	Kern	1,045
Alaska	3	Red Bay (Prince of Wales Island)		200
"	4	Kasaan Bay (Prince of Wales Island)		150
"	5	Ugashik (near Lake Beckerooff)		150
"	6	Russian Mountains (near Anicak)		400
"	7	Kahiltna (between Kahiltna River and Yentna River)		210
"	8	Tanana		400
Michigan	9		Marquette	2,100
"			Baraga	152
"			Dickinson	510
"				

State	No. on map	Area	County	Traverse miles
Montana	10	Townsend Valley	Broadwater	1,825
"		"	Jefferson	230
"		"	Lewis & Clark	270
"		"	Gallatin	200
"	11	Bozeman	Gallatin	1,600
"		"	Madison	275
"		"	Jefferson	175
"		"	Broadwater	50
"	12	Plentywood	Sheridan	567
Maine	13	Chamberlain	Piscataquis	1,990
"		"	Aroostook	110
"		"	Penobscot	100
"	14	Eastport	Washington	165
Nebraska	15	Scotts Bluff	Scotts Bluff	585
"		"	Sioux	285
South Dakota	16	Black Hills	Pennington	50
"		"	Custer	50
"	17	________	Lawrence	1,050
Wyoming	18	Saddle Back Hills	Carbon	442
"	19	Esterbrook	Albany	200
"		"	Converse	160
"	20	________	Washakie	550
Utah & Wyoming	21	Mesa Verde	Daggett & Sweetwater	800
Colorado	22	North Fort Collins	Larimer	220
Vermont	23	Walcott		50
Texas	24		Oldham	170
"			Potter	330
"	25	Texas Coastal Plain (centering around Karnes)		5,100
Kansas	26		Barton	110
"			Ellsworth	340
"			Rice	100

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

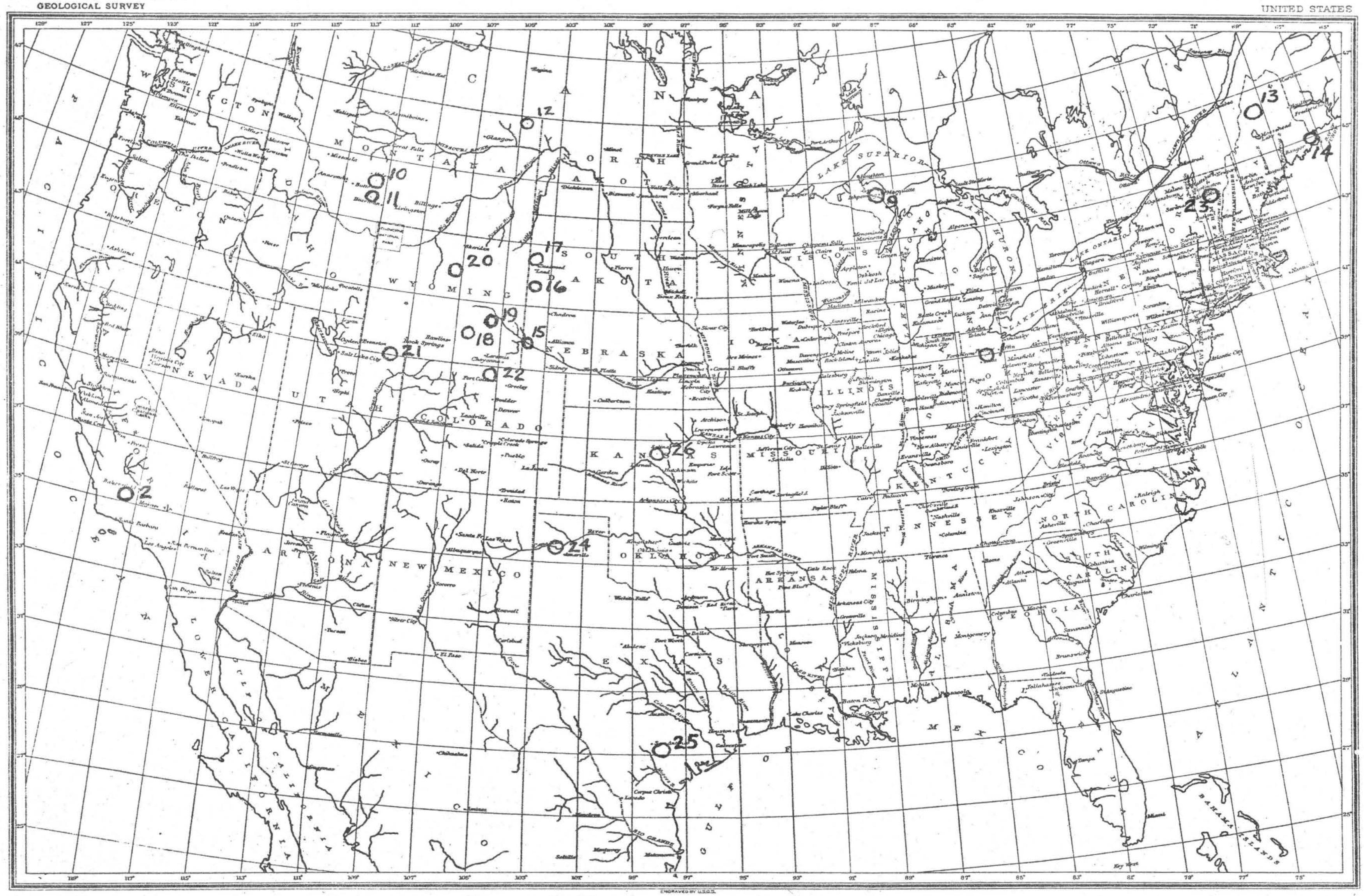


Figure 61. RADIOACTIVITY SURVEYS COMPLETED IN THE UNITED STATES, June 1 - November 30, 1955

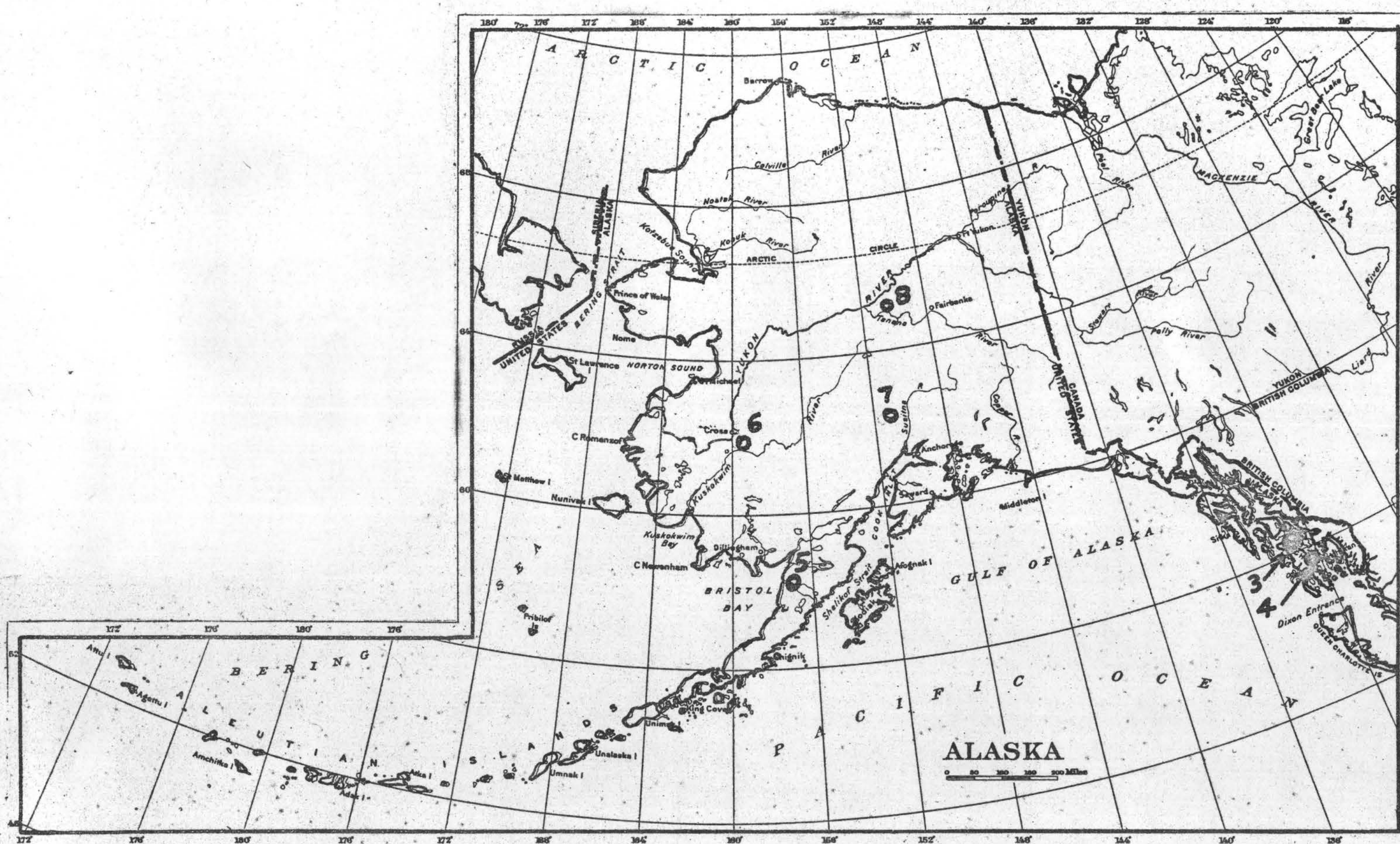


Figure 62. RADIOACTIVITY SURVEYS COMPLETED IN ALASKA, June 1 - November 30, 1955

URANIUM IN ALASKA

by

J. J. Matzko

No uranium occurrences of commercial grade were found in studies of sedimentary rocks of Cretaceous and Tertiary age and granite of Mesozoic age, east of Kotzebue Bay, west-central Alaska. The highest field reading obtained was 0.050 mr/hr from a gneissic granite on Kogoluktuk River.

An airborne radioactivity anomaly one-half mile west of Circle Hot Springs, Circle quadrangle, is apparently due to radioactive accessory minerals such as zircon and sphene in the granite.

The Bokan Mountain-Kendrick Bay radioactive area, Prince of Wales Island, Dixon Entrance quadrangle, discovered by airborne radioactivity reconnaissance by two prospectors, contains what appears at the present to be the best deposit of potential commercial grade uranium in Alaska. Primary and secondary minerals identified so far are thorianite, brannerite, bassetite, and novacekite. Preliminary examinations indicate that the radioactive minerals occur, (1) disseminated in the metasediments, (2) concentrated locally along the joints, and (3) along a prominent set of east-west trending structures.

The results of investigations made in previous years for radioactive deposits in Alaska have been published in the following U. S. Geological Survey Bulletins: 1024-A, "Radioactivity investigations in the Cache Creek area, Yentna district, Alaska, 1945", by G. D. Robinson, Helmuth Wedow, Jr., and J. B. Lyons; 1024-B, "Investigations for radioactive deposits in southeastern Alaska", by W. S. West and P. D. Benson; and

1024-C, "Radioactivity investigations in the Ear Mountain area, Alaska, 1945", by P. L. Killeen and R. J. Ordway.

ANALYTICAL SERVICE AND RESEARCH ON METHODS

Sample control and processing

by

J. J. Rowe

During the six-months period covered by this report, the number of samples received increased slightly. Work requests continued the previously noted trend toward analyses of more varied and difficult nature, and showed an increasing interest in geologic interpretations.

Although backlogs have increased slightly, they are well balanced considering the nature and type of work required. A study of the laboratory services and the functions of the Sample Control unit in providing more efficient control and routing of laboratory production has been started. This study will serve as a guide to the laboratories in future operations.

In the Denver laboratory improvements were made in the processing of samples to avoid contamination from steel grinding plates. Crusher jaws were redesigned to provide a minus-1/8-inch product, which is then further processed by Braun grinders equipped with ceramic plates.

Radioactivity

Analysis and services

by

F. J. Flanagan and J. N. Rosholt

During the report period 9,447 radioactivity determinations were made, 4,640 in the Washington laboratory and 4,807 in the Denver laboratory.

Table 17.--Analytical service and sample inventory, June 1, 1955 - December 1, 1955

Project or source	DETERMINATIONS Chemical U	Chemical Others	Radioactivity	Spectrographic Samples	X-ray	SAMPLES On Hand June 1	Rec'd June - Dec.	Completed Jun.-Dec.	On Hand Dec. 1
Washington laboratory									
AEC	236	41	787	48	100	17	975	936	56
Colorado Plateau ss.	---	---	---	---	---	---	531	---	531
Sandstone-Other than Plateau	8	9	8	142	11	---	481	158	323
Carbonaceous Rocks	237	178	422	181	15	106	354	336	124
Southeast Phosphates	742	1,020	2,566	---	14	1,793	1,429	3,044	178
Northwest Phosphates	323	2,023	927	---	---	611	436	927	120
Alaskan	35	10	7	21	17	7	60	51	16
Public Samples	500	9	641	30	113	296	2,813	2,957	152
Mineralogical Projects	90	354	9	256	245	179	802	617	364
Geochemistry of U	1,177	167	36	224	209	438	1,102	1,151	389
Miscellaneous	237	677	218	364	127	204	893	872	225
Total	3,585	4,488	5,621	1,266	851	3,651	9,876	11,049	2,478
Denver laboratory									
AEC	1,600	484	2,212	186	47	430	2,588	2,713	305
Plants and Soils	298	523	50	8	---	199	2,229	225	2,203
Colorado Plateau ss.	527	2,397	788	872	19	1,561	1,638	1,434	1,765
Sandstones-Other than Plateau	479	529	646	81	85	437	1,383	1,348	472
Veins, Igneous Rocks	193	414	192	192	33	490	758	1,036	212
Carbonaceous Rocks	190	296	214	213	39	392	451	446	397
Phosphates	18	29	130	18	5	13	155	155	13
Waters	583	662	---	12	---	67	752	605	214
Public Samples	48	3	101	13	1	20	108	78	50
Geochemistry of U	6	3	3	6	2	40	22	6	56
Miscellaneous	94	95	285	115	72	403	1,140	932	611
Total	4,036	5,435	4,621	1,716	303	4,052	11,224	8,978	6,298
Grand Total	7,621	9,923	10,242	2,982	1,154	7,703	21,100	20,167	8,776

At Denver 29 low-level alpha particle equivalent uranium determinations were made as well as 177 radiochemical determinations, which included analyses for Th^{232}, Th^{228}, Th^{230}, Pa^{231}, Ra^{226}, Ra^{223}, and Pb^{210}. In addition, 27 very low Ra^{226} determinations were made using the radon train apparatus. In an attempt to definitely establish the half-life of Th^{232}, further measurements of the specific activity of Th^{232}, Th^{228}, Ra^{224} and Bi^{212} isotopes in the Th^{232} decay series were continued. A great interest is being shown by geologists in disequilibrium studies in both uranium and thorium ores and in concentrations of their decay products. Requests for this type of work require radiochemical analyses for most of the isotopes listed above.

The decrease in radioactivity determinations at the Washington laboratory as compared with the previous six-months period is due partly to an increase in background count which for a time precluded the use of the unshielded coaxial counting technique. The unshielded background, which was from 27 to 30 c.p.m. when the laboratory was opened in 1949, increased to from 42 to 47 c.p.m. during the past year. This is due, it is believed, to gradual accumulation of dust on the walls and ceiling. Occasionally, when high-grade uranium or thorium ores are brought into the laboratory for study, background in the counting room rises to as much as 65 to 75 c.p.m. To eliminate this high and variable background the hinged doors of horizontal lead shields were removed and the open end placed over a 3-inch hole bored in the upper tier of the counting tables. The coaxial holder filled with sample is now raised through the hole in the table into the interior of the lead chamber during the counting period. By this procedure the background count has been reduced to a range of 19 to 23 c.p.m.

In the Denver laboratory a study of voltage variations was conducted primarily to increase the stability of several types of electronic laboratory equipment and provide a foundation for improving instrumental accuracy at the lower limits of analytical measurements. A third automatic sample changer unit for use in radiochemical analysis measurements was placed in operation. Work started on the design and fabrication of a gas-chamber type of alpha particle scintillation counter for use in the measurement of radon isotopes in the uranium and thorium series. Preliminary measurements using this general type of instrument were made during the determination of the magnitude of Rn^{220} emanation from thorium nitrate salts.

Research

Thorium analysis

Experiments were performed to determine methods of loading nuclear emulsions. A satisfactory solution of the problem appears to have been found by loading a known area of the nuclear emulsion with a known volume of a solution containing thorium and uranium. Preliminary study of the loaded plates does not indicate that diffusion of the solution occurs beyond the boundary of the controlled area. The distribution of the tracks within the controlled area appears to be quite uniform.

The three-channel gamma-ray spectrometer is about 95 percent complete. It is expected that this instrument will aid the determination of thorium and uranium in zircon and other minerals.

Half-life measurements were completed on three $Th(NO_3)_4$ samples known to be in equilibrium, and on one old thorite sample. The measurements were made by a radiochemical analysis and alpha counting of

Bi^{212}-Po^{212} and also by measuring the specific alpha activity of Tl^{208}. The precision of each method is better than one percent but the results differ by about 7 percent. The radiochemically determined λTh^{232} is 1.45 x 10^{-18} sec $^{-1}$ whereas the λTh^{232} determined from the alpha activity is 1.55 x 10^{-18}. Work is proceeding to determine the cause of the discrepancy between the two methods.

Equilibrium studies

Preliminary studies on measuring the thorium and uranium content of ores which are out of equilibrium were undertaken on samples from Wyoming. It is planned to do further work on these samples and establish a method of analysis.

Spectrography

Analysis and services

by

A. T. Myers and C. L. Waring

During the report period 1,125 samples for a total of 64,800 determinations were analyzed at the Washington laboratory, and 1,735 samples for a total of 98,544 determinations were analyzed at the Denver laboratory. Many of the routine analyses included in the above totals were analyzed by the semiquantitative method, reported to one-third of an order of magnitude. A wide variety of geologic materials were analyzed, including igneous rocks, vein material, uranium and other ore pulps, sediments (including shales, lignites, and phosphates), terrestrial and marine plant ashes, crude oil ashes, asphalts and brine, and water residues. As in the past, many uranium-bearing and other minerals were analyzed.

An increasing number of multiple oxides such as pyrochlore, samarskite, columbite, and tantalite, as well as other complex minerals like allanite were analyzed. These minerals, high in rare earths and other refractory elements that are difficult to analyze, have been submitted to aid X-ray and mineralogic analyses as well as to assist field geologists directly.

In addition to the usual sample load of ores, igneous rocks, and sediments, an increasing interest developed in the mineral type of sample. This is emphasized because it requires modification and improvement of the usual routine techniques, frequently making custom, rather than routine procedures necessary.

A paper, "A new ceramic buckboard and muller", by H. Bloom and P. R. Barnett, was published in Anal. Chem. v. 27, p. 1037, June, 1955.

Research

by

C. L. Waring

Lead age method

Guided by service requests studies were made to broaden the application of the spectrographic method for the determination of lead in the Larsen age procedure. The lead in four monazite samples was determined using the new monazite standards and the results compared with the figures obtained with the zircon standards. Agreement was good in all cases. Work is in progress in an attempt to explain why the spectrographic results on one sample of Mountain Pass monazite do not check with the results obtained by other methods.

The lead method normally used in the determination of lead in zircon (Larsen age method) was applied to granite and diabase standards. and found to be in agreement with the published averages.

Controlled atmosphere experiments

The development of a satisfactory method for the suppression of CN bands in the course of spectrographic work was concluded. Work that had been done previously included the design of a gas "jet" which possessed simplicity of operation and effectiveness in suppressing CN bands in the carbon arc. The residual CN interference was found to come from N_2 impurity in the gases used and from air entering the arc column because of turbulence in the gas flow. Sufficient reduction of CN band intensity is possible with the "jet" to remove most interference and make unwarranted the use of a more elaborate "jet" or gas chamber.

Reproducibility and line intensity tests were made by using three different kinds of rock samples which were arced in triplicate. Each series of tests was made in CO_2, He-O_2, flowing air, and still air. On the basis of these tests, the CO_2 atmosphere was found to afford the best average results. This and earlier experimentation resulted in the choice of CO_2 as the most satisfactory gas for use in the course of routine qualitative and semiquantitative spectrographic analyses.

Rapid scanning microphotometer

For the semiquantitative determinations, visual estimates are made aided by reference to standard plates. This may be done with an eyepiece or with greater precision with an optical comparator. Improved quantitative results with photographic recording are obtained by the use of a recording microphotometer. The commercially available instruments are too slow for many applications in which the precision exceeds errors elsewhere in the procedure, such as variable matrices and lack of internal standard. A direct reading microphotometer was rebuilt to make a recording microphotometer in which high precision is compromised in favor of scanning speed. A 10-inch spectrum on the new instrument may be scanned in 2 minutes. A direct reading Jarrell-Ash microphotometer was used for this purpose; the following changes and additions were made: (1) a plate carriage drive by means of an accurate screw and synchronous motor was installed, (2) a vacuum type, photoelectric cell was installed, and (3) a Brush oscillograph and amplifier attached for recording. This produces traces of spectra 4 cm high (intensity scale) and 60, 300, or 1500 cm long (wavelength scale) depending upon the paper speed used.

"An application of microphotometric scanning", by C. L. Waring, Mona Frank, and A. M. Sherwood, was published as U. S. Geological Survey Bulletin 1036-E in June 1955.

Infrared spectroscopy

by

R. G. Milkey

Services

Some typical materials analyzed by infrared spectroscopy included the organic extract of a limestone material, an oil sample from Alaska, the products of oxidation of spruce after digestion with uranyl sulfate, and a sample of iron bacteria precipitated from aqueous solution. The spectra of these materials were inspected for the types of unit structures such as hydroxyl, carbonyl, methyl and methylene, and aromatic or aliphatic groupings, and this information was added to the growing catalogue of data to be used to ascertain the origins of such naturally occurring materials.

Other organic samples included the products of the reduction of vanadate with glucose, lignin, lignite, and dextrose, which were analyzed for the types of reduction products obtained.

Samples of ghassoulite from Morocco were analyzed for comparison with the spectra of stevensite, and the similarity of structures of these minerals was corroborated. Samples of carbonate fluorapatite were analyzed to obtain information pertaining to structure; the spectra of carbonate fluorapatite contain distinctive absorption peaks which do not appear in the spectra of normal fluorapatite. They provide definite evidence that the carbonate in carbonate fluorapatite is not present as a separate phase of calcite or aragonite. Additional samples were analyzed to provide process control of an industrial liquid-liquid extraction process operated for the Atomic Energy Commission.

Methods development and basic studies

For purposes of improving analytical techniques, the following new equipment was acquired: (a) a high-pressure die for making potassium bromide windows, (b) a dental amalgamator, which disperses mechanically the powdered sample throughout the dispersing medium, and (c) the horizontal-stage motor-driven grinding wheel which facilitates the grinding of salt windows. Special liquid sampling cells were designed utilizing silver chloride windows; these will permit the analysis of many types of aqueous solutions.

Various research studies of interest in the field of infrared spectroscopy were carried on concurrently with the service work, including a comprehensive survey of the infrared absorption of the silicates, analysis of all available synthetic and naturally occurring vanadate compounds, a study of the infrared absorption due to hydroxyl and to molecular water, and analysis of aqueous solutions of various complex ions.

Chemistry

Analysis and services

by

Irving May and L. F. Rader, Jr.

During the report period a total of 15,426 chemical determinations were made, 6,819 at the Washington laboratory and 8,610 at the Denver laboratory (table 18). Approximately 58 percent of the determinations were for elements other than uranium, and the increasing demand for the more time-consuming analyses is evidenced by the fact that in the Denver laboratory alone, a total of about 1,000 more determinations were made for Se, As, F, S, and P than were requested during the previous period.

In the Washington laboratory a study of the flame photometric determination of calcium in phosphate rocks was initiated during this report period. This resulted in development of a tentative procedure which will be tested on a group of representative samples.

An apparatus was assembled for the isolation of carbon from rocks as barium carbonate. Carbon isotope ratios will be determined elsewhere on the carbon isolated from these samples.

A bank of gas-heated glass stills was assembled for the determination of fluorine. The compact arrangement of the unit reduces fatigue for the analyst.

Adaptation and development of methods applicable to particular problems of analysis continued. At the Denver laboratory a new volumetric method for determination of uranium was developed for routine determinations on ore

Table 18. Breakdown of completed determinations, Washington and Denver laboratories, June 1 - November 30, 1955

Type of Analyses	No. of Analyses	Type of Analyses	No. of Analyses
Uranium	6,468	Silicon	47
Vanadium	953	Carbon (micro)	54
Calcium carbonate	455	Arsenic	233
Calcium	330	Sodium	61
Gold	89	Potassium	62
Silver	89	Molybdenum	7
Copper	419	Magnesium	41
Lead	73	Rare earths	31
Antimony	11	Strontium	30
Zinc	70	Boron	30
Iron	626	Lithium	37
Manganese	62	Carbon dioxide	35
Phosphorus	1,318	Organic matter	248
Thorium	22	Acid insoluble	761
Aluminum	246	Ash	376
Fluorine	300	Dissolved solids	39
Selenium	572	pH	689
Sulfur	215	Miscellaneous	216
Quartz	111	Total	15,426

grade materials. This method eliminates the use of a Jones reductor and the need for removing the acid hydrogen sulfide group, thus shortening the method significantly without sacrificing precision. The reduction step is accomplished by addition of an excess of titanous sulfate solution in the presence of copper ion. An excess is indicated by the appearance of red copper metal, which is reoxidized with mercuric perchlorate before proceeding with the titration. Nickel and cobalt which may interfere in other methods do not affect the titanous sulfate method.

The training program for chemists from private industry in methods of analysis for uranium continued. Eleven chemists from private laboratories spent an average of four days each in the laboratory. Partly as a result of this training program, several comparative analytical studies were made between the Denver laboratory and other laboratories. The results were in reasonably close agreement, discrepancies being noted only where the volumetric method was used on samples containing less than 0.1 percent U_3O_8. Where possible the use of the faster fluorimetric method is being encouraged for the range of uranium near or below the threshold limit of acceptable precision with the volumetric method.

A paper, "Determination of thorium and rare-earth elements in cerium-earth minerals and ores", by M. K. Garron, D. L. Skinner, and R. E. Stevens, as published in Analytical Chemistry, v. 27, 1058-1061. A paper "Doverite, a new yttrium mineral", by W. L. Smith, J. Stone, D. D. Riska and H. Levine was published in Science, v. 122, no. 3157, 31.

Research

The analytical chemistry of thorium, by M. H. Fletcher, F. S. Grimaldi and Lillie Jenkins

Investigations on the thorium-thoron-tartaric acid systems were completed and three new spectrophotometric procedures were developed for the determination of thorium. The new procedures minimize the interference of several elements such as zirconium and tungsten and are useful for the direct determination of thorium in ores containing more than one percent ThO_2 and less than four percent TiO_2.

Research on thorium chemistry is now in a new phase, the development of rapid methods for the determination of small amounts of thorium. The initial objective is to separate, in one step, one microgram or more of ThO_2 from up to 30,000 times that amount of rare earths, Ti, Nd, Ta, Zr, Fe, and Sc. For this purpose the precipitation of thorium iodate from nitric acid medium containing tartaric acid, hydrogen peroxide, and 8-hydroxyquinoline is under study. Tartaric acid hinders the precipitation of zirconium while hydrogen peroxide is similarly effective with Ta, Nb, and Ti. Oxine prevents the catalytic decomposition of hydrogen peroxide which is especially serious in the presence of cerium. Substantial progress was made and the separation procedure appears very promising.

The determination of uranium by the spectrophotometric method, by H. I. Feinstein

The spectrophotometric determination of uranium by means of the azide ion was studied from the standpoint of applying the method to natural samples. Because aluminum interferes, aluminum nitrate cannot be used as the salting agent in the solvent extraction process for isolating uranium. Studies confirmed that uranium is quantitatively extracted by ethyl acetate when magnesium nitrate is used as a salting agent.

The determination of lead in a standard granite sample, by R. A. Powell and J. J. Warr

A cooperative study with six participating laboratories was planned to establish the lead content and homogeneity of a standard granite sample. Hydrofluoric acid for decomposing the samples was found to contain much lead and in preliminary work substantial amounts of hydrofluoric acid were purified by distillation.

The preparation of cuprous iodide, by Frank Cuttitta, J. J. Warr, and Ivan Barlow

A method was developed for the isolation of traces of copper and preparation and purification of cuprous iodide from such materials as dolomite, limestone, sea bottom muds and plants to assist in a study of the isotopic diffusion of copper. The sample is first ignited to remove organic matter and carbon dioxide, and then leached with hydrochloric acid. After filtering, copper sulfide is precipitated from the solution using lead as a carrier. Lead is removed by precipitation as lead sulfate and the copper is further purified by precipitation as cuprous thiocyanate and finally as cuprous iodide.

GEOCHEMICAL AND PETROLOGIC RESEARCH ON BASIC PRINCIPLES

Radon and helium studies

by

A. P. Pierce

Geologic studies in the West Panhandle field, Texas were completed during the report period. The principal conclusion reached from these studies is that uranium has been redistributed and concentrated in the interstices of rocks through which petroleum and associated waters and gases have migrated or accumulated. Evidence that this has occurred is shown by the epigenetic nature of occurrence, the composition, and the spatial distribution of the uraniferous asphaltite which is a product of these processes. Studies of the relationships of the uraniferous asphaltite to the host rock indicate that the processes responsible for its deposition have been associated in time with structural and diagenetic events including recrystallization, solution, cementation, and adsorption of metalliferous fractions of migrating petroleum. The result has been to make uranium and its daughter products easily accessible to fluids and gases.

The presence of relatively high concentrations of helium and radon in the gases associated with the asphaltite suggests that significant portions of these two gases are products of uranium that has been distributed in the manner described above.

The associations existing between uraniferous asphaltite, petroleum and helium-bearing gases in the Panhandle field are known to be present in several other areas of the United States. Consequently, the associations in the Panhandle field are not unique, nor necessarily uncommon.

Further research on the behavior of uranium during the diagenesis of sedimentary rocks is necessary to complete understanding of the origin of the uraniferous asphaltite and its contribution to helium in natural gases.

The evidence now available on the origin of the asphaltite indicates that the process responsible for its localization must have (1) operated in the presence of petroleum, or in a combination of petroleum and water, within the rock pores; (2) been capable of concentrating uranium and the other metals into the form of disseminated point-segregates; (3) operated independently of the type of rock in which concentration took place; and (4) been effective over broad structural provinces.

Distribution of uranium in igneous complexes

Uranium in the Precambrian "granites" of the Colorado Front Range

by

George Phair and David Gottfried

Semiquantitative spectrographic analyses on 12 samples indicate that the "Silver Plume"-type granites contain on the average more than ten times as much cerium-rare earths as do the corresponding rocks of the Boulder Creek-type. This difference is probably correlatable with the high monazite content of the Silver Plume as reported in TEI-540. Also probably correlatable with the abundance of monazite in a high thorium content (up to 100 ppm according to Hurley's gamma-ray spectrometer measurements), a fact which explains the unusual radioactivity of the Silver Plume-type rocks in the field. The differentiated rocks of the Boulder Creek intrusions contain only the normal amounts of thorium (less than 10 ppm) which may be expected in such calc-alkalic series. In general the Silver Plume-type rocks are somewhat more extreme differentiates than the Boulder Creek types. All may be genetically related in the sense of belonging to a single batholithic cycle, but it has become more and more evident that they do not constitute a simple differentiation series. If the alpha/lead method as applied to zircon from such complex rocks gives the age of emplacement, the preliminary data suggest an interval of about 300 million years elapsed between the intrusion of the Boulder Creek and of the more alkalic Silver Plume types. This agrees with the order of intrusion indicated by field relationships. Nearly identical ages of 700 million years have been obtained on two samples of Silver Plume type, one from the large Log Cabin batholith at the northern end of the range and one from a large Silver Plume-type dike cutting the rocks of the Boulder Creek batholith. A single determination on the more calcic rock comprising the "Silver Plume" at its type locality gave an age of 900 million years. Petrographic and chemical studies originally suggested that the Silver Plume granite at Silver Plume was transitional between the more leucocratic rocks comprising the main masses of the Silver Plume correlatives elsewhere and the more calcic rocks comprising the granitic end members of the Boulder Creek series. Two samples from the interior of the main Boulder Creek mass gave geologically acceptable ages of close to 100 million years. A single sample from the deformed, partly recrystallized mafic border of the same body gave an age of 700 million years. This may reflect recrystallization at the time the large Longs Peak-St. Vrain batholith, a Silver Plume correlative, was intruded. This body extends southward to within one mile of the deformed northern margin of the Boulder Creek batholith. Much more data is needed, however, before a final interpretation of any of these ages in terms of of geology can be made.

Uranium analyses on 5-gram splits of one hundred and fifty 25 to 50-pound samples covering the range of differentiation in the Boulder Creek batholith show the low uranium contents (with two exceptions all less than 7 ppm) expectable in such a calc-alkalic series. An interesting feature, illustrated in figure 63, is the pronounced tendency for the uranium contents of comparable rock types to be lowest in the northern third of the body and to increase roughly progressively towards the central and southern thirds. The possible reasons for this variation are now under study. During the past field season some 120 more samples were collected to fill gaps in the previous sampling pattern and for special purposes. The high uranium contents of certain border rocks previously reported seems to represent a local "hot spot"; the adjacent metasediments run at most about 50 percent high in uranium. A similar but more widespread border enrichment seems to be evident in the 20 samples so far analyzed from the Boulder Creek rocks comprising the Mt. Evans batholith.

Distribution of uranium in the Boulder Batholith, Montana

by

R. W. Chapman

Spectrographic, chemical, modal and accessory mineral data on 30 quartz monzonites are being assembled as the first step in preparation of a report. The tentative conclusions are: (1) no apparent relationship exists between the classification types of quartz monzonites in the batholith and their contents of uranium and other trace elements, the classification types having textural significance only; (2) uranium is

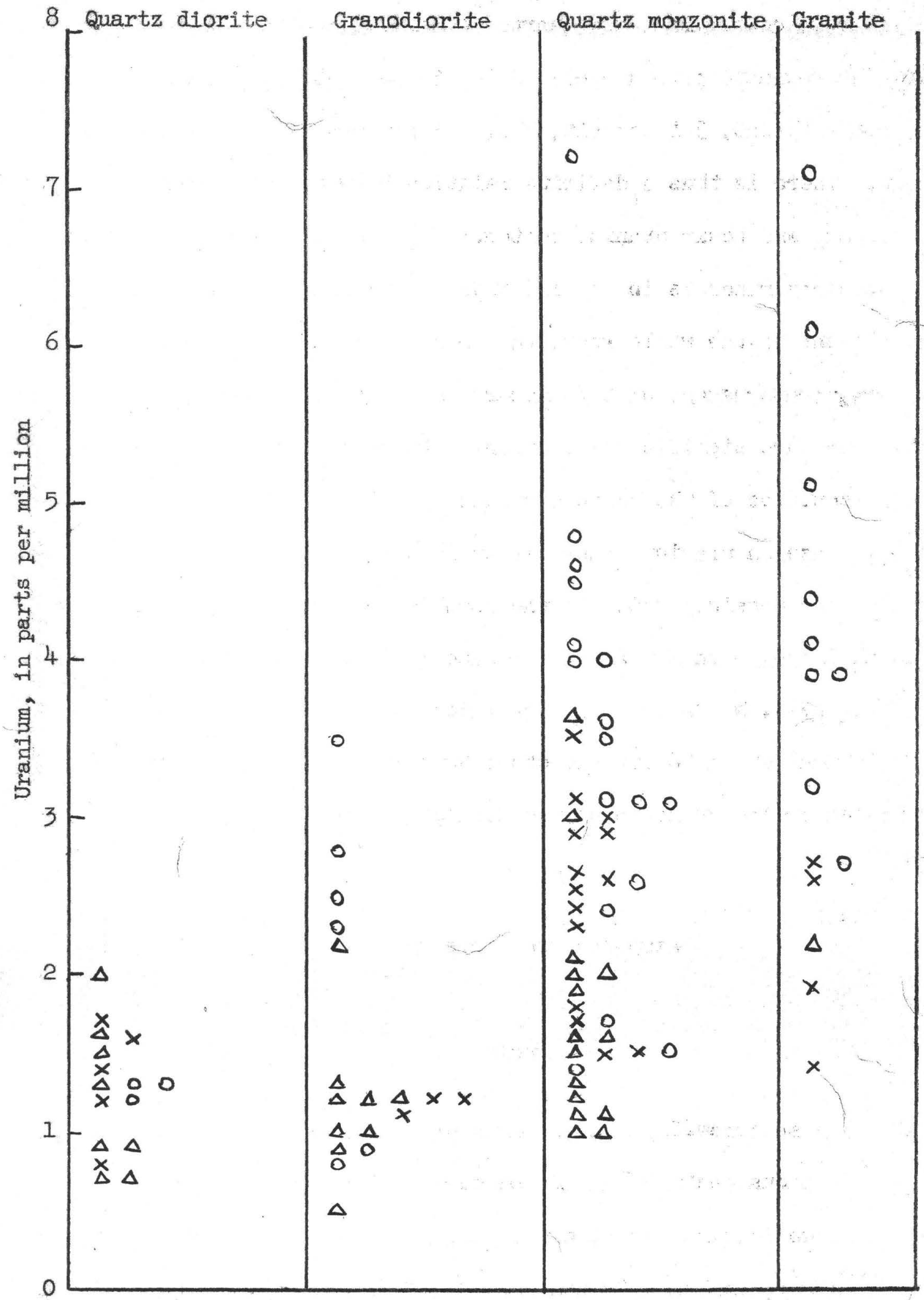


Figure 63.--Areal variation in uranium content of mapped rock types, Boulder Creek batholith, Colorado.

Δ = Northern part X = Central part O = Southern part markedly more abundant in those quartz monzonites whose oxides show the following approximate percentages: SiO_2, 65 percent; K_2O, 4 percent; Na_2O, 3 percent; CaO, 3-4 percent; MgO, 2.5 percent; and FeO plus Fe_2O_3, 5 percent. There is thus a definite relation between the chemical content of these rocks and their uranium content; (3) the total uranium content of the accessory minerals in any individual rock falls below the total uranium content of the whole rock; thus must of the uranium seems to be associated in some manner with feldspars and quartz; and (4) in the selected minerals there are significant relations between the percentage of uranium and the percentages of the various oxides. In the biotites, for example, with an increase in uranium, there is an increase in FeO and a decrease in MgO, Fe_2O_3, and possibly CaO. In the hornblendes, with increasing uranium, there is an increase in MgO and a decrease in FeO, Al_2O_3, and Fe_2O_3.

A paper by R. W. Chapman, D. Gottfried, and C. L. Waring, titled, "Age of the Boulder Batholith and other batholiths of western Montana", was published in the Bulletin of the Geological Society of America, v. 66, 607-610.

Gamma-ray spectrometry

by

P. M. Hurley

Gamma-ray spectrometry measurements on the Th/U ratios on accessory minerals in igneous rocks were made on several samples from New England, Canada, and Nova Scotia. In zircon separated from a single granite pluton the Th/U ratios appear to be constant. The Th/U ratios in zircon from these localities thus far has ranged from 0.2 to 0.6. These data indicate that nearly 90 percent of the radioactivity from the zircon tested is due to uranium. In pegmatitic crystals the ratios are more variable, ranging from 0.1 to 5.0.

Weathering, transportation and redeposition of uranium

by

A. M. Pommer

Oxidation potential and reducing capacity studies

Thermodynamically calculated pH-potential data agree well with electrometric determinations in reduced and oxidized vanadium solutions of varying pH.

Oxidation-potential studies and reducing capacity determinations on uranium-bearing minerals correlated well with other chemical and mineralogical determinations and showed that some carnotite-type deposits were derived from reduced minerals by moist-air oxidation.

The reduction of vanadium(V) solutions by wood or lignite

Reducing capacities of fresh wood, a series of degraded wood, lignin, and glucose in vanadium(V) and vanadium(IV) solutions were studied at elevated temperatures and pressures. It was shown that vanadium solutions may be reduced to the trivalent state by woody material. The reducing capacities of wood, degraded wood, and lignite were estimated from theoretical considerations, and it was shown that vanadium(V) solutions at elevated temperatures and pressures may be reduced by woody material to vanadium(IV) with as much as 60 percent efficiency. The amount of woody material required to yield typical concentrations of reduced uranium-vanadium ores is less than the amount normally present in typical sediments.

Mineral synthesis

by

A. M. Pommer

A reduced vanadium mineral with the composition $VO(OH)_4$, naturally occurring in South Dakota and New Mexico, was prepared by reduction of a vanadium(V) solution with wood at elevated temperature and pressure. Turanite was prepared by precipitation from solutions containing copper, calcium, and vanadate ions, at a pH of 9-10. Precipitates having a rauvite-like X-ray diffraction pattern were prepared from uranyl nitrate and vanadium(V) solutions.

Attempts to increase the grain size of carnotite and tyuyamunite or to prepare crystalline iron and aluminum vanadates by diffusion methods or heat and pressure were unsuccessful.

Zircon was synthesized hydrothermally from hydrofluoric and fluosilicic acid solutions with a temperature gradient of 250° C - 400° C between top and bottom of the bomb, at a pressure of about 2,000 psi.

Isotope geology and nuclear research

Geochronology

by

L. R. Stieff

During the report period 21 samples of uranium, thorium, and lead minerals were prepared as part of the Geochronology program. Lead iodides were prepared on 18 samples, isotopic analyses on 13 samples were received from the Mass Assay Laboratory, Oak Ridge, and 14 isotopic analyses were made in the USGS laboratory. Co-operative age studies were undertaken with Geological Survey projects in Massachusetts, South Dakota, and Wyoming and several other co-operative age studies on related mineral studies are in progress.

A joint age study with the members of the Geology Department, California Institute of Technology was initiated with the collection of four samples of stratigraphically well dated upper-Cretaceous quartz diorite from Baja California, Mexico. These samples are the first of a series in a long-range program for establishing reliable isotopic ages at key points in the geologic time scale. A small fossil collection was made to confirm the lower Cretaceous age of the sediments intruded by the quartz diorite. If preliminary age results on the accessory minerals of the quartz diorite are satisfactory, much more detailed stratigraphic, paleontologic, and isotopic age work will be undertaken.

In an effort to test a new area the age interpretations developed from the detailed study of the isotopic data on the uranium ores and the lead minerals of the Colorado Plateau, a suite of samples was collected from the uraniferous conglomerates of the Algoma district, Blind River area, Ontario, Canada. Preliminary isotopic data on some of the high grade samples show markedly different Pb^{207}/Pb^{206} ratios. Incomplete lead-uranium data also suggest an age pattern similar to that found for Plateau ores. The presence of galena, which contains predominantly radiogenic Pb^{206} and Pb^{207}, suggests that the presence of old radiogenic lead may account for the Blind River age anomalies as well as those found on the Colorado Plateau.

The first 12-inch radius mass spectrometer is expected to be in operation during January 1956. Redesign and construction of an electron bombardment-surface ionization source for the 6-inch mass spectrometer was completed and tested. The performance of the electron bombardment source is good and the sample requirements were reduced from approximately 10 mg to 1 mg. Using a vibrating reed electrometer, a measurable but inadequate signal was obtained when the source was operating by surface ionization. Additional changes in the source will be made to increase the signal produced by the surface ionization method.

During the report period the following isotopic ages, in relatively good agreement with each other, were obtained for Phillips mine uraninite, Peekskill quadrangle, Putman County, New York: Pb^{206}/U^{238} = 920 m.y., Pb^{207}/U^{235} = 928 m.y., Pb^{207}/Pb^{206} = 970 m.y., Pb^{208}/Th^{232} = 960 m.y. The Pb^{206}/U^{238} age of 920 m.y. is considered to be the most reliable of the four ages. A Larsen age of 620 m.y. was obtained from zircon from a granodiorite pegmatite cross cutting the hornblende gneiss and believed to be younger than other rocks in the area. Additional isotopic age studies are planned on zircons from the hornblende gneiss and granodiorite to confirm the 620 m.y. Larsen age.

Preliminary results on a monazite from Tamka Lake, North West Territory, Canada yielded the following results: Pb^{207}/Pb^{206} age = 2,640 m.y., total lead/alphas per mg/per hr = 2,610 m.y. Quantitative analyses for uranium and thorium are not yet complete. The good agreement between the Pb^{207}/Pb^{206} age and the modified "Larsen age" suggest that reasonably close agreement between the methods of age calculation might be expected. If this expectation is realized, the Tamba Lake monazite will be the oldest radioactive mineral on the North American Continent yet dated by isotopic methods.

"The interpretation of the $Pb^{206}/U^{238} < Pb^{207}/U^{235} \ll Pb^{207}/Pb^{206}$ age sequence of uranium ores", by L. R. Stieff and T. W. Stern, was published in the Proceedings of the United Nations International Conference on the Peaceful Uses of Atomic Energy.

Stable isotopes

by

Irving Friedman

The water content and D/H ratio of dissolved water contained in samples of tektites and other natural glasses was determined and it now appears that such glasses can be categorized by their water content. Most tektites can be classed as natural glasses containing less than 0.008 percent H_2O. A supposed tektite from Peru, described by Linck, and containing euhedral crystals of andalusite (5 mm long), biotite, potash feldspar, plagioclase feldspar, wollastonite, sillimanite, zircon, dunite, quartz, and cordierite, contains 0.23 percent H_2O. This places it in the same class as obsidian (0.08 to 0.5 percent H_2O). A possible origin of the "Americanite" is by the refusion of a sandstone. Libyan desert glass (97 percent SiO_2) contains about 0.07 percent water and again is quite close in water content to certain obsidians. The Libyan desert glass might have been formed by fusion of the Nubian quartzite by a meteorite impact. The "true" tektites are very anhydrous and at the present writing, all of the glasses that are known to have solidified at or near the earth's surface contain more than 0.05 percent water. At this juncture an extra-terrestrial origin for tektites would seem to be indicated.

Previous analysis of tektites shows that they range from 0.02 to 0.6 percent water, figures which probably are high by about one or two orders of magnitude. The method of vacuum fusion and conversion of the condensed water to hydrogen gas, used here, is capable of greater precision than the usual chemical techniques.

The analysis of gas in tektites is also probably in error. All authors, including the recent work of Suess, report CO_2, CO, and hydrogen as the predominant gas, with smaller amounts of H_2O. The present research fails to find any CO, CO_2, or hydrogen, but only H_2O. It is believed that the other reported gases were formed by the reaction of the water with the tektite and with carbon contained in the crucible.

The D/H ratio of water in the tektites covers the whole range of natural abundance. However, there may be a grouping of results indicating that the water in tektites is slightly richer in deuterium than the water in obsidian.

Deuterium analysis of ocean waters in cooperation with Woods Hole Oceanographic Institution were continued. Several hundred samples, representing stations in the Arctic, Northwest Passage, Baffin Bay, Norwegian Sea, Barents Sea, Irminger Sea and North Atlantic were analyzed. Plots of D/H vs. salinity permit ocean waters to be characterized in a fairly unique manner. Such data should give information about large scale oceanic circulations.

Isotope geology of lead

by

R. S. Cannon, Jr.

Chemical evaluation of samples collected as potential material for study of isotopic variations in the rock-lead of igneous and sedimentary rocks was virtually completed with the analysis of 70 additional samples for uranium by the fluorimetric method. The samples analyzed most recently include both plutonic and volcanic igneous rocks, limestones, and other kinds of geologic materials, so that the results do not lend themselves to generalization.

Geologic activity this period consisted entirely of completing a study of carnotite deposits in the Santa Fe formation at Cuyamungue in north-central New Mexico, discovered in 1954 while collecting samples for lead-isotope studies. This work included study of the geochemistry, geobotany, and economic geology of the deposits in cooperation with specialists in those fields. The deposits occur in unconsolidated clays and sands of late Tertiary age and must have been formed not earlier than late Miocene time. Yet, in both physical and chemical characteristics they bear resemblance to carnotite deposits in much older sandstones of the Colorado Plateau. In the extreme southeastern corner of the Colorado Plateau province, typical uranium deposits assumed to be of late Mesozoic or early Tertiary age occur in Jurassic Todilto limestone and Morrison formation less than 40 miles away from Cuyamungue. Because typical sandstone ores of two different geologic ages can be shown to coexist in such proximity, this area is of great interest for future research on ages of uranium ores by the lead-uranium method. The Cuyamungue deposits are so thoroughly oxidized that material suitable for age studies will not be obtained until they are explored below the permanent water table. The area should prove of interest also for future research on relationships between uranium deposits and volcanic ash. Present-day weathering of uraniferous vitric ash interbedded in the Santa Fe formation does set free some mobile uranium in ground waters, and the situation seems favorable for proving whether such ash was or was not the source of the uranium that was concentrated at some earlier time in the uranium deposits. The deposits are small and of low grade at the outcrop, but their potential cannot be evaluated until exploration penetrates below the water table. The range of available prospecting techniques has been reviewed and suggestions made concerning uranium prospecting in Tertiary continental sediments that contain volcanic ash, particularly in the Tertiary fill of the upper Rio Grande Valley.

Nuclear geology

by

F. E. Sentfle

During the past six months about 30 samples were run for Cu^{63}/Cu^{65} ratio. While small variations were noted in a few cases, the results were little above the experimental error expected. The ratio of Cu^{63}/Cu^{65} at the contact of a "roll" in the Peanut mine was slightly different from that in the adjoining sediments, but more recent runs indicate that this variation represented fractionation in the source. Similar small variations were noted in the native copper and other copper in the host rock. At this writing it is not certain that these variations are real. The only relatively large variation noted to date is in copper extracted from bottom muds from East Sound, Washington. Here it appears that anaerobic activity resulted in an exchange reaction which concentrated the heavy copper isotope. The Cu^{63}/Cu^{65} ratio was found to be 2.205 which represents about a 0.8 percent enrichment of the heavy isotope.

Five more analyses of the U^{235}/U^{238} ratio were obtained from the Mass Assay Laboratory, Oak Ridge. These last five represent uranium specimens from widely separated places on the Colorado Plateau.

Sample No.	Location	Wt. & U^{235}	Limit of Error
PK-18	Temple Mt., Utah	0.7115	± 0.0022
AE-1165	Mi Vida Mine, Utah	0.7119	± 0.0022
AE-1288	Paradox Valley, Colo.	0.7124	± 0.0017
AE-1271	Poison Canyon Mine, N. Mex.	0.7116	± 0.0022
AE-1260	Woodrow Pipe, Laguna, N. Mex.	0.7116	± 0.0022

As in the previous analyses no significant variations were noted.

A magnetic susceptibility curie balance was constructed to compare the magnetic properties of zircons from different places, and also to see if there is any correlation with the degree of metamictization of the zircons. The equipment is currently being calibrated. Further bombardment of zircon with alpha particles at Oak Ridge National Laboratory failed to produce further damage in the original specimens of zircon. New targets of fresh zircon were prepared but no further bombardment was made.

MINERALOGIC AND PETROGRAPHIC SERVICE AND RESEARCH ON BASIC PRINCIPLES

Services

by

E. J. Dwornik and George Ashby

The increase in the number of samples submitted by the public to the Washington laboratory for radioactivity analysis, which has been noted in the three previous semiannual reports, is still in evidence. During the present report period approximately 2,900 persons submitted a total of about 4,600 samples; this compares with 2,200 persons submitting 3,500 samples during the preceding six-month period. All of these samples are given routine mineralogical, petrological, and radioactivity analyses, more detailed work being done only if the samples are of interest to the Geological Survey. Special samples are also submitted by Geological Survey and AEC projects, many of these requiring detailed mineralogical and petrographic study. During the report period mineralogical reports were written for 240 such samples, as compared with 200 samples during the preceding period.

At the Denver laboratory 450 samples were processed. About 300 samples were examined by X-ray diffractometer analyses. There was a considerable increase in number and variety of minerals identified per sample, reflecting here as elsewhere both increasing knowledge and interest in mineralogy, and increasing complexity in ore types under investigation.

The use of autoradiographs to locate areas of radioactivity has become common practice in the laboratory. The radiographs are particularly useful in differentiating low-grade specimens with discrete radioactive minerals from those in which the radioactive elements are dispersed, as in limonite and carbonaceous material.

A large increase in samples of the "multiple-oxide" type such as samarskite, uranothorite, and pyrochlore has occurred during the last six months. In part this represents increasing interest from the general public in pegmatite sources, and attention to thorium sources of radioactivity. Many of these multiple oxide mineral samples are metamict, and many require concentration and heating before X-ray identification is possible. A metamict high-uranium thorite from El Paso County, Texas was particularly interesting in that it appeared quite deficient in both Ra^{228} and Ra^{226}; Ra^{228} has a half-life of 6.7 years, which suggests relatively rapid removal, in recent times, of this daughter product.

A preliminary investigation of the possible use of ultrasonics for mineral separations was made on a pink sandstone from the southern Black Hills. It showed that this method of separating constituents has considerable promise.

A detailed study of multiple geochemical factors involved in halo searching for ore is being made on an area in the southern Black Hills, South Dakota.

Electron microscopy and electron diffraction

by

E. J. Dwornik

A method was devised for interpreting transmission electron diffraction spot patterns of monoclinic crystals which orient with the plane of two crystallographic axes parallel to the plane of the specimen mount. If a monoclinic crystal orients with the (001) or (100) face parallel to the specimen mount the resulting spot pattern will represent the a* b* or b* c* reciprocal net plane projected onto the photographic plate at an angle of (β-90°). Such patterns will give directly the a and b or b and c unit cell constants. If a monoclinic crystal orients with the (010) face parallel to the specimen mount the spot pattern will represent the a* c* reciprocal net plane, and will give directly the h0l parameters and the β* angle. This method was used successfully in determining unit cell data for simplotite ($CaV_4O_9 \cdot 5H_2O$).

Electron microscope studies of a suite of clays from the Colorado Plateau revealed characteristic platy crystals typical of hydrous micas and montmorillonitic type material. Selected area diffraction of apparently different phases gave characteristic clay patterns indicating that vanadium is an integral part of the clay structure.

Other work included identification of various clay, uranium, and vanadium minerals; a particle size determination of zircon samples; a study of electron diffraction patterns of triclinic minerals in order to find a basis for interpreting such patterns; and studies of fine grained materials such as leucoxene, surface coatings on minerals, and chemical precipitates.

Research on techniques

by

E. J. Dwornik

Laboratory sampling has become an important factor in the study of the distribution of trace elements in rock. In order to determine the magnitude of sampling error, studies of sample splitting methods and grain size vs number relationship were initiated. In connection with these studies crushing tests using a laboratory roll mill were conducted to determine the resulting size distribution and the relation of uranium content to grain size in Conway granite.

An experimental design was set up by which the products of three different roll settings could be compared. Pre-sized samples of the granite (+10, -10+14 -14+20 mesh) were passed through the rolls at one setting and the resulting size distribution plotted. Comparison of these size distributions showed marked similarity in that distinct matching peaks were observed in all nine curves and that the size distributions were grouped according to the roll settings.

It was apparent that the original size of the material crushed by the rolls had no influence in the crushing operation except on those samples where the gap between the rolls approached the grain size of the material.

Chemical uranium analyses were made on all samples in each of four selected mesh sizes. The results of these analyses are shown in table 19. In eight of the nine size distributions the uranium content was greatest in the smallest sizes. There is also indication that increased crushing action of the rolls decreases the uranium content of the coarse size fractions.

X-ray services

by

George Ashby

During the last six months, 796 determinations were made on 650 samples. An extensive revision of the powder film file was completed with the exception of approximately 200 unidentified films. The latter

Table 19. Distribution of uranium in selected size fractions of Conway granite after crushing

Roll Setting (mesh)	Grain size	Original size	U, ppm -40 Mesh +50	Wt. %	U, ppm -80 Mesh +100	Wt. %	U, ppm -120 Mesh +140	Wt. %	U, ppm -270 Mesh	Wt. %
120	Sample 1		8.7	14.9	8.5	7.7	10.4	3.29	17.0	15.0
40	Sample 2	10	11.6	12.52	9.5	3.78	13.5	1.41	32.5	4.0
20	Sample 3		23.5	7.03	13.0	2.0	17.5	.69	45.0	2.7
120	Sample 4		9.0	17.84	8.5	7.40	27.5	2.9	24.0	14.8
40	Sample 5	-10 14	11.7	20.2	11.2	3.72	11.0	1.4	23.0	5.6
20	Sample 6		14.5	4.8	14.5	1.1	17.3	.4	33.0	1.45
120	Sample 7		13.5	18.5	8.5	7.0	11.0	3.2	17.0	12.9
40	Sample 8	-14 20	11.0	12.4	12.5	2.3	14.0	1.5	38.5	3.6
20	Sample 9		13.5	3.9	14.0	.7	15.5	.3	38.0	.9

were catalogued for further investigation. Seventy-three hundred films were catalogued alphabetically under mineral name, element, or chemical compound. This reference file represents one of the best collections of X-ray data on uranium ore mineralogy in the world.

An automatic sample changer was constructed for the X-ray diffractometer. It was designed to automatically record diffractometer charts from twelve samples during a sixteen hour period and thus triple the recording time by permitting unattended operation. The changer was successfully used on a set of 500 clay samples recently submitted to this laboratory.

Crystallography of uranium and associated minerals

by

H. T. Evans, Jr.

The study of the structures of uranyl complexes, begun last summer with the solution of the liebigite structure, has continued. The details of the structure of liebigite [$Ca_2UO_2(CO_3)_3.10H_2O$] were refined in two dimensions, and refinement of the third dimension is in progress. The essentially planar aspect of the carbonate groups in the $UO_2(CO_3)_3^{-4}$ complex ion was confirmed. Preliminary structure studies on johannite [$Cu(UO_2)_2(SO_4)_2(OH)_2.6H_2O$] revealed the positions of the uranium and copper atoms in the triclinic unit cell. Accurate intensity data were collected for the purpose of studying the constitution of the uranyl sulfate complex. This work was augmented by chemical studies of various uranyl complexes with the principal aim that of growing crystals suitable for structure analysis. Thus, large untwinned crystals of johannite greatly superior to the natural crystals were grown by a sealed tube method.

The studies on the uranium oxide hydrates were further extended to complete the physical characterization of the members of this complex series of minerals. The optical properties were measured and correlated with the structures. Fourier analyses of intensities measured for becquerelite were carried out in order to determine the structural details of the $UO_2(OH)_2$ sheet which is common to these minerals.

Chemical studies were initiated in the carnotite system. Procedures described in the literature for the preparation of carnotite from various melts were followed, but new, previously unrecorded products were obtained. Large yellow crystals of carnotite whose X-ray patterns correspond to the classical descriptions of the mineral were obtained from potassium metavanadate melts, but a new orange, pseudotetragonal form was obtained from potassium carbonate fusions. These crystals will be used for detailed structure analysis in order to determine the nature of the $(UO_2VO_4)^-$ sheet, especially since some doubt has been expressed concerning the validity of the structure of carnotite proposed by Sundberg and Sillen. Single crystals were prepared from metavanadate melts of the lithium, sodium, rubidium, cesium and thallium analogues of carnotite, and subjected to X-ray study.

New information was obtained on vanadium oxide structures. The crystal structure of a new oxide mineral from Carlile, South Dakota was solved. It was found to consist of the same zig-zag octahedron chains that occur in montroseite and paramontroseite, but linked into a sheet structure instead of a network structure. The sheets are held together by a system of hydrogen bonds. The probable formula is $V_2O_3 \cdot 2H_2O$, which implies that this mineral is also a primary one (not a weathering product), like montroseite ($V_2O_3 . H_2O$). This oxide was also identified in specimens from McKinley County, New Mexico, and in a synthetic product of a sealed bomb run experiment. This mineral is another example of a case where the X-ray structure analysis method provides the only approach to the problem of the chemical constitution of the mineral and its relation to others in the geochemical scheme.

A paper by H. T. Evans, Jr., and M. E. Mrose, titled "A crystal chemical study of montroseite and paramontroseite", was published in The American Mineralogist, v. 40, 861-75.

GEOPHYSICAL SERVICES AND RESEARCH ON METHODS AND PRINCIPLES

Development and maintenance of radiation detection equipment

by

W. W. Vaughn

The response of the carborne scintillation counter to a 25 mg Ra needle at 50-foot intervals to a maximum distance of 300 feet was plotted against horizontal distance. The scattered radiation measured in a plane, 8 feet from the surface of a homogeneous medium, was 100 percent of the values derived from the inverse square law. The instrument contained a 3-inch diameter by $1\frac{1}{2}$-inch thick NaI crystal. One might logically assume the scattering from a natural source of radiation in proximity with dense materials would be a greater percentage of the radiation as an integral reading.

Although the carborne scintillation counter was designed primarily to make a graph of radioactivity vs distance for road traverses or open terrain, other uses are being found for the equipment. In Karnes County, Texas, and similar areas, the instrument was used effectively as a tool for locating hidden faults.

A scintillation core scanner using four 2-inch x 2-inch NaI crystals shielded by 2 inches of lead was constructed. Preliminary tests indicate the instrument has five times the sensitivity of equipment previously used for this purpose. It is possible to detect a difference of .001 percent eU in the drill cores. The chamber which allows through passage of material is an axial bore 4 inches in diameter by 12 inches long. The sensitive area of the chamber measures 2 inches in length. The radial distance to the crystals is adjustable. The instrument automatically graphs radioactivity versus time or length of drill core. The design of similar instruments is being considered for continuously monitoring a process where radioactive solutions are transported by pipe or plastic tubing.

The development or selection of a suitable ratemeter for the quantitative measurement of radioactivity in a drill hole continues. This instrument is to be used in a jeep-mounted scintillation logger. It is obvious the best commercial instrument available for use under these rigorous circumstances will require further modification to obtain the necessary accuracy. Further tests are being made to determine the possibility of inhole spectral measurements with this equipment. Two simulated drill holes and a water tank 9 feet deep, 6 feet wide will be used in these experiments. The portable scintillation logger with the high-low range to log ore-grade materials as well as formations containing very little radioactivity, has been accepted widely as an effective tool in studying and correlating stratigraphy.

The development of a new circuit for an "emanation pulse differentiator" was begun. The original proto-type circuit will be used as a guide.

It has been determined that a super-sensitive portable scintillation counter of the type prospectors use will serve well to detect the radioactivity in uranium-bearing plants in place.

Further changes are being made in the scintillation counting equipment for the gamma-ray absorption experiment. It was recommended that a double differentiation amplifier be used in taking data. Fabrication of two such amplifiers has begun.

These were made to compare the sensitivity of a multi-geiger tube (as many as 24 GM tubes in parallel) survey meter to a scintillation counter. The sensitivity of the average scintillation counter with a

$1\frac{1}{2}$-inch-diameter by 1-inch-long NaI crystal is 100 percent greater than the multi-geiger tube equipment.

Research on utilizing transistorized circuits for impedance matching, amplification, etc., continues. The germanium transistors were too temperature-dependent for reliable field operation. The silicon varieties so far prove to be better in this respect.

A test system for classifying phototube and crystal combinations relative to their energy response was devised. Uniform energy dependency within a group of instruments is desirable from the standpoint of maintaining close calibration which is necessary with the gamma-ray loggers, etc.

The consulting maintenance and calibration service for all types of radiation equipment continues. At the request of the Atomic Energy Commission, a laboratory facility for fluorimetric and radiometric analyses and the maintenance and calibration of radiation detecting equipment was established in Lima, Peru.

Gamma-ray logging studies

by

C. M. Bunker

Development work on a jeep-mounted scintillation logger and a portable scintillation logger are still in progress.

Satisfactory reproducibility of measurements with the jeep-mounted unit have not been attained, due largely to lack of stability of the ratemeter employed. Several other commercial ratemeters are presently being tested in an attempt to develop an instrument satisfactory for this application. Similar difficulties were experienced with the portable logger, resulting mainly from temperature dependence.

In order to obtain uniform response among various scintillation logging units various components of the equipment are being rigidly tested. One of the less uniform components is the photomultiplier tube. A testing procedure has been established to determine various characteristics of commercially available tubes and with that information to write specifications to limit acceptance of tubes to those which lie within the tolerances demanded by the application in which the tubes will be used.

The power pack and surface circuitry unit of the scintillation logger was tested for variation in count rate response to a constant source through a temperature range of 39-130 degrees F; the total count rate variation was approximately 6 percent.

No visible variation in response was indicated from temperature tests on the probe in the 35-75 degree F. range; however, the count rate dropped by 70 percent as the temperature was increased to 135 degrees F. The temperature dependent component(s) of the probe was not determined.

In spite of the undesirable aspects of the equipment as described above, the scintillation logger has been employed effectively to obtain qualitative data on lithology that is superior to that provided by conventional Geiger counters.

Approximately 30 exploratory drill holes in the Oljeto Wash, Arizona-Utah area were gamma-ray logged with the portable scintillation logging equipment. The purpose of the work was to test the equipment under hot, dry, dusty conditions and to obtain more valid lithologic logs of the holes than were obtainable with Geiger equipment. The equipment withstood the field conditions with slight equipment modification indicated.

A group of water wells, oil wells, cisterns, and exploratory drill holes near Wichita Falls, Texas were logged and although the uranium mineralization present is not significant the scintillation log will be helpful in the interpretation of the lithology.

Several water wells located in valley fill in the Warm Springs Fault area north of Salt Lake City, Utah were gamma-ray logged with the portable scintillation logging equipment in conjunction with the Physical Behavior of Radon studies. The purpose of the logging was to determine lithology, variation of background in the wells versus radon content, and the location of uranium mineralization. The logs clearly showed lithologic breaks; however, the holes were generally too far apart and the strata too inconsistent to cross-section the area by using the logs. There was no apparent variation in background with radon content; however, this conclusion may be the result of too few data. Some anomalous, but not commercial grade, radioactivity was located.

Several drill holes were gamma-ray logged at Grants, New Mexico to determine the relationship between (1) the in-hole counting rate (2) radon content of the air in the drill hole and (3) uranium mineralization. The results of this investigation are given in Physical Behavior of Radon, p. 339.

In addition to the development work given above maintenance and service operations on the Geiger counter loggers currently in use was continued.

Five lightweight aluminum selsyn frames have been built to replace units made of steel. In addition to being unwieldly, the weight of the old ones created a physical hazard.

A replacement 2,000-foot capacity reel unit has been completed. Use of it will reduce in the in-shop time required to make a major repair or overhaul the logging equipment.

In order to maintain calibration among several logging units over a long period of time quality control must be maintained on all critical components; therefore, the count rate responses of all Geiger tubes used by the project are checked against a standard source with a ratemeter and scaler. In addition, the tubes in field use are returned periodically to the instrument shop and rechecked to eliminate any tubes that indicate a count-rate response drift.

Physical behavior of radon

by

A. S. Rogers

The investigation concerned with the delineation of faults in unconsolidated sediments by changes in the radon concentrations in well waters was continued in the Warm Springs Faults area north of Salt Lake City and was extended to the North Ogden, Utah area. Fifteen well-water samples were collected along a traverse perpendicular to both a known and a postulated fault trace in the Warm Springs Fault area. Radon, radium and uranium concentrations were as follows:

Rn - 304 to 2330 $\mu\mu c/l$
Ra - .1 to .4 $\mu\mu c/l$
U - 1.6 to 12.0 x 10^{-6} g/l

Results of the studies to date indicate that (1) the radon content of the ground waters correlates quite well with the uranium content, but not at all with the radium content, (2) radium content varies from 2 to 40 times less than equilibrium with the uranium content of the water and (3) radon content varies from several hundred to a thousand times greater than the equilibrium value based on the uranium content.

In the North Ogden area 325 wells were sampled in an area of about 25 square miles. As in the Warm Springs Fault area north of Salt Lake City, Utah no major correlation was noted between the radon content of the water and either the depth of the wells (10 feet to 800 feet) or the rate of discharge of the well. The pattern of radon distribution is much more complex than in the Warm Springs Fault area, although there appears to be a relation between high radon concentration and postulated fault traces. A possible relationship exists between changes in chemical composition and the radon content (100 to 3,000 micromicrocuries per liter) of the ground waters.

Carborne scintillation counter surveys revealed an area of about 2 square miles of high radioactivity (up to 20 times background) in the North Ogden area. This condition is believed to be due to the precipitation of some radioactive element from the waters issuing from Utah Hot Springs, which waters contain 5,800 micromicrocuries of radon per liter and 44 micromicrocuries of radium per liter. A detailed study is planned for this area during the next six months in conjunction with ground water investigations now in progress.

An investigation of radon in springs, wells, streams and reservoir water in the Huntsville, Utah area has begun. The radon concentrations from the several sources are as follows:

Springs - 270 to 3,200 micromicrocuries per liter
Water wells - 200 to 910 micromicrocuries per liter
Streams - 20 to 110 " " "
Reservoir (surface) - 10 " " "

Additional measurements will be required before an evaluation can be made.

Field work was substantially completed in the investigation of radon in drill hole air and soil gas in the vicinity of a uranium orebody near

Grants, New Mexico. General correlation was observed between the rise and fall of atmospheric pressure and the amount of radon in drill holes, the vertical position of maximum radon concentrations in the holes, and the maximum concentrations. The observed effect of wind velocity was different for different holes. No correlation was noted between surface temperature and radon concentrations in the holes. Gamma-ray logs show a gamma-ray component which is proportional to the radon concentration at each depth, within reasonable limits of error. Soil gas analyses for radon in the vicinity of the ore body showed no correlation with the theoretical radon halo over the ore body; the area appears to be not amenable to soil gas techniques of prospecting.

The locations of water samples taken in Clay County, Florida, are shown in figure 64; table 20 gives the corresponding radon concentrations and the respective depths at which the samples were taken.

Water samples were taken and analyzed for radon in Hillsborough and Polk Counties, Florida. The results, shown in figure 65 and table 21, indicate marked changes of radon concentration with depth in shallow drill holes. The unusually high radon concentrations occur with the uraniferous "leached zone" of the phosphatic Bone Valley formation, and to a lesser extent, with the less uraniferous but commercially phosphatic "matrix", or lower, part of the Bone Valley formation.

The determinations of radon concentration in water samples are estimated to be accurate with ±10 percent. There was some loss of radon in the collection of samples, however, as the procedure followed in the extraction of water from the turbid water of drill-holes involved some aeration of the water as it entered the sampling device. Two checks of the sampling device against one which did not involve an inherent loss of

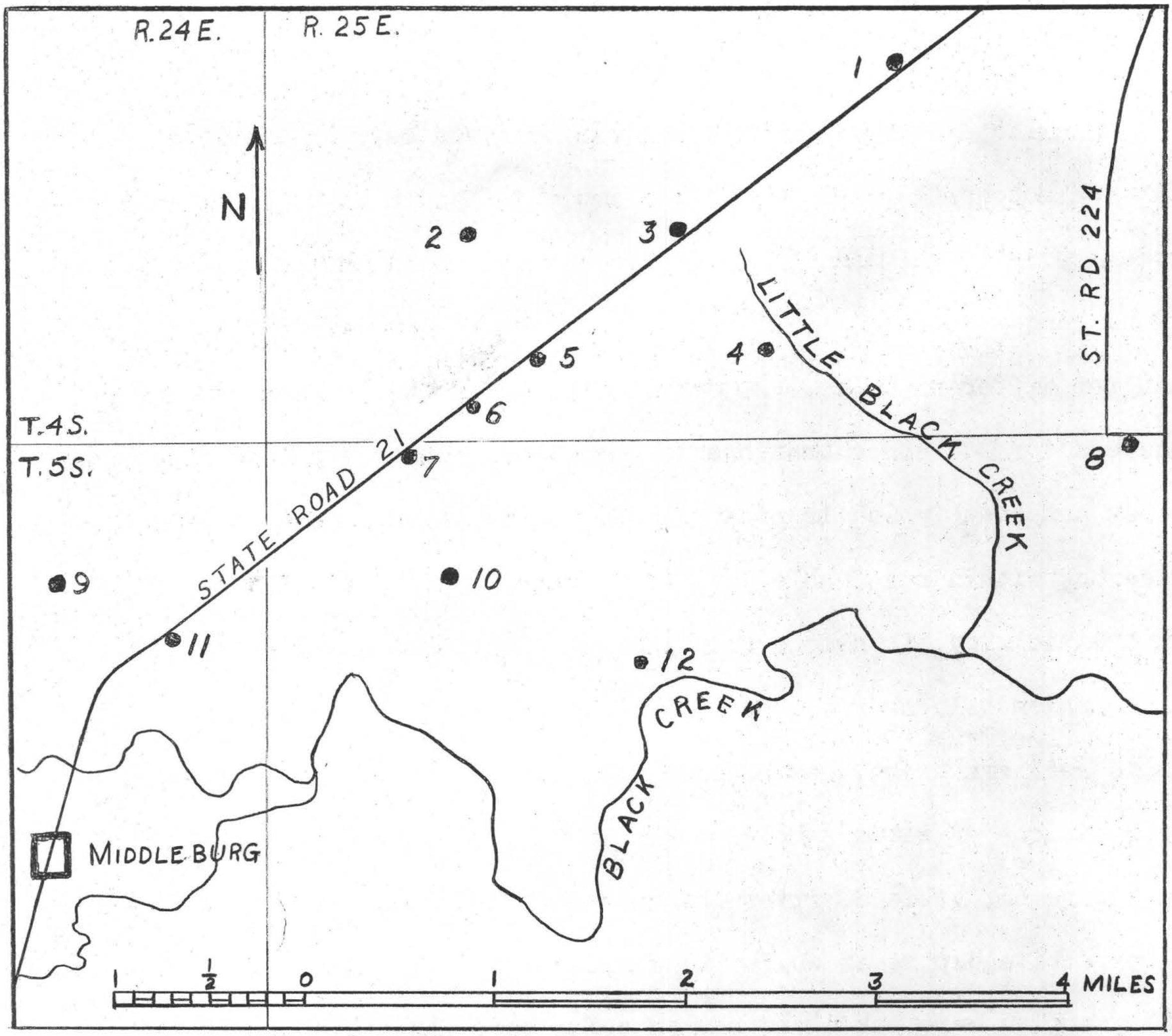


Figure 64.

RADON SAMPLE LOCATIONS, CLAY COUNTY, FLORIDA

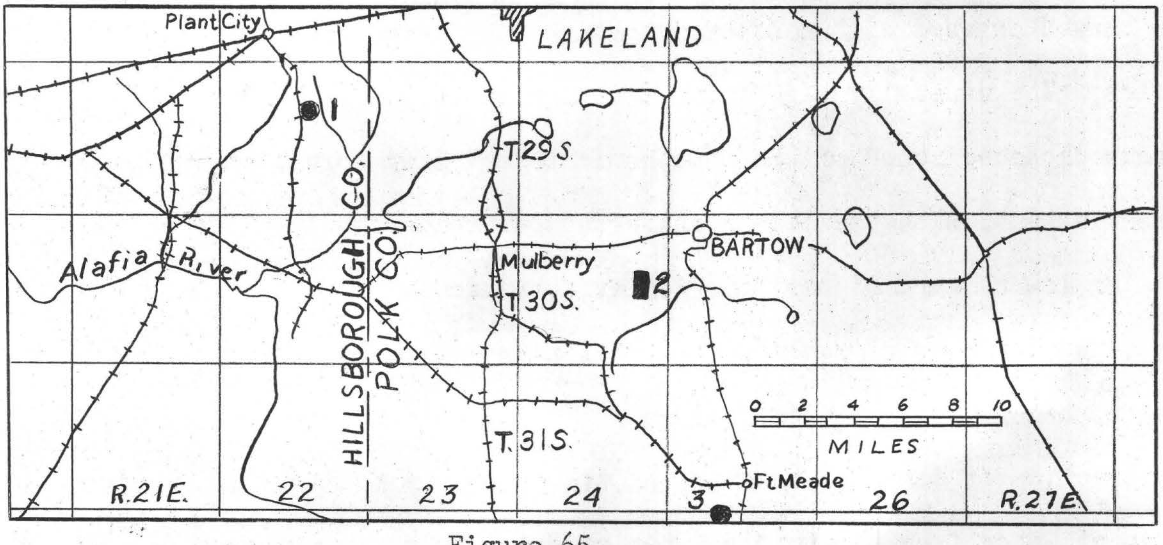


Figure 65.

RADON SAMPLE LOCATIONS, HILLSBOROUGH AND POLK COUNTIES, FLORIDA

Table 20. Radon analyses of water samples from Clay County, Florida

Location	Radon content 10^{-12} curies/liter	Depth (feet)	Remarks
1	270	11	
1	210	17	
1	270	30	
2	20	50	seeped thru threads of iron casing
3	2,250	12-14	
4	330	9-11	sample questionable, top of water table about 6 feet
5	1,100	10-12	
6	840	6	top of water table about 5 feet
6	780	7	
6	5,000	8	
6	3,400	11	
6	1,900	24	
7	10,000		freshly-pumped water from domestic well 27 feet deep
8	1,100	3-5	top of water table
8	480	30-32	
9	350	6	
9	510	7	
9	660	13	
9	490	16	
10	1,800	8-10	
11	1,900	8-11	top of water table at 5 feet
11	2,000	11 1/3	
12	90	6	top of water table
12	600	10	
12	1,100	20	

of radon indicated losses of 18 and 12 percent respectively. It is therefore likely that the radon concentrations cited for drill-hole waters are low by from 5 to 25 percent. Samples taken consecutively from the same point and depth showed relative agreement within 10 percent.

One water sample was analyzed in the field for both radon and radium and gave values of 19,000 $\mu\mu$c/l of radon and only 120 $\mu\mu$c/l of radium. Aliquots of some other samples for radon contained $\mu\mu$c/l of radium at the time of analysis. In no instance was radon in equilibrium with radium in solution.

Table 21. Radon analyses of water samples from Hillsborough and Polk Counties, Florida

Location	Radon content 10^{-12} curies/liter	Depth (feet)	Remarks
1	2,300	17-19	water from domestic well
2, Hole 1	7,300	35-37	drill hole water
2, Hole 2	9,600	40	drill hole water
2, Hole 3	8,000	33	drill hole water
2, Hole 3	5,200	35	drill hole water
2, Hole 3	120 of Radium	8	drill hole water
2, Hole 4	7,900	5-10	drill hole water
2, Hole 4	7,000	10	drill hole water
2, Hole 4	33,000	11	drill hole water
2, Hole 4	29,000	22	drill hole water
2, Hole 4	8,800	33	drill hole water
2, Hole 5	140,000	17	drill hole water, top of water table
2, Hole 5	84,000	24	drill hole water
2, Hole 5	46,000	34	drill hole water
2, Hole 6	57,000	14 1/2	drill hole water
2, Hole 6	54,000	19 1/3	drill hole water
2, Hole 6	36,000	28 1/2	drill hole water
2, Hole 6	1,300	35	drill hole water
2, Hole 6	3,000	40	drill hole water
3	51 (average)		water in pond adjacent to phosphate strip mine
3	43,000 (average)		seepage at top of "leached zone" (Bone Valley fm.) in phosphate strip mine
3	24,000		seepage at contact between "leached zone" and "matrix" of Bone Valley fm.
3	9,400		seepage 4-5 feet below "leached zone" - "matrix" contact (Bone Valley fm.)
3	9,600 (average)		seepage from top of Hawthorn fm.

Four air samples were taken from exploration drill holes located within a uraniferous area in the Black Hills. Two of the samples were taken at a depth of 60 feet in one hole and averaged 25 $\mu\mu$c/l. This hole was open to the atmosphere; the effluent air could be felt by the hand and caused an increase in scintillation counter reading from .015 to .020 mr/hr. Samples taken from two other holes, located within 70 feet of the first hole, contained 220 and 440 $\mu\mu$c/l, respectively, at the same depth; they were also open to the atmosphere but did not show evidence of vertical air movement. A moderate wind was blowing. It was concluded that air flow in the one drill hole was flushing radon to the surface, accounting for the relatively low radon concentration at depth, whereas the lack of air movement in the other holes was permitting a build-up of radon at depth.

Spring waters varied in radon content from less than 1 to 57,000 $\mu\mu$c/l. Values above 5,000 $\mu\mu$c/l in general correlated with nearby deposits of uranium of ore or sub-ore grade, while values below 5,000 $\mu\mu$c/l were obtained in areas believed to be barren. One sample from an unknown area contained 7,100 $\mu\mu$c/l, while two nearby springs contained 150 and less than 1 $\mu\mu$c/l, respectively.

Well waters varied from less than 1 to 7,400 $\mu\mu$c/l, the high value occurring above a known ore body. All other samples ran 1,300 $\mu\mu$c/l or less.

One stream was sampled at three points. Above the probable contact of the Fall River formation at the stream, three samples contained less than 10 $\mu\mu$c/l. Below the probable contact, a sample contained 290 $\mu\mu$c/l. It is possible that the increase in radon concentration represents the influence of ground water passing through anomalously uraniferous terrain.

Absorption and scattering of gamma-radiation

by

A. Y. Sakakura

The program for the solution on the Univac of the Boltzmann equation for gamma-rays from semi-infinite sources scattered into air has been checked, and solutions for various primary energies of the radium spectrum are now underway. One hundred and sixty hours have been utilized on the Univac, and the computation is proceeding at the rate of eight to 16 hours per week. It is estimated that another 200 hours are necessary for the radium spectrum, and 240 more for thorium and potassium.

With these solutions, given the spectral and angular response of any detector, the total response of any detector above semi-infinite sources of Ra, Th, or K can be computed. The efficacy, or the lack of efficacy, of spectral measurements for the determination of the composition of the source can be determined.

Results of the study of the motion of fluids through a porous medium previously reported has been found applicable to certain heat conduction problems. A joint study with Oak Ridge National Laboratory dealing with the asymptotic expansions of solutions of heat conduction equation in internally bounded cylindrical geometries has been completed and a report is in preparation.

A report on the study of gamma-ray measurements with airborne equipment over sources of several basic geometries has been completed.

Work on the measurement of radiation from a point source in a cylindrical cavity has been impeded by the unsuitability of commercially available A-1 amplifiers. Measurements obtained to date have not been satisfactorily reproducible. Consequently, a DD-2 amplifier, designed at the Oak Ridge National Laboratory for such purposes is presently under construction.

A spherical sodium iodide crystal will be used as an isotropic detector with an internally silvered glass tube as a light pipe.

Several designs for a directional gamma-ray detector for probing drill holes are being evaluated both mathematically and experimentally.

RESEARCH AND RESOURCE STUDIES

by

F. W. Stead

The objective of research and resource studies is to analyze and correlate on a national scale all available data on the geology of radioactive raw materials. Current information on the geologic distribution and types of uranium deposits was released in September 1955 as Map MR-2, "The uranium deposits of the United States." This map incorporates a brief text describing the major types of uranium deposits and the outlook for future development; it is for sale by the Geological Survey.

The nation-wide pattern of distribution of deposits changes continually as significant discoveries are made in new areas. Currently, 25 to 30 percent of ore-grade uranium in the United States is outside the Colorado Plateau region compared to less than 5 percent in 1951. Uranium deposits in terrestrial sandstones in regions of new discoveries, such as the Black Hills uplift, the Tertiary basins of Wyoming, and the Texas Coastal Plain, compare favorably with deposits in some districts of the Colorado Plateau. Recently discovered occurrences of ore-grade lignites and associated carbonaceous shales of the western Dakotas may be next in importance to deposits in terrestrial sandstones.

The following papers by members of the Resource and Research Group were published in the Proceedings of the United Nations International Conference on the Peaceful Uses of Atomic Energy:

"Uranium in terrestrial sedimentary rocks in the United States exclusive of the Colorado Plateau", by W. I. Finch.

"Relation of tectonic elements in Precambrian rocks to uranium deposits of the Cordilleran Foreland of the western United States", by F. W. Osterwald.

"The geology of uranium in the basins of Tertiary age in Wyoming and the Northern Great Plains", by J. D. Vine.

"Distribution of uranium deposits in the United States", by A. P. Butler, Jr., and R. W. Schnabel.

"Uranium-bearing coal in the United States", by J. D. Vine.

"Uranium in precipitates and evaporites in the United States", by K. G. Bell.

"Uranium in igneous rocks of the United States", by G. J. Neuerburg.

"The geology of thorium deposits in the United States", by W. S. Twenhofel and K. L. Buck.