Geology and Mineralogy

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CONTENTS

Page

Foreword........ 7
Geologic mapping........ 9
  Lisbon Valley, Utah-Colorado, by G. W. Weir and W. P. Puffett........ 9
  Laguna district, New Mexico, by R. H. Moench and J. S. Schlee........ 14
    Stratigraphic relations of the deposits........ 14
    Transmissivity of the host units........ 19
    Structural relations of the deposits........ 21
    Relations of uranium deposits to igneous rocks........ 24
    Forms and positions of the deposits........ 25
    Composition of the deposits........ 27
    Origin of the uranium deposits........ 28
    Resources in unexplored ground........ 30
  Grants area, New Mexico, by R. E. Thaden and E. S. Santos........ 32
    Stratigraphy........ 32
    Structure........ 35
    Uranium deposits........ 39
      Deposits in the Todilto limestone........ 39
      Deposits in the Westwater Canyon sandstone........ 41
      Deposits in the Brushy Basin shale........ 42
      Deposits in the Dakota sandstone........ 43
  Geologic maps of the Colorado Plateau, by D. G. Wyant,
    W. A. Fischer, P. L. Williams, and J. D. Vogel........ 44
  Southern Black Hills, South Dakota, by G. B. Gott........ 46
Geologic topical studies........ 46
  General stratigraphic studies, by L. C. Craig........ 46
  Lithologic studies, by R. A. Cadigan........ 47
    Rocks from the Fort Wingate locality, McKinley County,
      New Mexico........ 47
  San Rafael (Entrada) studies, by J. C. Wright........ 61
  Ambrosia Lake area, New Mexico, by H. C. Granger........ 66
  Reconnaissance for uranium and thorium in Alaska,
    by E. M. MacKevett, Jr........ 71
Geophysical investigations........ 73
  Regional geophysical studies of the Colorado Plateau,
    by H. R. Joesting and J. E. Case........ 73
  Geologic and geophysical studies, Coastal Plain, Texas,
    by D. H. Eargle, Alice D. Weeks, and R. M. Moxham........ 81
  Radiation laboratory, by W. W. Vaughn........ 88
Radioactivity investigations........ 91
  Radiogenic daughter products, Washington Laboratory,
    by F. E. Senftle........ 91
  Radiogenic daughter products, Denver Laboratory,
    by J. N. Rosholt, Jr........ 93

Page

Research programs.. 95
  Physical behavior of radon, by A. B. Tanner.................. 95
    Methods for extraction of radon from large air samples.......... 95
    Measurement of radon at uranium deposits by the emanation method.......... 95
  Distribution of uranium in igneous complexes, by David Gottfried.......... 102
    Uranium contents of the Koolau and Honolulu basalts of Oahu.......... 102
    Uranium content of an olivine basalt flow near Soda Springs, Idaho.......... 104
    Uranium in the diabase-granophyre sequence, Dillsburg, Pennsylvania.......... 106
    Uranium content of diabase-granophyric rocks from Fairfax County, Virginia.......... 106
    Uranium in rocks of the Shonkin Sag laccolith.......... 108
  Synthesis and solution chemistry of uranium, by I. A. Breger and A. M. Pommer.......... 110
    Mineral synthesis.......... 111
    pH potential studies.......... 112
    Coalified wood as a geothermometer.......... 112
    Impregnated sandstone.......... 113
    Woody materials in ore formation.......... 113
    Role of complexes in ore-forming fluid.......... 113
    rH studies.......... 113
    Weathering in ore bodies.......... 114
  Stable isotope analysis, by Irving Friedman.......... 114
  Nuclear geology, by F. E. Senftle.......... 115
  Nuclear irradiation, by Carl Bunker.......... 117
  Geochronology, by L. R. Stieff.......... 119
  Isotope geology of lead, by R. S. Cannon, Jr.......... 121
  Natural radioactivity of the atmosphere, by H. B. Evans.......... 123
  Thermoluminescence of radioactive minerals, by F. E. Senftle and A. Thorpe.......... 124
  Geochemistry of thorium, by George Phair.......... 126
  Geologic thermometry of radioactive materials, by D. B. Stewart and B. J. Skinner.......... 128
    The system albite-eucryptite-silica-water.......... 128
    The system ZnS-FeS-MnS-CdS.......... 129
    Other studies.......... 130
  Crystallography of uranium and associated minerals, by H. B. Evans, Jr.......... 130
  Infrared and ultraviolet radiation studies, by R. M. Moxham and W. W. Vaughn.......... 131

ILLUSTRATIONS

Page

Figure 1. Index map showing tentative order of, and progress in, compilation of 2° sheets of the Colorado Plateau geologic maps project.................................. 46
2. Graphs showing percentage rock composition, grain size, and sorting properties of sedimentary rocks in the Fort Wingate Ordnance Depot area, McKinley County, New Mexico.. 48
3. Map of original thickness of Todilto formation (New Mexico) and Pony Express formation (Colorado).... 62
4. Hypothetical paleogeography of the Colorado Plateau during deposition of the Todilto limestone............ 64
5. Regional geophysical surveys in the Colorado Plateau.... 74
6. Sketch showing some of the major structures of the central Colorado Plateau.............................. 77
7. Description of core of Columbia-Southern Chemical Corporation's Hole no. 606, Duval County, Texas....... 84
8. Description of core of Columbia-Southern Chemical Corporation's H. C. Gravis no. 1 core test, Duval County, Texas... 85
9. Map showing location of core tests in Texas Coastal Plain, Duval County, Texas............................ 86
10. Uranium content of different parts of an undifferentiated olivine basalt flow near Soda Springs, Idaho.................................. 105
11. Uranium content of different facies of the diabase-granophyre sequence near Dillsburg, Pennsylvania...... 107
12. Distribution of uranium in rocks of the diabase-granophyre sequence at Dillsburg, Pennsylvania........ 107
13. Distribution of rocks in the Shonkin Sag laccolith, Highwood Mountains, Montana.......................... 109
14. Preliminary calibration chart showing relationship between counts per second, formation density, and source-to-detector spacing............................ 118
15. Experimental density drill hole at Denver Federal Center.. 120
16. Electronic integrator for phosphorescence decay studies... 132

TABLES

Page

Table 1. Comparison of copper deposits and uranium deposits in the Lisbon Valley area, Utah-Colorado.............. 11
2. Sequence of formational units containing uranium deposits in the Laguna district...................... 15
3. Tabulated results of point-count composition analysis of 31 samples of Permian, Triassic, and Jurassic rocks from a measured section at the Fort Wingate Ordnance Depot, McKinley County, New Mexico.. 50
4. Comparison of calculated and experimental alpha absorption coefficients............................. 92
5. Uranium content of Koolau basalts, Oahu................. 103
6. Uranium content of Honolulu basalts, Oahu............... 103
7. Uranium content of diabase-granophyric rocks from Fairfax County, Virginia.............................. 108
8. Magnetic susceptibilities of natural TiO_2................ 116
9. Analyses of standard lead GS/4 at several laboratories.. 122
10. Magnetic susceptibility data on calcite sample from Las Cruces, New Mexico.......................... 125

FOREWORD

The Semiannual Reports, "Geologic Investigations of Radioactive Deposits," were originally prepared as administrative reports to the Atomic Energy Commission, but beginning with TEI-330 (issued in June 1953) each report in the series has been reissued and made available to the public by the Technical Information Service Extension of the Commission.

The papers in the Semiannual Report are of necessity preliminary in nature and are not edited to conform to Survey publication standards. Most of the reports cover work done during the six-months' period reported upon, with only enough former work included to provide a proper perspective. For projects for which field work has been completed, however, longer reports that are essentially expanded abstracts of the final Survey report are included. Two such reports in this volume are those on the Laguna district, New Mexico (pages 14-32) and the Grants district, New Mexico (pages 32-43).

Until July 1, 1958, the Survey's studies in the field of uranium geology were financed by the Division of Raw Materials and the Division of Research of the AEC. On that date, however, funds formerly supplied by the Division of Raw Materials were transferred to the Survey's direct appropriation; and the support furnished by the Division of Research is now being decreased gradually over a period of several years. Thus, the uranium program is now financed principally by the Survey's own funds; but because of the Commission's vital interest in and large responsibility for the Nation's uranium programs, the Survey

plans for the present at least to continue the issuance of Semiannual Reports, which as in the past will be reissued through the Technical Information Service Extension. By this means both the Commission and the general public will be kept informed of the Survey's work in uranium geology prior to formal publication of results.

During the past six months publications in the Survey's report series, or in scientific journals (as distinguished from preliminary reports, such as those contained in this volume) included four Survey Professional Papers, 15 Survey Bulletins or Bulletin Chapters, 26 Survey maps, and 18 papers and 15 abstracts in scientific journals. In addition, 18 papers by Survey scientists were published in the Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, held at Geneva, Switzerland in 1958.

Since June 1954, when easing of security restrictions made it possible to publish much material that previously had been classified, publications stemming from the Survey's uranium program include eight Professional Papers, 98 Bulletins or Bulletin Chapters, 53 Circulars, and 401 maps. During the same period 88 reports have been placed on open file and 26 reports have been reissued for distribution to the public by the Technical Information Service Extension.

GEOLOGIC MAPPING

Lisbon Valley, Utah-Colorado

by
G. W. Weir and W. P. Puffett

The Lisbon Valley area contains several hundred uranium-vanadium deposits, which range from small occurrences to large deposits that contain more than 1,000,000 tons of ore averaging about 0.4 percent U_3O_8. The ore is in the upper part of the Cutler formation of Permian age, the lower part of the Chinle formation of Late Triassic age, and the middle part of the Morrison formation of Late Jurassic age. A few minor occurrences of radioactive and vanadiferous rock have been found with copper deposits in the lower part of the Cutler formation and in the Burro Canyon formation of Early Cretaceous age.

The Lisbon Valley area contains a few dozen copper deposits, which range in size from small occurrences to deposits that have yielded more than 150,000 tons of ore averaging about 1.4 percent Cu. Most of this ore has come from the Dakota sandstone of Late Cretaceous age, but small copper deposits are found also in the Hermosa formation of Pennsylvanian age, the Cutler formation, the Chinle formation, the Kayenta formation of Jurassic(?) age, the Morrison formation, the Burro Canyon formation, and in brecciated igneous rock of Tertiary age in the La Sal Mountains. Copper minerals also occur in variable but generally small amounts in the uranium deposits.

Most of the copper and uranium-vanadium deposits form tabular bodies in virtually unaltered sandstone, a type of deposit whose origin has been the subject of much discussion. Because the copper deposits are mainly in fractured rock near faults over a wide stratigraphic range, and include a deposit in brecciated igneous rock, they are considered low-temperature hypogene deposits. The uranium-vanadium deposits do not occur in igneous rock nor generally near faults, but their geologic habits are otherwise similar, and like the copper deposits they show a wide stratigraphic range. The occurrence of copper minerals in many of the uranium-vanadium deposits, and of uranium and vanadium minerals in a few copper deposits, suggests a transition between the two kinds of deposits. The uranium-vanadium deposits, therefore, are considered also to be low-temperature hypogene deposits.

The chief similarities and differences between the uranium and copper deposits are presented in table 1.

The copper deposits in the igneous rocks of the La Sal Mountains are of hydrothermal origin (Hunt, 1958, p. 338, 355). The bedded copper deposits in sandstone and the vein-like accumulations in limestone in the Lisbon Valley area were most likely deposited from solutions that had the same or similar origin as the solutions that deposited copper in the igneous rocks. The ore solutions migrated through beds and along faults, especially the Lisbon Valley fault, and in so doing were undoubtedly modified by connate and

Table 1.--Comparison of copper deposits and uranium deposits in the Lisbon Valley area, Utah-Colorado

	Copper deposits		Uranium deposits		
Host rock	Igneous rock	Sedimentary rocks: Hermosa fm., Cutler fm., Chinle fm., Kayenta fm., Burro Canyon fm., Morrison fm., Dakota ss.	Cutler fm.	Chinle fm.	Morrison fm.
Approximate maximum size in thousands of tons	<1	Dakota ss. >100; others <1	>1	>1,000	100
Approximate grade	1% Cu	Dakota 2% Cu; others <1% Cu	0.1% U_3O_8 0.2% V_2O_5	0.4% U_3O_8 <1.0% V_2O_5	0.2% U_3O_8 1.0% V_2O_5
Chief ore minerals	Malachite, azurite, chrysocolla, chalcocite, bornite, chalcopyrite	Malachite, azurite, brochantite; chalcocite, chalcopyrite, native copper, copper oxides, covellite	Carnotite, becquerelite, vanadium hydromica	Uraninite, coffinite, montroseite	Carnotite, tyuyamunite, vanadium hydromica
Shape of ore bodies	Irregular pods and veins	Generally tabular. Thin veins in limestone of Hermosa fm.	Tabular lenses and irregular layers	Tabular lenses and irregular layers	Tabular lenses and curving layers
Lithology of host rock	Altered quartz diorite	Chiefly sandstone. Small occurrences in limestone	Sandstone	Sandstone, rarely mudstone	Sandstone
Degree of oxidation of ore minerals	Largely oxidized	Highly oxidized	Highly oxidized	Generally unoxidized	Highly oxidized
Alteration of host rock	Argillized and silicified	Minor. Some limonite and hematite staining and bleaching of reddish rocks	Minor. Irregular color blotching	Minor. Some color changes	Minor. Some interstratified and underlying mudstone altered from red to green
Association with carbonaceous material	None	Generally associated with carbonized plant fossils in Dakota sandstone and in sandstone in Hermosa fm. A little pyrobitumen in some Burro Canyon and Cutler occurrences. None in limestone of Hermosa fm.	Practically none	Rare to common carbonized plant fossils	Common to abundant carbonized plant fossils
Epigenetic gangue minerals	Quartz, calcite	Generally none; barite in one Cutler occurrence	None	Sporadic orange chert, barite and celestite	None
Presence of copper minerals in uranium-vanadium deposits and uranium-vanadium minerals in copper deposits	None	Generally none. Radioactive and vanadiferous minerals in two copper prospects in Burro Canyon fm. and one prospect in Cutler fm.	Copper carbonates locally common in several deposits	Copper carbonates, sulfides and native copper present sporadically for a few deposits	Copper carbonates sporadically common in several deposits
Association with geologic structure	Brecciated border zone of intrusive stock	Most deposits along the Lisbon Valley fault and subsidiary faults	None except on flank of Lisbon Valley anticline	None except most on flank of Lisbon Valley anticline	None

ground water in the sedimentary rocks. The sporadic occurrence of copper minerals with uranium-vanadium minerals suggests that these copper-bearing solutions also contained uranium and vanadium. The general separation into copper deposits and uranium-vanadium deposits may be due to the influences on ore deposition of differences of temperature, pressure, and chemical environment of the host rocks. The ores may have been precipitated by the action of changes in pH of the ore solutions resulting from contact with hydrogen sulfide in minor stratigraphic traps. The hydrogen sulfide was perhaps derived in part from plant remains in some of the ore-bearing formations, but a more adequate local source probably existed in buried petroliferous Paleozoic rocks.

The age of the copper deposits in the sedimentary rocks is generally assumed to be Tertiary, as much of the copper is in Cretaceous rocks associated with post-Cretaceous, presumably early Tertiary, faults. The age (based on isotopic data) of the uranium-vanadium deposits is undetermined (Miller and Kulp, 1958; Stieff and others, 1953), but if the major deposits are viewed as the results of a single process and event, they are certainly post-Late Jurassic, and a few occurrences of uranium and vanadium minerals in copper deposits in Lower Cretaceous rocks suggest that all these deposits are post-Early Cretaceous. As Tertiary sedimentary rocks are

lacking in this area most of the details of the Cenozoic history are unknown. The copper deposits in the igneous rocks of the La Sal Mountains attest Tertiary mineralization, and if all the copper and uranium-vanadium deposits are interrelated, the ores are Tertiary--perhaps fairly late in the Tertiary.

References

Hunt, C. B., 1958, Structural and igneous geology of the La Sal Mountains, Utah: U. S. Geol. Survey Prof. Paper 294-I, p. 305-364.

Miller, D. S., and Kulp, J. L., 1958, Isotopic study of some Colorado Plateau ores: Econ. Geology, v. 53, p. 937-948.

Stieff, L.R., Stern, T. W., and Milkey, R. G., 1953, A preliminary determination of the age of some uranium ores of the Colorado Plateaus of the lead-uranium method: U. S. Geol. Survey Circ. 271, 19 p.

Laguna District, New Mexico

by

R. H. Moench and J. S. Schlee

The Laguna district is on the eastern side of the Colorado Plateau, about 45 miles west of Albuquerque, New Mexico. Because of the considerable production of uranium ore from the Jackpile mine, the area is one of the most productive uranium districts in the United States. According to Hilpert and Moench (1958, p. 527) the district constitutes the eastern end of the "southern San Juan basin mineral belt."

Stratigraphic relations of the deposits

All productive uranium deposits in the Laguna district are in sedimentary rocks of Jurassic age. The stratigraphic distribution of the uranium deposits, and the salient characteristics of the ore-bearing sequence, are summarized in table 2. The upper part of the Chinle formation of Triassic age, and many units of the Mesaverde group of Cretaceous age, are also exposed in the area. These units, however, have no apparent bearing on the uranium deposits and will not be discussed further.

The upper sandstone unit of the Entrada sandstone is about 90 feet thick where mineralized, but ranges to as much as 160 feet thick several miles to the southwest. It is fine grained, well sorted, and moderately well cemented with calcite. The unit contains an upper, nearly white zone and a lower reddish-orange zone, and locally near the base of the white zone a thin purple zone. The zoning is not controlled by stratigraphy. The reddish-orange and purple colors are imparted by finely disseminated hematite. Apparently hematite has been leached from the white

Table 2.--Sequence of formational units containing uranium deposits in the Laguna district, New Mexico

System		Thickness (feet)	Character and distribution	Uranium deposits
Cretaceous	Dakota sandstone	5-100	Fine- to medium-grained quartz sandstone, locally conglomeratic. Generally carbonaceous shale and locally coal at base.	Some small nonproductive deposits near base and in close relation to carbonaceous material.
Unconformity				
Jurassic	Morrison formation	0-600	"Jackpile" sandstone; dominantly nearly white sandstone containing thin beds of mudstone. As much as 200 feet thick, and confined to a belt about 12 miles wide that extends northeastward across the district.	Contains largest deposits in district.
			Brushy Basin member; dominantly a greenish-gray mudstone with abundant sandstone units. Ranges from 0 feet thick south of Laguna to about 450 feet thick north of Laguna.	Contains few small deposits in sandstone units.
	Bluff sandstone	about 300	Thick-bedded fine- to medium-grained sandstone.	Contains no deposits.
	Summerville formation	90	Fine-grained sandstone beds, generally one to several feet thick, alternating with thinner beds of siltstone.	Contains no deposits.
	Todilto limestone	5-85	Fetid dense gray laminated limestone; massive in upper part. Includes an upper unit of anhydrite and gypsum that ranges from discontinuous masses at south to continuous unit to the north.	Contains many small deposits. The anhydrite-gypsum member is barren.
	Entrada sandstone	150-250	Three units: basal discontinuous reddish orange sandstone, intermediate red siltstone, and upper sandstone. The upper sandstone contains two distinct units--a lower reddish-orange unit and an upper white unit; it is 90 to 160 feet thick.	Contains a few small deposits in upper white sandstone

zone, and detrital magnetite and ilmenite have been largely altered and removed. As evidence of this hypothesis, channel samples reveal about 1.8 percent total iron (as Fe_2O_3) in red sandstone, but only about 0.5 percent total iron in white sandstone. Although the purple sandstone has an iron-rich appearance, the darkest material contains less iron than the red sandstone. All of the uranium deposits in the Entrada are in the upper white sandstone.

The Todilto limestone contains two main units--a thin, extensive limestone unit at the base, and an upper less extensive, but locally much thicker gypsum-anhydrite unit. The limestone is gray and when freshly broken has a fetid odor. Except where coarsely recrystallized along fractures, it is fine-grained and thinly bedded in the lower part, and medium-grained and massive in the upper part. In the extreme southern part of the area the limestone thins to a knife edge, and its thickness in much of the area is about 10 feet. Where it is mineralized the limestone is as much as 35 feet thick. Such local thickenings appear to occupy broad, east-trending pre-Dakota synclines and on the corresponding anticlines the limestone is considerably thinner. In much of the area the limestone is conspicuously folded and faulted; most of these structures are entirely within the limestone unit, but some involve the overlying and underlying formational contacts.

The gypsum-anhydrite unit ranges up to about 75 feet thick, and forms an extensive sheet in the northern part of the area. To the south it is discontinuous, and like the limestone, occupies broad pre-Dakota synclines. Where exposed at the surface the unit is composed entirely of gypsum but in the deeper drill holes it is largely anhydrite.

The gypsum is nowhere mineralized, nor is the underlying limestone mineralized where the gypsum is now exposed. This relationship, however, may be misleading, because in one area of extensively mineralized Todilto limestone there is some evidence that gypsum was present at the time of mineralization. Here a rock termed "gypsum breccia residue" occupies the stratigraphic position of the gypsum. The gypsum breccia residue is marginal to the main gypsum unit, and is a brown porous mixture of fragmental sandstone and limestone from which gypsum apparently has been leached. The breccia is interpreted as having been formed by the conversion of anhydrite to gypsum during removal of overburden in latest Tertiary and Quaternary time, and by recent leaching of gypsum from the breccia at or near the present surface. As the uranium deposits probably formed at a much earlier time, the presence of the gypsum breccia residue suggests that gypsum was present during mineralization.

The Summerville and Bluff formations overlying the Todilto constitute an essentially barren stratigraphic interval of about 400 feet. The Bluff sandstone is homogeneous and well sorted, and the Summerville formation is composed of interstratified sandstone, siltstone, and mudstone.

Economically the Morrison formation is the most important unit in the district, and by far the preponderance of uranium deposits is in the uppermost member, the so-called Jackpile sandstone. The Morrison formation ranges in thickness from nil a few miles south of Laguna to as much as 600 feet a few miles north of Laguna; its thickness is controlled largely by the angular unconformity at the base of the Dakota sandstone. The Brushy Basin member, which forms the bulk of the formation, is as much as 450 feet thick. It is composed dominantly of greenish-gray bentonitic mudstone, but includes many beds of fluvial subarkose, and in many places such sandstone makes up as much as 50 percent of the section. One bed of sandstone near the base of the member is more persistent than most and may correlate with the Westwater Canyon member, the main ore-bearing unit in the Ambrosia Lake district (Hilpert and Moench, 1958, p. 527). Between this sandstone bed and the base of the formation is a zone averaging about 30 feet thick composed of grayish-red and greenish-gray mudstone, siltstone and sandstone that may correlate with the Recapture Creek member west of Mount Taylor (Hilpert and Moench, 1958, p. 527). The sandstone beds of the Brushy Basin member contain a few small uranium deposits.

The so-called Jackpile sandstone is as much as 200 feet thick, but is confined to a belt about 12 miles wide that extends easterly and northeasterly across the district. The original length of the belt is not known, but available data indicate a minimum length of about 35 miles. As the unit is truncated at its top by the Dakota sandstone the original thickness of the so-called Jackpile sandstone is not known. Sedimentary structures indicate a northeasterly direction of sediment transport parallel to the elongation of the unit, and by comparison with younger sediments on the Gulf Coast the sandstone probably represents a fluvial deltaic plain deposit with distributaries to the northeast (Schlee, 1957). From a knowledge of the pre-Dakota folds (see below), combined with observations that the sandstone-mudstone ratio of the Brushy Basin member increases in the vicinity of the belt of the so-called Jackpile sandstone and that the Brushy Basin is abnormally thick in the same area, it is interpreted that the deposition of the so-called Jackpile sandstone and possibly of the entire Morrison formation was controlled by a broad, northeast-trending depression that formed during sedimentation.

The so-called Jackpile sandstone is friable, light colored, locally nearly white, and is composed dominantly of quartz, but contains much feldspar and rock fragments. In its upper parts it is weakly cemented primarily by white clay (mostly kaolin) and near its base by quartz and some calcite; but in places the three cementing materials may be found in a single specimen. In addition the proportional detrital quartz content increases near the top of the unit, the feldspar and rock fragments having been altered to clay. Leopold (1943) has noted the occurrence of kaolin beds and zones at the top of the Morrison formation at widely spaced localities in northwest New Mexico and northeast Arizona, and concluded that they were the product of chemical weathering during moist climate which prevailed during part of the time between Jurassic and Cretaceous deposition. The vertical compositional and textural changes within the so-called Jackpile sandstone support Leopold's interpretation.

Transmissivity of the host units

The transmissivity of a stratigraphic unit may be defined in terms of the permeability of the rocks and the dimensions of the unit. The characteristics of the rocks of the Laguna area are known sufficiently well to distinguish qualitatively between relatively permeable and relatively impermeable units, and as the dimensions of the units are known, relatively transmissive and relatively nontransmissive units can be distinguished.

The Entrada sandstone is one of the most transmissive units of the region. The thick upper sandstone unit of the formation extends as a single bed over a great area; it is homogeneous, well sorted, only moderately well cemented, and is known to be a good aquifer. In contrast the overlying Todilto limestone, though extensive, is thin. More important, the rock is probably quite impermeable, for it contains little visible pore space. In thin section grain boundaries are tight, and the abundant silty laminae in the laminated zone are completely cemented with clay or calcite. The unit may be slightly more permeable where it is deformed by intraformational folds, and solutions might be able to move along the axes of such folds. However, many of the mineralized intraformational flowage folds are not known to involve the lower few feet of the limestone, and this condition presents a perplexing problem of access for uranium-bearing solutions. Much of the ore is concentrated along siltstone laminae which may be the most permeable part of the rock, but some is in the apparently impermeable massive zone, to which the only access is the tight grain boundary now occupied by uraninite.

The large quantities of water that must be pumped from mines below the water table attest to the permeability of the so-called Jackpile sandstone. This unit, however, is limited in extent, and before Quaternary erosion was probably confined on all sides except possibly on its northeastern extremities by relatively impermeable units. The underlying bentonitic mudstones of the Brushy Basin member are probably quite impermeable. The overlying sandstone of the Dakota is probably quite permeable, but the unit contains abundant black shale, much of it at the base of the unit and in direct contact with the so-called Jackpile sandstone. The presence of the basal black shale should have impeded the exchange of solutions between the Dakota and the so-called Jackpile sandstone from the time of burial until Pleistocene (?) erosion.

Further, the so-called Jackpile sandstone is essentially parallel to the strike of the Dakota and younger rocks on the southeast corner of the San Juan basin, so that structural tilting probably did not influence strongly the movement of solutions within the unit.

Structural relations of the deposits

Although the strata in most of the Laguna district are nearly flat-lying, three general periods of deformation are recognized; pre-Dakota or largely Jurassic, early Tertiary, and middle Tertiary to Quaternary. Only structures of the first period show an obvious influence on the distribution and localization of the uranium deposits.

The first period of deformation--during Jurassic time and possibly extending into Early Cretaceous time--produced two sets of folds and smaller associated structures. The major set of folds consists of broad gentle sinuous warps that generally trend easterly. The largest of these warps is perhaps several miles wide and has an amplitude of a few hundred feet. This set is essentially parallel to the northern margin of a broad highland that existed in central and southern New Mexico in Jurassic time (McKee and others, 1956).

The second set of folds trends persistently N. 10°-30° W., nearly at right angles to the major set. Most folds are about a half a mile across, have amplitudes of as much as 100 feet, and characteristically form small structural depressions in otherwise nearly flat-lying strata. They apparently were formed under gentle, nearly east-west tension during Jurassic sedimentation.

The Todilto limestone is commonly deformed into a great variety of structures that are largely intraformational. Although fractures are present, the characteristics of plastic deformation are dominant and a wide variety of folds is exposed. These folds generally parallel both sets of larger pre-Dakota folds, and appear to be in part responsible for the observed thickening of the limestone in the synclines and thinning on the anticlines. All data suggest that the folds were formed by flowage of poorly consolidated calcareous muds down the limbs of the broad folds.

Cylindrical collapse structures, or sandstone pipes, are abundantly exposed in the Summerville and Bluff formations and less abundantly in the Morrison formation. They are vertical in orientation and range from 1 inch to 200 feet in diameter and from 1 foot to 300 feet high. None is known to penetrate the Todilto limestone or the Dakota sandstone. Their general stratigraphic range, therefore, is about 1,000 feet. Most of the pipes are concentrated in belts that occupy the steep flanks or troughs of pre-Dakota synclines. The tops of some pipes are well exposed and provide a basis for determining their time of origin; that is, the pipes are truncated at their tops by the uppermost sedimentary units that they cut, indicating that they formed during the deposition of the units that contain them.

The pre-Dakota folds of both sets formed prior to the deposition of the Dakota sandstone, and in part contemporaneously with the deposition of the Jurassic rocks above the Entrada sandstone. Broad folds are truncated by the Dakota sandstone, indicating their pre-Dakota age. The association of sandstone pipes which formed during sedimentation, and intraformational folds which probably formed during and shortly after Todilto deposition, with large pre-Dakota folds suggests that the larger folds likewise were formed, at least in part, during sedimentation. In addition the deposition of the so-called Jackpile sandstone, and possibly of the entire Morrison formation, may have been controlled by a broad, east- to northeast-trending structural depression.

The post-Dakota structures formed during the second period of deformation include a gentle northerly to westerly dip into the San Juan basin, a number of gentle anticlines, synclines, basins, and domes near the east side of the area, and a north-trending intensely faulted zone that marks approximately the boundary between the Colorado Plateau and the Rio Grande depression. In addition, the rocks throughout the area are systematically jointed and faulted.

From a knowledge of the structural geology of many parts of the Rio Grande depression, and from the experimental work of Cloos (1955) and the theoretical work of Anderson (1942) and Hubbert (1951), the post-Dakota structures of the Laguna district are consistent with the interpretation that the region was subjected to two stages of deformation in Tertiary time. The first stage, possibly initiated in latest Cretaceous time, produced the larger folds under east-west compression. The second stage, from middle Tertiary through Quaternary times, produced the dominant fracture system of the area under east-west tension.

From the available evidence only structures (in addition to sedimentary features) related to the first, or pre-Dakota deformation, effectively localized uranium deposits. Intraformational flowage folds are the dominant control in the Todilto limestone, and two sandstone pipes are known to have localized uranium in the so-called Jackpile sandstone. In addition the north ore body of the Jackpile mine may have been controlled in part by a gentle north-northwest-trending pre-Dakota anticline. On the other hand there is no direct indication that post-Dakota folds or fractures localized any deposits.

Relations of uranium deposits to igneous rocks

Igneous activity has been intense in the Laguna area from late Tertiary to Recent times. It probably began with the intrusion of diabasic sills and dikes, followed by the formation of a large stratified volcano, Mount Taylor, which in turn was closely followed by sporadic outpourings of basaltic lava from many pipes and fissure vents in the immediate vicinity of Mount Taylor.

The interconnecting diabasic sills and dikes east of Mount Taylor probably were intruded contemporaneously, though this intrusion is not accurately dated. The dikes dominantly follow the prominent north-trending fracture set, and the sills, in turn, are jointed and locally faulted by the same set. This suggests that the diabase was intruded contemporaneously with fracturing mostly in middle to late Tertiary time. Inclusions of the diabase were found in a volcanic pipe that probably supplied one of the earliest basaltic flows; the diabasic rocks are thus at least older than what may be the oldest basaltic flows. These oldest basaltic flows were extruded essentially contemporaneously with the latest stages of the Mount Taylor eruptions, and the diabasic rocks probably were earlier than or contemporaneous with the oldest of the Mount Taylor stages.

The volcanic rocks of Mount Taylor consist dominantly of pyroclastics and flows of rhyolite, trachyte, and latite, and dikes of porphyritic andesite (Hunt, 1938). The basaltic flows, pipes, and fissure vents in the immediate vicinity are composed dominantly of olivine basalt and contain some olivine andesite. Both the Mount Taylor stratovolcano and the oldest basaltic flows rest on an erosion surface that probably is younger than the major structural developments in the Rio Grande trough. The oldest basaltic flows are probably overlain by some of the pyroclastics from Mount Taylor, and overlying basaltic flows intertongue with an alluvial cone built out from the upper part of the mountain. This condition suggests that there was little, if any, break in time between the Mount Taylor eruptions and the extrusion of the basaltic flows. Younger basaltic flows rest on younger erosion surfaces, and some flows follow the present drainage.

The distribution pattern of the known uranium deposits in the mineral belt area does not suggest a spatial relationship to the igneous rocks (Hilpert and Moench, 1958, p. 531). Furthermore, the diabasic dikes and sills, which probably are the oldest igneous rocks, intrude and displace many uranium deposits in the Laguna district and metamorphose them along the contacts. As these rocks are younger than the deposits, it is unlikely that they influenced the localization or origin of the deposits.

Forms and positions of the deposits

The external form assumed by a deposit is controlled largely by the features that localized it. The deposits in limestone tend to be strongly elongate or pencil-like, because they are localized by intraformational folds; and deposits in sandstone pipes tend to be pipe-like because they are localized mainly by the ring faults that bound the pipes. The large deposits in sandstones, however, lack well-defined controls. They are semi-tabular, roughly parallel to the large stratification, and tend to be elongate either parallel to the dominant sedimentary trends or to gentle pre-Dakota folds.

In detail the deposits show considerable independence with respect to sedimentary structures. Typically the semi-tabular deposits in sandstone are figuratively suspended within the host rocks. Although thin mudstone beds locally mark the boundary of ore, more frequently the upper and lower boundaries are not marked by impermeable barriers and commonly cut through the middle of thick sedimentation units.

Roll structures, similar to those that have been described by others in other parts of the Colorado Plateau, are characteristic of all semi-tabular deposits in sandstone, and may be inferred from drill data to exist in at least one deposit in limestone. The axes of the rolls tend to parallel the long dimensions of the deposits, and therefore the sedimentary or tectonic structures that localized the deposits. In section the rolls, by definition, cut sharply across the sedimentary structures.

Vertical ore rods, which apparently are peculiar to the Laguna district, are present in some deposits in the so-called Jackpile sandstone. The rods are as much as 2 feet high, 2 inches in diameter, and tend to occupy the lower-grade parts of ore bodies. Where present at all they are abundant. They are not miniature collapse structures, for sedimentary structures pass through them without disturbance. The significance of the rods is not known, but probably they were formed by gravity-controlled movement of solutions.

A group of many small deposits in the Todilto limestone and Entrada sandstone occurs in a small area known as the Sandy mine. In plan the deposits are concentrated mostly on the flank of a gentle pre-Dakota monocline. High on the flank of the monocline they are in the Entrada sandstone, whereas near the synclinal bend they are well up in the overlying Todilto limestone. In short the deposits constitute a nearly horizontal group that cuts across the tilted formational boundary.

Composition of the deposits

As pointed out in TEI-740, p. 77-81 much of the unoxidized ore in the Laguna district is composed of an intimate mixture of uranium (largely in coffinite) and organic carbon; the carbon is largely responsible for the dark coloring of the ore. The proportion of uranium to carbon varies greatly from one deposit to another, but all deposits in sandstone, and possibly those in limestone as well, seem to have detectable amounts of carbon. Judging from the texture and distribution of the carbonaceous material, it was probably derived from a fluid.

X-ray studies reveal that much of the low-valent uranium in the non-calcareous sandstone ores is in coffinite, and in the calcareous sandstone (Entrada) both coffinite and uraninite are present. Insufficient material for X-ray study was available from deposits in limestone in the Laguna district, but by comparison with deposits in limestone in the Ambrosia Lake district the low-valent uranium is probably largely in uraninite. Though not abundant, vanadium is present in all deposits. It is largely in a fine-grained mixed-layer mica-montmorillonite, and some chlorite. Sulfides, mostly pyrite, are also present, and are locally abundant. In the Woodrow mine pyrite and marcasite are abundant, and small amounts of chalcopyrite are also present.

In parts of all deposits uranium is in the hexavalent state. It is assumed that this hexavalent uranium formed by oxidation of minerals containing tetravalent uranium. The minerals containing hexavalent uranium are too numerous to warrant listing here, but tyuyamunite and carnotite appear to be most abundant.

Origin of the uranium deposits

Although the uranium deposits of the Laguna district differ in form and were localized by different features, they probably had a common origin. The close association of deposits in the Entrada sandstone and Todilto limestone suggests a common origin for these deposits. In turn the semitabular deposits in the Entrada and so-called Jackpile sandstones are similar in character. The deposits in sandstone pipes differ markedly from other deposits in form, as governed by the localizing structures. However, in the Jackpile mine the top of one weakly mineralized sandstone pipe is exposed. The pipe is mineralized at about the elevation of the north ore body, and to an unknown depth; but it is not mineralized above this level even though it contains abundant carbonaceous debris. As the ores in the pipe and in the north ore body are compositionally similar, the positional relation between the two deposits suggests a common origin.

The available evidence suggests that the ores were deposited in a near-surface environment below a water table. It is not proposed that the water table marked the upper boundary of ore, but at least it may have been a level above which ore was not precipitated. This interpretation may account for the presence of abundant and varied forms of barren carbonaceous material a few feet above the Jackpile deposit, and the typical figurative suspension of deposits in the middle of their host rocks. That a nearly horizontal group of deposits cuts across the tilted Entrada-Todilto contact is more convincing evidence that a water table partly controlled uranium deposition.

As the strata probably were saturated from the time of burial by the Dakota sandstone until late Tertiary or Quaternary uplift and erosion, the periods of incomplete saturation are likely to have been limited to pre-Dakota and Quaternary times. The localization of the ores by a combination of sedimentary features and structures that formed prior to the deposition of the Dakota sandstone, and not by younger structures, is consistent with the interpretation that the ores were deposited under near-surface conditions prior to burial by Cretaceous and younger rocks.

Such near-surface conditions are also consistent with the interpreted limited transmissivity of the Todilto limestone and so-called Jackpile sandstone. Although the Todilto ores are perplexing, the abundance of intraformational structures is evidence that the rock passed through a plastic, poorly consolidated stage before complete consolidation was achieved. Perhaps during this stage the rock was more permeable and more transmissive to solutions than later. Similarly the so-called Jackpile sandstone may have received its ores before it became restricted by erosional truncation and burial beneath the Dakota. Before burial solutions undoubtedly could have moved much more freely than after burial. Further, if after burial the only possible access to the unit for the uranium-bearing solutions was through the Dakota sandstone, the question of why the pyritiferous black shales localized so little uranium (apparently none in the vicinity of the large deposits a short distance below) must be answered.

The origin of the actual boundary of ore is not known, but to account for roll forms, two solutions seem to be required (Shawe, 1956, p. 241). The character of the two solutions is not known; possibly both were ground waters that differed with respect to temperature, salinity, or contained organic material. From the composition of the ores one solution may have been (1) an organic fluid (petroleum) or (2) an organic substance in aqueous solution (dissolved plant extracts). Determination of which of the two possibilities is correct depends in part upon the results of chemical work now in progress, but (2) is more consistent with the interpreted near-surface environment of ore deposition.

Resources in unexplored ground

Hilpert and Moench (1958, p. 537) suggest that the uranium deposits on the southern margin of the San Juan basin are largely confined to a belt at least 20 miles wide and 85 miles long that extends northwesterly from the Laguna district, through the Ambrosia Lake district, thence at least as far as Gallup, New Mexico. They propose the term "southern San Juan basin mineral belt" for this belt of uranium deposits.

Although the reasons for the existence of this belt are not fully known, the belt appears to be related to a number of controlling and definitive geologic features. In addition to the Jurassic highland and the southern limits of the Todilto limestone and the Morrison formation, it parallels the easterly trend of the major Jurassic folds, the dominant orientation of the intraformational folds in the Todilto limestone, the elongation of the thickest parts of the host sandstones of the Morrison formation, the dominant known sedimentary trends within these host sandstones, and, finally, the individual belts of deposits, such as the group that contains the Paguate, Jackpile, M-6 and many other smaller deposits.

Exploration of the Laguna district should be governed by the known distribution of the main ore-bearing unit, the so-called Jackpile sandstone. Deposits in the Entrada and Todilto formations are economically insignificant and only small deposits are known to exist in the sandstone beds of the Brushy Basin member. As the so-called Jackpile sandstone is rather narrowly restricted and is elongated northeasterly, exploration should be similarly restricted. In addition the larger deposits should be found in the thicker central part of the unit, as pointed out by Hilpert and Freeman (1956, p. 302).

Although only small deposits are known to exist in the sandstone beds of the Brushy Basin member, these beds may contain large deposits, as do their possible equivalents in the Ambrosia Lake district. Such beds are known to be thicker and more abundant where the so-called Jackpile sandstone is present, and this is interpreted to mean that the deposition of both this unit and the sandstone of the Brushy Basin member was controlled to a large extent by contemporaneous subsidence of a broad tectonic trough. The thicker parts of both units, therefore, are probably coextensive. Further, from their similarities, both are probably equally favorable units. Unfortunately most exploratory drilling has been deep enough to define only the so-called Jackpile sandstone; an additional maximum of 450 feet might well reveal large deposits in deeper sandstone beds.

From available knowledge the positions of specific ore bodies cannot be predicted and it has not been possible to define specific controls for the larger ore bodies. It is suggested that where pre-Dakota structures are suspected from drilling information, they should be traced by further drilling in a north-northwesterly direction. It is not suggested, however, that all pre-Dakota structures contain ore, or that all ore bodies are localized by pre-Dakota structures.

References

Anderson, E. M., 1942, The dynamics of faulting and dyke formation with applications to Britain: Oliver and Boyd, London.

Cloos, Ernst, 1955, Experimental analysis of fracture patterns; Geol. Soc. America Bull., v. 66, no. 3, p. 241-256.

Hilpert, L. S., and Freeman, V. L., 1956, Guides to uranium deposits in the Morrison formation, Gallup-Laguna area, New Mexico: U. S. Geol. Survey Prof. Paper 300, p. 299-302.

Hilpert, L. S., and Moench, R. H., 1958, Uranium deposits of the southern part of the San Juan basin, New Mexico, in Proc. of the 2nd United Nations International Conf. on the Peaceful Uses of Atomic Energy, v. 2, United Nations, Geneva, 1958.

Hubbert, M. K., 1951, Mechanical basis for certain familiar geologic features: Geol. Soc. America Bull., v. 62, p. 355-372.

Hunt, C. B., 1938, Igneous geology and structure of the Mount Taylor volcanic field, New Mexico: U. S. Geol. Survey Prof. Paper 189-B, p. 51-80.

Leopold, L. B., 1943, Climatic character of the interval between the Jurassic and Cretaceous in New Mexico and Arizona: Jour. Geology, v. 41, p. 56-62.

McKee, E. D., et al, 1956, Paleotectonic maps of the Jurassic System: U. S. Geol. Survey, Misc. Geol. Inv. Map I-175.

Schlee, J. S., 1957, Petrology of the Jackpile sandstone, New Mexico (abs.): Geol. Soc. America Bull., v. 68, no. 12, p. 1793.

Shawe, D. R., 1956, Significance of roll ore bodies in genesis of uranium-vanadium deposits on the Colorado: U. S. Geol. Survey Prof. Paper 300, p. 239-241.

Grants area, New Mexico

by

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Stratigraphy

The aggregate thickness of consolidated sedimentary rocks in the Grants area, which comprises about 365 square miles in McKinley and Valencia Counites, New Mexico, is about 5,200 feet. The Precambrian basement complex consists largely of metamorphosed rhyolitic and granitic rocks and is overlain unconformably by the Abo formation, Yeso formation, and Glorieta sandstone of Permain age. These rocks underlie the area but do not crop out within its limits. The oldest unit exposed is the San Andres formation of Permian age. Overlying the karst surface of the San Andres formation in ascending order are patches of the Moenkopi formation, the Chinle formation, and the Lukachukai member of the Wingate formation, all of Triassic age. The medial silty member of the Entrada sandstone of Late Jurassic age disconformably overlies the Wingate sand-sandstone; other Jurassic units are, in ascending order, the upper sandy member of the Entrada sandstone, the Todilto limestone, the Summerville formation, the Bluff sandstone, and the Morrison formation. In this area the Morrison consists of three members: the Recapture shale member at the base, overlain successively by the Westwater Canyon sandstone member and the Brushy Basin shale member.

In the southern part of the Grants area the Summerville formation and the Bluff sandstone grade laterally into a bright-yellow eolian sandstone known as the Zuni sandstone; in the western part of the area the position of the lower part of the Recapture shale member of the Morrison formation is occupied by an upper tongue of the Zuni sandstone.

Cretaceous rocks exposed in the area include the Dakota sandstone, the Mancos shale, and the Mesaverde group. The Mesaverde group is composed of three formations: the Gallup sandstone, the Crevasse Canyon formation, and the Point Lookout sandstone. In the Grants area the Crevasse Canyon formation has been subdivided into four members; in ascending order these are the Dilco coal member, a lower sandstone member, the Dalton sandstone member, and the Gibson coal member. Transgression and regression of the Cretaceous sea was responsible for widespread intertonguing of the several Cretaceous units. The top of the main body of the Mancos shale tongues with the Gallup sandstone and splits it into three units. The two lower units of the Gallup pinch out to the east, and the lowermost sandstone unit is present only in the western part of the area. The Mulatto, an upper tongue of the Mancos, overlies the lower sandstone member of the Crevasse Canyon and splits that formation into two parts.

The entire Morrison formation and the lower Cretaceous units pinch out to the south in the southern part of the Grants area.

All of the Tertiary rocks in the Grants area are volcanic. The oldest probably are of Miocene age and are correlative with the early activity of Mt. Taylor. Rhyolitic pumiceous ejecta from a source on East Grants Ridge are spread widely over a folded and eroded bedrock surface of Cretaceous age. Porous banded rhyolite and obsidian cut the fragmental material in the crater and apparently formed a dome-shaped crater filling. Basaltic dikes and plugs of Pliocene age are injected along faults, and basaltic flows are spread over both the earlier igneous rocks and the sedimentary rocks.

Igneous activity in the Grants area extended into Pleistocene time. El Tintero cinder cone, in the western part of the area, was the source of at least five extensive flows and numerous smaller flows. The five larger flows are separated from each other by alluvium that ranges in thickness from less than an inch to several feet. The Zuni volcanic centers, south of the area, are the source of many large flows in and around the town of Grants. The latest of these flows, the McCartys flow of Nichols (1933) is thought to be of protohistoric age. A large basalt flow, which had as its source two small cinder cones in the Zuni Mountains, also issued from Zuni Canyon into the valley of the Rio San Jose not far west of Grants.

Pleistocene and Recent sedimentary deposits include saprolite derived from silty shale, alluvium of several ages, dune sand, talus, and landslide debris. Two small spring deposits of porous silty limestone, in places filled with fossil reeds, are along a major fault in the valley of the Rio San Jose just south of Grants. These deposits are thought to be of Pleistocene age.

Structure

The Grants area is along the southern boundary of the San Juan Basin, an asymmetric structural depression, nearly circular in plan, in northwestern New Mexico and southwestern Colorado. The San Juan Basin is bounded on the west by the Defiance uplift, on the north by the San Juan Mountains, on the east by the Nacimiento uplift, and on the south by the Zuni Mountains. Strata in most of the basin dip gently northward but are sharply upturned against the base of the San Juan Mountains in southwestern Colorado. The regional dip is about 3°N in the southern part of the basin but increases to 5°N along the northeast flank of the Zuni Mountains. In the Grants area the major structural features are (1) the Zuni Mountains uplift, which is mainly responsible for the regional dip in the area; (2) the northerly trending Mt. Taylor syncline, which largely separates the area from the deposits of the Mt. Taylor volcanic center to the east, and (3) large fault zones, which locally have modified the regional dip and the position of the older structures.

Field evidence indicates rather definitely the sequence and date of development of many of the structural elements in the Grants area. Other structures, however, can be dated only tentatively. Structural distortion of major magnitude apparently began in Jurassic time with the gradual rise of the old highland southwest of the Grants area. This highland contributed material to the sediments deposited during Jurassic time. As the Morrison and younger formations pinch out to the south approximately along the axis of the Zuni Mountains, and as the Zunis lie between the old highland and the San Juan Basin, an early rise of the Zunis prior to their main uplift must have occurred. This rise resulted in shallow dips that bear about N 30° E.

Folding also took place at this time; the folds differ in amplitude and width in the various formations. Intraformational folds within the Todilto limestone range to as much as 90 feet in width and 9 feet in amplitude; folds that involve the Entrada-Todilto contact are 2,000 to 6,000 feet wide and 40 feet in amplitude. Within the Morrison formation, which was deposited simultaneously with the folding, the folds range from 1 to several miles wide and are as much as 100 feet in amplitude. All of the folds trend from N 80° E to S 70° E, about normal to the regional dip. Cylindrical slump structures also developed during Jurassic time in the Summerville sandstone, the Bluff sandstone, and the lower part of the Morrison formation.

The main uplift of the Zunis in early Tertiary time increased the regional northeasterly dip to its present 3° to 5° range. Greater dips are present (1) near the Ambrosia dome, (2) near large faults along which the rocks have been dragged, (3) on the steep western flank of the Mt. Taylor syncline, where dips in excess of 45° have been measured, and (4) near East Grants Ridge, where dips in excess of 80° have been measured on large blocks of sedimentary rocks which apparently foundered in the vicinity of a large volcanic crater.

Jointing and intraformational folds in the Todilto limestone that trend about N. 15° W. and N. 75° E. were developed strongly during uplift of the Zunis. These features are approximately in shear positions with respect to the direction of regional shortening. Lateral slickensides on the N. 15° W. joints show that movement has been right-lateral; on the N. 75° E. joints movement has been left-lateral. Where small linear features have been displaced, movement on each joint surface is between 1/2 inch and 1 1/2 inches. Intraformational folds in the Todilto that have these orientations have abundant helicalfractures which in the northerly trending folds are sinistral and in the easterly trending folds are dextral, conforming to the lateral displacements seen on the major joints in these directions.

Final uplift of the Zuni Mountains took place in late Oligocene time, about the time of deposition of the uranium ores. A general uplift of the Colorado Plateau region followed. This uplift appears to have been accompanied by development of the Mt. Taylor syncline, a broad asymmetric structure along the east edge of the Grants area that is steep on the west flank and has a maximum structural relief of about 2,000 feet. It is possible that this fold lies over a deep-seated fault, an outlier of the block faulting that was simultaneously developing structures of the Basin and Range type at the edge of the Plateau some tens of miles to the east. Other folds, with widths of several miles and low amplitudes, developed to the west. Thrust faults and another set of large intraformational folds were developed in the Todilto limestone. The direction of faulting appears to have been to the east. These folds and faults are oriented about N. 20° E., approximately parallel to the Mt. Taylor syncline, but it is not believed that they are related closely to the syncline. They appear rather to be related to intermittent east-west compression or dragging near the surface during a late stage of the epeirogenic uplift of the Plateau.

The Mt. Taylor syncline is interrupted at several places by very large fault zones that developed shortly after formation of the syncline. The faults are about 5 miles apart and 30 miles long; they extend northeastward from the northeast flank of the Zuni uplift, and may be related to transmission of lateral stresses eastward around the Precambrian core of the Zunis. Lateral displacement is dominant on all these faults of northeasterly trend although most also have minor dip-slip displacement. The greatest known lateral displacement is on the large fault zone that extends along the scarp west of the village of San Rafael, passes below two calcareous spring deposits through East Grants Ridge, where the position of four basaltic cinder cones and a large rhyolite body were probably controlled by it, and trends thence directly in the direction of the Mt. Taylor cone. The west side of the Mt. Taylor syncline is offset right-laterally by this fault a distance of more than 21,000 feet.

This period of faulting probably perisisted from the middle Miocene into the Pleistocene and may have been accompanied by post uplift brecciation and copper-fluorite mineralization in the Zunis. It also was accompanied by eruption of the Mt. Taylor volcanic rocks, by the development of many late Pliocene and Pleistocene basalt cones and flows, most of which are on the large faults, and probably by some subsidence in the vicinity of Mt. Taylor. Near the end of this time minor normal faulting took place along the major joint system, producing a complicated series of minor horst and graben structures that offset the copper-fluorite ore. Basaltic dikes were injected into this joint system at about this time, particularly in the southern part of the area and just east of the area near Mt. Taylor. Normal faulting may have continued into Recent time.

Uranium deposits

Commercial deposits of uranium ore have been found in four rock units in the Grants area, and small concentrations of radioactive minerals have been found in all formations from the Precambrian to the Mesaverde group of Cretaceous age. The commercial deposits occur in the Todilto limestone, the Westwater Canyon sandstone member and the Brushy Basin shale member of the Morrison formation, all of Jurassic age, and in the Dakota sandstone of Cretaceous age. The deposits in the Todilto limestone are expected to produce a few million tons of ore from small high-grade ore bodies that range in size from 1,000 tons to 150,000 tons. Deposits in the Westwater Canyon member of the Morrison formation are expected to produce some tens of millions of tons of ore containing about 0.2 percent U_3O_8. Deposits in the Brushy Basin shale member of the Morrison formation and in the Dakota sandstone are small and few in number, and probably will produce less than 20,000 tons of ore.

Deposits in the Todilto limestone

The Todilto consists of three units of gray to brownish-gray limestone; a lower flat-bedded unit, a middle crinkly-bedded unit, and an upper massive unit. The lower and middle units are dense and microcrystalline, the massive upper unit is largely recrystallized. The Todilto, especially the lower units, contains thin beds of organic material and scattered ostracodes. The freshly broken limestone has a fetid odor. The content of insolubles ranges from a few percent in the lower units to 60 percent or more in the massive unit where the Todilto grades with and tongues into the overlying Summerville formation. In the Grants area the Todilto limestone contains practically no gypsum, but 10 to 20 miles to the east it is composed predominantly of gypsum.

Ore deposits in the Todilto limestone occur in the synclinal portions of broad folds, particularly the easterly trending folds, and more specifically in small intraformational anticlines associated with the broad folds. The ore has selectively replaced the limestone. In any one deposit the ore tends to be localized in one or another of the three main Todilto units to the exclusion of the other units, and within a unit it may occupy one thin bed to the exclusion of overlying and underlying beds. At places the ore stops abruptly against an open fracture, but elsewhere it has been deposited abundantly along small tight fractures.

The principal unoxidized ore minerals are uraninite and häggite, with smaller amounts of coffinite and paramontroseite. The principal oxidized minerals are tyuyamunite and uranophane, although numerous other minerals occur in small amounts. The heterogeneous distribution of vanadium and uranium, which have a ratio of about 1:1, is responsible for the unexpected juxtaposition of such minerals as hewettite and uranophane. Oxidation takes place principally along fractures and bedding planes and along formation contacts. Extensive slumping of insoluble residual materials has taken place in fractures and other places where oxidation is far advanced. Gangue minerals within and close to ore horizons are calcite, fluorite, barite, pyrite, and hematite.

Deposits in the Westwater Canyon sandstone

The Westwater Canyon sandstone member of the Morrison formation is predominantly a medium- to coarse-grained, crossbedded, fluviatile sandstone containing mudstone lenses and disseminated mudstone fragments of various sizes. Folds, developed in part during deposition of the Westwater Canyon, controlled stream courses and deposition. Carbonaceous matter in the form of coalified tree trunks and trash pockets is common. In addition, carbonaceous material of unknown origin and composition that appears to have been introduced in a fluid state impregnates the ore-bearing sandstone. Laterally migrating ore solutions and fluids carrying organic matter became concentrated in thick sandstone units in synclines and were further controlled on a smaller scale by mudstone lenses, intraformational unconformities, and impermeable sandstone lenses.

Reaction between the ore solutions and the organic-rich fluids probably caused the precipitation of uranium minerals. Unoxidized ore is invariably closely associated with carbonaceous matter but later solution and migration of uranium and vanadium has emplaced oxidized ore minerals in some noncarbonaceous sandstone. Fluctuations of the ground-water table appear to have influenced the redistribution and oxidation of the ore deposits.

The principal ore minerals are coffinite and a poorly characterized high-grade compound or compounds that may be oxidized products of coffinite or residues of metallo-organic compounds. Montroseite and paramontroseite are commonly found along fractures but are not abundant. The V:U ratio is low and the distribution of these elements is heterogeneous, so although tyuyamunite is the commonest oxidized mineral, vanadium minerals such as pascoite, and uranium minerals such as uranophane and meta-autunite are not rare. Native selenium, ferroselite, and radiobarite have been found in the Ambrosia Lake mines. Gangue minerals are calcite and, in smaller quantities, pyrite.

In some parts of the area a tongue of the Westwater Canyon sandstone member 0 to 45 feet thick is separated from the main body of the Westwater Canyon by a 10-to 20-foot tongue of the Brushy Basin shale member. Because this Westwater Canyon tongue contains some large ore bodies where the main body of the Westwater Canyon is barren, it received special attention in the early days of prospecting and was given the name "Poison Canyon tongue". The lithology of the tongue and the distribution of ore deposits in it are the same as in the main body of the Westwater Canyon sandstone member.

Deposits in the Brushy Basin shale

Deposits in channel sandstone units near the top of the Brushy Basin shale member are similar in most respects to those in the Westwater Canyon sandstone member. The host rock is arkosic, clayey, strongly cross-bedded, and poorly cemented, and invariably is similar to sandstone of the Westwater Canyon sandstone member, in contrast to other barren channel sandstone units in the Brushy Basin. The channel sandstones near and in the Grants area are several hundred to several thousand feet wide and as much as 70 feet thick. They trend northeasterly, as do sedimentary structures in the rest of the Morrison formation. Ore is confined largely to areas near fossil wood and trash pockets. Organic fluids, apparently derived from the wood, formed dark aureoles of carbonaceous material around large logs, or generally vertical curtain-like bands. Elsewhere the fluids were carried laterally to stratigraphic traps, where their degradation products are now associated in "roll-type" deposits.

Deposits in the Dakota sandstone

The Dakota sandstone consists of a basal unit, absent in places, of alternating yellow, gray, or purplish sandy siltstone, carbonaceous siltstone, and coal, and an upper unit made up of a number of broadly lenticular intercalated sandstone lenses, a few of which are separated by lenticular layers of coal or carbonaceous claystone. In places the sandstone lenses form complex channel systems which trend northerly or slightly easterly. The only mines in the Grants area from which ore has been taken are in such a channel system. Near the surface the deposits are oxidized and contain mainly carnotite and tyuyaminite, but more deeply buried deposits to the west of the area contain uraninite. Ore-bearing solutions apparently moved laterally down the dip and reacted with organic compounds to cause the precipitation of ore minerals. The uranium was later oxidized and redistributed and now is found near the ends of individual sandstone lenses, along crossbed interfaces and shale lenses, and in the vicinity of trash pockets.

Reference

Nichols, R. L., 1933, Quaternary geology of the San Jose Valley, New Mexico, (Abst): Geol. Soc. America Proc., p. 453.

Geologic maps of the Colorado Plateau

by

D. G. Wyant, W. A Fischer, P. L. Williams and
J. D. Vogel

During the report period, work continued on the Moab and Albuquerque 2° sheets, and work started on the Cortez 2° sheet (See fig. 1). Revision of the Shiprock sheet, completed during the last report period, was recessed during this report period. The Moab sheet is 97 percent compiled; the Albuquerque sheet is about 50 percent compiled; and the Cortez sheet is about 30 percent compiled.

All the photogeologic effort in the Colorado Plateau has continued to be directed toward compilation of maps at a scale of 1:62,500 in support of the project. Approximately 1,200 square miles was mapped during the report period: about 430 square miles in the Albuquerque 2° sheet, and about 770 square miles in the Moab 2° sheet. In the preparation of these maps high-altitude photographs were used in conjunction with the radial planimetric plotter and the Kelsh and Balplex plotters.

During the report period three 7 1/2-minute quadrangles and five 15-minute quadrangles were published in the Miscellaneous Geologic Investigation series:

I-227. Photogeologic map of the Iris SE and Doyleville SW quadrangles, Saguache County, Colorado, by Kathleen McQueen.

I-278. Photogeologic map of the Coach Creek SE quadrangle, Grand County, Utah, and Mesa County, Colorado, by R. J. Hackman.

I-279. Photogeologic map of the Coach Creek NE quadrangle, Grand County, Utah, and Mesa County, Colorado, by R. J. Hackman.

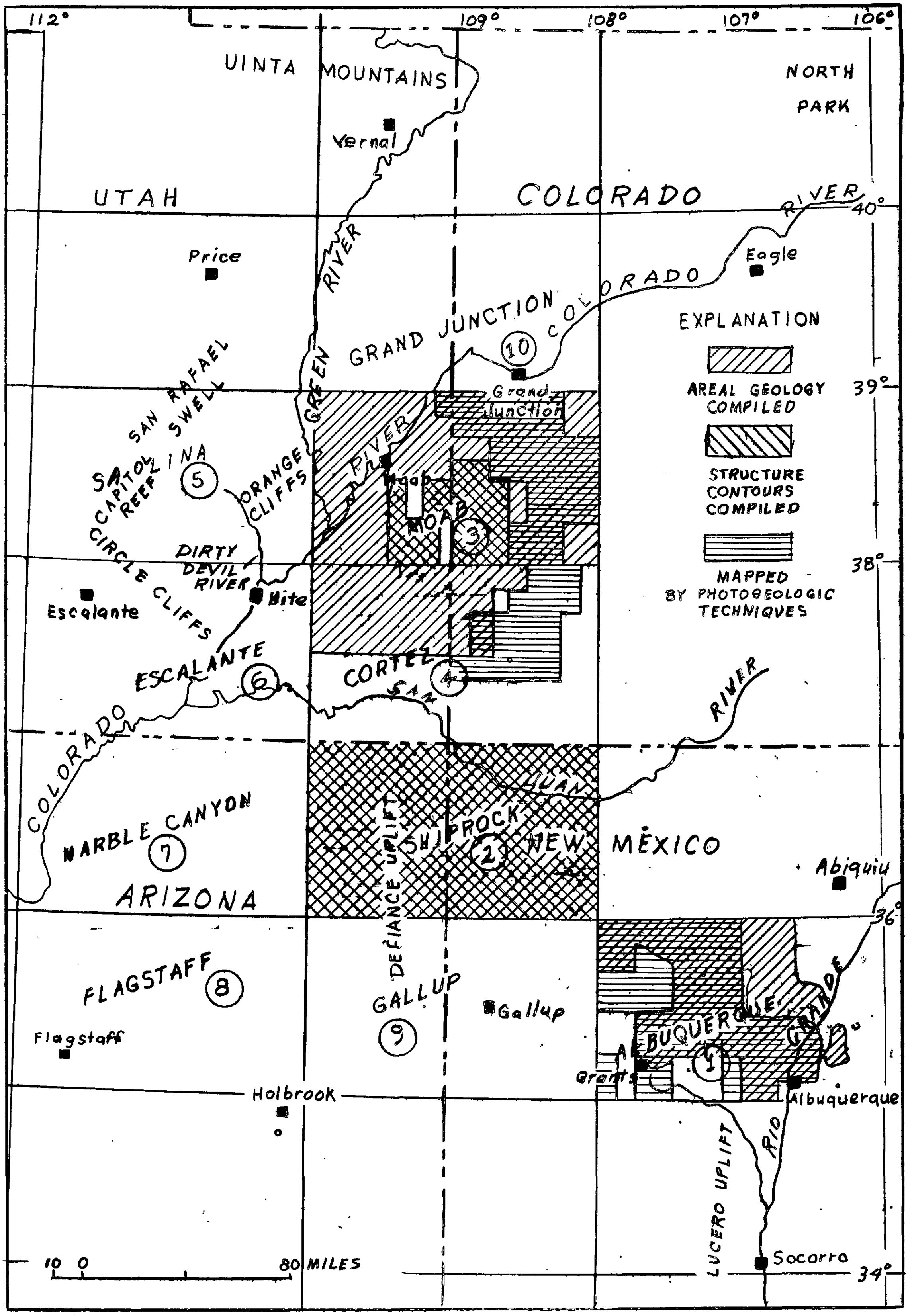


Fig. 1.--Index map showing tentative order of, and progress in, compilation of 2° sheets of the Colorado Plateau geologic maps project.

I-280. Photogeologic map of the Mount Ellen-4 quadrangle, Wayne County, Utah, by W. R. Hemphill.

I-281. Photogeologic map of the Yellow Jacket quadrangle, Montezuma and Dolores Counties, Colorado, by R. J. Hackman.

I-282. Photogeologic map of the Delta quadrangle, Montrose and Delta Counties, Colorado, by C. H. Marshall.

I-283. Photogeologic map of the Norwood-1 quadrangle, Montrose and Ouray Counties, Colorado, by C. H. Marshall.

Southern Black Hills, South Dakota

by

Garland Gott

During the past six months work on the Southern Black Hills project has been limited to compilation of maps and preparation of reports. Results of investigations to date have been reported in previous Semi-annual Reports, (see TEI-690, p. 170 - 224; TEI-700, p. 83 - 88; TEI 740, p. 83 - 99; TEI-750, p. 32 - 43). Additional work in the area is planned for the summer of 1959.

Preliminary geologic and structure maps of the Cascade Springs quadrangle, by E. V. Post, D. W. Lane, and N. P. Cuppels, were published during the report period as MF maps 207-212.

GEOLOGIC TOPICAL STUDIES

General stratigraphic studies

by

L. C. Craig

Work on both the Paleozoic and Cretaceous sedimentary rocks on the Colorado Plateau was in recess during this report period. Work was focused on the preparation of a detailed report on the Morrison formation of the Colorado Plateau region.

Lithologic studies

by

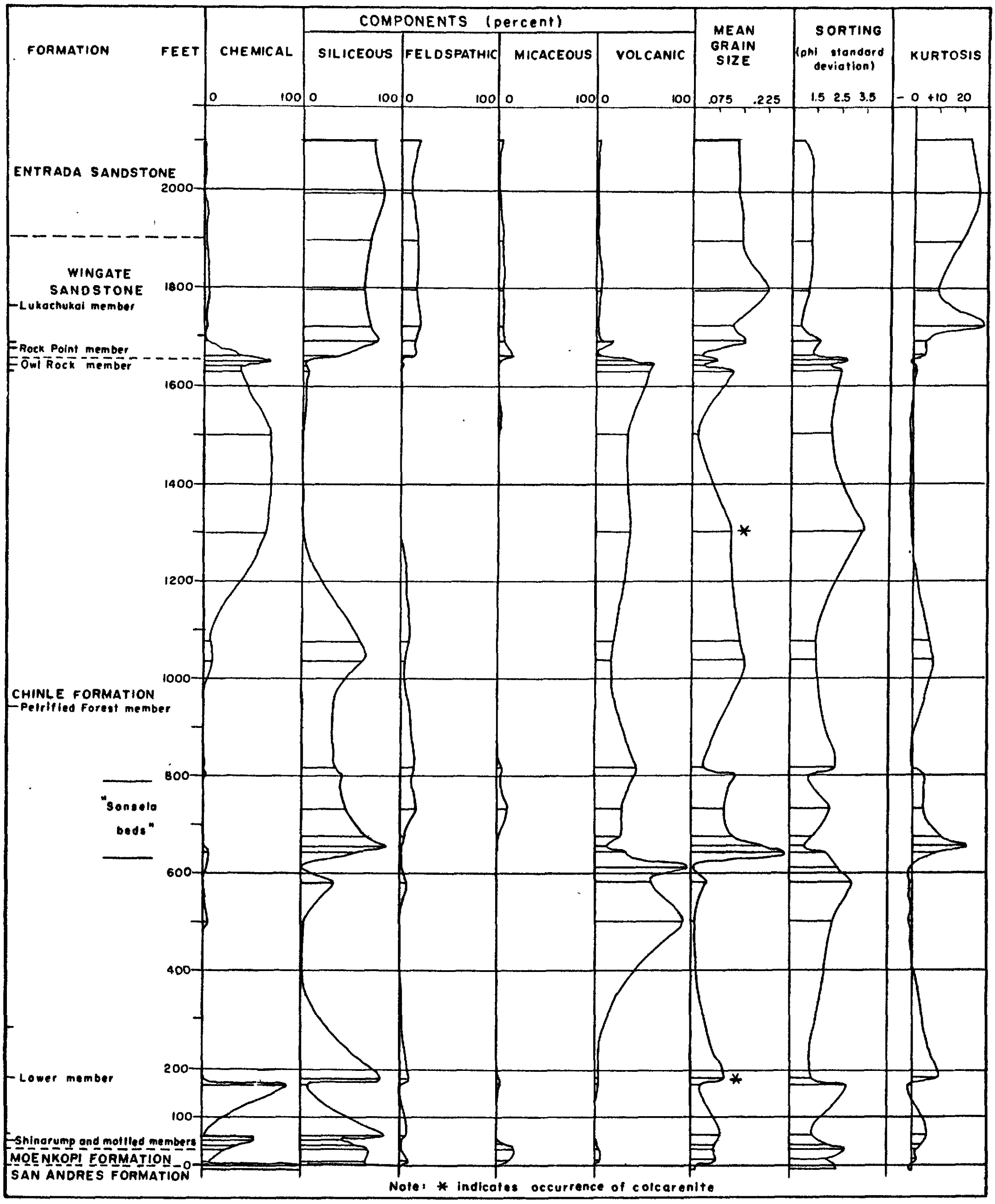
R. A. Cadigan

Lithologic studies of sedimentary rocks during the report period included: (1) revision of the final report on the Morrison formation of the Colorado Plateau area; (2) studies of Jurassic and Cretaceous rocks of the southern Black Hills area, Wyoming and South Dakota; and (3) tabulation and interpretation of data on Permian, Triassic, and Jurassic rocks in McKinley County, New Mexico.

Rocks from the Fort Wingate locality, McKinley County, N. Mex.

Typical of the rocks studied in McKinley County are those in a measured stratigraphic section at the Fort Wingate Ordnance Depot. The section contains over 2,100 feet of sediments ranging from the Limestone member of the San Andres formation of Permian age through the lower part of the Entrada sandstone of Jurassic age. The sequence of strata is similar to or equivalent in part to that presented in TEI-700, p. 124-139, covering the St. George area, Utah.

Thirty-one samples were collected at the Ft. Wingate locality. Methods of analysis consisted of point-counting of rock thin sections, as reported in TEI-700, and standard grain size analysis involving the sieving and pipetting of disaggregated sediments. Results of the study in terms of percentage of 5 rock components, mean grain size, sorting and kurtosis are summarized in figure 2. Stratigraphic boundaries, and sample distribution are shown in feet, to scale. The



Note: * indicates occurrence of calcarenite

FIGURE 2.-GRAPHS SHOWING THE PERCENTAGE ROCK COMPOSITION, GRAIN SIZE, AND SORTING PROPERTIES IN SEDIMENTARY ROCKS IN THE FORT WINGATE ORDNANCE DEPOT AREA, McKINLEY COUNTY, NEW MEXICO

datum plane used is the top of the Limestone member of the San Andres formation.

More complete compositional data in terms of 18 components are listed in table 3.

Chemical components are high in the Limestone member of the San Andres formation, and in the iron-oxide impregnated interstitial clay of the Shinarump and Mottled members at the base of the Chinle formation, and in the Lower member and Owl Rock member of the Chinle formation.

Siliceous components are high in the basal and middle parts of the Chinle formation, with wide variation, and are consistently high in the Wingate and Entrada sandstones.

Feldspathic components are relatively high in the Petrified Forest member of the Chinle formation and in the Wingate and Entrada sandstones. The feldspars of the Petrified Forest member are almost entirely sodic plagioclase in fragments of crystal tuff in the form of microscopic laths and phenocrysts. The feldspars of the Wingate and Entrada sandstones are almost equally divided between potassic and sodic feldspar.

Variations in the proportion of micaceous components do not appear noteworthy except for the high value in the Moenkopi formation and in the base of the Chinle formation, which is attributable to the relatively high proportion of rock fragments (silicified limestone, chert, phyllite).

Volcanic components are most characteristic of the Petrified Forest member of the Chinle formation. The most conspicuous volcanic rock

Table 3.--Tabulated results of point-count composition analyses of 31 samples of Permian, Traissic, and Jurassic rocks from a measured section at the Fort Wingate Ordnance Depot, McKinley County, New Mexico

Formation	San Andres formation		Moenkopi formation	
Distance above top of San Andres formation (ft.)	-10	-1	5.0	32
Sample number	L2892	L2893	L2390	L2894
Chemical components excluding silica				
Calcite and dolomite, barite, gypsum	100.0	99.6	* 1.2	---
Red interstitial iron oxides, and impregnations	---	---	5.4	* 8.8
Total	100.0	99.6	6.6	8.8
Siliceous components				
Quartz grains and overgrowths	T	0.4	51.8	36.2
Quartzite fragments	---	---	2.0	2.4
Chert, detrital	---	---	12.4	30.2
Chert, chalcedony, interstitial	---	---	---	---
Total	---	0.4	66.2	68.8
Feldspar and feldspar derived components				
Potash feldspar	---	---	0.2	---
Plagioclase feldspar	---	---	3.8	1.6
Kaolinite and kaolinitic clays	T	---	6.0	0.8
Total	---	---	10.0	2.4
Dark mineral and micaceous rock fragments and related material				
Mica flakes and books	---	---	0.4	0.4
Illite and micaceous clays	---	---	2.8	*14.0
Micaceous and basaltic rock frags.	---	---	9.4	2.0
"Heavy minerals"	---	---	---	---
Miscellaneous (usually unidentified opaque minerals)	---	---	---	0.4
Total	---	---	12.6	16.8
Volcanic components				
Altered tuff and felsitic rock fragments	---	---	4.6	3.2
Montmorillonite and related clay mixtures	---	---	---	---
Altered ash (clay mixtures, shard relics, etc.)	---	---	---	---
Total	---	---	4.6	3.2
Notes on composition			*percent barite	*Illite-iron oxide matrix

Table 3.--Continued

Formation	Chinle formation				
	Shinarump member			Lower member	
Distance above top of San Andres formation (ft.)	37	49	56.3	165	175
Sample number	L2895	L2896	L2391	L2897	L2392
Chemical components excluding silica					
Calcite and dolomite, barite, gypsum	---	---	---	86.0	---
Red interstitial iron oxides and impregnations	*33.8	*55.0	3.8	---	1.6
Total	33.8	55.0	3.8	*86.0	1.6
Siliceous components					
Quartz grains and overgrowths	47.4	40.2	84.2	6.4	80.8
Quartzite fragments	---	0.6	0.4	0.2	0.4
Chert, detrital	8.4	1.2	1.2	---	---
Chert, chalcedony, interstitial	---	---	---	---	---
Total	55.8	42.0	85.8	6.6	81.2
Feldspar and feldspar derived components					
Potash feldspar	---	0.2	---	---	---
Plagioclase feldspar	1.0	1.6	1.0	0.4	2.4
Kaolinite and kaolinitic clays	---	---	8.4	---	9.8
Total	1.0	1.8	9.4	0.4	12.2
Dark mineral and micaceous rock fragments and related material					
Mica flakes and books	---	---	0.4	---	0.6
Illite and micaceous clays	* 8.2	---	---	---	* 1.2
Micaceous and basaltic rock frags.	---	---	---	3.8	0.2
"Heavy minerals"	0.2	---	---	---	0.2
Miscellaneous (usually unidentified opaque minerals)	---	0.2	---	---	---
Total	8.4	0.2	0.4	3.8	2.2
Volcanic components					
Altered tuff and felsitic rock fragments	1.0	1.0	0.6	---	2.8
Montmorillonite and related clay mixtures	---	---	---	3.2	---
Altered ash (clay mixtures, shard relics, etc.)	---	---	---	---	---
Total	1.0	1.0	0.6	3.2	2.8
Notes on composition	*Chlorite-montmorillonite iron oxide matrix	*Iron oxide chlorite montmorillonite		*Calcarenite (rounded pellets)	*Large chlorite grains

Table 3.--Continued

Formation	Chinle formation Petrified Forest member				
Distance above top of San Andres formation (ft.)	500	579	613	643	653
Sample number	L2891	L2387	L2388	L2389[1]	L2364[1]
Chemical components excluding silica					
Calcite and dolomite, barite, gypsum	0.8	---	---	5.8	0.2
Red interstitial iron oxides and impregnations	5.6	---	---	0.2	---
Total	6.4	---	---	6.0	0.2
Siliceous components					
Quartz grains and overgrowths	2.4	30.0	0.4	58.6	87.4
Quartzite fragments	---	2.0	---	0.4	---
Chert, detrital	---	1.0	---	1.0	---
Chert, chalcedony, interstitial	---	---	---	---	---
Total	2.4	33.0	0.4	60.0	87.4
Feldspar and feldspar derived components					
Potash feldspar	---	---	1.2	0.4	0.2
Plagioclase feldspar	---	8.2	1.0	2.2	1.2
Kaolinite and kaolinitic clays	---	1.2	---	---	---
Total	---	9.4	2.2	2.6	1.4
Dark mineral and micaceous rock fragments and related material					
Mica flakes and books	---	0.2	---	0.2	---
Illite and micaceous clays	---	---	---	0.2	---
Micaceous and basaltic rock frags.	---	---	---	---	---
"Heavy minerals"	---	0.2	---	0.2	---
Miscellaneous (usually unidentified opaque minerals)	---	0.2	---	0.2	---
Total	---	0.6	---	0.8	---
Volcanic components					
Altered tuff and felsitic rock fragments	0.4	8.2	0.8	19.8	3.0
Montmorillonite and related clay mixtures	90.4	---	96.6	9.4	---
Altered ash (clay mixtures, shard relics, etc.)	0.4	*48.8	---	1.4	* 8.0
Total	91.2	57.0	97.4	30.6	11.0
Notes on composition		*Chloritized ash matrix			*Chloritized ash, tuff grains

[1] Sonsela beds

Table 3.--Continued

Formation	Chinle formation Petrified Forest member				
Distance above top of San Andres formation (ft.)	673 1/	728 1/	803	817	1035
Sample number	L2365	L2366	L2367	L2368	L2369
Chemical components excluding silica					
Calcite and dolomite, barite, gypsum	0.8	0.6	2.0	---	9.6
Red interstitial iron oxides and impregnations	0.2	---	0.2	---	---
Total	1.0	0.6	2.2	---	9.6
Siliceous components					
Quartz grains and overgrowths	64.4	44.0	40.0	32.8	65.0
Quartzite fragments	0.6	0.2	1.4	1.6	1.0
Chert, detrital	0.6	0.2	1.6	1.4	0.6
Chert, chalcedony, interstitial	---	---	---	---	---
Total	65.6	44.4	43.0	35.8	66.6
Feldspar and feldspar derived components					
Potash feldspar	---	---	---	0.2	---
Plagioclase feldspar	6.2	17.0	12.0	14.8	6.4
Kaolinite and kaolinitic clays	---	---	---	---	---
Total	6.2	17.0	12.0	15.0	6.4
Dark mineral and micaceous rock fragments and related material					
Mica flakes and books	---	1.0	0.2	0.4	---
Illite and micaceous clays	0.4	7.0	---	0.4	---
Micaceous and basaltic rock frags.	0.8	1.4	0.4	1.6	---
"Heavy minerals"	---	---	0.2	0.4	---
Miscellaneous (usually unidentified opaque minerals)	0.8	1.4	1.8	4.0	0.6
Total	2.0	10.8	2.6	6.8	0.6
Volcanic components					
Altered tuff and felsitic rock fragments	5.2	16.6	12.2	6.2	15.4
Montmorillonite and related clay mixtures	0.2	---	1.2	1.8	---
Altered ash (clay mixtures, shard relics, etc.)	*19.8	*10.6	*26.8	*34.4	* 1.4
Total	25.2	27.2	40.2	41.4	16.8
Notes on composition	*Chlorite	*Chloritized tuff grains and ash	*Chloritized ash and tuff grains	*Chloritized	*Chloritized

1/ Sonsela beds

Table 3.--Continued

Formation	Chinle formation Petrified Forest member		
Distance above top of San Andres formation (ft.)	1074	1302	1502
Sample number	L2370	L2886	L2887
Chemical components excluding silica			
Calcite and dolomite, barite, gypsum	7.2	*64.2)	
Red interstitial iron oxides, and impregnations	0.2	---)	68.0
Total	7.4	64.2	68.0
Siliceous components			
Quartz grains and overgrowths	60.0	---	0.4
Quartzite fragments	0.6	---	---
Chert, detrital	0.6	---	---
Chert, chalcedony, interstitial	---	---	---
Total	61.2	---	0.4
Feldspar and feldpar derived components			
Potash feldspar	---	---	---
Plagioclase feldspar	11.2	0.2	---
Kaolinite and kaolinitic clays	---	---	---
Total	11.2	0.2	---
Dark mineral and micaceous rock fragments and related material			
Mica flakes and books	---	---	---
Illite and micaceous clays	---	---	---
Micaceous and basaltic rock frags.	0.2	---	---
"Heavy minerals"	---	---	---
Miscellaneous (usually unidentified opaque minerals)	0.6	0.2	---
Total	0.8	0.2	---
Volcanic components			
Altered tuff and felsitic rock fragments	18.6	1.2	31.6
Montmorillonite and related clay mixtures	---	34.2	---
Altered ash (clay mixtures, shard relics, etc.)	0.8	---	---
Total	19.4	35.4	31.6
Notes on composition	Chloritized tuff	*Ashy calcarenite (pellets)	Ash pellets in carbonate matrix

Table 3.--Continued

Formation	Chinle formation Owl Rock member		
Distance above top of San Andres formation (ft.)	1628	1635	1640
Sample number	L2888	L2698	L2889
Chemical components excluding silica			
Calcite and dolomite, barite, gypsum	*37.6	*35.0	*66.8
Red interstitial iron oxides, and impregnations	---	---	---
Total	37.6	35.0	66.8
Siliceous components			
Quartz grains and overgrowths	0.2	2.0	0.4
Quartzite fragments	---	---	---
Chert, detrital	---	---	---
Chert, chalcedony, interstitial	* 7.4	---	* 2.2
Total	7.6	2.0	2.6
Feldspar and feldspar derived components			
Potash feldspar	---	1.0	---
Plagioclase feldspar	---	2.0	---
Kaolinite and kaolinitic clays	---	---	---
Total	---	3.0	---
Dark mineral and micaceous rock fragments and related material			
Mica flakes and books	---	---	---
Illite and micaceous clays	---	---	---
Micaceous and basaltic rock frags.	---	---	---
"Heavy minerals"	---	---	---
Miscellaneous (usually unidentified opaque minerals)	---	---	---
Total	---	---	---
Volcanic components			
Altered tuff and felsitic rock fragments	16.6	---	*29.6
Montmorillonite and related clay mixtures	38.2	---	1.0
Altered ash (clay mixtures, shard relics, etc.)	---	*60.0	---
Total	54.8	60.0	30.6
Notes on composition	*Carbonate-silica replacement	*Carbonate replacement of ash bed	*Carbonate-silica replacing tuff

Table 3.--Continued

Formation	Wingate sandstone Rock Point member	Lukachukai member	
Distance above top of San Andres formation (ft.)	1660	1691	1718
Sample number	L2890	L2384	L2415
Chemical components excluding silica			
Calcite and dolomite, barite, gypsum	33.8	---	2.6
Red interstitial iron oxides, and impregnations	0.6	0.4	---
Total	34.4	0.4	2.6
Siliceous components			
Quartz grains and overgrowths	37.0	59.8	70.2
Quartzite fragments	---	---	---
Chert, detrital	0.4	16.4	1.4
Chert, chalcedony, interstitial	---	0.4	---
Total	37.4	76.6	71.6
Feldspar and feldspar derived components			
Potash feldspar	5.2	9.0	12.8
Plagioclase feldspar	9.6	5.4	8.4
Kaolinite and kaolinitic clays	0.2	1.0	---
Total	15.0	15.4	21.2
Dark mineral and micaceous rock fragments and related material			
Mica flakes and books	1.2	---	---
Illite and micaceous clays	11.0	5.4	3.0
Micaceous and basaltic rock frags.	---	---	---
"Heavy minerals"	0.6	---	0.2
Miscellaneous (usually unidentified opaque minerals)	0.4	0.2	0.4
Total	13.2	5.6	3.6
Volcanic components			
Altered tuff and felsitic rock fragments	---	2.0	1.0
Montmorillonite and related clay mixtures	---	---	---
Altered ash (clay mixtures, shard relics, etc.)	---	---	---
Total	---	2.0	1.0

Table 3.--Continued

Formation	Wingate sandstone Lukachukai member		Entrada sandstone	
Distance above top of San Andres formation (ft.)	1794.1	1896	1996	2099
Sample number	L2467	L2416	L2386	L2385
Chemical components excluding silica				
Calcite and dolomite, barite, gypsum	5.0	3.2	0.2	0.6
Red interstitial iron oxides, and impregnations	1.0	0.6	---	0.2
Total	6.0	3.8	0.2	0.8
Siliceous components				
Quartz grains and overgrowths	61.2	70.6	85.8	71.8
Quartzite fragments	---	0.6	---	0.4
Chert, detrital	3.4	1.0	0.2	2.5
Chert, chalcedony, interstitial	0.2	---	---	---
Total	64.8	72.2	86.0	74.7
Feldspar and feldspar derived components				
Potash feldspar	9.6	11.4	---	12.2
Plagioclase feldspar	8.2	6.6	11.4	7.2
Kaolinite and kaolinitic clays	---	---	0.2	---
Total	17.8	18.0	11.6	19.4
Dark mineral and micaceous rock fragments and related material				
Mica flakes and books	0.2	---	---	---
Illite and micaceous clays	5.4	4.0	0.6	1.8
Micaceous and basaltic rock frags.	0.2	0.2	---	---
"Heavy minerals"	0.2	0.4	---	0.2
Miscellaneous (usually unidentified opaque minerals)	0.2	0.2	---	0.4
Total	6.2	4.8	0.6	2.4
Volcanic components				
Altered tuff and felsitic rock fragments	5.2	1.2	1.6	2.7
Montmorillonite and related clay mixtures	---	---	---	---
Altered ash (clay mixtures, shard relics, etc.)	---	---	---	---
Total	5.2	1.2	1.6	2.7

fragments are grains of felsitic igneous rock which contain lath-shaped perfectly euhedral sodic feldspar phenocrysts in a nearly isotropic groundmass. Other grains believed to be derived from extrusive igneous rocks are: partly isotropic grains containing ragged-looking aggregate polarized microcrystals, and mica bundles, partly altered to chlorite or montmorillonite; nearly isotropic grains which are completely altered to clay and which have a swirled internal (vitrophyric?) arrangement of montmorillonite microcrystals; rather nondescript grains with quartz and feldspar anhedral crystals in a partly isotropic groundmass. The matrix of the rocks in the Petrified Forest member is believed to have been originally composed of ash which is now altered to montmorillonite, and chlorite and montmorillonite-chlorite mixtures, such as "corrensite" (clay mineral identifications by J. C. Hathaway, USGS, written communication, 1959).

Grain size, sorting and kurtosis measures indicate that the coarsest material sampled was a medium-grained sandstone in the Sonsela beds of the Petrified Forest member. The best-sorted material sampled was a sandstone in the Lukachakai member of the Wingate sandstone. The highest kurtosis values were found in the Lukachukai member of the eolian(?) Wingate sandstone and in the Entrada sandstone.

The sequence of geologic events affecting the deposition of sediments at the Ft. Wingate locality, as interpreted from the texture and composition of these rocks, is as follows: The Limestone member of the San Andres formation of Permian age represents a period of quiescence. The Moenkopi formation of Triassic age indicates an abrupt increase in the supply of detritus from a source area activated by low to medium tectonic uplift; deposition was fairly rapid. The Shinarump and Mottled members of the Chinle formation of Triassic age indicate a continuation of the conditions above followed by a decrease in rate of subsidence and, therefore, deposition. The Lower member of the Chinle formation with its carbonate and calcarenite beds indicates a slight increase in the rate of subsidence and a temporary decrease in the supply of detritus from the source area. The Petrified Forest member represents moderate to rapid subsidence and the accumulation of much ashy mud derived from a volcanically active source area, then a decrease in the rate of subsidence which brought coarser soda-rich volcanic debris into the area as indicated by the sandy Sonsela beds. The high kurtosis values indicate the presence of reworked material in the Lower Sonsela which in turn is interpreted as an evidence of a low rate of subsidence and deposition. Deposition of the Sonsela beds was followed by an increase in the rate of subsidence and continued uplift and volcanic activity in the source areas. The upper part of the Petrified Forest member and the Owl Rock member of the Chinle formation are marked by an increased liminess and calcarenite which suggests an erratic supply of detritus resulting from fluctuations in the volcanic activity in the source area. The Wingate sandstone of Triassic age and the Entrada sandstones of Jurassic age were deposited under conditions approaching quiescence; the period of volcanic activity was essentially over and tectonic uplift in the source and subsidence in the area of deposition proceeded at a low rate.

The increased proportion of potassic to sodic feldspar suggests derivation of Wingate and Entrada sands from a different source from that which supplied material for the Moenkopi and Chinle formations.

The high clay content and iron oxide impregnation of the fine-grained sandstone of the Shinarump member of the Chinle formation are indicative of lithology favorable for the deposition of uranium. The absence of channel-type sedimentary structures and fossil wood, the predominance of chlorite and montmorillonite clay minerals, and the minor proportions of kaolinite and absence of illite are not considered favorable. In view of the lack of wide variation of thickness of the Shinarump in the Fort Wingate area and its probable consistency of composition, the occurrence of significant uranium ore deposits in that unit in the Fort Wingate area is considered possible but not probable.

The Sonsela beds contain sandstone of the texture and structure common to uranium host rocks. The absence of kaolinite or coaly material, on the other hand, is interpreted as evidence of lithologic conditions unfavorable to the precipitation and accumulation of uranium ore deposits.

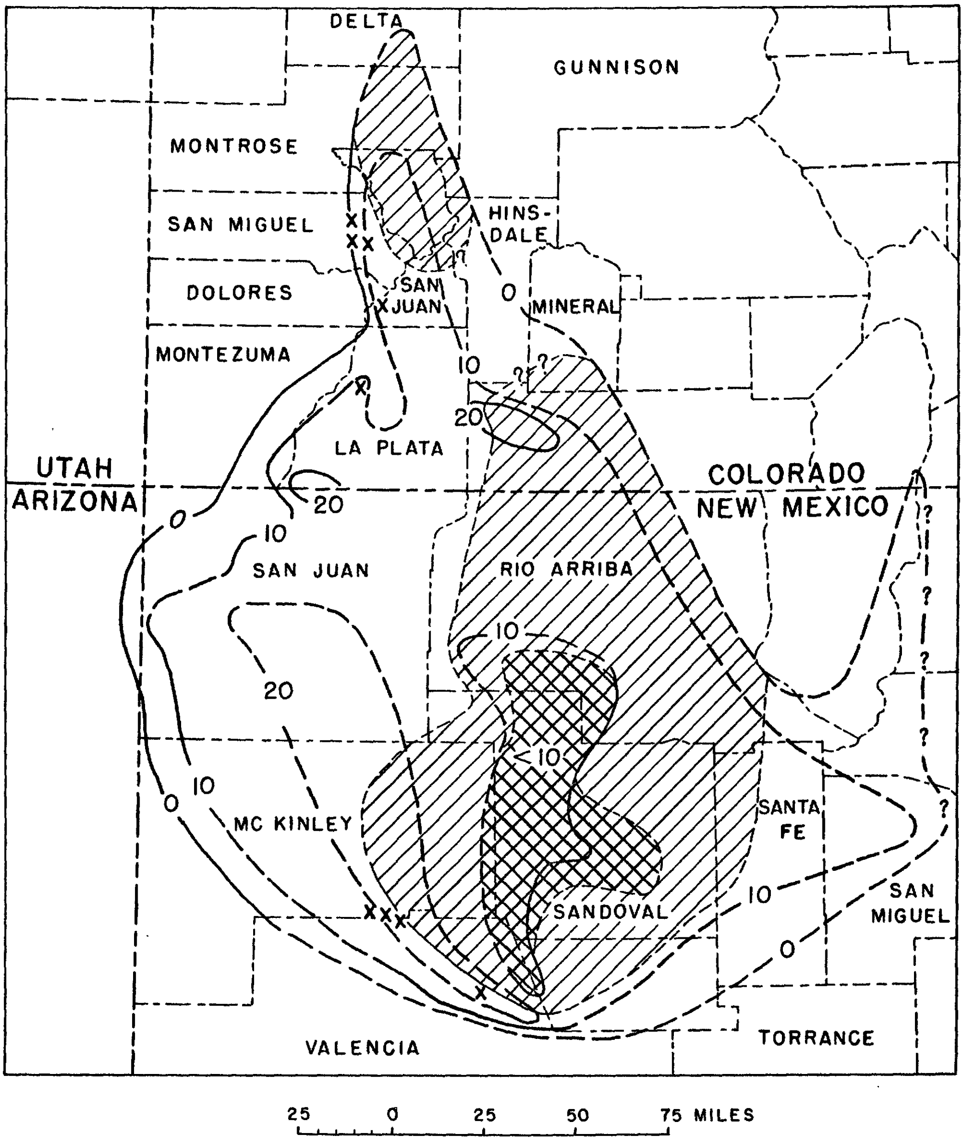
San Rafael (Entrada) studies

By J. C. Wright

The distribution and lithologic nature of the San Rafael group were outlined in TEI-740, pages 139-146. Cross-strata studies of the basal conglomeratic sandstone of the Curtis formation were summarized in TEI-750, pages 59-65. The dip of these cross-strata showed northeastward sediment transport; this northeastward transport direction is an abrupt reorientation of an earlier persistent westward transport direction. At nearly the same time as the transport-reversal, a large saline lake or marine lagoon formed in the southeast part of the Colorado Plateau; the distribution and thickness of limestone and gypsum-anhydrite in this basin are shown in figure 3. The distribution of these thin chemical deposits is an important key to understanding the paleogeography, which is shown graphically in figure 4.

Figure 3 has been compiled from all available data. More than 200 points afford good control for most of the margin of the basin. The subsurface of the central deeper part of the San Juan basin has been interpreted from lithologic well-logs prepared by the American Stratigraphic Company of Denver. The wells drilled thus far permit rough outlines of the major features, but do not clearly delineate smaller details. The east edge of the basin in New Mexico is very indefinite: some sporadic outcrops and subsurface occurrences are known at least 50 miles east of the limit shown here, but the limestone is absent over most of the area east of the indicated limit.

The absence of gypsum-anhydrite all along the west side of the basin may have been caused by an influx of fresh, less saline water on that side of the basin. It is also notable that a thin (less than 10 feet) central



—10— Isopach of limestone thickness ; dashed where control inadequate ; eastern limit uncertain (see text)

▨ Gypsum-anhydrite present overlying limestone

▩ Gypsum-anhydrite overlying limestone, exceeds 75 feet in thickness

X Productive uranium-vanadium deposits, closely associated with the limestone

FIGURE 3.-MAP OF ORIGINAL THICKNESS OF TODILTO FORMATION (NEW MEXICO) AND PONY EXPRESS FORMATION (COLORADO)

area of limestone is nearly coincident with a thick (greater than 75 feet) area of gypsum-anhydrite, which suggests that sulfate deposition probably began in the central part of the basin while limestone deposition persisted along the edges. Finally, all the associated productive uranium-vanadium deposits are near the western edge of the limestone. The deposits shown in New Mexico are in the Todilto limestone; those in Colorado are about 5 to 10 feet beneath the base of the Pony Express limestone member of the Wanakah formation, in the Entrada sandstone. This spatial association suggests that the edge of the limestone probably played a significant chemical or physical role in localizing the uranium-vanadium deposits.

The chemical sediments just described formed most probably in a large lake (see fig. 4), fed by drainage from the southwest and ponded against residual remnants of the ancestral Rockies on the northeast. The "low deltaic plain" is interpreted as the environment in which the basal part of the Summerville formation was deposited. Along its southwestern limit the coarser, crossbedded strata of the Winsor and Cow Springs formations grade into the deltaic plain deposits; these formations are believed to indicate mixed eolian and fluvial environments. A systematic northeastward decrease in average grain size (from very fine grained sand to clay) across the deltaic plain suggests northeastward sediment transport. The area indicated as a "broad, flat, marine beach area" is that in which glauconitic limy sandstone of the lower part of the Curtis formation occupies approximately the stratigraphic interval of the Todilto limestone. The cross-strata plotted in the southern lobe of this area have a consistent northeastward dip; the poor sorting and carbonaceous woody trash of the sandstone in which the crossbeds occur suggest that the original marine beach deposits (glauconite and marine

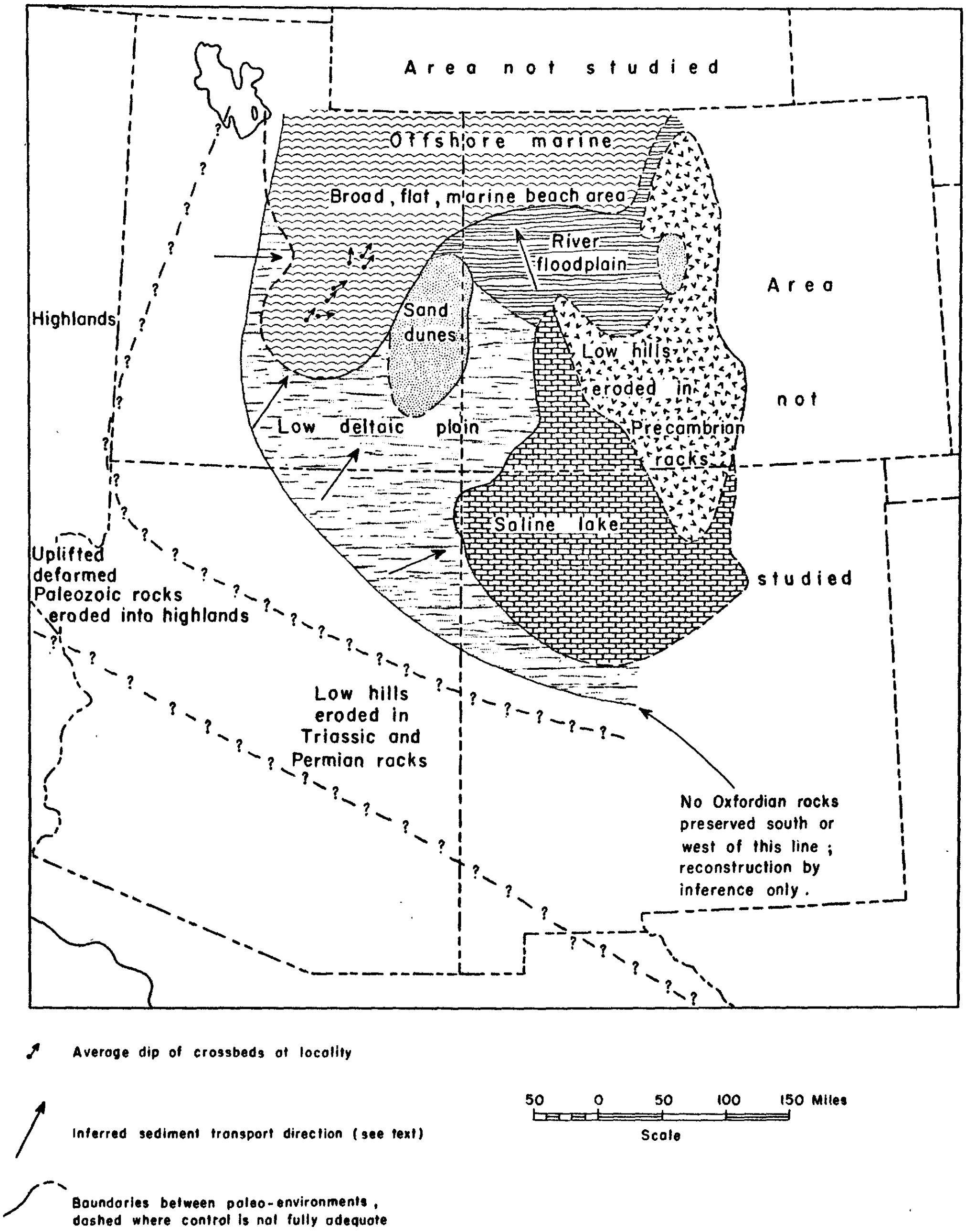


FIGURE 4.- HYPOTHETICAL PALEOGEOGRAPHY OF THE COLORADO PLATEAU DURING DEPOSITION OF THE TODILTO LIMESTONE

invertebrate fossils are also present) may have been locally reworked in a fluvial channel system. The "sand dunes" in eastern Utah are inferred from the quartzose, well-sorted, crossbedded Moab sandstone member of the Entrada sandstone; the smaller sand dune area in central Colorado is suggested by the Garo sandstone of Gould and others (1947) of Jurassic(?) age. The "river floodplain" is inferred in part from the Summerville formation in west-central Colorado (along the lower Gunnison River), and in part from a basal sequence of the Morrison formation in the central part of the state (along the upper tributaries of the Colorado River). These units are sandiest at the southeast; they either thin to the northwest, or grade to the northwest into the Curtis formation. In the low hills eroded in Precambrian rocks (fig. 4) sediments equivalent in age to the Todilto limestone are absent so far as known, and the Morrison formation lies directly on the Precambrian at most places.

The chemical deposits of the Todilto limestone have been interpreted by most workers (Baker, Dane, and Reeside, 1947, p. 1667-8; Harshbarger, Repenning, and Irwin, 1957, p. 46-48) as forming in a marine lagoon, because of the considerable sulfate deposits, and because of the possible connections to the marine trough where the Curtis formed. Recently Kirkland (1958) has stressed the nonmarine affinities of the scant organic remains--ostracodes, fish, and plants--in the limestone, and accordingly proposed its deposition in a saline lake. The regional study summarized here suggests that the basin of saline deposition was isolated from the marine seaway in which the Curtis formed, and that its principal inflow was from streams to the southwest. It is thus considered as a saline lake. The formation of this lake can be attributed to the disrupted drainage caused by the reversal in sediment transport direction from westward to northeastward.

The following papers were published during the period:

Wright, J. C., and Dickey, D. D., 1958, Pre-Morrison Jurassic strata of southeastern Utah in Sanborn, A. F. (ed.), Guidebook to the geology of the Paradox basin: Intermountain Assoc. Petroleum Geologists, p. 172-181, Salt Lake City, Utah.

____________, 1958, Upper Jurassic strata of the Colorado Plateau as a record of tectonic history in the eastern Great Basin (abs.): Geol. Soc. America Bull., v. 69, no. 12, pt. 2, p. 1667.

References

Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., 1947, Revised correlation of Jurassic formation of parts of Utah, Arizona, New Mexico, and Colorado: Am. Assoc. Petroleum Geologists Bull., v. 31, p. 1664-1668.

Gould, D. B., and others, 1947, in Rocky Mtn. Assoc. Geologists Guidebook Field Conf., June 16-19, p. 39.

Harshbarger, J. W., Repenning, C. A., and Irwin, J. H., 1957, Stratigraphy of the uppermost Triassic and the Jurassic rocks of the Navajo country: U. S. Geol. Survey Prof. Paper 291, 74 p.

Kirkland, Douglas, 1958, The environment of deposition of the Jurassic Todilto basin, northwestern New Mexico (abs.), in New Mexico Geol. Soc. Guidebook, 9th Field Conf., p. 203, Socorro, New Mexico.

Ambrosia Lake area, New Mexico

by

H. C. Granger

The Ambrosia Lake project was started in July 1959 to study the localization, mineralization, and origin of the uranium deposits in that area. Three geologists are now assigned to the project.

Ore production in the Ambrosia Lake district is being increased in an effort to meet the requirements of the five mills in the area, which have an aggregate capacity of approximately 11,000 tons of ore per day. At the present rate of progress approximately 40 linear miles of new mine workings per year are being driven in ore. Most of this advance is being made in fewer than ten mines, although the rate of development is increasing rapidly in several other mines whose shafts have been sunk only recently.

The regional structure and other features in the Ambrosia Lake district have been studied by Hilpert and Corey (see TEI-690, p. 366-381). The surface geology of most of the Ambrosia Lake area has been mapped by Thaden (see p.32-44, this report). The field work for this project, therefore, consists almost entirely of mine mapping and sampling. To date, the geology of approximately 12.5 linear miles of mine workings has been mapped (in plan) on 1:480 scale and 5.5 miles of mine walls have been mapped on 1:240 scale.

Five mines were chosen as representative of the various types of deposits in the district, and which are adequately developed to permit mapping without interfering with the mining procedure. These mines are:

1). Rio de Oro, Sec. 11 (Dysart Shaft No. 1): Representative of a "dry" ore body with several ore horizons and a range in degrees of oxidation and leaching.

2). Kermac, Sec. 10: This is the western extension of the Rio de Oro deposit but is much more highly fractured and faulted.

3). Calumet and Hecla, Sec. 23 (Marquez mine): Representative of a "dry" ore body that displays very little visual evidence of oxidation or leaching. It is also representative of ore bodies in the Poison Canyon sandstone in contrast to the others which are in the Westwater member of the Morrison formation (for the distinction between these units see report by Thaden, p. 42).

4). Phillips, Sec. 28 (Ann Lee shaft): Representative of wet mines in which oxidation is minimal.

5). Homestake-Sapin, Sec. 15: Chosen because of its position at the present ground-water table and the wide range of degrees of oxidation, leaching, and redistribution. Also selected because of an apparent control of supergene ore by the joint system.

Although basically similar, other ore deposits in the district apparently have characteristics that set them apart from those noted above and these deposits require additional study to permit comparisons throughout the district. These are being studied as time and personnel permit.

The host rocks for the deposits (Westwater and Poison Canyon sandstones) are very fine- to coarse-grained, cross-stratified sandstones. Typical features of these sandstones are interstratified lenticular mudstone strata and shallow intraformational disconformities that are traceable for a few to several hundred feet. The mudstone lenses represent sites of deposition from very slow moving waters and the disconformities represent broad scour surfaces. The disconformities are commonly overlain by mudstone conglomerate or medium- to very coarse-grained sandstones. The host rocks were apparently deposited from braided streams traversing a broad featureless plain dotted with shallow ponds.

The primary (?) parts of the ore deposits are closely associated with a black carbonaceous substance which, for lack of a better name, will be called kerogen (Forsman and Hunt, 1958). The kerogen forms layers that are generally parallel to the regional stratification but locally may abruptly or gradually change stratigraphic position. Typically, the kerogen bodies are from a few inches to several feet thick and are elongate in a west-northwesterly direction. In many places they are stacked one above the other, separated by intervals of a few to several tens of feet of barren sandstone. Deviations from the typical shape are fairly common.

The mudstone layers and disconformities, especially where overlain by mudstone conglomerate, have exerted a control over the localization of the kerogen. The kerogen layers closely conform to these features in many places and rarely cut abruptly across them. It appears as if the mudstones and disconformities acted as a series of baffles in a generally permeable sandstone medium and directed the attitude of the kerogen layers by shunting them from one baffle to the next. Hence, the kerogen may underlie, overlie, or enclose the mudstones and disconformities.

The kerogen coats sand grains, fills intergranular spaces, and has replaced fossil wood and bone fragments. The color ranges from brown to jet black and there are apparently several varieties. Polished surfaces and autoradiographs disclose marked differences in the reflectivity and radioactivity even in homogeneous-appearing fossil wood fragments.

The kerogen ranges from weakly uraniferous to a uranium content of at least 15 percent. Even in a single kerogen-impregnated layer in the sandstone the uranium content may show a wide variation from top to bottom with no consistent relationship being apparent.

The only low-valent uranium mineral identified in the kerogen, to date, is coffinite. It is not yet known if all the uranium in the kerogen is in the form of coffinite. Under oxidizing conditions, of course, secondary minerals form in the kerogen-impregnated sandstone, and where oxidation has been strong enough, the kerogen has been removed.

In the Homestake-Sapin Sec. 15 mine, much of the deposit shows no relationship to kerogen. The ore is spottily distributed in an unknown form through the barren-appearing sandstone. It is suspected that this ore represents uranium leached from nearby kerogen ore bodies and redistributed inthe surrounding rocks. The zones of reprecipitation are believed to be related to paleo-ground water levels. Movement of the ground water was augmented by a strong northwesterly-trending joint set. Very likely other ore in the district that is seemingly unrelated to kerogen may have had a similar supergene origin.

Secondary uranium minerals may be divided into two general groups: (1) pre-mining and (2) post-mining. Metatyuyamunite is the only pre-mining secondary uranium mineral identified in ore bodies that do not crop out. At the Poison Canyon, and other deposits that are exposed at the surface, tyuyamunite and autunite have also been identified. Two post-mining secondary uranium minerals have been identified: zippeite and andersonite. The zippeite grows as an efflorescent coating on ore surfaces in the mines above the water table. Andersonite grows as an efflorescent mineral associated with thenardite on damp mine walls below the water level. It only forms where evaporation appears to be about equal to the rate of water seepage.

Several vanadium minerals have been identified, all of which are believed to be supergene or secondary although they range from V^{+3} to V^{+5} minerals. These are montroseite, paramontroseite, metatyuyamunite, tyuyamunite, and pascoite. Montroseite and paramontroseite fill fractures and are sparsely disseminated in the ore zones. Metatyuyamunite and tyuyamunite occur in similar manner under strongly oxidizing conditions. Pascoite occurs as efflorescent coatings on fracture surfaces and on mine walls. Yellow, orange, and green varieties all give the X-ray pattern of pascoite.

Other minerals that have been identified consist of jordisite, ilsemannite, native selenium (both red and gray varieties), ferroselite, barite and radiobarite, pyrite, marcasite, and anatase.

Reference

Forsman, J. P., and Hunt, J. M., 1958, Insoluble organic matter (kerogen) in sedimentary rocks: Geochim. et Cosmochim. Acta, v. 15, no. 3, p. 170-182.

Reconnaissance for uranium and thorium in Alaska

by

E. M. MacKevett, Jr.

During the report period a comprehensive report concerning geologic investigations of the Bokan Mountain uranium-thorium area on Prince of Wales Island, Alaska, was completed. The area includes about 71 square miles on the southern part of Prince of Wales Island that is underlain mostly by plutonic rocks. Metamorphic and volcanic rocks, probably of Devonian age, underlie about 5 percent of the area. The plutonic rocks are largely or entirely Cretaceous in age and range from pyroxenite to peralkaline granite and syenite, but they consist preponderantly of diorite, quartz diorite, granodiorite, and quartz monzonite. The peralkaline granite, an uncommon rock type, forms a boss about 3 square miles in extent and contains abnormal quantities of many minor elements. Pegmatite and aplite dikes are common in and near the boss, but uncommon elsewhere. Fine-grained mafic dikes, chiefly andesites and dacities, are abundant throughout most of the area, and a few related dikes are sparsely distributed. The rocks are cut by numerous faults and joints.

Most of the uranium-thorium deposits are genetically related to the peralkaline granite, and occur either in the boss or within an altered (albitized) aureole surrounding the boss that is as much as a mile wide. The uranium-thorium deposits have four modes of occurrence: (1) concentrations of uranium-thorium-bearing accessory minerals in the peralkaline granite, which account for a small part of the Ross-Adams deposit; (2) in veins or local replacements that contain uranium-thorium minerals of hydrothermal origin in or near fractures; this is the dominant occurrence of most of the Bokan Mountain area uranium-thorium deposits; (3) disseminated primary uranium-thorium minerals that are syngenetic in pegmatite and aplite dikes; and (4) uranium-thorium minerals of hydrothermal origin occupying interstices in clastic meta-sedimentary rocks; the only known occurrence of this type in the area is at the Cheri prospect.

Many radioactive minerals and a few minerals that contain rare earths and niobates were identified during the investigation. They are preponderantly primary minerals. The principal ore minerals from the Ross-Adams mine, the largest known uranium-thorium deposit in the area, are uranothorite and uranoan thorianite. These minerals and/or uraninite, brannerite, allanite, ellsworthite, and monazite have been identified as the sources of anomalous radioactivity from most of the other deposits. The rare earth minerals parasite and bastnaesite(?) are minor associates of some of the uranium-thorium deposits. Most of the uranium-thorium deposits also contain calcite and hematite, and subordinate amounts of fluorite, quartz, pyrite, and chlorite. An endeavor was also made to trace the distribution of 36 minor elements throughout the plutonic sequence and in the aplite and pegmatite dikes related to the peralkaline granite.

The Bokan Mountain area also contains copper and gold deposits, which are the sites of a few old prospects, and iron deposits that have recently interested mining companies.

GEOPHYSICAL INVESTIGATIONS

Regional geophysical studies, Colorado Plateau

by

H. R. Joesting and J. E. Case

Regional geophysical surveys have been made of the central part of the Colorado Plateau (see fig. 5) to gain information on regional geology, buried basement rocks, and regional controls of the occurrence of uranium and petroleum. The surveys have involved the systematic collection of magnetic, gravimetric and subsurface geologic data, and analysis of the data in terms of geologic structure and structural trends, and of the depth, topography and composition of basement rocks and younger intrusive rocks.

Field work was essentially finished in the fall of 1958. The past six months have been devoted to computing Bouguer gravity anomalies, plotting and contouring gravity data on base maps, preparing simplified areal geologic maps, preparing subsurface structure contour and isopach maps based on available drill hole information, and compiling second derivative and other specialized maps to aid in the interpretation of geophysical data.

Complete Bouguer gravity anomalies were computed for stations established last summer in the Abajo Mts., Utah, and in the Ute Mts., Colorado, and the data were contoured. A Bouguer anomaly map of the Moab 2° AMS sheet was completed on mylar ready for final drafting, and a similar map of the adjoining Cortez 2° sheet is in preparation.

Generalized geologic maps of the Moab and Cortez 2° sheets have also been prepared, largely from material supplied by the Plateau

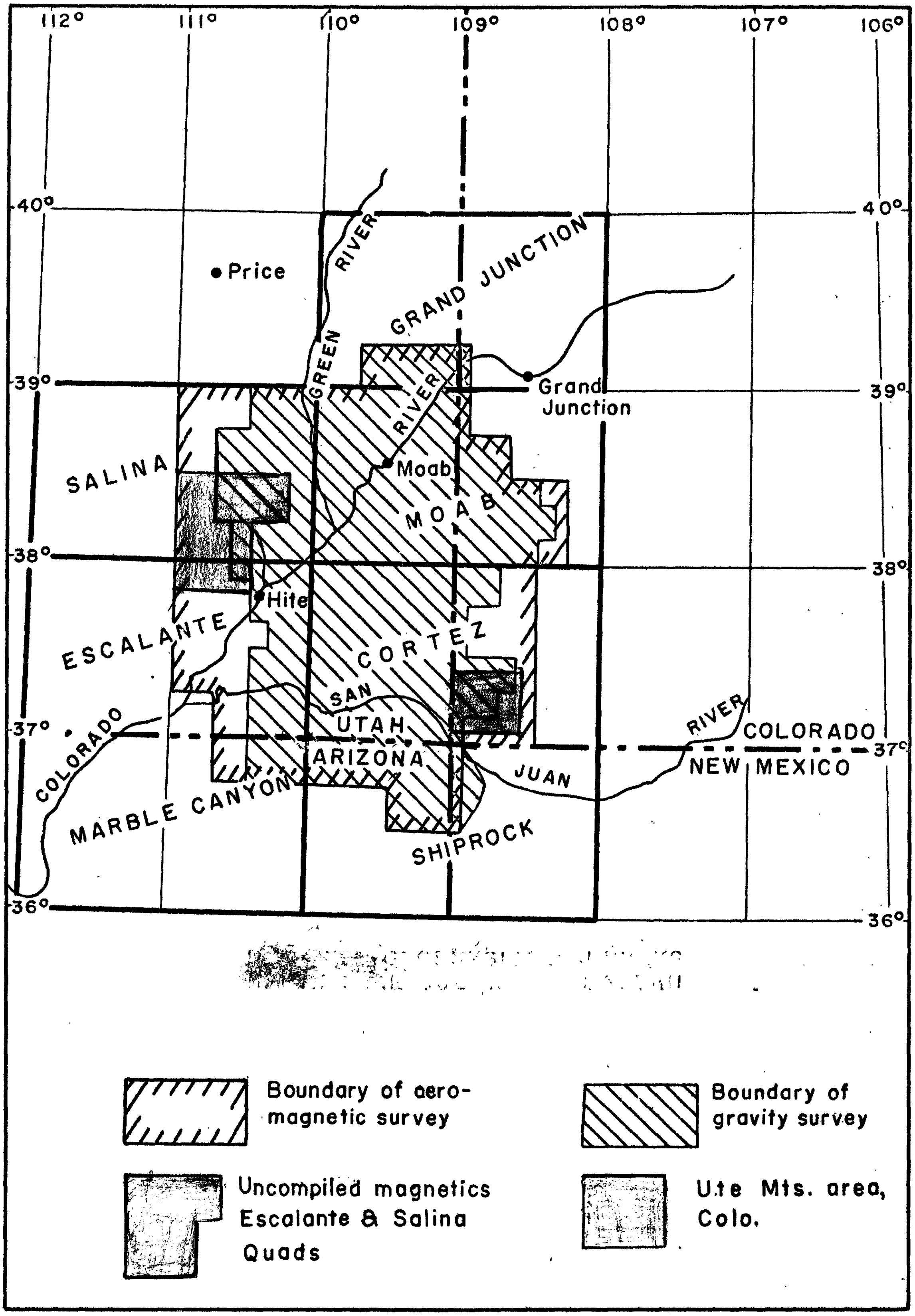


Fig. 5.--Regional geophysical surveys in central Colorado Plateau

geologic maps project, and maps of the remaining areas will be prepared when time is available. The generalized geologic maps will help relate rock-type and regional structure to the magnetics and gravimetry of the area. To emphasize these large-scale relationships, contiguous formations with similar densities or magnetic properties have been lumped, and minor structures with no measurable gravitational or magnetic effects have been omitted. Nine units have been used in preparing the maps: Quaternary, Cretaceous, Jurassic, Triassic (including the Kayenta formation), Permian, Pennsylvanian (including the Rico formation), Precambrian, and Tertiary intrusive rocks. The generalized geologic maps (and also the magnetic and gravity maps) will be published at a scale of 1:250,000, the same scale as the more detailed geologic maps of the Colorado Plateau being prepared by the Plateau Geologic Maps Project.

An aeromagnetic survey of the Ute Mts. area, Colorado, was made in April to fill a hole in the aeromagnetic coverage (see fig. 5) and to provide additional information on the structural environment and forms of the laccolithic intrusions of the Colorado Plateau. An effort is also being made to compile, on enlarged AMS maps, the aeromagnetic data covering the western part of the area. These data have not been compiled hitherto because suitable base maps were not available. Most of the area is in the Salina 2° quadrangle, for which a 1:250,000 map has recently been published.

A few days were devoted to estimating depths to sources of magnetic anomalies for the purpose of preparing a basement contour map. The estimated depths compared closely with depths to basement in the few localities where drill hole information is available.

According to magnetic and gravity evidence, the dominant compositional and structural basement trends in the central Colorado Plateau are northwesterly and northeasterly. The northwesterly trends are generally older, and are displaced laterally to the left by the northeast trends. The faulted monocline bounding the Uncompahgre Plateau and the piercement salt anticlines of the Paradox Basin are conformable with the northwesterly basement trends (see fig. 6).

Two other large monoclines, the steep-dipping fronts of the Monument Upwarp and the San Rafael Swell, are in part related to northeasterly basement trends, but are crossed by the older northwesterly trends with no apparent offset. They were initiated by minor uplift during late Paleozoic time, according to drilling evidence, but most of the uplift occurred during late Mesozoic or early Cenozoic time, and is probably much later than most of the basement structures indicated by the magnetic and gravity trends.

Along the ancestral Uncompahgre highland, on the other hand, profound deformation took place during Pennsylvanian and Permian time, and possibly earlier; and the uplift was renewed during the early Cenozoic. In addition to being conformable with the northwesterly basement trends, the Uncompahgre Uplift is characterized by a diverse magnetic pattern, in marked contrast to a uniform pattern over the deep basin which lies immediately to the southwest. The diverse magnetic pattern is in accord with the large variety of Precambrian crystalline rocks known to occur in the uplift; whereas the uniform pattern over the basin requires basement rocks of low, uniform susceptibility, such as the Needles Mountain quartzite in the nearby Don Juan Mountains, or the thick series of quartzite, conglomerate and shale in the Uinta Mountains.

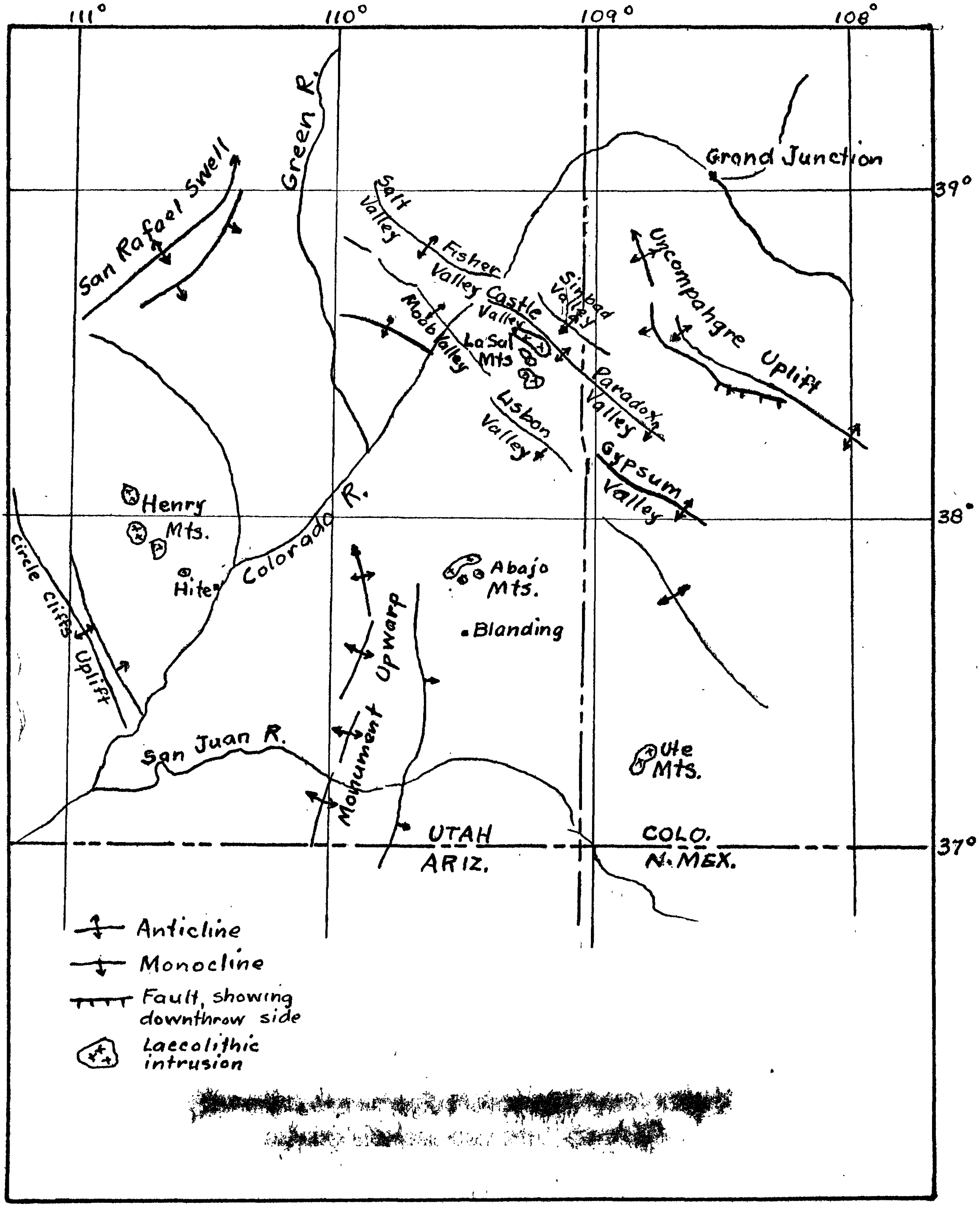


Fig. 6.--Sketch showing some of the major structures of the central Colorado Plateau.

The contrast in the magnetic patterns of the basement rocks suggests that an ancestral uplift and basin may have originated during Precambrian time. On the other hand, it may have resulted from removal by erosion of a great thickness of Precambrian rocks of relatively low susceptibility during late Paleozoic time, when the ancestral Uncompahgre highland was raised many thousands of feet, thereby exposing crystalline rocks different from those underlying the adjoining part of the basin.

The piercement salt anticlines of the Paradox Basin, just southwest of the Uncompahgre front, coincide with northwest-striking regional gravity gradients. They also coincide to a considerable degree with regional magnetic gradients, though there is no magnetic expression in some areas where the basement rocks are apparently of low magnetic susceptibility. In any event, the regional gradients probably represent zones of displacement which controlled the position of the salt anticlines.

Along the northwest flank of the La Sal Mountains a northeast-striking basement trend is indicated by gravity and magnetic gradients. This trend coincides with left lateral offsets of the salt anticlines. Thus, Fisher Valley is offset southwest with respect to Sinbad Valley, Castle Valley is similarly offset with respect to Paradox Valley, and Moab-Spanish Valley with respect to Gypsum Valley. The lateral displacement is apparently pre-Mancos in age, as Mancos rocks are not displaced; but it is younger than the main northwesterly trends which control the emplacement of salt. A similar left lateral displacement occurs near the southeast end of Paradox Valley, and is reflected by a corresponding displacement of the magnetic contours.

The stocks and laccoliths of the North and South La Sal Mountains were emplaced along previously existing salt anticlines: North Mountain along the Castle Valley-Paradox Valley anticlines, and South Mountain along the Moab Valley-Gypsum Valley anticlines. The Middle Mountain intrusions are not associated with a salt anticline.

Graticule analyses of the gravity data indicate that the salt intrusion beneath Sinbad Valley is about 11,000 feet thick, beneath Fisher Valley about 9,000 feet and beneath Castle Valley about 8,000 feet. Gravity evidence also suggests that the cores of these anticlines are denser than the cores of the salt anticlines to the southwest; in other words the clastic material in the Paradox evaporites increases toward the Uncompahgre uplift.

A large magnetic high, extending south from the Abajo Mountains to Blanding, indicates that crystalline rocks lie at comparatively shallow depths under part of the Blanding basin. The depth to the source of the anomaly is estimated to be about 4,000 feet beneath the surface, or 1,500 feet above sea level; whereas the depth to basement from stratigraphic evidence is estimated to be about 8,500 feet or 3,000 feet below sea level.

In outline and position the magnetic high appears to be associated with a large igneous intrusion, similar to, though larger than, the laccoliths and stocks of the Abajo Mountains. A similar origin is not likely, however, as the Abajos are Cenozoic in age whereas a Blanding basin intrusion would perforce be pre-Jurassic, as the Jurassic rocks in the immediate area are not domed or folded. The underlying Pennsylvanian rocks contain evaporites estimated to be about 1,200 feet thick in the Blanding area. The evaporites yield by plastic flow under small differential pressure, and would therefore be readily displaced by an igneous intrusion, but the displaced salt, although it would flow plastically, would of necessity deform the overlying rocks, so that there would be some structural expression of a large intrusion.

Other possible explanations for the existence of shallow crystalline rock in the Blanding basin are: a pre-Jurassic igneous intrusion, a prominent erosional topographic high in the basement consisting of relatively magnetic rock, or an uplifted segment of magnetic basement rock. No igneous intrusions older than Jurassic and younger than Precambrian are known in the Colorado Plateau; and the extremely large topographic relief that would be required of the basement surface is not in accord with evidence from other parts of the Plateau. We must therefore assume tentatively that the magnetic anomaly is of tectonic origin, resulting from a raised segment of magnetic basement rocks, and extending eastward from the structural front of the Monument upwarp. Such an uplift may have occurred in late Paleozoic time, when there was intense tectonic activity over much of the Colorado Plateau. The Monument upwarp was only slightly active at that time, however.

It is interesting to note that the Abajo Mountains may have elements of structural control similar to those of the La Sal Mountains. The emplacement of the La Sals may have been determined in large part by pre-existing structural zones. The structural environment of the Abajos may be similar in many respects, but further analysis is required before final conclusions can be made.

Geologic and Geophysical Studies, Coastal Plain Area, Texas

by

D. H. Eargle, Alice D. Weeks and R. M. Moxham

Investigation has been started on the distribution of radioactive materials in south Texas, where one of the most unique uranium deposits discovered in recent years occurs. This is the Palangana Dome deposit in shallow sediments of late Tertiary age covering the cap rock of Palangana salt dome, south Texas (Moxham, 1958). This dome is in east-central Duval County, Texas, about 100 miles north of the Rio Grande, and about 70 miles west of the Gulf of Mexico. The surface expression of the dome is a circular depression in the brush-covered partly dissected plain called the Reynosa Plateau by some authors, but the Reynosa Plain by Deussen (1924). The plain is a gently rolling upland, inclined southeast toward the coast, at elevations above sea level ranging from about 1,000 feet along the westward facing Bordas escarpment in western Duval County to about 300 feet along its eastern edge in eastern Duval County. The plain is crossed by southeastward flowing streams which have broad alluvial valleys and which have dissected the broad uplands to depths of about a hundred feet. Such a stream is Piedras Pintas Creek, south of Palangana Dome, a tributary of which drains the basin over the dome.

The rim of the basin is a series of hills forming a circular pattern about 2 miles in diameter and about 80 to 100 feet above the bottom of the basin. The bottom of the basin is almost flat, having a relief of only about 25 feet, and the lowest elevation above sea level is about 410 feet.

The surface of the Reynosa Plain lies wholly within the outcrop of the Goliad sand of Pliocene age. A strong caliche cap as much as 5 feet thick is common except in the alluvial valleys. The thin residual soil above the caliche is generally reddish and sandy. The streams which cross it are generally dry except after the occasional rains.

Sulfur deposits in the upper part of the caprock were mined as late as 1935. Oil was discovered initially in shallow sands above the caprock in 1928 by National Oil Company. The discovery well like the few later producers was depleted rather rapidly and to date Palangana has produced only 6,600 barrels of oil (Corpus Christi Geol. Soc., 1957, p. 17). Salt brine is currently being produced from the dome by Columbia-Southern Chemical Corporation, and the brine is being pumped to tanks on the rim surrounding the dome, from which it flows by gravity to the chemical plant in Corpus Christi.

Intensive exploration of the dome for oil and gas, sulfur, salt, potash, and, lately, uranium have outlined the general features of the geology of the dome and the surrounding area. The top of the salt is a little more than 800 feet below the surface, and the caprock at about 450 to 500 feet below the surface of the basin. The surface of the caprock is somewhat irregular but relatively flat, and that of the salt is said to be flat (Barton, 1925); the sides of the dome are steep, the dip averaging about 70° where it has been determined (Barton, 1925). The salt core is about 10,000 feet in diameter at the 1,000-foot contour below sea level, and almost circular in outline. The flanking sediments into which the salt was intruded are also steeply dipping, but the sediments covering the caprock are almost level (see sections of the sulfur-producing area in Barton, 1936, p. 258). The caprock consists of successive layers, from the top down, of limestone, gypsum and anhydrite.

The nearly flat-lying sediments above the caprock consist of about

300 feet of Goliad sand with a basal conglomerate of medium- to coarse-grained sand and scattered pebbles of chert. This overlies about 100 or 150 feet of fine-grained sand and sandy clays, possibly the Lagarto clay (Barton, 1936, p. 261), of Miocene(?) age. In the thin basal conglomerate of the Goliad sand several horse teeth, and a fragment of a tooth of a large dog, Amphicyon sp., have recently been found. The horse teeth were said by Dr. J. A. Wilson of the University of Texas to be definitely of the fauna found in the Lapara sand member of the Goliad, and the dog tooth to range from lower Miocene to lower Pliocene. The uranium deposits are found chiefly in the southwestern quadrant of the area of the dome, in tabular masses of irregular outline. A shaft and exploratory tunnel have been opened into one of the deposits, but no mining other than for test samples has been carried on up to the present time. The mining has been confined to this basal conglomeratic sand of the Goliad formation.

Figure 7[1] shows the lithology of the sediments overlying the cap-rock and of the ore zone, as revealed in a core taken in the southwestern quadrant of the dome. The lithology of that core is compared with that of an exploratory test well taken 3 miles northwest of the center of the dome, as shown in Figure 8 (for location of test wells, see Fig. 9). Although the lithology of the two cores is similar, the

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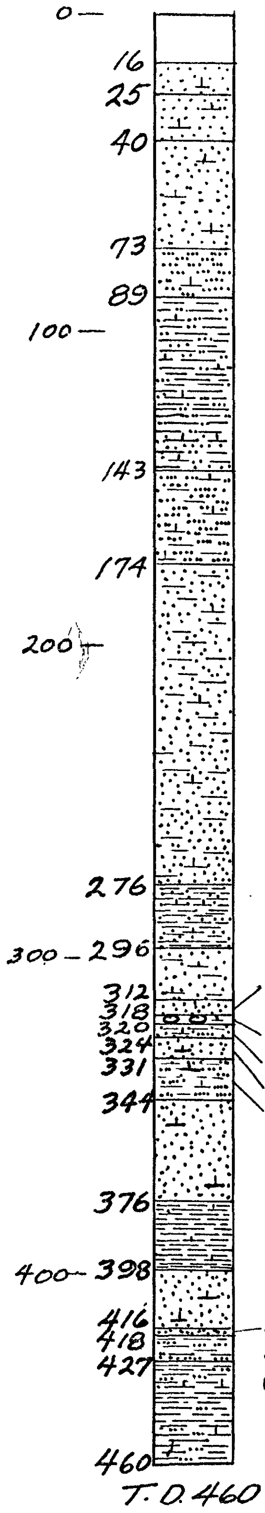
[1] Abbreviations used in core descriptions in Figures 7 and 8 are:

sltst--siltstone
sst --sandstone
cgl --conglomerate
vf,f,m,c-very-fine-, fine-, medium-, coarse-grained
slty --silty
cly --clayey

calc --calcareous
pnkh --pinkish
yel,yelh-yellow, yellowish
gy,gyh --gray, grayish
grn,grnh-green, greenish
tr --trace

sdy--sandy
v--very

HOLE NO. 606



No core.

Sst, yelh-gy, f, non- to slightly calc, poorly sorted.

Sst, pnkh-gy, f, caliche nodules, MnO_2 speckled.

Sst, gyh-orange-pink with zones of pale-yelh-brown, soft, vf-f. Calc concretions abundant.

Sltst, sdy, gyh-orange-pink to pale-orange-brown, vf sd grains. MnO_2 spots.

Clay, slty, light-brown mottled with light-gray, slickensided. Calc concretions.

Sltst, cly, light-brown. Abundant calc concretions.

Sst, cly, light-brown, f-vf, varicolored grains, poorly-bedded mottled with dark-yelh-orange 203-205'; yelh-orange, gyh-red, gyh-orange, and pnkh gy to 226'. Gyh-orange-pink 226-276'.

Clay, sdy, light-grnh-gy, vf, microscopic pyrite grains.

Sst, slightly cly, light-grnh-gy, f. Dk-yelh-orange, m, 300-303'.

Sst, grnh-gy, f-m, varicolored grains of chert, a grn mineral; tr biotite, moonstone, pyrite.

Cgl, clay-ball, f-sand matrix, pyrite.

Sst, sltst, and clay, grnh-gy.

Sst, gy, vf.

Sltst and clay, grnh-gy.

Sst, light-grnh-gy, f-vf, sparse foraminifers (reworked).

Clay, light-grnh-gy, smooth, dissem pyrite. Lower 2' f sdy.

Sst, light-grnh-gy, vf-f. Tr pyrite. Upper 2' cly.

Sst, same as above, crossbedded and hard.

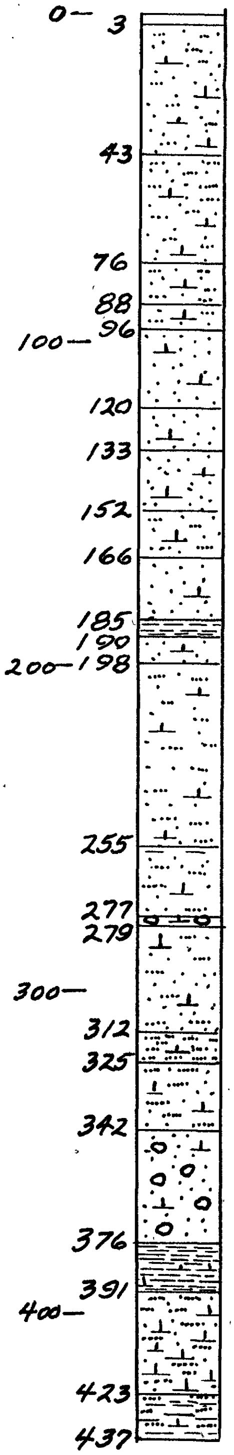
Sltst & clay, light-grnh-gy, bedded to crossbedded, dissem pyrite.

Clay, locally slty and sdy, light-grnh-gy, slickensided; scattered pyrite.

Fig. 7.—Description of core of Columbia-Southern Chemical Corporation's Hole No. 606, SW quadrant of Palangana salt dome, Duval County, Texas

H. C. GRAVIS NO. 1

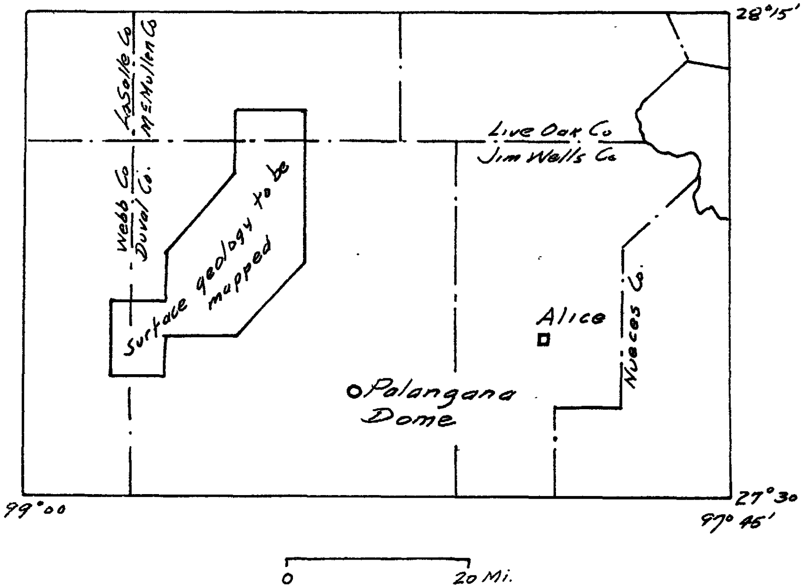
Dry drilled to 155', cored below 155' (water level).
All samples moderately calcareous except where noted.



0– 3	Soil.
3	Sand, slty, pnkh-gy, f-vf, grades into gyh-orange-pink & pale red at 20'.
43	Sst, v slty, gyh-pink, f-vf.
76	Sand, slty, gyh-orange-pink, f-vf, v loose. Lower 2' clean sand.
88	Sand, slty, gyh-orange-pink, f-vf.
96	Sand, gyh-pink, vf-f, loose. Tr limonite staining.
120	Sand, pale-orange, f, loose.
133	Sand, pale-gyh-orange, f-m, moist 140-155', vf-f 145-152'.
152	Sst, slty, pale-orange, f-vf. Tr MnO$_2$ & limonite.
166	Sst, pale-gyh-orange, vf-f.
185	Clay, v-pale-orange, v calc, some gyh-orange slty vf sst.
190	Sst, pale-orange, f-m. Lower 2' sdy clay.
198	Sst, slty, pale-gyh-orange to v-pale-orange, vf-m, some calc concretions. Tr limonite locally.
255	Sltst & sst interbedded, pale pnkh- to yelh-gy. Upper 2' cly. Some calc concretions and tr limonite.
277	Cgl, clay-ball, v-light-yelh-gy, rounded clay balls, max ¼", matrix of f-m sand.
279	Sst, slty, yelh-gy to gyh-orange, f-vf. Upper 2' pale-reddish-brown sltst.
312	Sltst, sdy, light-yelh-gy to gyh-orange-pink. Calc concretions.
325	Sst, v slty, pale-orange-yelh-brown, m-c. White calc concretions ¼" to 2".
342	Sst with clay pebbles, pale-orange-yelh-brown, m-c. Pebbles ¼" to 2".
376	Clay, gyh-orange, lumpy with calc concretions.
391	Sltst, sdy, yelh-gy, grades down into v-pale-orange cly sltst. Lower 4' slightly sdy and moderately hard.
423	Clay, v slty, v-pale-orange, some is gyh-orange. Tr MnO$_2$.
437	

T.D. 437'

Fig. 8.—Description of core of Columbia-Southern Chemical Corporation's H. C. Gravis No. 1 core test, 3 miles northwest of center of Palangana salt dome, Duval County, Texas.



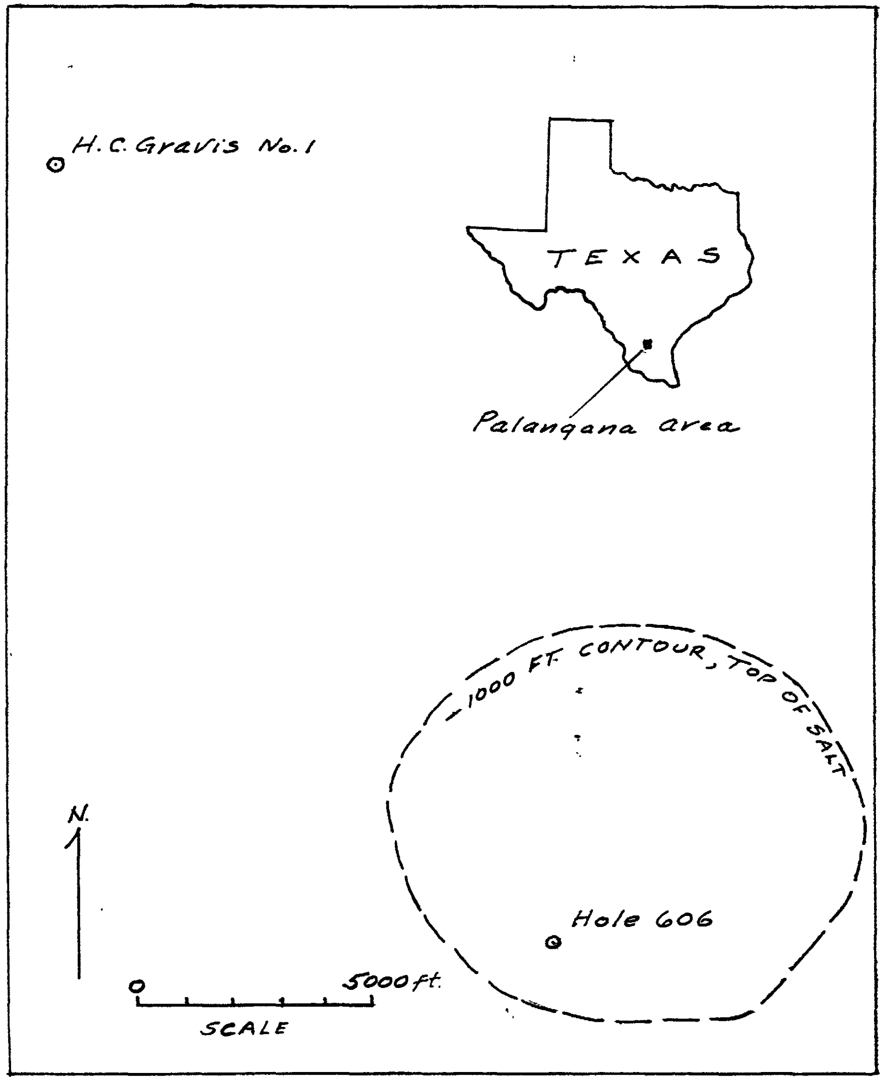


Fig. 9. Index maps, Texas Coastal Plain area

color of the ore zone and underlying beds in the well on top of the dome (Fig. 7) is conspicuously different from the correlative zone in the well off the dome. Whereas in the off-dome well the rocks are grayish-orange-pink, yellowish-gray, and pale orange, the color of the ore zone and underlying beds of the well on the dome is chiefly greenish-gray.

The greenish-gray color of the sediments and the disseminated pyrite in the ore zone and under it are due chiefly to the reducing environment of the H_2S emanating from the caprock of the salt dome. Under investigation is the possibility that the sediments under the Goliad on the dome are older than those directly under the Goliad on the flanks of the dome. The uranium in the ore zone seems to be chiefly disseminated sooty pitchblende with a small amount of finely crystalline uraninite. It is postulated that the reducing environment has caused precipitation of uranium, probably from uranyl carbonate solution in ground water.

Several papers on the structure, mineralogy, ore deposits, and physical properties of the ore and host rocks were given at the St. Louis meeting of The Geological Society of America in November 1958, and abstracts of these papers were published in the proceedings of the Society.

References

Barton, D. C., 1925, Salt domes of South Texas: Am. Assoc. Petroleum Geologists Bull., v. 9, p. 536-589.

____________, 1936, Surface fracture system of South Texas, in: Gulf Coast Oil fields, Am. Assoc. Petrol. Geologists, Tulsa, Oklahoma, p. 251-269.

References (Continued)

Corpus Christi Geological Society, 1957, South Texas salt domes: (Guidebook) Annual field trip, Corpus Christi, Texas, 30 p.

Deussen, A., 1924, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey, Prof. Paper 126, 139 p.

Moxham, R. M., 1958, Geologic evaluation of airborne radioactivity survey data: Proc. of the 2nd Int. Conf. on the Peaceful Uses of Atomic Energy, Geneva, v. 2, p. 815-819.

Radiation Laboratory

by

W. W. Vaughn

An instrument designed to study phosphorescent decay systems in minerals was constructed and is described in detail in "Infrared and ultraviolet radiation studies."

A portable beryllium detector using the gamma-neutron reaction, similar to that described by Brownell (1958) was constructed. A source of gamma-radiation irradiates the beryllium, causing neutrons to be emitted. The detecting element consists of a B^{10} polyester with a zinc sulfide coating. Light flashes are created in the phosphor from the alpha activity released by the neutron in the B^{10}. By proper pulse height discrimination the background gamma activity is reduced to zero so that neutrons emitted from the beryllium are the only ones counted. The equipment was field tested in and around the Boomer Mine in Badger Flats near Lake George, Colorado where the beryllium occurs in decomposed beryl and bertrandite. The BeO content of a grab sample can be estimated rather closely, probably to within less than 1 percent. A demonstration and explanation of the instrument and procedure was given for the benefit of the miners in the area. It was noted that modification of this technique could provide a method of on-the-spot analysis for much needed mine-control of beryllium.

Also, in this area, the instrument could be used very effectively as a reconnaissance tool to determine the occurrence of beryllium in outcrops, regardless of the host mineral.

A setup using a single-channel pulse-height analyzer and scintillation technique and pulse-height analysis rather than geiger tube operation increases the effective sensitivity of the technique.

A 10-channel unit-control timer named the "Unitrol Decatimer," accurate to within 1/10 second, was constructed for O_{16} and O_{18} studies. This instrument is a versatile timer allowing one or more channels to be pre-selected for individual or collective operation.

A control system was designed for remote operation of an emergency standby-gasoline-driven generator for the mass spectrometer laboratory in Denver. In case of power line failure, the generator is automatically cranked, run through a warmup cycle and connected to the distribution system.

Instrumentation for alpha counting, using the flask technique, was further refined. With this technique, a glass flask coated internally with silver-activated zinc sulfide is placed in contact with the cathode surface of a phototube. The scintillations occurring in the flask as a result of the radon gas are counted and recorded by a conventional instrument. The sensitivity is approximately 9.5×10^{-12} c/li.

A regulated current supply for a mass spectrometer magnet was completed. Final drawings of the schematic and an operations description were prepared.

Materials to build a precision 90-cps power supply for an analog computer were determined and obtained. The computer will provide for the solution of 12 simultaneous linear equations with similar coefficients.

Instrumentation and technical assemblies for seismic model studies were prepared. An unregulated 1,000 volt, 1/4 amp power supply using 4 silicon rectifiers in a full wave bridge was designed and constructed.

Several flash units were tested for high intensity short duration light pulses. The Kemlite DX flash tube, when fired from a 525 mfd capacitor charged to 450 volts, showed a light rise time of 25 microseconds to 90 percent of the peak value and a total decay time of 8 milliseconds. The pulse was observed with a 6199 photo multiplier. A .01 ohm 100 watt resistance was built to measure the arc or glow current. A rise of 20 microseconds to 150 amperes was shown.

A saline submersion time meter for recording the submersion period of electrodes in salt water was designed and constructed.

A blast-time synchronizer for correlating shot instant with seismic profile was redesigned.

A battery charger and a control panel for induced polarization studies were constructed for physical properties studies.

A ratiometer and an amplifier were constructed for the electromagnetic studies.

A soil gas sampling device for obtaining a gas sample from a pre-selected zone at depth in a bore hole was contructed.

Reference

Brownell, G. M., 1958, Beryllium detector for field exploration (abs.) Geol. Soc. America, v. 69, no. 12, pt., p. 1542.

RADIOACTIVITY INVESTIGATIONS

Radiogenic Daughter Products, Washington laboratory

by
F. E. Senftle

During the report period work on radiogenic daughter-products was limited to two areas of research: (1) a comparison of the ion chamber and scintillation counter for alpha counting as applied to the precise measurement of the alpha absorption coefficient of monazite, and (2) the development of an alpha spectrometer which can be applied to the alpha-lead age measuring technique.

Alpha Counting. Eight well analyzed monazite specimens were counted repeatedly by several techniques to obtain the true thick source alpha count. Besides the conventional ion chamber measurements, the same samples were measured by a single crystal alpha scintillation counter. This counter was constructed with a 90 micron CsI crystal and was operated with the sample and crystal at 105° K. At this temperature, the radioactive gases in the sample were solidified and remained in situ. This fact, together with the increased efficiency of the crystal at the low temperature used, made the scintillation counter data superior to that taken with the ionization chamber. A comparison of the experimental data with that calculated by the Bragg-Kleeman law is shown in table 4. Although the samples represent a drastic change in Th/U ratio, the absorption coefficient remains essentially constant. This result was not anticipated as the stopping power of a material increases with the alpha energy.

Table 4. Comparison of calculated and experimental alpha absorption coefficients.

Sample no.	Location	Th/U	Absorption coefficient		
			Ion chamber	Scintillation counter	Bragg-Kleeman
R 8109	Brazil	54	3.45	3.04	3.27
Byron Bay	Byron Bay	23	2.98	2.91	3.23
BD-10A	Yucca Valley	57	2.98	3.04	3.10
C-4032	Amelia, Virginia	284	3.49	3.01	3.28
47297	Connecticut	25	3.24	3.03	3.27
96858	Petaca, N. Mexico	46	2.93	3.01	3.19
AN-516007	Montana	72	2.83	3.03	3.16
SQ-81	Mountain Pass, California	1325	2.97	3.00	3.22

Alpha Spectrometer. All effort was directed to improving the resolution of the CsI crystals which will help also to improve the understanding of the basic factors that control the resolution. Work has been slowed because of frequent electronic irregularities in the multichannel analyzer.

Studies were made on the distribution of light from the crystals and correlation with crystal diameter. A surprising development resulted from the high index of refraction of CsI. Almost 50 percent of the light output travelled along the sides of the crystal, and a substantial amount of the remaining 50 percent was lost from the crystal. Studies of the light loss with thickness and crystal shape indicated where certain improvements could be made. With the newest modifications a resolution of 2.6 percent can be obtained for Po^{210} alpha particles. As far as known, this is the best resolution that has ever been reported for an alpha scintillation spectrometer. As soon as the remaining difficulties are resolved in the present instrument it is planned to make alpha spectra on the zircon and monazite specimens.

Radiogenic Daughter Products, Denver laboratory

by

J. N. Rosholt, Jr.

During the report period 612 radiochemical determinations were made, including analyses for Pa^{231}, Th^{232} , Th^{230}, Ra^{226}, Rn^{222}, and Pb^{210}. In addition, 57 low-level alpha equivalent uranium measurements were made. Twenty-six radioluxographs were provided, the majority of which were for Nevada Test-Site material.

Several samples of a fresh-water limestone from Pliocene and Miocene tuff deposits in Fremont County and Natrona County, Wyoming, were found to contain up to 0.16 percent thorium. Further work was done on this material to separate a large amount of the thorium-bearing constituent in an attempt to localize the thorium. A large fraction of the thorium is associated with the fine clay size material contained in the limestone. Preliminary analyses on size separations show that the thorium content increases as particle sizes decrease. The 0.5-1.0 micron size particles contain at least 10 percent thorium. A reconnaissance of over 100 readily available limestones from a variety of locations failed to show any encouraging traces of similar thorium anomalies.

The radiochemical analyses are nearly completed for the detailed investigation of radioactive disequilibrium and its applications in the major sandstone type uranium deposits of the western United States. Controlled, interrelated samples are used for each deposit with the completed work including a total of approximately 280 samples. This amounts to approximately 1,400 isotope determinations. In addition to the deposits listed in TEI-740, p. 268, deposits at the Palangana Salt Dome, Duval County, Texas, the Mi Vida Mine, San Juan County, Utah, the Cougar Mine, San Miguel County, Colorado, are being investigated. It is also anticipated that controlled samples from the Shirley Basin district of Wyoming can be added to this list.

The following papers were published during this period:

Rosholt, J. N., 1959, Natural Radioactivity of the Uranium Series, U. S. Geol. Survey Bull. 1084-A.

Dooley, J. R., Jr., 1958, The Radioluxograph, a Fast, Simple Type of Autoradiograph, United Nations International Conference on the Peaceful Uses of Atomic Energy, 2nd, Geneva, UN 1762.

Rosholt, J. N., 1958, Radioactive Disequilibrium Studies as an Aid in Understanding the Natural Migration of Uranium and its Decay Products, United Nations International Conference on the Peaceful Uses of Atomic Energy, 2nd, Geneva, UN 772.

RESEARCH PROGRAMS

Physical Behavior of Radon

by

A. B. Tanner

Methods for extraction of radon from large air samples

In connection with studies of naturally occurring radioactivity, a way was sought to measure the average radon content of near-surface air independent of its daughter products. Collection and measurement of radon itself, rather than of its decay products, was deemed necessary because equilibrium does not generally prevail among radon and its decay products in free air (Behounek and Majerova, 1956). Three methods were considered: adsorption on charcoal, absorption by organic liquids, and condensation to liquid radon by means of a low-temperature bath.

Adsorption of radon on charcoal was suggested by Rutherford in 1906 and has been used intermittently since then for many investigations of atmospheric and breath radon concentrations (see references). The method consists of passing the air to be analyzed through tubes containing active carbon, usually in the form of powdered coconut charcoal, at ambient or lower temperature. If the flow rate is not excessive and the air is first dried, radon is removed from the air. The efficiency of extraction, according to various investigators, ranges from about 50% to nearly 100%. By heating the charcoal to dull redness (about 700° C.) and flushing it with a carrier gas, the concentrated radon may be almost quantitatively removed to a conventional measuring instrument, such as an ionization chamber or an electroscope. Disadvantages of the method are the gradual reduction of the adsorption capacity of the charcoal through use, the large volumes of charcoal needed for sampling at flow rates of orders greater than 10 cc/sec, and the heating required to remove radon from the charcoal.

The distribution, "concentration", solubility", or "partition", ratio for a gas in a system consisting of liquid and air phases is the ratio of the concentration of the gas in the liquid to that in the air when the two phases are exposed to each other long enough to attain equilibrium. Absorption of radon by organic liquids makes use of the very favorable distribution ratio for organic liquids. For example, for carbon disulfide the distribution ratio is 23.1 at 18°C. and characteristically increases with decreasing temperature so that at -18°C. it is 50.3 (Ramstedt, 1911). By use of this principle in a flow system similar to that for extraction of krypton and xenon from gases, developed by Steinberg and Manowitz (1958), radon could be quantitatively (greater than 99%) removed from air at a high flow rate. Such a system would, however, be excessively complex for untended remote stations, and would be prohibitively expensive if many units were to be used.

Radon can be removed quantitatively from air if it can be cooled to about -150°C., at which temperature it is condensed almost completely. Passage of the air stream over a metallic surface in contact with liquid air (-183°C.) for several seconds suffices for the purpose of the investigation. By passing the air to be analyzed through a chamber efficient for heat extraction when immersed in a liquid air bath, the radon may be concentrated. It may be transferred to a measuring instrument by removing the chamber from the liquid air bath, allowing it to warm up, and flushing it with a carrier gas. The principal disadvantage of the system is the liquid air requirement.

Systems for both the adsorption-on-charcoal method and the condensation-at-low-temperature method were designed, using the best information that could be found in the literature to guide the design. The condensation method was selected, using a system which is expected to extract about 95% of the radon from a 24-hr sample of 1 m^3 of air and to require 4 to 8 liters of liquid air daily. As the system is yet untested, it is not known whether its performance will meet the requirements of the study.

Measurement of radon at uranium deposits by the emanation method

Experimental work was done in 1957 (TEI-700, p. 243-246) to furnish some information on the distribution of radon in the vicinity of shallow uranium ore bodies by the measurement of radon in soil gas, commonly referred to as the emanation method. Since then theoretical studies have been made and much more literature, some new and some old, has been found, most of which concerns Soviet work.

The basic concept of the emanation method has been that the mobility of emanation isotopes, particularly that of radon, permits migration of radioactive emanation by diffusion and transport for a distance through rock and soil overburden greater than the effective distance of penetration of gamma rays through the same overburden. Coupled with the greater sensitivity of instruments for measuring emanation than those for measuring gamma radiation, emanation migration has been considered as providing an exploration method capable of penetrating more overburden than that penetrated by gamma surveying. Alternatively, the migration of radium in solution and the subsequent release of radon near enough to the surface may cause either emanation or gamma-ray anomalies that have the same characteristics as those arising from the migration of radon only. The distinction between the latter ("gaseous aureoles" in the Soviet literature) and the former ("salt aureoles") has not been given sufficient emphasis until recently (Baranov, 1956, p. 247; Grammakov and others, 1958; Bulashevich, 1958). As a result of this failure to distinguish the mechanisms involved and of doubt about the effects of meteorological changes and departure of the overburden from the ideal homogeneous porous medium, estimates of the depth of penetration of methods based on radon migration have ranged from less than 5 cm to several hundred feet.

Theoretical consideration can provide realistic upper limits to the depth of penetration of the emanation method based on radon migration. During the report period, the maximum radon concentration observable in soil gas above an infinite plane layer source of radon was calculated for the case of steady-state transport by a gas stream moving upward through the source layer at normal incidence. Using the notation,

$N_{h\ max}$ = maximum observable radon concentration at distance h from source layer (curies/cm^3 of soil gas),

h = distance from observation point to upper boundary (cm),

s = thickness of source layer (cm),

e = emanating power of source rock (TEI-690, p. 523-533),

R = radium content of source rock (g Ra^{226}/g rock),

d = density of source rock (g/cm^3),

p = porosity of source layer,

the maximum observable concentration, neglecting diffusion, was found to be

$$N_{h\ max} = \frac{e\,R\,d}{p} \exp\left[\frac{h}{s}\log_e\left(\frac{h}{s}\right) - \left(\frac{h}{s}+1\right)\log_e\left(\frac{h}{s}+1\right)\right]$$

at the optimum velocity of transport. Because the depth and source thickness parameters are included in the argument of the exponential factor, and because the argument is necessarily negative, the variation of the maximum observable concentration is much less than the variation of the ratio of depth to source thickness. If an anomaly is detected which can reasonably be expected to be due to radon transport by soil gas moving upward through a plane source layer, the above equation shows the relations among the various physical parameters involved for optimum efficiency of transport. Except for the presence of fissures, the non-ideal conditions actually existing at a prospect have the effect of diminishing the efficiency of transport and hence of causing the source radium concentration or thickness to be underestimated. This estimation cannot be made if fissures or highly permeable channels lead to the source, but such conditions are readily shown by sharp anomalies.

The concentration of radon at an observation point above a similar source, but involving upward and downward diffusion from the source in addition to upward transport, was also obtained in terms of the source and depth parameters. The solution is so complex as to make it useless in its present form and to prevent finding a maximum observable concentration in terms of the source parameters and of the parameters of transport velocity and diffusion coefficients. The related but simpler problem of finding the observable concentration in terms of the radon flux across the upper source boundary, the transport ("convection") velocity, and the diffusion coefficient of the overburden has been solved by Soviet geophysicists (see references). They have estimated the depth of penetration of the method based on radon migration to be from 6 to 13 meters.

The theoretical solutions discussed above were applied to the results obtained through soil gas investigations in Karnes Co., Texas (TEI-700, p. 243-246). It was found that the radon concentration gradients observed in soil gas could not possibly have been created by the mechanism of radon migration. It is necessary to conclude that the anomaly observed must have been related primarily to the concentration of the parent radium in proximity to the sampling points. The anomaly was therefore one of the "salt aureole" type.

Geological Survey Bulletin 1052-E, "Physical behavior and geologic control of radon in mountain streams," by Allen S. Rogers, was published during the report period.

References

(Adsorption on charcoal)

Boyle, R. W., 1909, The absorption of radioactive emanations by charcoal: Phil. Mag., 17, p. 374-389.

Eve, A. S., 1907, On the amount of radium emanation in the atmosphere near the earth's surface: Phil. Mag., 14, p. 724-733.

Hultqvist, Bengt, 1956, Studies on naturally occurring ionizing radiations with special reference to radiation doses in Swedish houses of various types: Kungl. Svenska Vetensk. Handl. 6, No. 3.

Hursh, J. B., 1954, Measurements of breath radon by charcoal adsorption: Nucleonics, 12, p. 62-65.

Satterly, John, 1908, The amount of radium emanation in the atmosphere: Phil.Mag., 16, p. 584-615.

______________, 1910, Some experiments on the absorption of radium emanation by coconut charcoal: Phil. Mag., 20, p. 778-788.

______________, 1910, On the amount of radium emanation in the lower regions of the atmosphere and its variations with the weather: Phil. Mag., 20, p. 1-36.

(Absorption by organic liquids)

Běhounek, F., 1925, New method of determining the content of radium emanation in the atmosphere: Jour. ;hys. radium, 6, p. 397-400.

Ramstedt, E., 1911, quoted from Le Radium, 8, p. 253, by Bagnall, K. W., 1957, Chemistry of the rare radioelements: Academic Press, New York, p. 111.

Steinberg, M., and Manowitz, B., 1958, An absorption process for recovery of fission product noble gases: Brookhaven Natl. Lab. Rept. BNL 493 (T-115).

(Condensation at low temperature)

Ashman, G. C., 1908, A quantitative determination of the radium emanation in the atmosphere: Am. Jour. Sci., 26, p. 119-122.

Rutherford, Ernest, 1909, Condensation of the radium emanation: Phil. Mag., 17, p. 723-729.

Rutherford, Ernest, and Soddy, Frederick, 1903: Phil. Mag., 5, p. 361.

(Emanation method)

Baranov, V. I., 1956, Radiometriya (2d Ed., Rev.): Academy of Sciences (USSR), Moscow, p. 274.

Bogoslavskaya, T. N., Grammakov, A. G., Kirikov, A. P., and Tverskoy, P. N., 1932, Otvyet k rabotye Kavgolovskoy opytno-metodicheskoy partiy v 1931 g. (Report of the works of the Kavgolovo experimental-methodical party): Vsyesoyuznogo Geol.-Razv. Ob"yedin., Izv., 51, 1283-1293.

Bulashevich, Iu. P., 1958, The gamma-emanation method of classification anomalies in radioactivity: Second Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, 1958, Vol. 2, p. 825-829.

Grammakov, A. G., and others, 1958, Some theoretical and methodical problems of radiometric prospecting and survey: Second Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, 1958, Vol. 2, p. 732-743.

Kirikov, A. P., Tverskoy, P. N., and Grammakov, A. G., 1932, K voprosu ob emanatsionnom metode poiskov radioaktivnykh ob"yektov (On the question of the emanation method of searching for radio active deposits): Vsyesoyuznogo Geol.-Razv. Ob"yedin., Izv. 51, p. 1269-1282.

Ridland, G. C., 1945, Use of the Geiger-Muller counter in the search for pitchblende-bearing veins at Great Bear Lake, Canada: Am. Inst. Min. Metall. Engineers Trans., 164, p. 117-124.

(Equilibrium among radon and its decay products in air)

Běhounek, F., and Majerová, M., 1956, Radon content of the air: Nature, 178, p. 1457.

Distribution of uranium in igneous complexes

by

David Gottfried

During this report period uranium analyses were obtained on suites of igneous rocks from some basaltic provinces and on small differentiated bodies of widely different chemical composition. The basaltic rocks analyzed for uranium include the tholeiitic Koolau basalts and the alkalic Honolulu basalts of Oahu and some olivine basalts from Idaho. The differentiated bodies include the diabase-granophyre sequence from Dillsburg, Pennsylvania; suites of rocks ranging from diabase to granophyre from Fairfax, Virginia; and the potassic-rich rocks from the Shonkin Sag laccolith, Montana.

Uranium content of the Koolau and Honolulu basalts of Oahu

The Koolau basalts of Oahu contain significantly larger amounts of silica than most Hawaiian basalt. Normative quartz is present in nearly all analyzed rocks of this series. The rocks are fairly uniform texturally and show little variation with regard to their petrographic range. Uranium analyses made on 7 of the samples described by Wentworth and Winchell (1947) are listed in table 5. They vary little with regard to their uranium content, the average content being 0.32 parts per million of uranium. The average chemical composition of the Koolau series is very similar to the Triassic basalts of New Jersey which contain an average of 1.0 part per million uranium (Gottfried, TEI-750, p. 100).

Table 5.--Uranium content of Koolau basalts,[1] Oahu

Sample No.	percent SiO_2[2]	Uranium (ppm)
9980	50.97	.30
9986	50.59	.32
9948	49.62	.27
10396	48.74	.27
11320	48.28	.27
10404	51.20	.54
10398	52.30	.30

[1] Samples obtained from H. Powers, U. S. G. S.

[2] Wentworth and Winchell (1947)

Table 6.--Uranium content of Honolulu basalts,[1] Oahu

Sample No.	percent SiO_2[2]	Uranium (ppm)
9960	36.75	3.2
10402	43.94	1.0
9962	45.13	1.2
9982	42.86	.58
10400	37.10	2.4
9961	38.57	2.1
10399	36.70	2.4

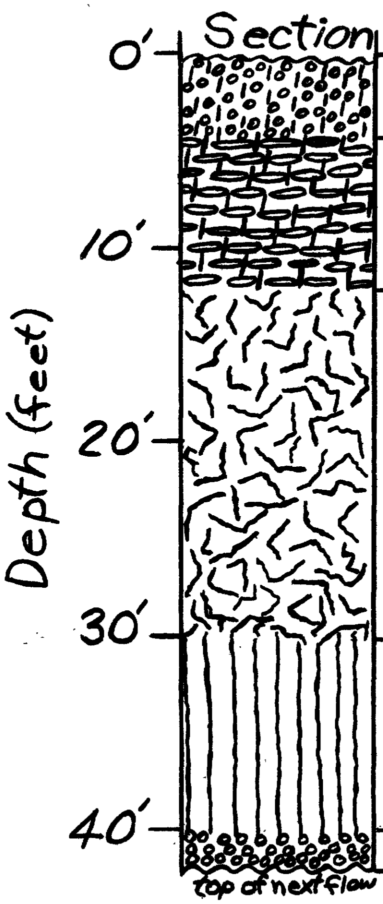
[1] Samples obtained from H. Powers, U. S. G. S.

[2] Winchell (1947)

The volcanic rocks of the Honolulu series overlie the Koolau series and are separated from them by a long erosion interval. They are present in considerably smaller amounts than the more siliceous basalts of the Hawaiian Islands. Chemically and petrographically they are distinct from the Koolau basalts. The volcanic rocks of the Honolulu series consist mainly of nepheline basalt, nepheline basanite and nepheline-melilite basalts. Nepheline is the most characteristic mineral of these lavas. Chemical analyses of these rocks reported by Winchell (1947) show that they have at least five percent less silica than the least siliceous basalt of the Koolau series. Uranium analyses on 7 of these alkalic rocks for which chemical analyses are available are given in table 6. They contain significantly larger amounts of uranium than the Koolau basalts.

Uranium content of an olivine basalt flow near Soda Springs, Idaho

To test the variation of uranium in an undifferentiated basalt flow, five samples of olivine basalt from an area near Soda Springs, Idaho were analyzed. The location of each sample from the flow, the character of the different parts of the flow and the uranium analyses are shown in Fig. 10. The samples and their descriptions were supplied by Frank Armstrong of the Geological Survey. The uranium content of the flow is relatively uniform. However, too few samples were analyzed to determine whether the small variations are significant.



Description	Sample No.	U (ppm)
Vescicular top	H-A23-1	0.43
Flattened vesicules	H-A23-5	0.60
Blocky, massive	H-A23-2	0.45
Columnar joints massive	H-A23-3	0.35
Vesicular, glassy bottom	H-A23-4	0.43

Figure 10.- Uranium content of different parts of an undifferentiated olivine basalt flow near Soda Springs, Idaho.

Uranium in the diabase-granophyre sequence
Dillsburg, Pennsylvania

Uranium analyses were made on ten rocks of the diabase-granophyre sequence to correlate uranium content with the chemical composition of the rocks. The uranium analyses were made on the same samples that were analyzed chemically and spectrographically and described by Hotz (1953).

Eight of the samples are from a drill hole and represent a series of rocks gradational from the upper chilled diabase to granophyre. Two other samples of diabase are from chilled contact facies of other bodies. The uranium analyses for the 8 samples from a drill core are shown on fig. 11, which is modified from a similar figure by Hotz (1953). Fig. 12 shows the relationship of uranium to chemical composition on a variation diagram. Uranium increases from about 0.5 parts per million in the chilled zone to about 3.0 parts per million in the granophyre.

Uranium content of diabase-granophyric rocks from
Fairfax County, Virginia

A suite of 29 igneous rocks ranging in composition from diabase to granophyre, most of the samples being from the Manassas quadrangle, Fairfax County, Virginia, were analyzed for uranium. These rocks are being studied by E. Chao of the Geological Survey who has supplied the samples and information on their petrographic characteristics.

The typical diabase of the area consists essentially of monoclinic pyroxene and labradorite. An intermediate phase contains amphibole, a less calcic plagioclase and a little quartz. The granophyric late phase contains albitic plagioclase feldspar, amphibole and quartz. The

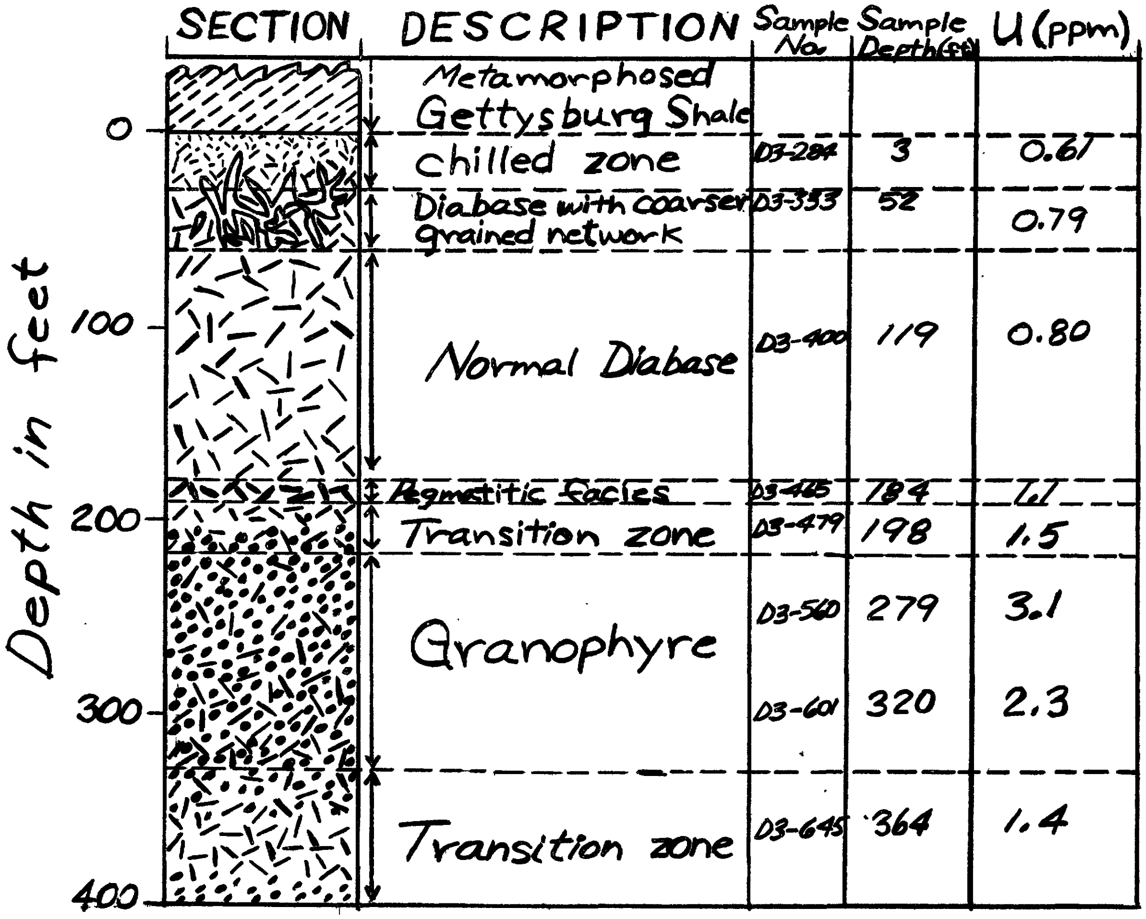


Figure 11.-Uranium content of different facies of the Diabase-Granophyre sequence near Dillsburg, Pennsylvania.

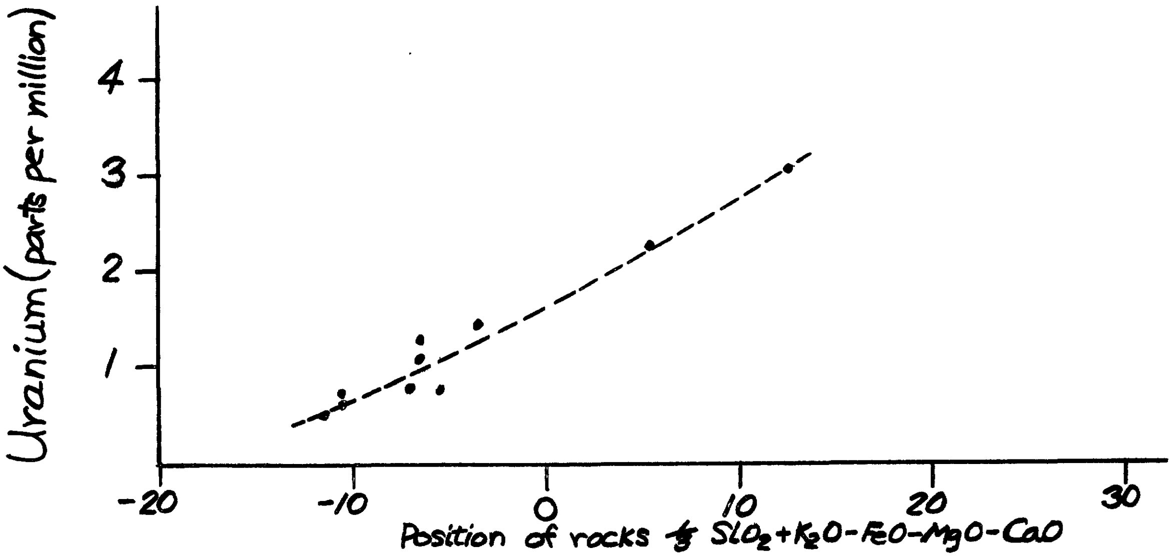


Figure 12.-Distribution of uranium in rocks of the diabase-granophyre sequence at Dillsburg, Pennsylvania.

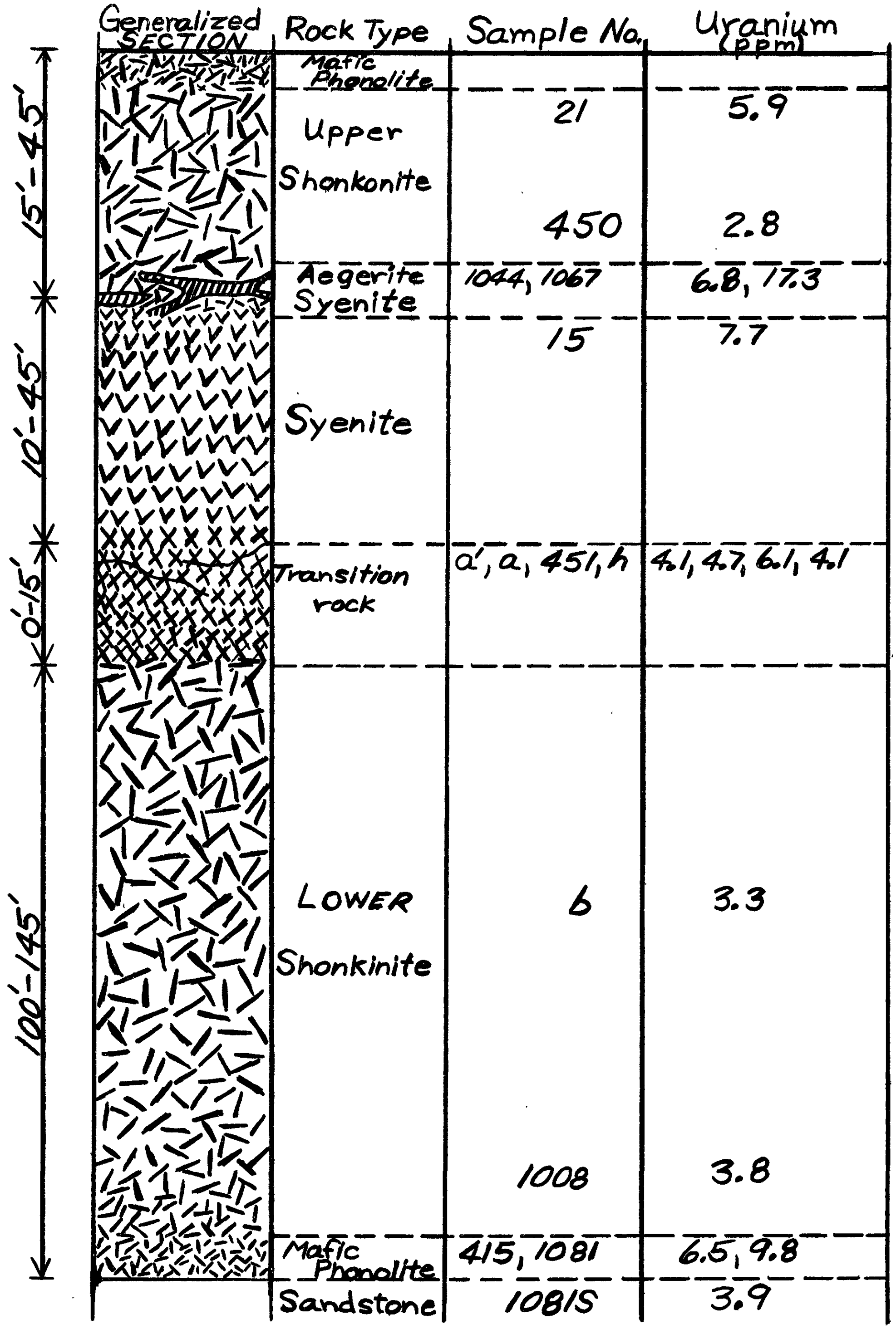
average uranium content of these petrographic types is given in table 7. The typical diabase averages 0.56 parts per million uranium; the intermediate phase 1.4 parts per million, and the granophyric rocks 2.5 parts per million. There is nearly a five fold enrichment of uranium in the granophyric rocks over the typical diabase.

Table 7.--Uranium content of diabase-granophyric rocks from Fairfax County, Virginia

Rock type	No. of samples	Uranium ppm range	Uranium ppm average
Typical diabase	20	0.22 - 0.69	0.56
Intermediate phase	5	0.76 - 2.0	1.4
Granophyric	4	1.9 - 3.3	2.5

Uranium in rocks of the Shonkin Sag Laccolith

The Shonkin Sag laccolith consists mainly of four rock types: shonkinite, syenite, transition rock which separates shonkinite and syenite; and aegerite syenite. Chemically these rocks are unusually high in potassium for rocks containing from about 45 to 50 percent silica. The approximate position of the rocks analyzed for uranium is shown in fig. 13, along with their uranium content. The chilled shonkinite (mafic phonolite) is represented by two samples from the lower contact. They contain 6.5 and 9.8 parts per million uranium. The mafic phonolite is transitional to the lower shonkinite, two samples of which contain 3.3 and 3.8 parts per million uranium. The transition rocks run from 4.1 to 6.1 parts per million and the syenite 7.7 parts per million uranium. The aegerite syenite is intrusive into the enclosing rocks as horizontal dikes. Two samples of this rock contain 6.8 and 17.3 parts per million



Rock Type	Sample No.	Uranium (ppm)
Mafic Phonolite		
Upper Shonkonite	21	5.9
	450	2.8
Aegerite Syenite	1044, 1067	6.8, 17.3
Syenite	15	7.7
Transition rock	a', a, 451, h	4.1, 4.7, 6.1, 4.1
LOWER Shonkinite	6	3.3
	1008	3.8
Mafic Phonolite	415, 1081	6.5, 9.8
Sandstone	1081S	3.9

Figure 13.-Distribution of uranium in rocks of the Shonkin Sag Laccolith, Highwood Mountains, Montana. Generalized section of laccolith (after Hurlbut 1939).

uranium. Two samples from the upper shonkinite contain 2.8 and 5.9 parts per million uranium. A sample of sandstone from the lower contact contains 3.9 parts per million of uranium. According to Hurlbut (1939) most of the rocks were derived from a homogeneous magma which differentiated in place. The behavior of uranium during differentiation is not as systematic as in the diabase-granophyre sequences. There is, however, a general trend of increasing uranium content in the later differentiates. These laccolithic rocks show a several fold enrichment of uranium over rocks of the diabase-granophyre bodies.

References

Winchell, H., 1947, Honolulu series, Oahu, Hawaii: Geol. Soc. of America Bull., v. 58, p. 1-48.

Wentworth, C. K., and Winchell, H., Koolau basalt series Oahu, Hawaii: Geol. Soc. of America Bull., v. 58, p. 49-78.

Hotz, P. E., 1953, Petrology of granophyre in diabase near Dillsburg, Pennsylvania: Geol. Soc. of America Bull., v. 64, pp. 675-704.

Hurlbut, C. S., 1939, Igneous rocks of the Highwood Mountains, Montana, Part I, The Laccoliths: Geol. Soc. of America Bull., v. 50, p. 1043-1112.

Synthesis and Solution Chemistry of Uranium

by

I. A. Breger and A. M. Pommer

This project was initiated in November, 1955, to study the stability relations of minerals of importance in uranium prospecting and technology; the mechanism by which mineralizing solutions move to the site of deposition and the nature of the ions in these solutions; and the mechanism by which such minerals are precipitated from solution. Summarized below are the studies that have been completed or that will be nearing completion when the project is terminated in June of 1959.

Mineral synthesis

A number of new minerals, identified by X-ray diffraction, could not be completely characterized because of finely intergrown impurities. Synthesis of these minerals in pure form permitted their complete descriptions and resulted in papers on ningyoite, a hydrated calcium uranous phosphate from Japan, and weeksite, a hydrated uranium silicate from Juab County, Utah.

The conditions under which some minerals form were investigated as a function of pH. Epithermal temperatures and moderate pressures were selected for the experiments which were carried out in an autoclave, in sealed tubes, or in Morey bombs. Systems studied included: (1) hydrated vanadium oxides (resulting in the original syntheses of duttonite, doloresite, and haggite), (2) uranyl silicates including clarkeite, boltwoodite, and weeksite, (3) uranium-vanadium minerals such as carnotite, tyuyamunite, uvanite, and rauvite, (4) uranium compounds having a schoepite-like structure, and (5) a vanadium (III) analogue of jarosite.

The conditions of formation of potassium and calcium vanadate compounds at temperatures between 25° and 100° C were investigated as a function of pH and temperature, and pH-temperature diagrams were constructed from experimental data.

The effect of woody material as a reducing agent in mineral synthesis was investigated, and it was shown that wood is an effective reducing agent for vanadium (V) solutions. Its effective equivalent weight was computed and determined, and it was used in the preparation of reduced vanadium minerals and uraninite. Attempts to use a coalified log of sub-bituminous rank from the Colorado Plateau in the preparation of uraninite led to somewhat ambiguous results. In sulfide-free uranyl solutions it led to the formation of uraninite only under unlikely geologic conditions, while in sulfide-bearing uranium (VI) solutions the necessary presence of coal to formation of uraninite was not clearly established. In the copper system turanite, antlerite, atacamite, chalconatronite, and malachite were synthesized. Powellite was prepared and its solubility product and free energy were determined.

pH-Potential Studies

Thermodynamic data were used to construct pH-potential diagrams of the V-H_2O, U-H_2O and U-H_2O-CO_2 systems, as well as to show the equilibrium distribution of dissolved sulfur species in water in pH-potential space. The vanadium pH-potential diagram also was constructed from experimental data collected by means of a multiple pH-potential recorder designed and constructed for the purpose. The effect of temperature upon the precipitation of hydrated vanadium oxides from aqueous solutions was studied experimentally.

Coalified wood as a geothermometer

Studies are being conducted to determine the quantity of humic material extractable from a coalified log by alkali at temperatures between 100° and 150° C. Using a carefully selected suite of logs from operating mines of the Colorado Plateau, initial interpretation of the data suggests that these logs were never exposed to temperatures above 130° in the presence of alkaline solutions such as those which are thought to have carried uranium into the region.

Impregnated sandstone

Mechanical and chemical isolates were prepared from a sandstone highly impregated with organic material from the Ambrosia Lake region, New Mexico. The composition of the organic material is very similar to that reported for similar isolates from other parts of the Colorado Plateau. Infrared analysis, chemical composition, and physical properties all preclude petroleum and point strongly to humic substances as the progenitor of this material.

Woody material in ore formation

In view of the success of woody material as reducing agent in mineral synthesis, and the field association of coalified wood with uranium or vanadium ores, a table was constructed which permits the determination of the quantity of woody material necessary to cause the formation by reduction of an ore-body of known tonnage and grade.

Role of complexes in ore-forming fluid

The effect of carbonate complexing upon ore-forming fluids bearing uranium, copper, or both was investigated and it was shown that this complexing agent is reasonable for many conditions of ore-formation. The role of humic acid as complexing agent was investigated, and it was shown that humic acid is a compound having a definite equivalent weight on titration. This will make possible the use of humic acid solutions of known normality, a prerequisite in any study of humic acid complexing.

rH Studies

Thermodynamic calculations showed that rH, the negative logarithm of the hydrogen pressure of a solution, is a useful parameter for predicting the type of oxides or hydrated oxides in equilibrium with the solution.

Weathering in ore bodies

Suites of samples of vanadium-uranium ores from the Colorado Plateau were chemically and mineralogically studied in detail and evidence was presented to indicate that the ores must originally have been precipitated in the reduced form. The conclusions from field and laboratory data were concordant.

The following papers were published during the report period:

Phillips, H. F., and Breger, I. A., 1958, Isolation and identification of an ester from a crude oil: Geochim. et Cosmochim. Acta, v. 15, p. 51-56.

Pommer, A. M., Breger, I. A., Phillips, H. F., and Chandler, J. C., 1958, Preliminary studies of the formation of uraninite under simulated Colorado Plateau conditions, Bull. Geol. Soc. Am., v. 69, No. 12, Part 2, p. 1767-1768 (Abstract).

Magin, G. B., Jr., Jansen, G. J., and Levin, B., 1959, Synthesis of sabugalite: Am. Mineralogist, v. 44, p. 419-422.

Jansen, G. J., Magin, G. B., Jr., and Levin, B., 1959, Synthesis of bastnaesite, Am. Mineralogist, v. 44, p. 180-181.

Stable Isotope Analysis

by

Irving Friedman

The deuterium content of 200 fresh waters of the United States was determined during the period. The samples were mainly surface waters, but some precipitation also was analyzed. These analyses plus those done previously give a good cross section of the deuterium content of surface waters of the United States.

The study of deuterium fractionation during natural evaporation continued. Samples of water allowed to evaporate aboard a ship cruising in the Gulf of Mexico, and samples of water collected in Scammon's Lagoon, Baja California, support the thesis that evaporation in these environments is an equilibrium process. However, the conditions of evaporation in such environments will yield a brine, the deuterium content of which is not too different from that of ocean water. The deuterium fractionation that occurs when gypsum precipitates from an evaporating brine is being investigated.

The following papers were published during the period:

Friedman, Irving and Smith, R. L., 1959, Geochemical method for dating obsidian artifacts: Science, vol. 129, no. 3358, p. 1285, (abs.).

Friedman, Irving and Smith, R. L., 1958, The deuterium content of water in some volcanic glasses: Geochimica et Cosmochimica Acta, vol. 15, no. 3, p. 218-228.

Firedman, Irving, 1958, The water, deuterium, gas, and uranium content of tektites: Geochimica et Cosmochimica Acta, vol. 14, no. 4, p. 316-322.

Nuclear Geology
by
F. E. Senftle

Experimental work on determination of the magnetic susceptibility of TiO_2 was completed during the last six months. A number of measurements were made to verify the old data or check the interpretation. Table 8 shows the results on several samples of natural rutile, anatase, and brookite that were run to compare with the data already reported for synthetic TiO_2.

Work on the magnetic susceptibility of tektites and obsidians also was completed. During the last six months about 35 to 40 specimens were measured. Significant differences were noted between tektites and obsidians.

Work is continuing on evaluation of the magnetic susceptibility of coffinite and related uranium minerals. Little success has been obtained in determining the exact formula for the mineral, but some of the data seem to indicate that it may differ from the approximate formula generally given.

Table 8.--Magnetic susceptibilities of natural TiO_2.

Crystallographic form	U. S. National Museum no.	Location	χ (x 10^{-6} emu/gram)
Rutile	2063	Blumberg, near Adelaide, S. Australia	1.07
	R-2076	Alexander Co., North Carolina	0.98
	112990	Brooks Farm, North Carolina	0.95
	52-mt-5*	Beach Sand, Melbourne, Australia	0.91
	45-mt-47*	Beach Sand, Vero Beach, North Carolina	0.83
Anatase	R-2097	Diamantina, Brazil	0.19
	112990	Brooks Farm, North Carolina	0.24
	2103	Tasdatsch, Tavetsch, Switzerland	0.36
Brookite	97016	Magnet Cover, Arkansas	1.15
	1710	Somerville, Massachusetts	0.83
	81463	Ulster Co., New York	0.26
	R-2108	Von der Soule viven, Tyrol, Switzerland	0.63-1.53

*U. S. Geological Survey sample numbers.

The variation in the magnetic susceptibility of ZnS with iron content, and also of $BaTiO_3$ with Nd content was worked out.

Some work also was done to correlate the effect of radiation damage in zircon with magnetic susceptibility. So far only preliminary data have been obtained.

An improved technique for making susceptibility measurements has been developed. The new technique permits determination of the susceptibility as an absolute without comparison with a standard sample. The new method will enhance the accuracy of that currently being used.

The following paper was published during the period:

Walker, Edward, Cuttitta, Frank, and Senftle, F. E., 1958, Some natural variations in the relative abundance of copper isotopes: Geochemica et Cosmochimica Acta, vol. 15, no. 3, p. 183-194.

Nuclear Irradiation

By
Carl Bunker

The general objective of this project is to develop borehole nuclear irradiation equipment and techniques to obtain in situ data on density, water content and, ultimately, mineral identity. Work currently is concerned with development of a logging unit to obtain quantitative in situ density data. The present experimental unit utilizes a 150-millicurie source of cobalt-60, a scintillation detector, and a single-channel pulse-height analyzer. The amount of lead shielding required between the radioisotope source and the detector is being investigated in simulated formations of various density. Results to date indicate that .5 to .6 foot of lead shielding is required for the source now being used (Fig. 14).

Several densities in the range of 43 to 146 pounds per cubic foot are being used in the simulated formations composed of sand, cement, salt,

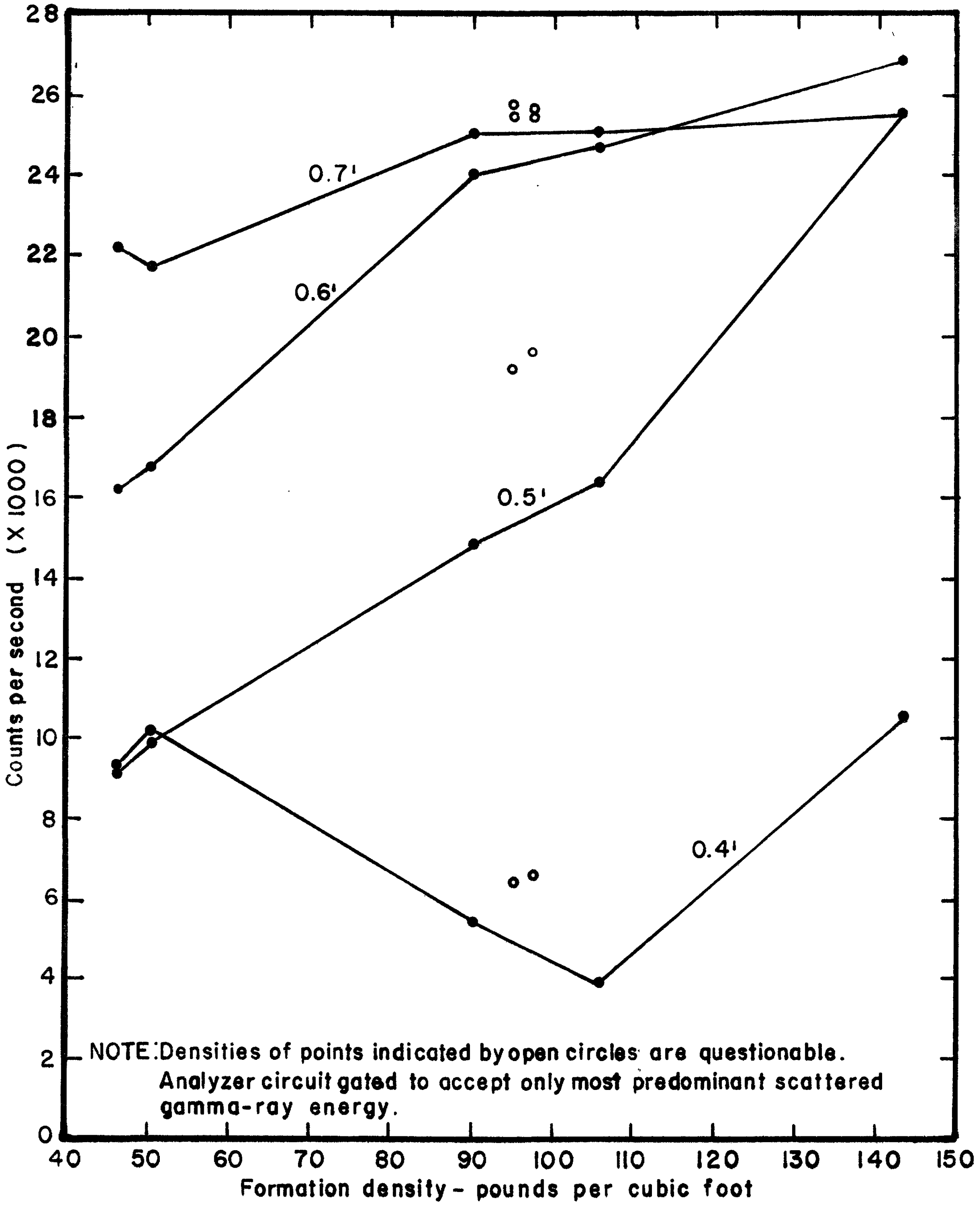


FIGURE 14. PRELIMINARY CALIBRATION CHART SHOWING RELATIONSHIP AMONG COUNTS PER SECOND, FORMATION DENSITY, AND SOURCE-TO-DETECTOR SPACING

and fluorspar. Density logs of the simulated formations indicate that in situ density can be determined by the gamma-gamma technique within an accuracy of about 5 percent. Optimum results were obtained by gating the pulse height analyzer at about 0.7 mev and by utilizing a window width of two percent (Fig. 14).

A shallow drill hole at the Denver Federal Center was logged with the instrument described above. Apparent density changes (Fig. 15) were observable on the density logs, some of which correlated with anomalies observed with an experimental acoustic velocity logger. Quantitative density data from the logs are indeterminable because in-hole conditions cannot be related at present to those in simulated formations.

The objectives of the investigations during the next few months will be: (1) to reduce the error in in situ density determinations, (2) to investigate the efficacy of other source sizes and types (especially cesium-137) and source-to-detector spacings, and (3) to relate density-log data to laboratory density analyses. Preliminary experiments to determine soil moisture with a logging unit will be started.

Geochronology

by
L. R. Stieff

During this report period approximately 50 samples of radioactive minerals and galena were prepared for chemical and isotopic analysis. Analytical work was completed on approximately 70 samples.

Isotopic analyses were completed on two groups of galenas from the Coeur d'Alene district. Also, isotopic data were obtained on the lead in two feldspars from the Gem Stocks of Cretaceous age from the Coeur d'Alene area. The Gem Stocks were considered as the possible source of, or

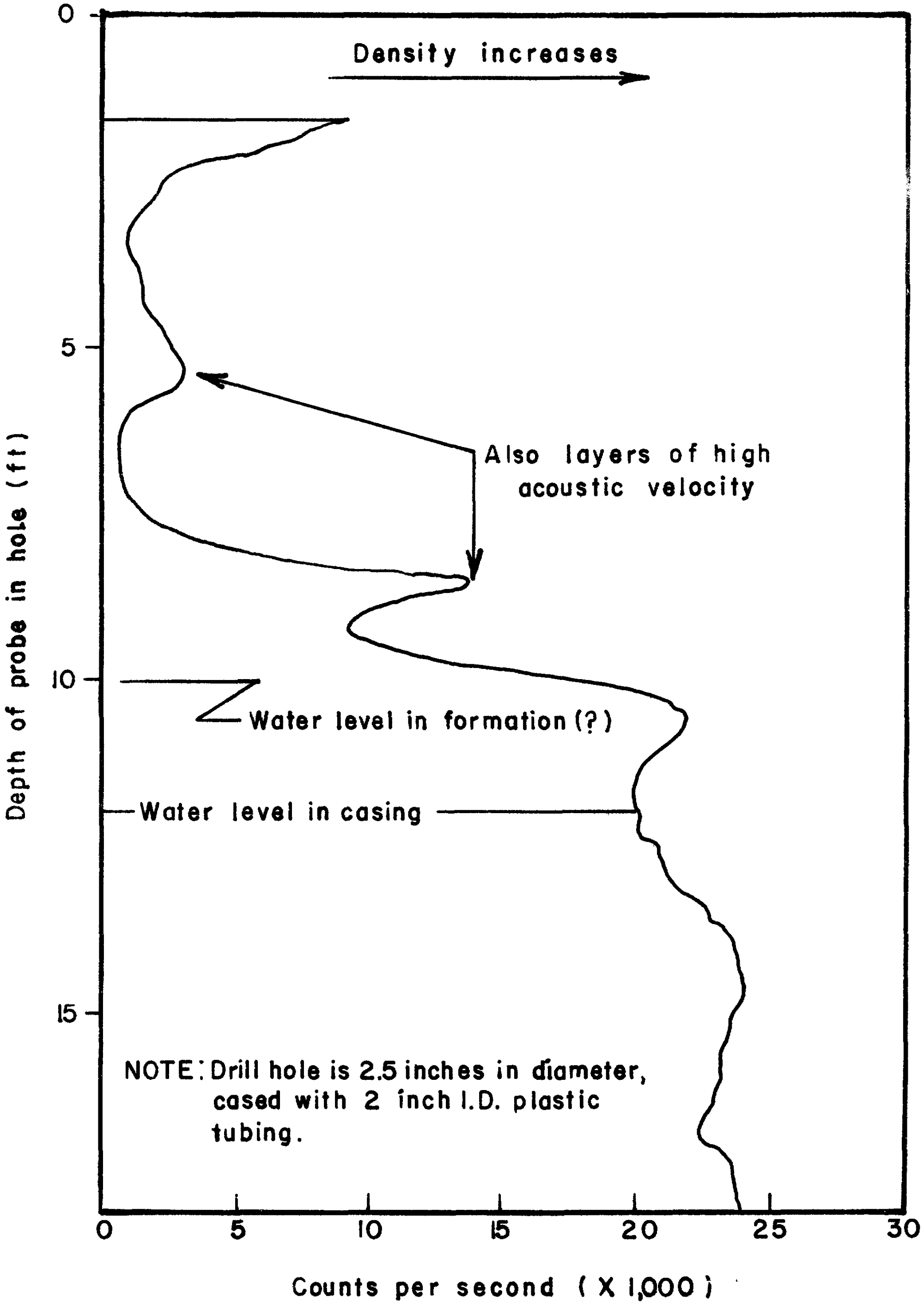


FIGURE 15. EXPERIMENTAL DENSITY LOG OF DRILL HOLE AT THE DENVER FEDERAL CENTER

directly related to, the major base metal mineralization in the mining district. From the preliminary isotopic data it would appear that the lead in the Gem Stock feldspars is relatively "modern" in isotopic composition. In contrast, the isotopic composition of the lead in the ore deposits of the district is "primitive." Thus, it seems unlikely on the basis of these determinations that the source of the Gem Stock or the stocks themselves could have provided the lead for the ore solutions.

Studies were undertaken on the quantitative determination of lead in zircon using wet chemical, optical spectrographic and isotope dilution methods. Within the last few years persistent and unresolved differences have been noted between the three methods. As a result of these studies some modifications were made in the spectrographic techniques. The changes seem to bring the spectrographic and isotope dilution methods into quite close agreement.

The following paper was published during the period:

Stieff, L. R., Stern, T. W., Oshiro, S., and Senftle, F. E., Tables for the calculation of lead isotope ages. U. S. Geological Survey Professional Paper 334A.

Isotope geology of lead

by

R. S. Cannon, Jr.

Important progress during the past six months has been made in determining the quality of isotope analyses. A study of Oak Ridge data on the GS/4 standard lead has shown that the precision of the isotope analyses is related to instrumental conditions recorded at the time of analysis. Using the GS/4 standard lead data as control, it is possible to define the quality of data on other samples that have been run concurrently during the past two years. Results show that good analyses have a reproducibility of better than 0.5 percent for measurement of the ratios of Pb^{204} to the other isotopes.

The results for GS/4 are compared with those published by Toronto and Harwell (Farquhar, Palmer, and Aitken, 1953) in Table 9. Unfortunately the agreement between laboratories is not as close as the precision of the individual laboratories. For many geologic interpretations it is desirable to know the isotopic abundances to at least one part per thousand, for some others even to one part in ten thousand. The available data on the evolution of ordinary lead in the earth's crust show that the percentage of stable Pb^{204} (to which all variations in the radiogenic isotopes must be referred) has been changing at a rate of about .01 percentage unit every hundred million years. The discrepancies between laboratories on the standard lead in Table 9 can be thought of as an uncertainty of more than 200 million years concerning the evolution of lead. This raises the question whether comparison of data published by different laboratories is geologically meaningful, and also points out the need for an absolute standard upon which all laboratories can calibrate their mass-spectrometers. One of the principal goals of this project is to prepare a synthetic standard by mixing purified stable lead isotopes.

Table 9. Analyses of standard lead GS/4 at several laboratories.

Pb^{204}	Pb^{206}	Pb^{207}	Pb^{208}	Laboratory	Author
1.44	23.69	22.54	52.33	Toronto	Farquhar et al, 1953
1.45	23.64	22.61	52.30	Harwell	Farquhar et al, 1953
1.46	23.59	22.56	52.40	Oak Ridge	Present report

Reference

Farquhar, R. M., Palmer, G. H., and Aitken, K. L., 1953, A comparison of lead isotope analysis techniques: Nature, v. 172, p. 860.

Natural Radioactivity of the Atmosphere

by

H. B. Evans

Investigation of radon-in-air sampling methods to test the carborne incremental (filter) sampling system reveal that the system (described in previous semiannual reports) performs satisfactorily, but more reliable data could be obtained by increasing the rate of air flow through the filter and by providing an air scoop to funnel air directly to the air intake.

Evaluation of incremental sampling as a means of monitoring radon efflux from the ground was accomplished by conducting air sample and gamma-ray traverses in a variety of widely scattered geologic settings. In selected areas in the Wasatch Mountains near Salt Lake City, Utah, the location of air sample and gamma-ray maxima and minima correspond to individual lithologic units or contacts between lithologic units. In some instances, air sampling used in conjunction with gamma-ray surveys provides a potential means of locating permeable zones and of estimating the relative permeability of lithologic units traversed. The major features, radon daughter and gamma-ray profiles, do not vary greatly at different times, but profile detail and activity levels are dependent on vehicle velocity, traverse direction, sampling interval, soil moisture, and wind. A vehicle speed of about 5 mph provided the most uniform air sampling results.

Air sampling for radon daughter products over near-surface uranium deposits in Karnes County, Texas and in the Thomas Range, Utah was as

effective as carborne gamma-ray surveying in defining the highly mineralized areas of the radioactive deposits in these areas. It is likely, however, that abnormal amounts of radon do not migrate to the surface from ore at depths exceeding one to five meters unless radium haloes exist or unless fracturing has occurred in the overlying rock.

Energy discrimination in gamma-ray surveys, whether conducted to locate radioactive deposits or to aid in geologic field studies, would provide a means of determining the types of radioactive minerals present in rocks situated near the survey traverse.

Radon daughter and gamma-ray anomalies were found near the Utah Hot Springs; radon daughter anomalies were also observed in the vicinity of inferred fault zones where no apparent gamma-ray abnormalities exist. The results of air sample traverses crossing the Warm Springs fault showed that radon daughter concentration is highest near the fault.

The vertical distribution of radon daughter products in the lower atmosphere is probably controlled by the height of inversion layers and by wind. The general level of air sample activity at a particular sample station appears to be partially dependent on the radioactivity of the rocks over which the wind moves.

Thermoluminescence of Radioactive Minerals

by

F. E. Senftle and A. Thorpe

The thermoluminescent light emitted when a mineral is heated is caused by trapped electrons in an excited energy state dropping back to normal. The energy difference between the two states is emitted in the form of light. Magnetic susceptibility measurements of clear calcite before and after heating showed no significant change in susceptibility.

However, a blue-green calcite sample from Las Cruces, New Mexico gave data on the blue and green portions as shown in Table 10.

Table 10.--Magnetic susceptibility data on calcite sample from Las Cruces, New Mexico

	Blue		Green	
	χ (x 10^{-6} emu/g)	(x 10^{-4} emu/g)	χ (x 10^{-6} emu/g)	(x 10^{-4} emu/g)
Natural crystal	-0.41	4.28	-0.31	4.42
Heated, and X-rayed	-0.29	28.9	-0.91	93.9
Heated, X-rayed and reheated to 500° C	-0.07	28.2	-	-

The T. L. peaks after an X-ray dose for 10 min. at 50 kv. were several times larger than the natural peaks. Why the susceptibility of the blue calcite dropped after the X-ray treatment was not obvious. Another interesting feature of these measurements is the substantial increase in the ferromagnetic effect after the X-ray treatment.

To shed light on the original problem two related experiments were performed.

(1) The magnetic susceptibility of a clear natural calcite was measured after carefully annealing out all of the natural T-L peaks. This specimen was then given sufficient exposure to X-rays to make it purple from F-center formation. Careful magnetic measurements showed a small change in the magnetic susceptibility that was barely measurable above the experimental error.

(2) The magnetic susceptibility of a specimen of relatively fresh non-metamict zircon, distinctly purple in color, was accurately measured. The specimen was then heated to 600° C in a helium atmosphere for one hour.

The F-centers were completely bleached, leaving a clear granular sugar-like zircon. Again the magnetic susceptibility was measured but no change was noted.

From these experiments it may be concluded that the change in susceptibility due to trapped electrons such as F-centers must be small. It may therefore be assumed that the number formed by any T-L process will probably be small and hence not detected by magnetic susceptibility measurements.

Geochemistry of Thorium

by

George Phair

Thirty-one rocks from the Boulder Creek batholith, ranging from quartz diorite to granite, were analyzed for Zr, Ce, La, and Y by recently developed methods of quantitative spectrography. The same rocks had been previously analyzed for major constituents, for U, and for Th. Results showed that Zr and Y reflect original magmatic differentiation. Along with TiO_2 and P_2O_5, Zr and Y drop to one-third of their initial values as total SiO_2 increases from 58.0 percent to 71.0 percent. Semiquantitative spectrographic analyses indicate that nearly all the Y in the rocks is tied up in sphene and apatite. The level of Y in these minerals is higher than that of Ce and La by several fold.

Nevertheless, when La rises above the limits of detection (.006) in the bulk rock, as it does in 16 out of 31 of the samples studied, it is found to be several times as abundant as Y. It occurs in measurable amounts in, and only in, those rocks showing visible allanite in thin section. Because the allanite is a sporadic late introduction in these rocks it is not surprising that La shows little tendency to vary either up or down with differentiation (SiO_2) except that it is invariably absent from the quartz diorites, the most mafic rocks of the complex.

Owing to its poor sensitivity (limit of detection, .04 percent--well above its normal range in igneous rocks) Ce was found in only one of the samples studied. This sample was the one richest also in allanite, total La, and leachable Ce (1+4 HCl). Other workers have shown that La and Ce form a lanthanide couple, the amount of one varying linearly with the amount of the other. Hence the La probably provides a suitable index of the total Ce when the latter is below the indicated limits of detection. By plotting the analytical data for total Ce, total La, and leachable Ce on a map it has been possible to define quantitatively a N-S belt of maximum Ce and La fringing on the west the less deformed and less altered interior part of the massif, characterized by maximum U and Th contents. That allanite is at a maximum within this N-S belt of rare-earth enrichment has been confirmed by actual separation of allanite from the rocks, a rather laborious stepwise separation involving among other things 3 different densities of Clerici's solution.

Petrographic and mineralogic studies of the thorium ores from the Wet Mountains, Custer Co., Colorado continued. The high rare earth content in a sample was found to be tied up in apatite giving an X-ray powder pattern intermediate between normal apatite and the rare-earth phosphate britholite. From the same sample, however, what appears to be a new mineral, the thorian analog of the newly described hydrated calcium uranous phosphate, ningoite, was separated. Consisting of major Ca, Th, Fe, and P_2O_5 by spectrographic analysis the new mineral gave the X-ray pattern of rhabdophane before treating, and of monazite after heating. Thus both compositionally and structurally it resembles ningoite except that major U is replaced by major

Th. After several month's tedious handpicking enough reasonably pure sample (100 mg), to permit a complete chemical analysis was obtained.

Geologic Thermometry of Radioactive Materials

by

D. B. Stewart and B. J. Skinner

During the report period intensive work continued on the systems albite-eucryptite-silica-water and ZnS-FeS-MnS-CdS.

The system albite-eucryptite-silica-water

A discussion of the early work in this system was included in TEI 750 (p. 141-142). Work continued along two main lines of investigation, the binary join eucryptite-silica and the water-saturated liquidus in the quaternary albite-eucryptite-silica-water.

a. The join eucryptite-silica. Glasses were prepared from eucryptite composition to eucryptite 20-silica 80 composition at five percent intervals, and these were used for further studies on the crystallography and composition range of phases crystallizing along this join.

Single crystals with β-spodumene structure were prepared with the composition of petalite. These crystals were satisfactory for single crystal X-ray work, and were studied by Howard Evans of Survey laboratories in Washington, D. C. He determined that they were tetragonal, space group $P4_22_1$, a_o 7.504 Å, c_o 9.0372 Å. The structure appears similar to that of silica-K, a tetragonal form of SiO_2, having a_o 7.46Å and c_o 8.59 Å. Compounds having a β-spodumene structure were synthesized from the composition of spodumene (eucryptite 67.71 silica 32.29) to eucryptite 33.86 silica 66.14. This is a true solid solution series in that no phase changes occur between the limits specified. The unit cell edges of β-spodumene decrease linearly with increasing silica content from a_o 7.5332 Å and c_o 9.1540 Å at pure spodumene to a_o 7.4832 Å and c_o 9.0004 Å at spodumene 50, silica 50. Work will continue for defining the limits of solid solution of the β-spodumene structure.

b. The saturated liquidus in the system albite-eucryptite-silica-water. Numerous glasses were prepared along the joins albite-eucryptite and albite-spodumene. The liquidus in the system albite-eucryptite-water was determined at 2000 bars H 0 pressure. The liquidus was found to have a four phase point (albite + α-eucryptite + liquid + vapor) at 733 ± 3° C. The ratio of the solid phases is approximately 81 percent albite, 19 percent α-eucryptite. Li does not appear to replace Na in albite nor does Na replace Li in α-eucryptite to any measurable extent in the range investigated. Further runs on the H_2O-saturated liquidus will be continued to define the minimum melting composition in the system and see if it falls near the composition of the spodumene-bearing zones in zoned pegmatites.

The system ZnS-FeS-MnS-CdS

The work on this system is nearly completed. Isothermal sections in the system ZnS-FeS-MnS were completed at 700° C, 800° C, 950° C, and 1050° C. The 800° C section is nearly complete in the system ZnS-FeS-CdS. This work demonstrates that both Mn and Cd cause a large reduction in the solubility of Fe in ZnS. It is definitely incorrect to ignore the Mn and Cd content of natural sphalerites in applying the sphalerite geothermometer to ore deposits. The phases encountered in this work were sphalerite (Zn,Fe,Mn,Cd)S cubic, wurtzite (Zn,Fe,Mn,Cd)S hexagonal, pyrrhotite FeS hexagonal, alabandite (Mn,Fe)S cubic, greenockite (Cd,Zn,Fe)S, hexagonal. The extents of solid solution of the elements specified for each compound (e.g., Fe, Mn and Cd in the case of sphalerite) were determined and the compositions of coexisting phases determined in 2 and 3 phase fields in each isothermal section. In addition to the single phases previously specified the following 2 and 3 phase fields were encountered in the system ZnS-FeS-MnS, wurtzite + sphalerite, sphalerite + pyrrhotite, pyrrhotite + alabandite, alabandite + wurtzite, pyrrhotite + wurtzite, sphalerite + wurtzite + pyrrhotite, wurtzite + alabandite + pyrrhotite. In the system ZnS-FeS-CdS the following 2 and 3 phase fields were encountered, sphalerite + pyrrhotite, sphalerite + wurtzite, greenockite + pyrrhotite, sphalerite + wurtzite + pyrrhotite.

Other studies

The heating stage for the X-ray diffractometer was cased in mullite and the necessary supports to fit it to the diffractometer completed. Initial studies show that it is extremely easy to align in the X-ray beam, but no runs at high temperature were attempted.

The following paper was published during the period:

Stewart, D. B., 1959, Narsarsukite from Sage Creek, Sweet grass Hills Montana, Am. Min. 44, p. 265-273.

Crystallography of Uranium and Associated Minerals

by
H. T. Evans, Jr.

Work during this period was concentrated mainly on the crystal chemistry of the carnotite and autunite groups of minerals.

The new least-squares analysis program for the Datatron was applied to the cesium analog of carnotite, $Cs_2(UO_2)_2V_2O_8$, thus making possible the accurate delineation of the oxygen coordination around vanadium in this structure. It was found that vanadium is in a square pyramid coordination, similar to that found in KV_3O_8, $K_3V_5O_{15}$ and certain other structures. The apical vanadium-oxygen distance is characteristically short, 1.58 Å., indicating that this bond involves nearly two electron-pairs.

The crystal structure of "abernathyite" was completely analyzed, and constitutes the first complete structure analysis of a member of the autunite group. The surprising result in this case was there is no evidence for the presence of any potassium, and the formula must be $HUO_2AsO_4 \cdot 4H_2O$, rather than that originally proposed. This formula previously was assigned to the mineral troegerite. The identity of abernathyite is being further investigated. The crystal structure of metatorbernite is now under study.

The following paper was published during the period:

Bystrom, A. M., and Evans, H. T., Jr., Crystal Structure of $K_3V_5O_{14}$, Acta Chemica Scandinavica, vol. 13, p. 377-378, 1959.

Infrared and Ultraviolet Radiation Studies

by
R. M. Moxham and W. W. Vaughn

The objectives of the project are (1) to investigate the phosphorescent properties of selected minerals and (2) to examine the passive infrared reconnaissance systems developed for military use and to determine to what extent such systems may be applicable to geophysical exploration.

During the report period laboratory work was undertaken to design an instrument (Fig. 16) to quantitatively evaluate several parameters of interest with respect to phosphorescence studies including the shape and amplitude of the energy output from a pulsed exciting source, the phosphorescence efficiency of selected minerals, and the relation of pulse rate to system efficiency.

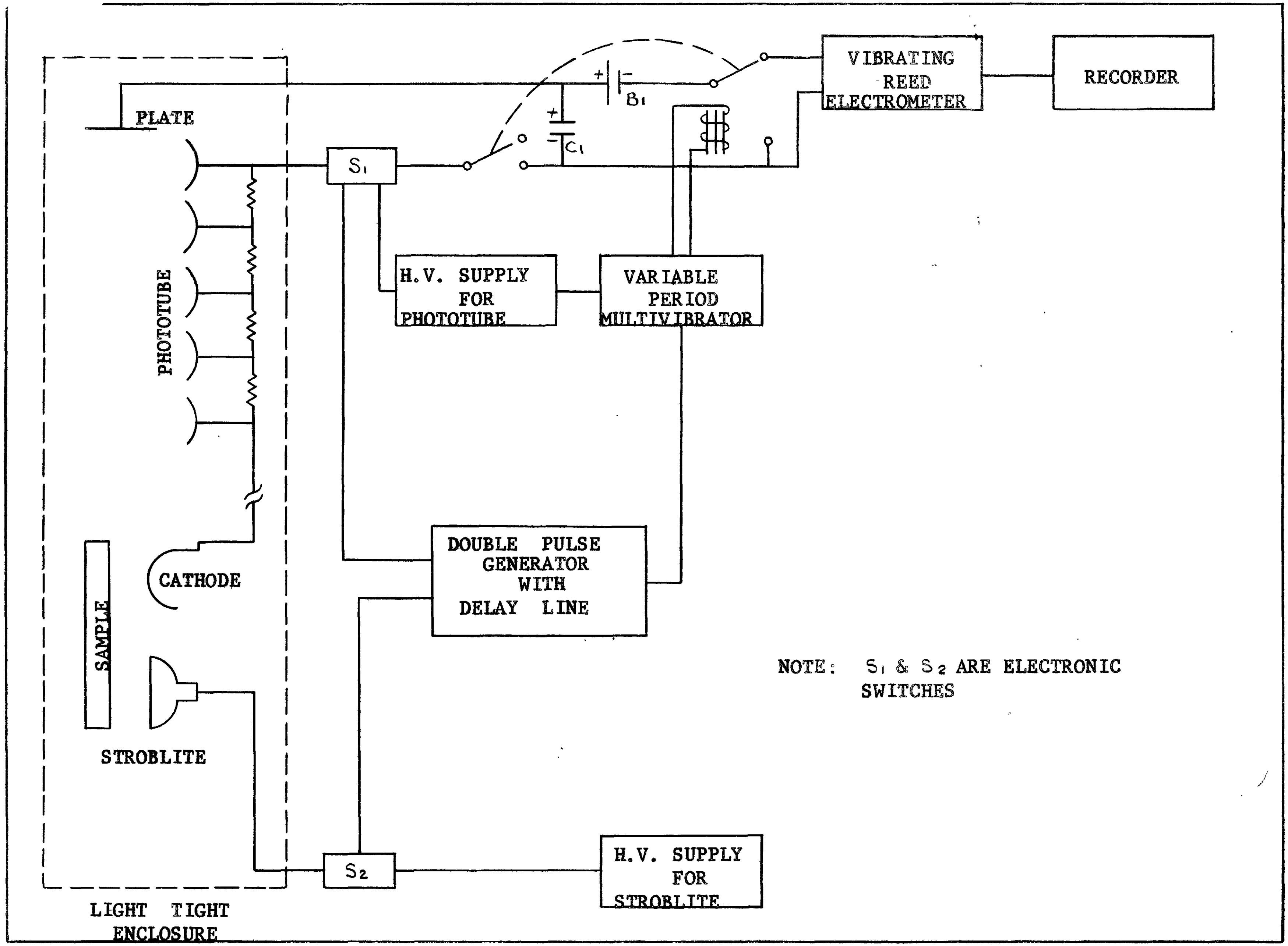


FIGURE 16. ELECTRONIC INTEGRATOR FOR PHOSPHORESCENCE DECAY STUDIES

A sample of the mineral is placed in a light-tight enclosure containing an exciting source (in this instance a gas filled flash tube) and a phosphorescence sensing element. The high energy exciting source is pulsed while the phototube is nonconductive. When the exciting source is extinguished, the phototube is turned on and the phosphorescence is recorded. A double-pulse generator synchronizes the exciting and sensing elements so as to prevent illumination of the cathode surface of the phototube while the light source is on. A delay line allows the on-cycle of the phototube to be adjusted in time with relation to the light pulse. This is necessary to obtain the proper signal to background noise ratio. In this case the signal is the decaying phosphorescence and the noise is the trailing edge of the energizing light pulse. The charge on the integrating capacitor, C_1, being shunted by the electron current in the phototube, is proportional to the phosphorescence. The output of the phototube or charge on C_1 is connected through the charging battery, B_1, to a vibrating reed electrometer and is recorded as a function of time. The charging cycle of C_1 by B_1 is controlled through a variable period multivibrator.

Tests so far have dealt only with the energy output of the exciting source. Preliminary results indicate that the light output drops to zero in about 8 milliseconds, so that the remainder of the cycle would be available for detection and measurement of the phosphorescence.