Geology and Mineralogy

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GEOLOGICAL SURVEY

GEOLOGIC INVESTIGATIONS OF RADIOACTIVE DEPOSITS

SEMIANNUAL PROGRESS REPORT*

June 1 to November 30, 1959

December 1959

Trace Elements Investigations Report 752

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FOREWORD

The Geological Survey's studies of the geology of radioactive deposits under the sponsorship of the Division of Raw Materials of the Atomic Energy Commission were started in 1948, and a related program of research, under the sponsorship of the Division of Research of the Commission, was inaugurated in 1952. The program sponsored by the Division of Raw Materials was transferred to the Survey's direct appropriation in 1958, and that supported by the Division of Research is expected to be transferred in 1960.

From 1948 to 1952 the Survey submitted administrative reports to the Commission each quarter, but in November 1952 the reporting was changed to a semiannual basis in line with the Commission's practice of reporting semiannually to the Congress. All of the Survey's quarterly reports, and its first Semiannual report, were classified. In 1953 security restrictions were relaxed and the first Semiannual Report of that year, Trace Elements Investigations Report 330, titled "Search for and Geology of Radioactive Deposits", issued in June 1953, was made available to the public by the Technical Information Service of the Commission. All Semiannual reports since that time have been available to the public under the title "Geologic Investigations of Radioactive Deposits". Reports in this series to date are:

TEI-390, issued December, 1953
TEI-440, issued June 1954
TEI-490, issued December 1954
TEI-540, issued June 1955
TEI-590, issued December 1955
TEI-620, issued June 1956
TEI-640, issued December 1956
TEI-690, issued June 1957
TEI-700, issued December 1957
TEI-740, issued June 1958
TEI-750, issued December 1958
TEI-751, issued June 1959

Although the Survey's program in uranium geology is now supported almost entirely by its own funds, periodic reports will continue to be made to the Commission because of that organization's vital interest in and responsibility for the Nation's uranium programs. The Survey plans, however, to issue future periodic reports annually in line with the Commission's recently announced policy of reporting to the Congress annually rather than semiannually. Accordingly, the next of the series will be transmitted in December 1960. During the interval between periodic reports the Divisions of Raw Materials and Research will be kept informed of noteworthy developments, as in the past, through the medium of Trace Elements Reports.

SURVEY PUBLICATIONS ON URANIUM GEOLOGY

The Trace Elements Report series, which includes the Semiannual Reports, was designed to meet the peculiar conditions under which the uranium program was operated; the primary purpose of this series of reports was to keep the Commission informed on the progress of the program being conducted in its behalf. Since 1953 a number of Trace Elements Reports, including all of the Semiannual reports, have been made available to the public. These reports, however, are preliminary in nature and have not been edited to conform to the Survey's publication standards.

Since the removal of security restrictions and the transition of field and laboratory work in the uranium program toward longer range objectives, the Survey has emphasized the preparation of final reports on the various projects as they are completed, and an increasing number of such reports have been and are now being processed for publication. During the past six months reports stemming from this program include 3 Professional Papers, 18 Bulletins or Bulletin chapters, and 13 maps in the various Survey series.

Eleven papers and a number of abstracts have been published in scientific journals, and scientists participating in the program presented 11 papers at the meeting of the Geological Society of America in Pittsburgh in November 1959.

Since 1954 Survey publications on uranium and nuclear geology include 11 Professional Papers, 115 Bulletins or Bulletin chapters, 53 Circulars, and 414 maps. During the same period the number of papers published in scientific journals by Survey scientists working on the uranium program totals more than 200, and more than 100 reports have been placed on open file for inspection by the public. As one indication of the contribution of the Survey in uranium and nuclear geology, it is worthy of mention that 61 papers by Survey scientists were published in June 1956 in the Proceedings of the first United Nations Conference on the Peaceful Uses of Atomic Energy, and 18 papers were published in 1958 in the Proceedings of the Second International Conference on that subject.

Every effort is being made to publish reports on completed phases of the uranium program as expeditiously as possible, and it is anticipated that a large number of additional publications will be made available in 1960.

GEOLOGIC MAPPING

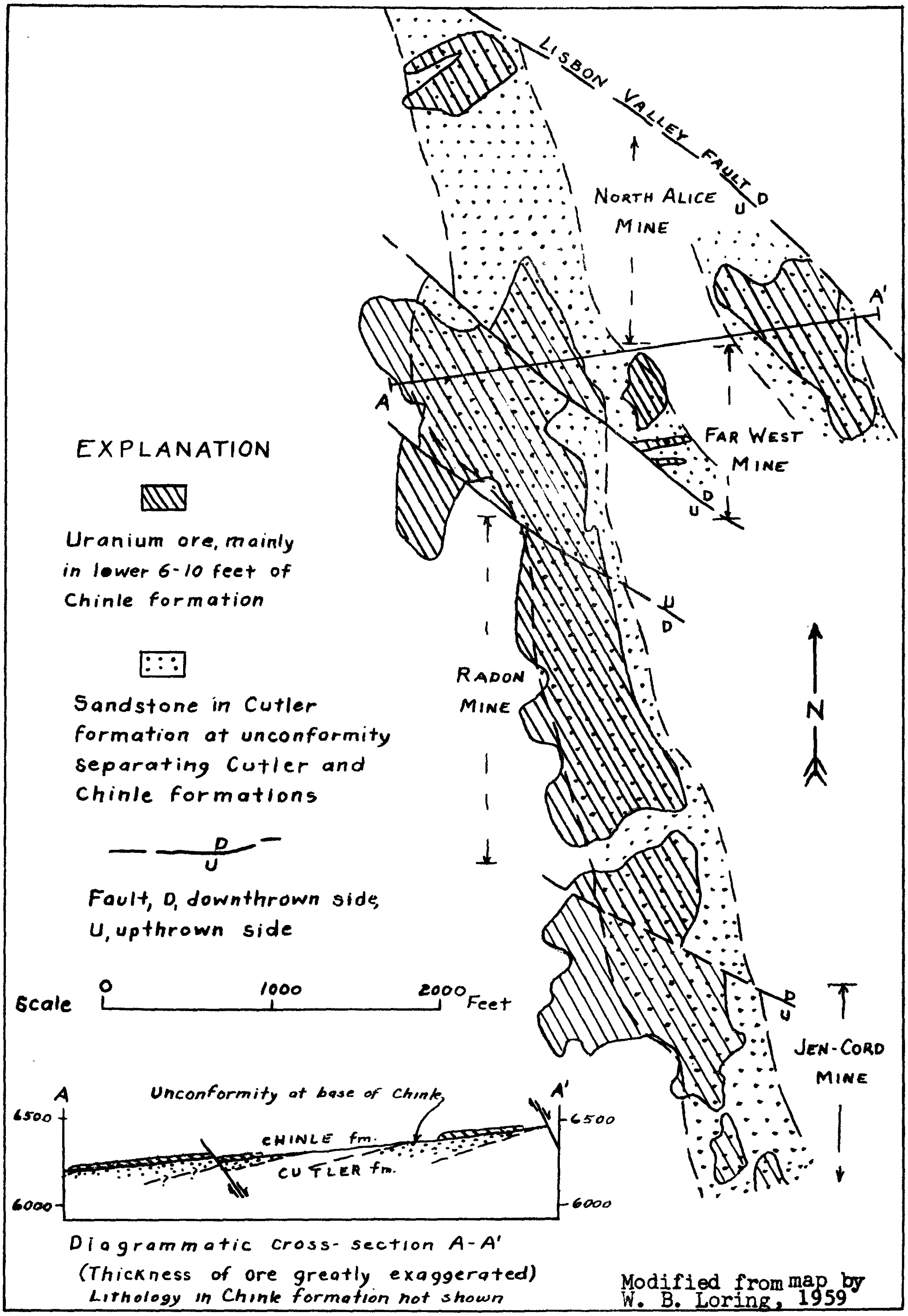
Lisbon Valley, Utah-Colorado

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

Study of the uranium deposits in the Big Indian mining district has revealed a correlation between the ore deposits at the base of the Chinle formation of Late Triassic age and the lithology of the Cutler formation of Permian age, at the angular unconformity that separates the two formations. Specifically, the color and lithology of the Cutler at the unconformity form an excellent guide to exploration for uranium in the overlying Chinle.

In the Big Indian district the upper part of the Cutler is composed of alternating beds of sandstone and mudstone ranging from 25 to 50 feet in thickness. Where truncated by the unconformity, these units form relatively broad bands at the top of the formation. Detailed mapping of mines and known ore deposits has shown that most of the ore bodies in the basal Chinle overlie the sandstone units of the underlying Cutler. Figure 1 shows this relationship in the northwestern part of the district, and studies of mines in other parts of the district indicate that the same situation prevails there also.

The Cutler sandstone in general is arkosic, and is composed of quartz, feldspar, biotite, and clay with sparse accessory minerals. Locally it contains lenses of relatively coarse conglomerate, and in some areas mudstone pellets form much of the rock. The sandstone beneath the ore-bearing portions of the Chinle formation in the district is light gray to buff,



Modified from map by W. B. Loring, 1959

Fig. 1.--Sketch map showing relationship between uranium ore bodies in Chinle formation and sandstone in Cutler formation, northwestern part of Big Indian mining district, San Juan County, Utah

fairly well sorted, poorly to firmly cemented, and locally calcareous; biotite and clay are abundant. Laterally and vertically away from the areas overlain by ore the sandstone is darker, light to dark brownish-red, and more firmly cemented. All gradations exist between the two types of sandstones and in many places the sandstone is blotchy, a mixture of both the darker and lighter colors.

The lighter colored sandstone probably represents an altered phase of the Cutler. The alteration was perhaps caused by passage along the unconformity of ore-bearing solutions that mineralized the overlying Chinle formation. The color of mudstone in the Cutler formation underlying ore has been changed from red to greenish gray. Mudstone pellets in the blotchy sandstone commonly have a reddish core surrounded by green mudstone, and the sandstone is bleached around the mudstone pellets for distances of an inch to several inches.

Mine workings generally expose only the upper 2 to 4 feet of Cutler sandstone beneath the unconformity. Good exposures show that the color change or alteration of the sandstone is in general parallel to the unconformity and crosscuts the bedding. The thickness of altered rock below the unconformity ranges from a few inches to several feet, and does not correlate closely with either the thickness or the uranium content of the overlying ore in the Chinle. Near the down-dip margins of ore, however, the color of the underlying Cutler sandstone commonly changes from the lighter to darker color within a few inches, and where it is red at the unconformity the overlying Chinle is barren.

Figure 1 shows that the sandstone beneath the ore bodies in the northwest part of the district is a single stratum or two closely spaced strata that represent a single sandstone unit within the Cutler formation. Projection of this band of sandstone along strike to the southeast suggests it is the same unit that underlies nearly all the ore bodies in the northwest part of the district, from the North Alice incline southeastward through the Standard mine. A similar sandstone is found in the southeastern part of the district beneath the ore bodies in the Divide Incline mine and the Continental No. 1 Incline mine (fig. 2).

A prominent light-colored sandstone in the Cutler formation that crops out at the rim of Big Indian Wash southeast of the Standard mine is correlated by projection with the sandstone beneath the mines in the northwestern part of the district. Mapping of the outcrop of this sandstone proved that it is a continuous unit that extends to the mining area in the southeastern part of the district. Although valley fill covers the outcrop of the Cutler formation near the southeast mines, the sandstone at the unconformity is probably the same stratigraphic unit that underlies the ore bodies in the northwest part of the district. Figure 2 shows the outcrop and projections of this sandstone unit under the ore-bearing areas. From this map it can be seen that the Chinle is barren of ore deposits in the areas where the sandstone unit in the Cutler is not cut by the unconformity between the two formations.

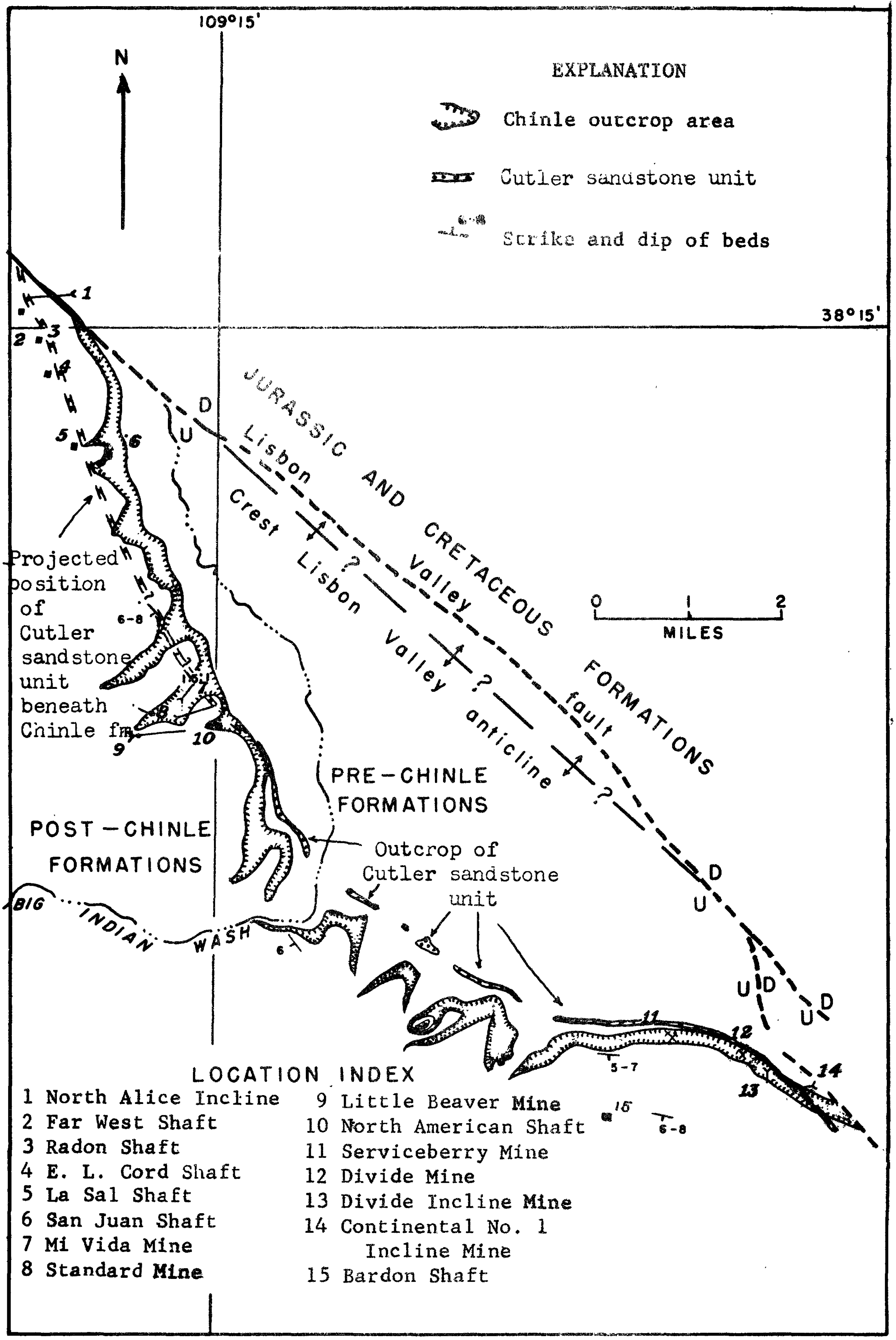


Fig. 2 .— Sketch map of Big Indian Wash area showing relation of mines to outcrop of Chinle formation and outcrop and underground projection of Cutler sandstone unit, San Juan County, Utah

Some deposits of considerable size do not lie above the projection of the sandstone unit discussed above. Among these are deposits mined at the Bardon shaft and possibly those at the Little Beaver mine. In these two mines sandstone in the Cutler formation, similar to that found under other ore bodies in the district, underlies the ore. This suggests that other sandstone units stratigraphically higher in the Cutler formation and truncated by the unconformity may represent additional favorable areas in which uranium ore bodies might be found in the Chinle formation.

Geologic maps of the Colorado Plateau

by

D. G. Wyant, W. A. Fischer, P. L. Williams,
J. D. Vogel, and R. B. O'Sullivan

During the report period work continued on the Moab, Albuquerque, and Cortez 2° sheets (fig. 3), and revision of the Shiprock sheet was virtually completed. Ninety-seven percent of the Moab sheet has been structure contoured and arrangements are underway to obtain data that will permit accurate plotting of ore deposits. The geology has been compiled on about 70 percent of the Albuquerque sheet and on about 86 percent of the Cortez sheet. Brief field trips were made to check and revise mapping in key areas, to determine igneous rock types and to examine structure.

Since July 1, 1959 all photogeologic effort in the Colorado Plateau has been directed towards compilation of maps at a scale of 1:62,500 for use in compilation of the 2° maps. Some of these maps will be published separately. Approximately 430 square miles of the Albuquerque sheet have

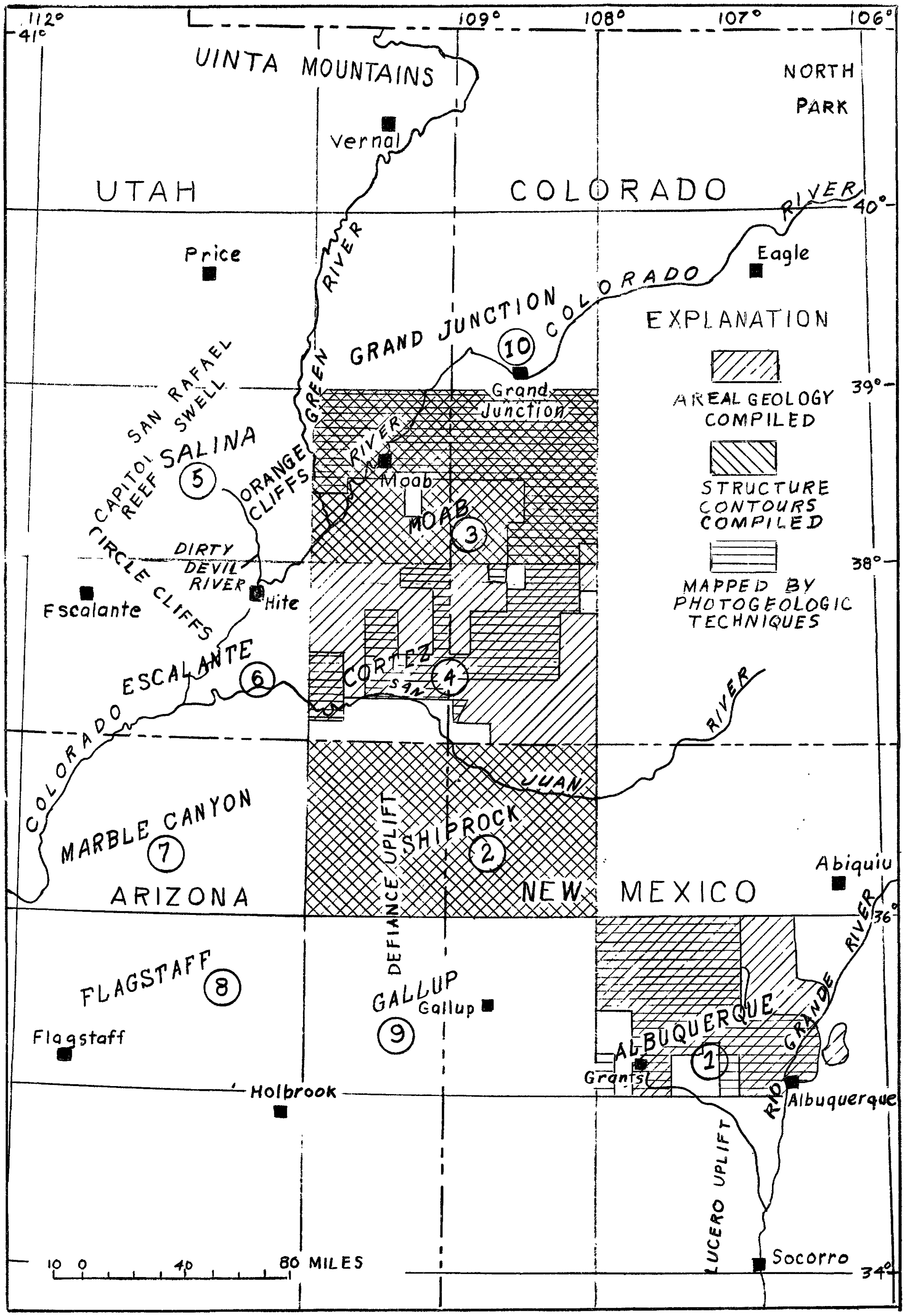


Fig. 3 --Index map showing tentative order of, and progress in, compilation of 2° sheets of the Colorado Plateau geologic maps.

been mapped during this report period. An additional area covering 1,850 square miles was recompiled for structural information in the Moab sheet. Three selected horizons in this area which had previously been compiled on Soil Conservation Service planimetric base maps were recompiled on the Army Map Service topographic base. In the preparation of the maps high altitude photographs were used in conjunction with the radial planimetric plotter and the Kelsh plotter.

During the report period photogeologic maps of four 7½-minute quadrangles in the Colorado Plateau were published in the Miscellaneous Geologic Investigations series. These were:

I-293	Hurricane Cliffs 2 NW quadrangle, Mohave County, Arizona, by J. S. Pomeroy
I-294	Notom 1 quadrangle, Wayne County, Utah, by W. R. Hemphill
I-295	Desert Lake 4 quadrangle, Emery and Carbon Counties, Utah by C. H. Marshall
I-201	Flat Top Mountain NE quadrangle, Carbon County, Wyoming, by A. B. Olson

GEOLOGIC TOPICAL STUDIES

General stratigraphic studies

by

L. C. Craig

Work on the Paleozoic and Cretaceous sedimentary rocks on the Colorado Plateau was recessed throughout this report period, which was spent in the preparation of a detailed report on the Morrison formation in the Colorado Plateau region. In September 1959, a typescript of 173 stratigraphic sections of the Morrison formation and adjacent beds was placed on open file in Washington, D. C., Denver, Colorado, and Salt Lake City, Utah.

San Rafael (Entrada) studies

by

J. C. Wright

Preparation of the final report on the stratigraphy of the San Rafael group was continued during this report period. A general summary of the group was given in TEI-740, p. 139-146, and special topics were reported in TEI-750, p. 59-65 and TEI-751, p. 61-66.

Lithologic studies

by

R. A. Cadigan

All preliminary synthesis of data was suspended during this report period as work was begun on the preparation of a detailed report on the petrology of sedimentary rocks of Triassic age of the Colorado Plateau region.

The following paper was published during the report period:

Stewart, John H., Williams, G. A., Albee, Howard F., and Raup, Omer B., 1959, Stratigraphy of Triassic and associated formations in part of the Colorado Plateau region: with a section on sedimentary petrology by Robert A. Cadigan: U. S. Geol. Survey Bull. 1046-Q, 90 p.

Ambrosia Lake area, New Mexico

by

H. C. Granger, E. S. Santos, B. G. Dean, and F. B. Moore

During the report period approximately 10 man months were spent in field work and the remainder in office and laboratory work. Each of the four geologists assigned to the project is responsible for determining the geology of two or more deposits in the district as well as for aiding in summarizing the geologic relationships of the district as a whole. The studies presently emphasize (1) regional and local structural and stratigraphic controls; (2) origin and emplacement of kerogen; (3) element distribution; and (4) petrography and mineralogy.

Kerogen studies

Kerogen (Forsman and Hunt, 1958) was described in the preceding semiannual report (TEI-751, p. 66-70) as an organic material that impregnates large volumes of the host rock in the Ambrosia Lake area and with which much of the uranium is associated. In its natural state the kerogen is relatively inert, being almost completely insoluble in organic solvents, strong acids, and strong bases. A series of experiments, in which the authors were aided by Irving Frost of the Geological Survey, has shown that partial oxidation of the Ambrosia Lake kerogen will convert at least some of it to a "humic-acid"-like material that is readily soluble in alkaline solutions and insoluble in acids. Our experiments show also that precipitation occurs under nearly neutral conditions in the presence of a strong eloctrolyte such as sodium chloride. These data indicate that the seemingly inert kerogen might readily be moved under natural conditions. Details of more complete experiments of a similar type involving organic matter in the Chattanooga shale are given by Kinney and Schwartz (1957).

Infra-red absorption characteristics of the kerogen and its partial oxidation products suggest a closer resemblance to coals than to petroleum products. These characteristics and other physical and chemical data, (I. A. Breger, written communication) are strong evidence that the kerogen is a coaly derivative from degrading plant material rather than a petroleum residue as has been widely supposed.

It is well known that during the peat stage of coalification much of the organic matter is soluble in water, particularly alkaline water. Subsequent to the peat stage the organic matter can be made soluble by oxidation. These facts suggest a mechanism by which the kerogen now present in the host rock may have been transported and precipitated through many successive cycles under natural conditions.

At present two general hypotheses concerning the source and localization of kerogen are being considered. These are described briefly below:

(1) For any stream flowing over permeable rock there must be a certain amount of underflow, and the dissolved solids in the underflow water must be a function of the composition of the stream water modified by the chemical

environment imposed by the permeable stream bed. Under certain conditions it is reasonable to infer that the margins of the underflow are marked by a fairly sharp interface with relatively stagnant groundwater. Assuming that some of the streams during Westwater Canyon and Poison Canyon (the host rocks) time carried a dissolved complement of humic acids derived from degrading vegetation somewhere upstream, the underflow would also contain humic acids. Assuming further that the composition of the stagnant (?) groundwater was such that it would cause the precipitation of humic acids, precipitation of these acids in the pores of the rock at the interface between the underflow and groundwater might be expected. Fluctuations of this interface, upward or downward, would tend respectively to preserve or to dissolve and redistribute the precipitate.

(2) There is evidence that the Dakota sandstone overlaps the Morrison formation on the Zuni uplift because of Early Cretaceous erosion (Rapaport, Hadfield, and Olson, 1952). The basal Dakota in much of this area is a black, fissile, carbonaceous, coal-bearing shale. During Cretaceous time, therefore, the exposed edge of the Morrison formation was overlain for a while by a highly vegetated, boggy terrain. Humic acids derived from degrading vegetal matter might conceivably have been washed down dip through the permeable Westwater Canyon member of the Morrison formation until they came in contact with saline waters that had accumulated in the aquifers of the San Juan Basin. At this point precipitation of the humic acid would occur. As in the previous hypothesis ((1) above) preservation of the humic precipitate would depend on fluctuations of the upper boundary of the saline groundwater.

It may be safely assumed that the humic acid precipitate would be an excellent accumulator of uranium and certain other metals. The original sources of the uranium and the time of introduction of the mineralizing solutions would be immaterial. They could have been the same solutions that carried the humic acids or any number of solutions introduced at later times. Natural changes or radiation from the uranium would tend to convert the humic precipitate to an insoluble form (Breger and Deul, written communication, 1955) and so preserve it against removal.

It remains now to test the hypotheses by field work and supporting laboratory studies. Either hypothesis could be the correct one but the second one may be more tenable because of the excellent humic acid source that was available during early Dakota deposition.

Ore varieties

At least three distinguishable varieties of unoxidized ore occur in the deposits. Two of these, which have been given the field names black ore and brown ore, are considered to be primary because of lack of evidence that they were preceded by earlier ore or have been redistributed. The third variety is obviously later, being controlled in part by joints and faults that cut the black and brown ore. It is here called purple-brown ore.

Black ore consists of black, coffinite-impregnated kerogen that forms thin films on sand grains and fills interstices. Sandstone containing this material usually contains enough uranium to make it of ore grade even though the coating on each sand grain may be almost vanishingly thin. The ore is commonly speckled with small white patches of interstitial kaolinite. Brown ore locally forms a border zone around black ore bodies.

Brown ore is similar to black ore in its occurrence and general appearance except that the color of the kerogen is brownish. The brown kerogen coats sand grains but rarely if ever fills interstices. As a rule the brown ore contains less organic matter than the black ore, but the color differences are not due entirely to this fact. As is the case with the black ore, the rock containing brown ore us usually speckled with kaolinite patches of various sizes.

The uranium in black ore occurs largely as coffinite disseminated in the kerogen. The uranium mineral in brown ore has not been identified but is assumed to be coffinite.

Both black and brown ores appear to be stratigraphically controlled. Faults invariably cut these ores and no evidence for a fault or joint control has been observed.

The black ore occurs typically in fine- to medium-grained sandstone whereas the brown ore occurs in medium- to coarse-grained sandstone. This, however, is by no means a hard-and-fast rule.

The purple-brown ore is a redistributed ore and the coloration is due very little, if at all, to organic matter. Each sand grain has an extremely thin coat of an unidentified brownish to purplish-brown material which imparts most of the color to the rock. There are, in addition, minute black acicular and columnar crystals perched singly or in aggregates on many of the sand grains; these locally impart a darker color to the rock. The crystals have been tentatively identified by X-ray powder pattern as paramontroseite and coffinite.

The range of hues and shades in purple-brown ore is considerable. The darkest ore is approximately brownish black and the palest is very light gray. In general, the darker the ore, the more pronounced is the purple cast and the higher the uranium and vanadium contents.

Purple-brown ore appears to be controlled by most of the stratigraphic features that control black and brown ore, as well as by faults and joints. In several deposits strongly jointed zones are favorable for purple-brown ore although the joints themselves are ordinarily vanadium-rich rather than uranium-rich. In some deposits it has been observed that purple brown ore layers thicken abruptly adjacent to faults. In some instances the ore does not appear to cross the fault. All large concentrations of purple-brown ore are in areas that have concentrations of joints or faults and all are adjacent to or near black ore layers that have been affected by oxidation. In a faulted area in the Kermac Sec. 22 mine, called the "stacked" ore body, purple-brown ore occurs sporadically throughout a vertical range of more than 100 feet. Individual bodies of purple-brown ore are commonly thicker than black or brown ore bodies, but do not have as great lateral extent.

Element distribution

A few significant results concerning element distribution in the ore have been obtained from the chemical and mineralogical data accumulated so far.

(1) Molybdenum is concentrated near concentrations of uranium but the two elements rarely occur in the same sample.

(2) Concentrations of molybdenum, as jordisite (?)-rich streaks along crossbedding and more massive impregnations, apparently mark the terminations of some ore bodies. The jordisite locally overlies, underlies, and "wraps around" the edges of the ore bodies.

(3) Selenium is most highly concentrated in deposits above the water table or in deposits that show evidence of oxidation below the water table.

(4) Selenium concentrations are common at the margin of ore bodies, particularly at the upper surface of an ore layer, but rarely in the middle of an ore layer.

(5) Native selenium is found most commonly in fractures within 2 feet of an interface between strongly oxidized (limonitic) and unoxidized (pyritic) sandstone.

(6) Vanadium is most strongly concentrated in deposits above the water table or in deposits that show evidence of oxidation below the water table.

The data are as yet too sparse to give accurate uranium-vanadium ratios but the U/V ratio definitely tends to be larger in black ore than in purple-brown ore.

(7) Vanadium minerals (montroseite and paramontroseite) are commonly localized in joints and fractures, but uranium minerals are rare in fractures except in the form of the highly oxidized tyuyamunite. Uranium is generally disseminated in the enclosing sandstone.

Mineralogy

The most interesting mineralogical development during the report period was the discovery of pitchblende in a fracture and vug at the Kermac Sec. 22 mine. This is the first reported occurrence of pitchblende or uraninite in the Ambrosia Lake district proper although it had been reported from some of the near-surface deposits in the Poison Canyon sandstone (Konigsmark, 1958).

The occurrence was reported by Dave Smouse, mine geologist, and was later sampled by H. C. Granger of the Survey. Identification was verified by X-ray powder pattern by E. J. Young of the Geological Survey. The fracture in which the pitchblende was found trends northwesterly and is on the 6450 level approximately 100 feet below the original water table. The pitchblende occurs largely as a jet black, botryoidal layer, 1 mm. thick, on the fracture and vug surfaces. Locally it is more massive. Syneresis cracks are abundant. The adjacent sandstone contains more than a normal amount of fine-grained disseminated pyrite and the interior of the vug is filled with coarse grained calcite.

It is presently believed that the pitchblende is much later than the original deposition of uranium. It is significant that the occurrence is in a deposit that has been extensively affected by oxidation and one that contains large amounts of purple-brown ore.

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Kinney, C. R., and Schwartz, Donald, 1957, Partial air oxidation of Chattanooga uraniferous black shale: Industrial and Engineering Chemistry, v. 49, no. 7, p. 1125-1130.

Konigsmark, T. A., 1958, Uranium deposits in the Morrison formation on the northeast flank of the Zuni uplift exclusive of Ambrosia Lake, New Mexico: U.S.A.E.C., RME-115.

Rapaport, Irving, Hadfield, J, P., and Olson, R. H., 1952, Jurassic rocks of the Zuni uplift, New Mexico: U.S.A.E.C., RMO-642.

Shirley Basin, Wyoming

by

E. N. Harshman

Field work in the Shirley Basin started in August 1959 and was suspended for the winter in November; it will be resumed in June 1960. Topographic maps of the area were not available for the 1959 field season and areal geologic mapping therefore was not attempted. Preliminary topography for the eastern half of the Basin will be available for the 1960 field season.

A preliminary paleogeological map of the pre-Wind River erosion surface has been prepared, using a reasonably accurate claim map and claim corners located in the field, for horizontal control. Elevations on the pre-Wind River surface were established by aneroid surveys and detailed logging of cuttings from approximately 700 holes drilled in a 200 square-mile area. This surface, on which the ore-bearing Wind River formation was deposited, is of moderate relief with a well-developed drainage pattern. It ranges in altitude from about 6400 feet to somewhat more than 7200 feet and lies from a few feet to more than 700 feet below the present ground surface.

Water samples were collected from springs in and on the margins of the Basin as well as from wells drilled for domestic use and for dewatering purposes in preparation for mining. Analyses for uranium and other elements are being made by the Geological Survey.

Water-level measurements were made in those drill holes not caved above the water table - about 400 of the 700 holes examined. A contour map of the ground water table will be prepared from these data.

Samples of core from two of the major ore bodies in the area were made available to the Survey for analysis and microscopic study. Preliminary analytical work indicates that the Shirley Basin ore contains only trace amounts of metals other than uranium. The uranium content of the ore-grade material (+ 0.10 percent U) may be as much as 20 percent higher than equivalent uranium determinations indicate.

GEOPHYSICAL INVESTIGATIONS

Regional geophysical studies of the Colorado Plateau

by

H. R. Joesting

Status of magnetic and gravity maps

Aeromagnetic maps of the Ute Mountains in Colorado, and of the Orange Cliffs, Mt. Ellen, and Factory Butte 15 minute quadrangles near the Henry Mountains in Utah, were compiled during the report period. Remaining to be compiled is the high-level aeromagnetic survey of the Henry Mountains.

The compiled maps are now ready to be adjusted to the AMS 2° maps of the central Colorado Plateau, which will be used as a base for the published maps. Parts of 7 AMS 2° maps are involved: Grand Junction, Moab, Salina, Cortez, Escalante, Shiprock, and Marble Canyon. (See index map, TEI-751, p. 74). All of the AMS maps are now available except the Grand Junction sheet, which is scheduled for publication in January 1960.

The regional gravity maps, which will cover a somewhat smaller area, are likewise nearly completed. Some terrain corrections which will be computed by use of the Survey's computer, and subsequent contouring, remain to be done in the Cortez quadrangle.

Field work

Regional gravity surveys were carried out in the summer of 1959 along the southern edge of the Colorado Plateau in New Mexico. The purpose of the surveys is to obtain information on regional geology, especially on the important Grants and Laguna uranium districts. Major structures involved are the Rio Grande depression and the adjacent Nacimiento and Sandia uplifts, the Mt. Taylor igneous centers, and the Zuni and Defiance uplifts. The region is of considerable geologic interest because it includes Basin and Range structural elements as well as Plateau structure; and the Rio Grande trough is a continuation of the San Luis and other structural troughs of the Rocky Mountains.

Work was started in the Rio Grande depression and continued westward along the southern edge of the Colorado Plateau to the Grants uranium district. Parts of the Zuni uplift and the Mt. Taylor lava fields were also covered, as well as parts of the Sandia Uplift, east of the Rio Grande depression (Figure 4).

Prior to the regional gravity survey about 5 days were spent establishing a calibration loop near Albuquerque and a gravity base net in west-central New Mexico and east-central Arizona. Using a light airplane, and a newly available La Coste-Romberg portable geodetic gravity meter with world-wide range and zero drift on loan from the Army Map Service, about 9 hours flying time was required to establish 21 base stations at accessible landing strips between Albuquerque, New Mexico and Holbrook, Arizona. These were supplemented by 35 other base stations, established by auto along main highways. In all, 56 base stations were established in 5 days, plus ties to Woollard's airport gravity bases in Albuquerque and at Holoman Air Force Base in New Mexico.

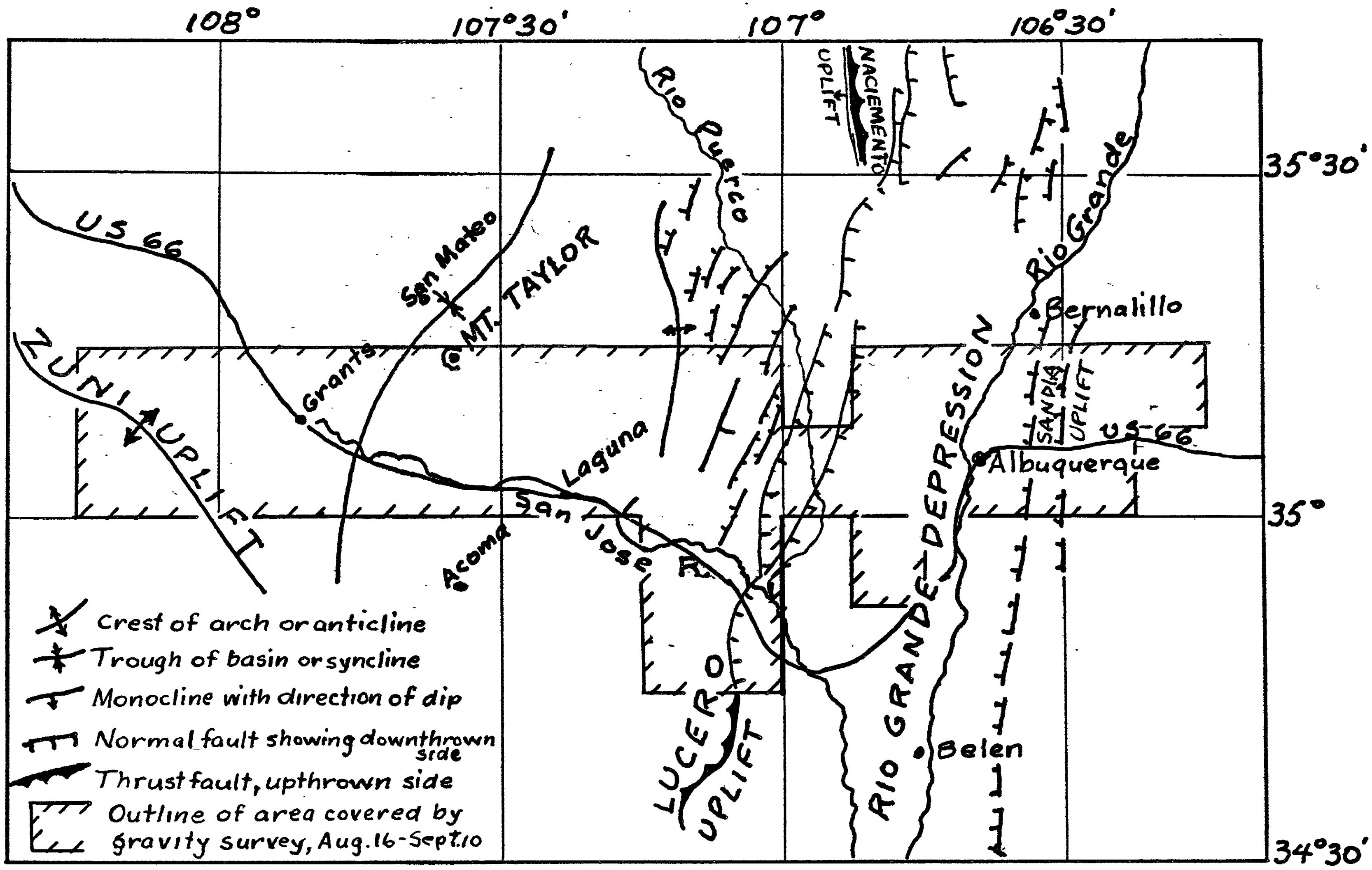


Fig. 4. Sketch showing some of major structures of Southern Colorado Plateau and adjoining regions, and area covered in 1959 by gravity survey

The La Coste-Romberg meter was mainly responsible for the rapid coverage, because its wide range and freedom from drift eliminated the need for re-setting, or for three-step looping. The use of a light plane also speeded the work.

About 3 weeks were then spent on conducting the regional gravity survey, with stations spaced at approximately 1-mile intervals along roads. Stations were located by use of $7\frac{1}{2}$-minute topographic maps and elevations were taken for the most part from bench marks and spot elevations.

A total of 685 gravity stations was established with a Worden meter in 22 days field work in twenty-nine $7\frac{1}{2}$-minute quadrangles, for an average of 31 stations a day. This is about twice the rate of the regional surveys farther north on the Colorado Plateau. The higher rate was a result mainly of the good elevation control (bench marks and spot elevations), so that altimetry was seldom required. For the most part, also, the less accessible areas were not surveyed, so that subsequent work will be somewhat slower on the average.

About 100 samples were collected during the field season for determination of densities and magnetic properties of the rocks involved. The samples include specimens of the Paleozoic limestones and clastic rocks of the region, of Tertiary and Quaternary volcanic rocks, and of Precambrian granite, gneiss and related rocks. The Mesozoic and Cenozoic sedimentary rocks have not yet been sampled. Oriented specimens were obtained from several horizons and at several localities of the San Jose lava flows near McCarty, New Mexico. As these flows are only a few hundred years old, the specimens may throw some light on reversals in remanent magnetization.

About 500 chips from the core of Anaconda Test Well No. 1, near Bluewater, New Mexico, were made available through the cooperation of R. D. Lynn, Resident Geologist of Anaconda, and S. W. West of the Albuquerque office of the Survey. The well was cored continuously from the base of the Chinle formation of Triassic age to about 600 feet into the gneissic basement, which was encountered at about 2,500 feet. As chips were taken at every change in lithology, it should be possible to obtain excellent information on densities of the pre-Mesozoic rocks near Bluewater.

A number of well logs and considerable information on ground water in the Rio Grande Valley were furnished by L. J. Bjorklund and B. W. Maxwell of the Albuquerque office. This information, together with density profiles, will aid in estimating the density of the alluvial Santa Fe formation, which may be more than 10,000 feet thick in the Rio Grande depression near Albuquerque.

Large gravity anomalies have been found associated with the Rio Grande depression; however, it may be difficult to obtain reliable estimates of the depth of the structure because the rock densities and contrasts in density are not well known. Aeromagnetic data, when available, may help resolve this difficulty, as it will then be feasible to make estimates of depths to magnetic rocks in the Precambrian basement.

Dip needle readings were taken over several basaltic and andesite lava fields near Mt. Taylor and in other localities. The readings indicate that although many of the flows are moderately magnetic, they will have only a small effect on aeromagnetic measurements made 1,000 feet or more above the surface, except over vents and plugs and possibly at the edge of flows. The gravimetric effects of the flows should likewise be small, as the flows are usually thin and their upper parts tend to be highly vesicular and hence of low density. As a consequence, the lava flows will probably not mask the magnetic and gravity effects of the underlying basement rocks.

Precambrian rocks exposed in the Sandia and Zuni uplifts consist largely of acidic and intermediate types, with only a small proportion of mafic rocks. If they are representative of the basement rocks in the whole region, the associated magnetic and gravity anomalies are likely to be comparatively small. On the other hand, relatively large effects are anticipated over the Rio Grande depression, where the alluvial Santa Fe formation is probably in fault contact with Precambrian rocks.

We are greatly indebted to the Albuquerque offices of the Survey for supplying considerable geologic information, as well as office space and other facilities. The permission of the Tribal Councils of the Acoma and Laguna Pueblos to conduct gravity and geologic investigations on tribal lands is also gratefully acknowledged.

Test drilling

Rocks of Mississippian age were penetrated at a depth of 7,544 feet (sea level elevation -971 feet) in a wildcat discovery well drilled by Pure Oil Company northeast of the Lisbon Valley salt anticline, San Juan County, Utah. The exact location is NE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 10 T. 30 S. R. 24 E. The well is scheduled to go to Cambrian rocks, which are estimated to lie 10,000 feet beneath the surface. This estimate agrees closely with an estimated depth of 10,000 feet to Precambrian rocks, made in the same locality from magnetic data, and reported in Professional Paper 316-C, "Regional geophysical studies in the Lisbon Valley area", by Byerly and Joesting which is scheduled for release late in November 1959

The following paper was published during the period:

Joesting, H. R., and Byerly, P. Edward, 1958, Regional geophysical investigations of the Uravan area, Colorado: U. S. Geol. Survey Prof. Paper 316-A.

Reports

A revision of the manuscript on the aeromagnetic and gravity surveys of the La Sal Mountains area, Utah, has been completed and a preliminary general report discussing the regional geologic implications of the aeromagnetic and gravity surveys of parts of the Moab and Cortez AMS 2° quadrangles of Colorado and Utah is now being reviewed. The area covered includes a large part of the Paradox Salt Basin and the bordering uplifts (Fig. 5).

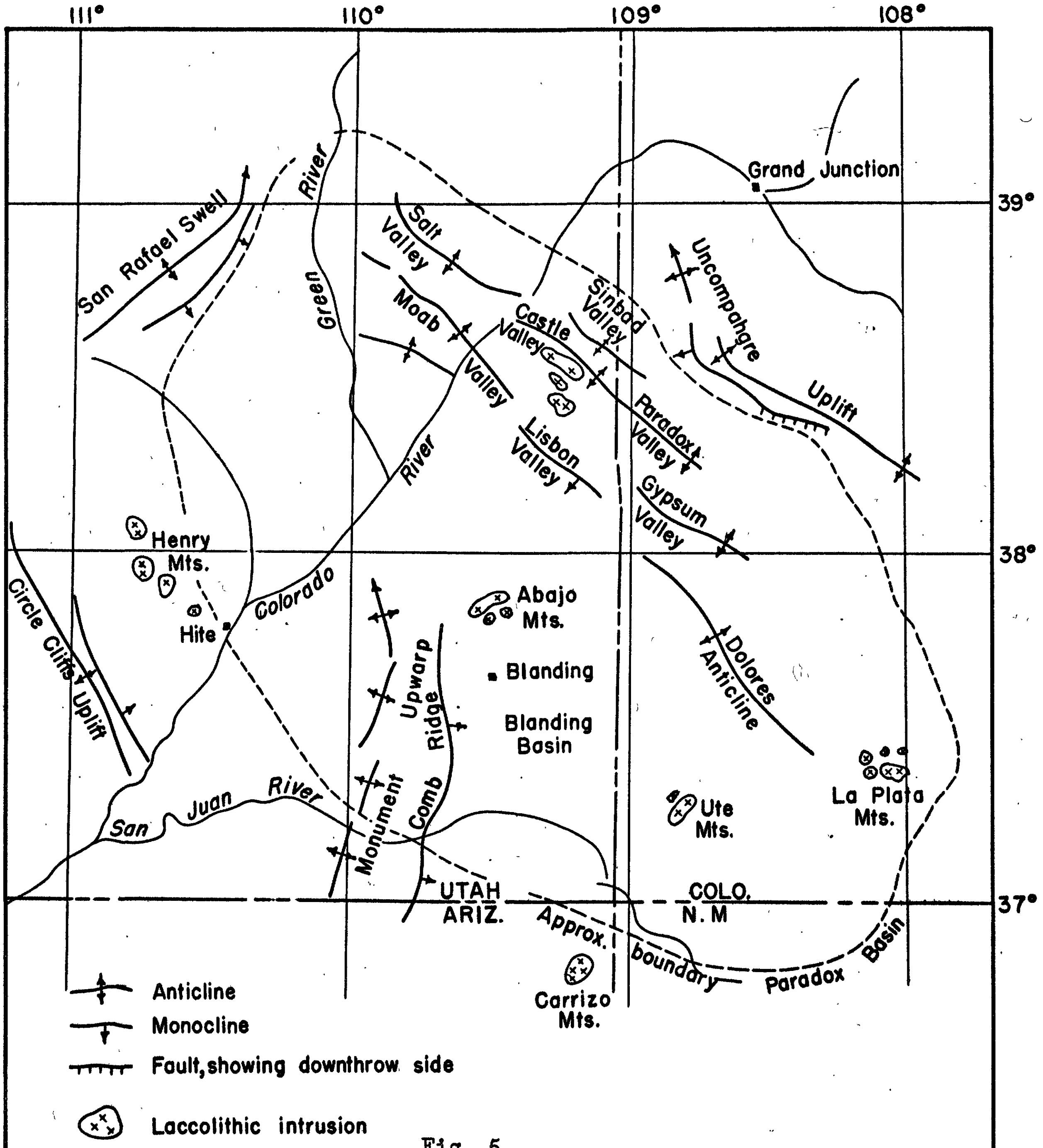


Fig. 5

SKETCH SHOWING SOME OF MAJOR STRUCTURES OF THE CENTRAL COLORADO PLATEAUS

The main conclusions in the general report and other reports prepared to date are:

(1) All of the larger geologic features, such as monoclinal uplifts, salt anticlines, laccolithic mountains, as well as regional structural trends, have associated magnetic and gravity effects.

(2) A number of regional magnetic and gravity trends, indicative of structural and compositional trends in the Precambrian basement rocks, cross the surface structural trends. The cross trends are related to pre-Permian and perhaps to much older structures and lithologies.

(3) The ancestral Uncompahgre highland and the adjoining basin on the southwest (the basin is part of the Paradox Fold and Fault Belt of Kelley), may have existed in Precambrian time. This interpretation is based on geophysical evidence of a considerable thickness of Precambrian metasedimentary rocks in the basin, and a complex of crystalline rocks in the uplift. The Uncompahgre structural front is the dividing line between the two provinces.

(4) Northwest of the Utah-Colorado border the Uncompahgre Uplift plunges under gently folded Cretaceous rocks, but the pre-Cretaceous structure continued northwestward to the Uinta Basin.

(5) The deepest part of the Paradox Basin lies immediately southwest of the Uncompahgre structural front, about coincident with the Sager's Wash and Nucla synclines.

(6) The salt cores of Paradox and Sinbad anticlines have amplitudes of about 10,000 feet. The cores of the Gypsum Valley, Moab Valley and Salt Valley anticlines are of comparable amplitude, whereas those of Lisbon and Fisher Valleys and the Pine Ridge salt anticline are smaller.

(7) Basement structural trends coincide with and probably controlled the position of the larger salt anticlines. North and South Mountains of the La Sal group were intruded along two of these structural trends and probably were similarly controlled.

(8) A basement shelf and in some areas a basement ridge with no apparent surface expression bounds the area of large salt anticlines on the southwest and the Blanding Basin on the west. The shelf, which is somewhat complex in outline, is intermediate in depth between the Monument Upwarp and the deeper basins. In a broad way it could be considered a northward and eastward extension of an ancestral Monument Upwarp. Evidence that the Precambrian basement under the shelf is considerably shallower than might be anticipated from stratigraphic evidence is based on gravity trends, and on magnetic anomalies indicative of comparatively shallow sources to magnetic rocks, which are assumed to lie at the surface of the basement.

(9) Regional structural trends cross the main axis of Monument Upwarp and the adjoining Blanding Basin. They are mostly Permian or pre-Permian in age, as they are in general not evident in the Permian and younger rocks; thus they are older than the present uplift and basin. In two parts of Blanding Basin there is evidence of an anomalously shallow basement.

Geophysical Studies in Uranium Geology

by

R. M. Hazlewood

During this report period a backlog of gravity stations from the northern Black Hills of Wyoming and South Dakota were reduced and compiled on a base map at a scale of 1:125,000. A Bouguer anomaly map with a 1 milligal contour interval was completed for the area covered thus far.

Preliminary interpretation indicates that the major gravity features of the northern Black Hills are a series of gravity highs and lows which trend parallel to the eastern flank of the Black Hills uplift; a gravity high which trends approximately N. 30° west through the east-central part of the uplift and is associated with a series of amphibolite dikes; and a small gravity anomaly associated with a dome west of Bear Butte laccolith.

During September an additional 150 gravity stations were occupied and three base stations were set in the northern Black Hills of Wyoming. Reduction and the interpretation of these data are in progress. Preliminary inspection shows a steep gravity gradient along the western flank of the northern Black Hills which correlates well with the known geology.

During the next six months the compilation and interpretation of gravity data of the northern Black Hills will be continued. Field work will be started in this area in early spring.

Texas Coastal Plain Geophysical and Geological Studies

by
Alice Weeks and D. H. Eargle

Exploration for determining the extent, thickness and grade of the uranium ore on Palangana Dome, Duval County, Texas, has been continued during the summer by Susquehana-Western, Inc. Several cores from the ore zone have been examined by the writers and, as an initial phase of working out the geologic history of the dome, a geologic profile from the surface outcrop of the principal ore-bearing zone as shown by Sayre (1937), the base of the Goliad sand of Pliocene age, to the dome has been prepared (figure 6).

Approximate elevations of 13 core holes, drilled by Columbia-Southern Chemical Corporation in 1956 off the dome in exploring for uranium, were determined by altimeter. The complete cores of the two off-dome holes that were available have been examined and compared with holes on the dome (Eargle, Weeks and Moxham, 1959), and electric logs of the holes have been correlated.

The section (figure 6) shows that the base of the Goliad dips southeastward at the rate of about 40 feet per mile, whereas the surface profile slopes at an average rate of about 25 feet per mile. Across the dome, however, the dip flattens to almost horizontal, but steepens sharply on the downdip side. The Goliad sand overlaps in a gentle unconformity the Lagarto clay at Miocene age and the Oakville sand, and in western Duval County it rests on the Catahoula tuff of probable lower Miocene age.

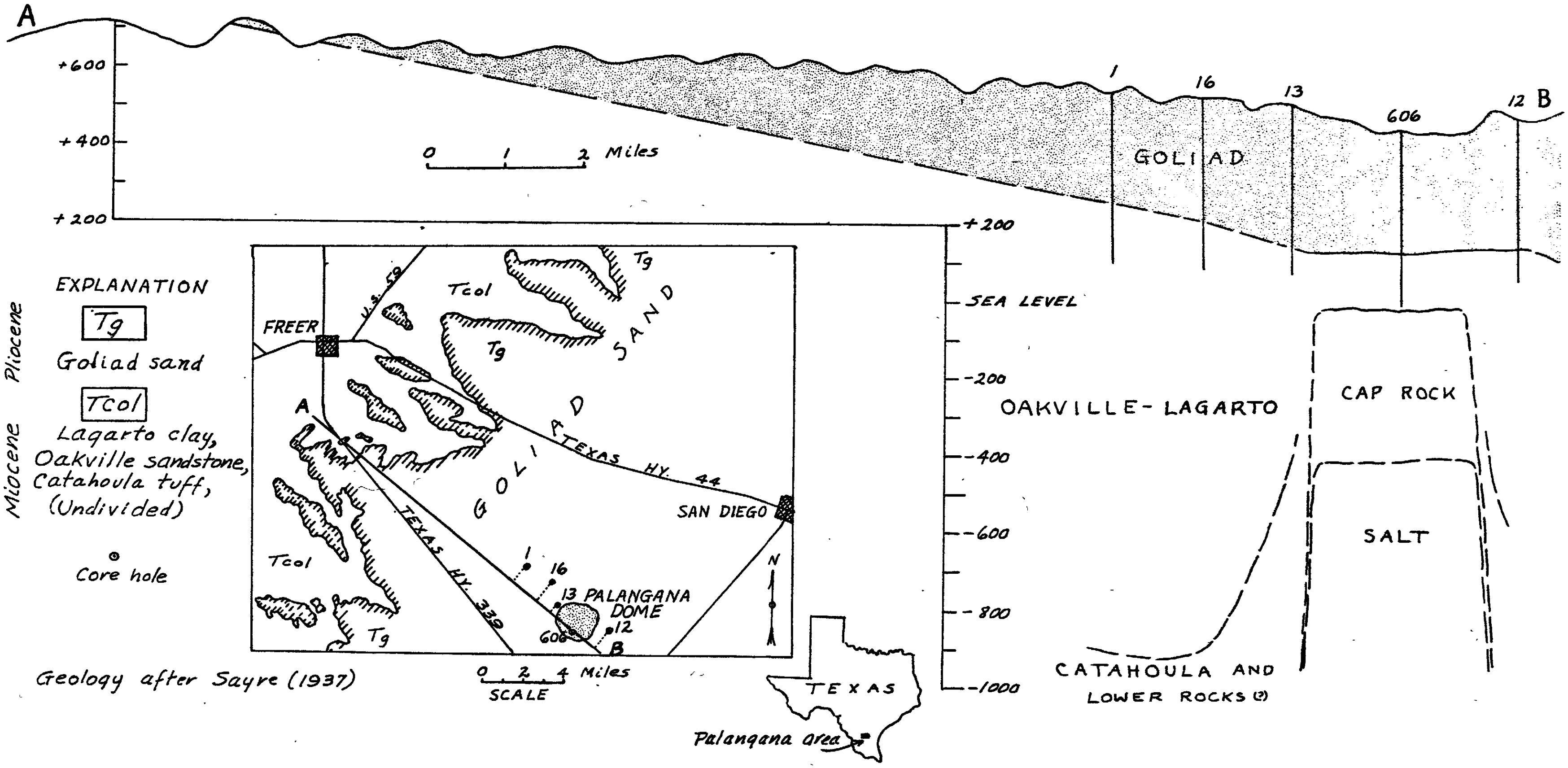


Fig. 6-SECTION SHOWING RELATION OF GOLIAD SAND TO PALANGANA DOME, DUVAL COUNTY, TEXAS

No igneous intrusions are known in Duval County, but the Tertiary sediments contain large quantities of volcanic detritus, and the Catahoula in particular is composed almost entirely of volcanic material which was described by Bailey (1926) as chiefly andesite, trachyandesite, and soda trachyte. The nearest intrusions are the Uvalde plugs about 120 miles to the northwest along the Balcones fault zone. It is generally supposed, however, that the Uvalde plugs are a less likely source of the Catahoula than the igneous rocks of the Big Bend country 300 miles to the northwest. Recent work by Gottfried (see Distribution of uranium and thorium in igneous rocks, p. 0 this volume) has shown that the alkaline rocks of the Big Bend country are higher in uranium than average igneous rocks.

A vertical suite of samples through the ore zone in the prospect mine at Palangana is being studied in detail. Semiquantitative spectrographic analyses show that the ore sandstone is highly calcareous and contains uranium and traces of molybdenum and vanadium. The concentration factors over average sandstone are several hundred for uranium, about 75 for molybdenum, and about 5 for vanadium. Although the molybdenum and vanadium concentrations are much lower than that of uranium, it is interesting to note the presence of these elements which commonly accompany uranium in the Colorado Plateau. According to Garrels et al. (1957) uranium, molybdenum, and vanadium can all be transported in mildly reducing, moderately alkaline solutions. These three elements together with iron

Figure 7.--Fe,U,Mo, and V CONTENT OF SUITE OF SAMPLES PALANGANA DOME, DUVAL COUNTY, TEXAS

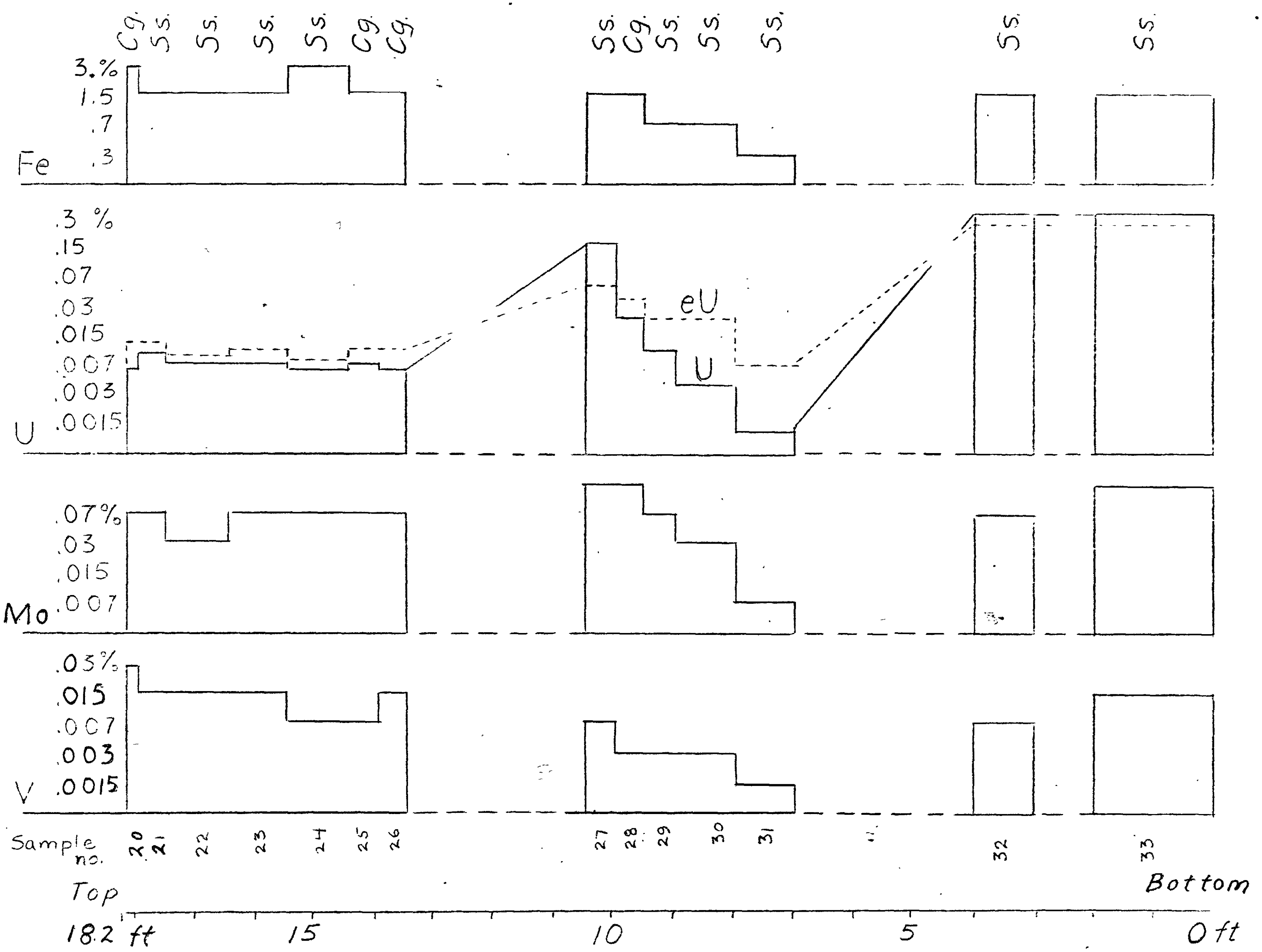
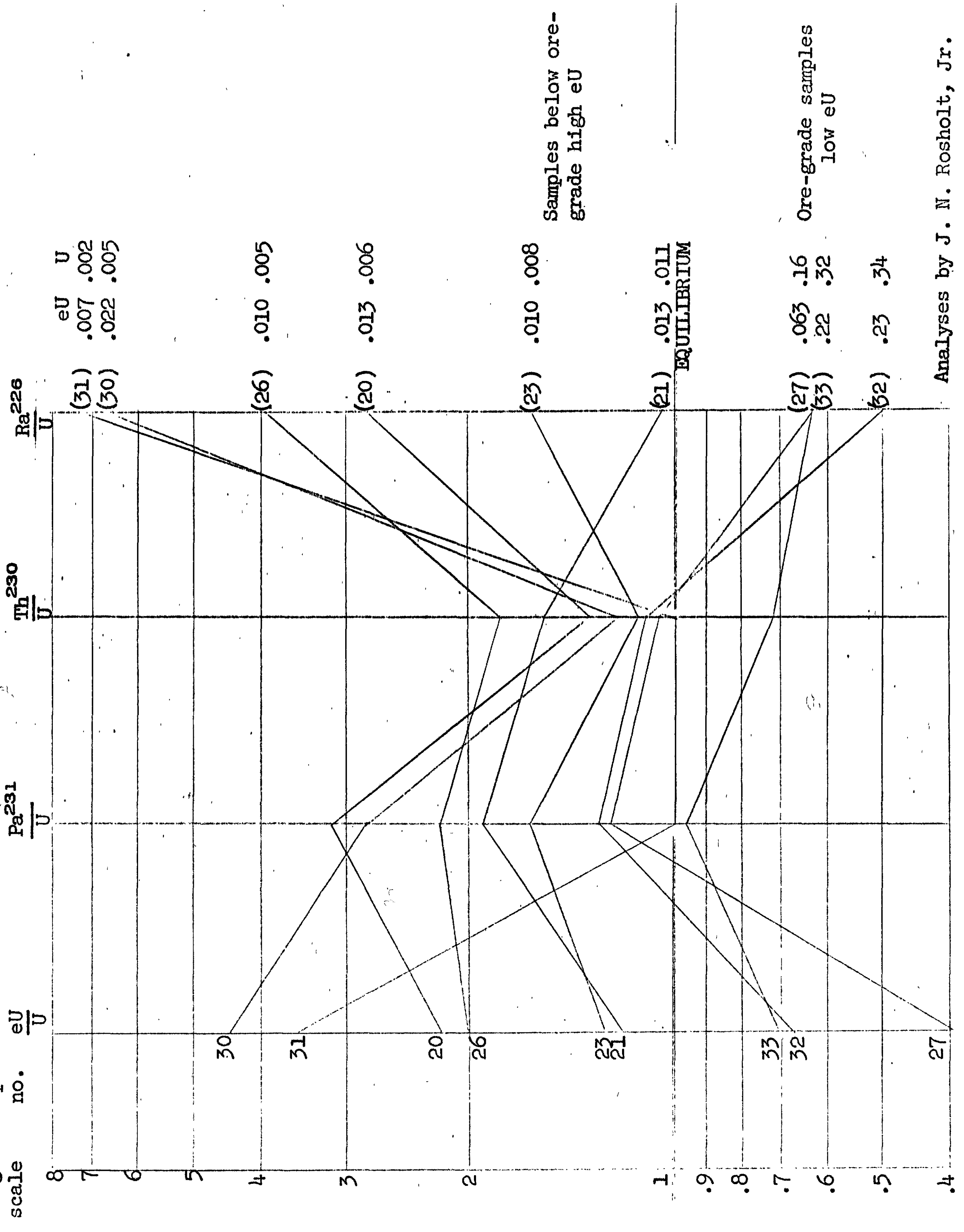


Figure 8.--RATIOS OF URANIUM DAUGHTER PRODUCTS SHOWING RADIOACTIVE DISEQUILIBRIUM



are all redox active elements, and would be precipitated in the reducing environment of H_2S gas. Iron in these samples is chiefly in pyrite and the correlation of iron with the other redox active elements is shown in figure 7. The carbonate content in this ore zone is high, ranging from 17 to 37 percent. The highest carbonate content **is** in the only firmly cemented sandstone, at 12 feet in the suite (fig. 7) where uranium-vanadium-molybdenum and iron are lowest. The spectrographic analyses also show strontium, yttrium, and scandium to be above the average for sandstone as given by Green (1959).

The equivalent uranium content in this suite of samples varies considerably from the uranium content. The samples were analyzed radiochemically by J. R. Rosholt, Jr. of the Survey to determine the nature of the disequilibrium. If the uranium and its daughter products were in perfect equilibrium all the ratios would be one and would be shown by a straight line (see fig. 8). The three samples of ore grade in this suite gave a low radioactive count and all the samples that are below ore-grade gave a high radioactive count. The diagram shows that radium is quite variable in these samples but it is not known as yet whether radium was added to or uranium was extracted from a particular sample. It is obvious that migration is actively taking place and that in spite of moderately reducing conditions produced by the H_2S, the uranium is not very firmly fixed.

It is postulated that uranium was leached by alkaline carbonate water from the volcanic detritus in the Catahoula and possibly other Tertiary sediments to the northwest of Palangana. Some uranium remained in the caliche deposits at the surface outcrops of the Catahoula, and some of the uranyl carbonate in solution migrated downdip in permeable beds confined by the less permeable Lagarto clay or other clay beds until it reached the reducing environment above the salt dome. The precipitated uranium is very fine-grained and disseminated. Fluctuations in the water table, the volume and salinity of the water, and the amount of H_2S affect the precipitation and migration of the uranium. Thus the deposit is very young and probably is still in the process of formation or modification.

A paper on the "Deposition of uranium at Palangana salt dome, Duval County, Texas" by A. D. Weeks and D. H. Eargle was presented at G. S. A. meetings in Pittsburgh, Pa. in November, 1959.

A paper on the "Role of diagenesis in sandstone-type uranium deposits" by A. D. Weeks presented at the Geological Society of Washington Nov. 11, 1959 stressed the importance and interrelation of many diagenetic processes in the uranium deposits of the Tertiary rocks of the Texas Coastal Plain, and suggested that many of these processes may have been important in the early history of the Colorado Plateau uranium deposits. Diagenesis is important in the host rocks of the sandstone-type deposits because they are chiefly arkosic or tuffaceous sandstone, representing alluvial plains, basin fill, coastal plains or lacustrine deposits. These sediments are very highly reactive silicates in the sedimentary environment compared to sediments with end-products of weathering such as quartz sand, illitic clays, and carbonates. With the right climatic and ground water conditions, tuffaceous sediments can develop an alkaline carbonate pore water, a sort-of-built-in-solvent for uranium, molybdenum, vanadium or copper. The migration of these solutions, the nature of the various precipitants for the ore elements, and the subsequent geologic history of each region produce some variety of deposits.

References

Eargle, D. H., Weeks, Alice D., and Moxham, R. M., 1959, Geologic and geophysical studies, coastal plain area, Texas: in Geologic investigations of radioactive deposits, Semiannual Progress Report for December 1, 1958 to May 31, 1959. U. S. Geol. Survey TEI 751, pp. 81-88.

Garrels, R. M., Hostetler, P. B., Christ, C. L., and Weeks, A. D., 1957, Stability of uranium, vanadium, copper, and molybdenum minerals in natural waters at low temperatures and pressures; (abs.) Geol. Soc. Amer. Bull. v. 68, p. 1732.

Green, Jack, 1959, Geochemical table of the elements for 1959: Geol. Soc. Amer. Bull. v. 70, pp. 1127-1184.

Sayre, A. N., 1937, Geology and ground-water resources of Duval County, Texas: U. S. Geol. Survey WSP 776, 116 pages.

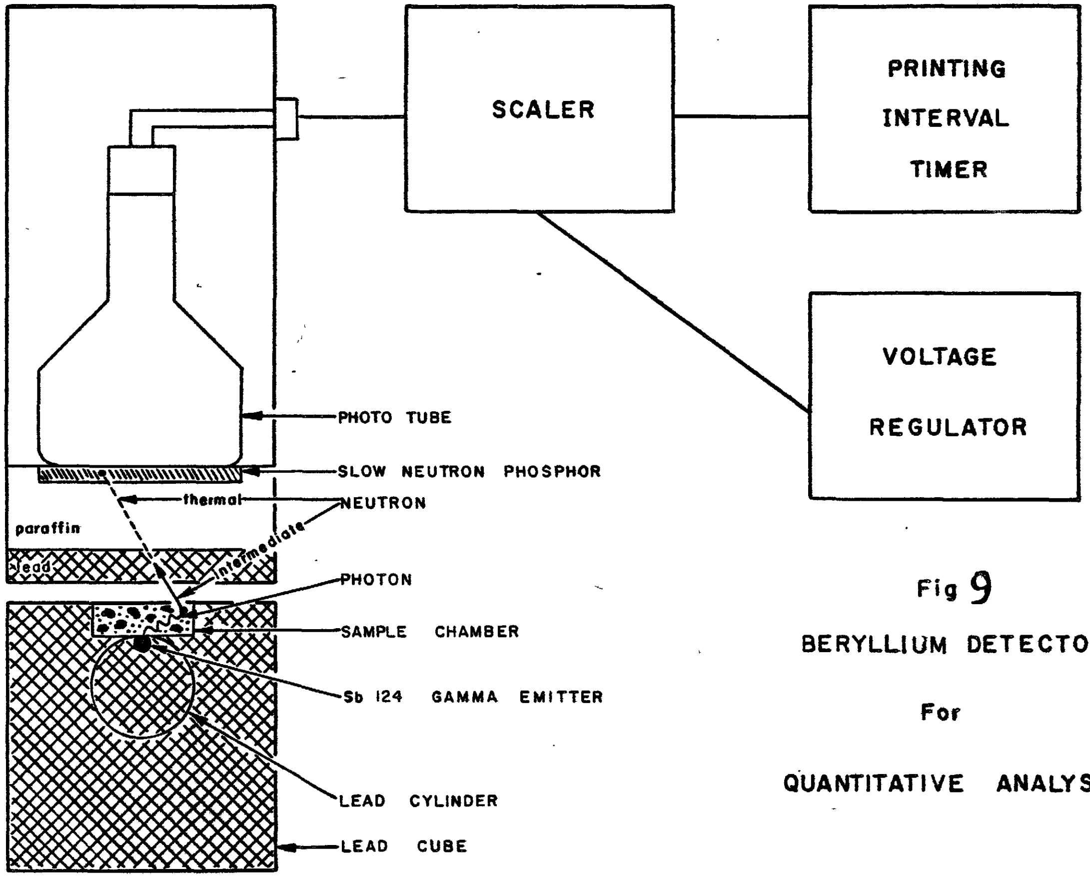


Fig 9
BERYLLIUM DETECTOR
For
QUANTITATIVE ANALYSIS

Electronics laboratory
by
W. W. Vaughn

A second beryllium detector based on that described in TEI-751, p. 88-89, was constructed during the report period for quantitative determination of the beryllium content of mineral samples (see fig. 9). Standards were prepared and a calibration curve (fig. 10) established. The instrument was tested for approximately two weeks near the Boomer mine in the Lake George district, Colorado with highly satisfactory results. The sample preparation time is about two minutes and the analysis period is five minutes.

An automatic multi-timing device, (fig. 11) the "Unitrol Decatimer", was constructed for use in oxygen isotope ratio studies. The device is highly flexible and provides a means by which one to ten timers are started and stopped either simultaneously or individually with a 0.1 second accuracy for each channel. The accumulative time period is 10,000 seconds.

High voltage, low voltage, and regulator circuits (fig. 12) for a DC magnet to be used in laboratory magnetic studies have been redesigned. The changes were necessary to swing the current in the magnet load (7,000 ohms) uniformly from 0 to 350 milliamperes. Construction has been completed and the instrument works satisfactorily. It is possible that there may be some residual magnetization in the magnet which will

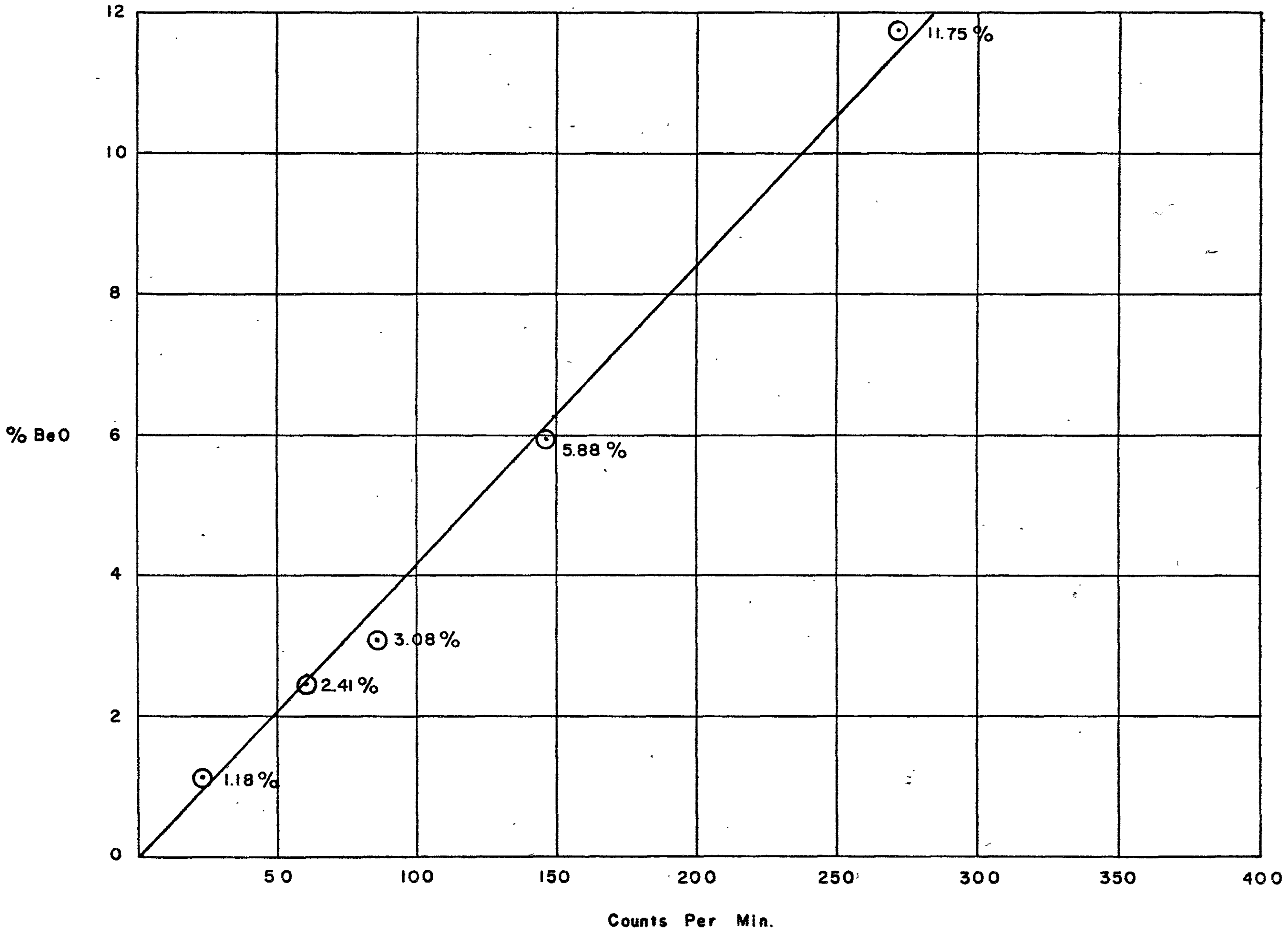


Fig 10 - CALIBRATION CURVE for BERYLLIUM DETECTOR be troublesome in the demagnetization runs. If this occurs and is eliminated electronically, the instrument will be further modified or a method of bucking the original current to get a neutral field will be supplied.

As a result of a recent test run on pressure-induced thermoluminescence glow curves, and of the revived interest in pressure systems in rock in general, the thermoluminescence equipment has been modified by the use of aluminum oxide ceramic (85% Al_2O_3) sample holders. Considerable assistance has been given members of the Survey who are concerned with evaluating thermoluminescence and its possible application to pressure considerations in nature.

Instrumentation for the study of infrared-phosphorescence decay in minerals, mentioned in the last Semiannual Report (TEI-751, p. 131-133) was constructed and tested during this report period (See Infrared and ultraviolet radiation studies, p.118, this volume).

A method has been devised for making small containers for various types of sample materials. Acetate plastic sheet, .020 inch thick, is heated to approximately 100° Centigrade and placed over a form from which the air is drawn through small holes. The plastic material, while still pliable, is drawn down quickly and conforms exactly to the shape of the mold. By inverting the mold a second container which serves as a top to the first molding can be made. An ordinary vacuum cleaner provides sufficient vacuum for this purpose; all that is needed is the plastic sheet,

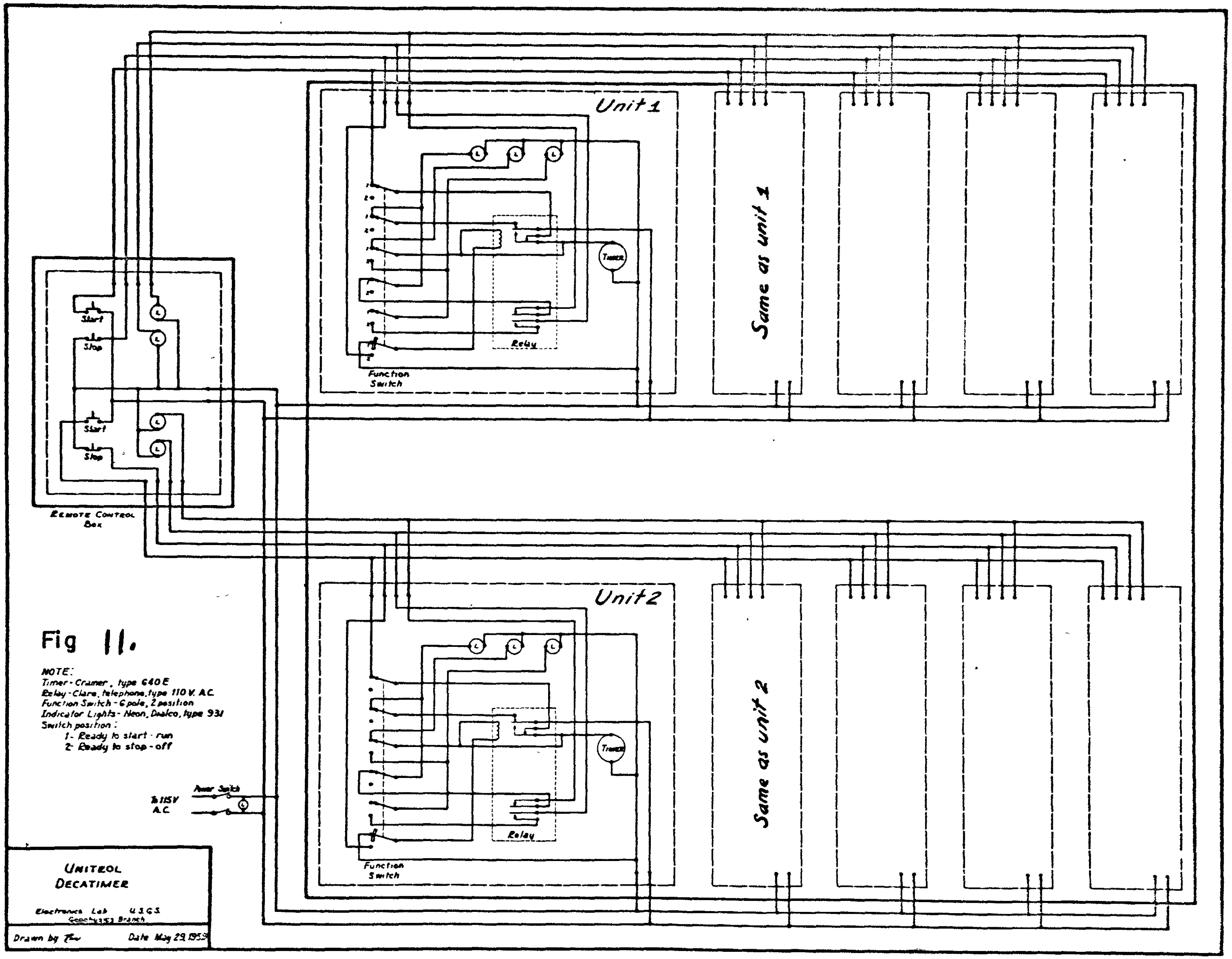


Fig 11.

NOTE:
Timer - Cramer, type 640 E
Relay - Clare, telephone, type 110 V. A.C.
Function Switch - 6 pole, 2 position
Indicator Lights - Neon, Dialco, type 931
Switch position:
1- Ready to start - run
2- Ready to stop - off

UNITROL
DECATIMER

Electronics Lab U.S.G.S.
Geophysics Branch

Drawn by Tan Date May 29 1953

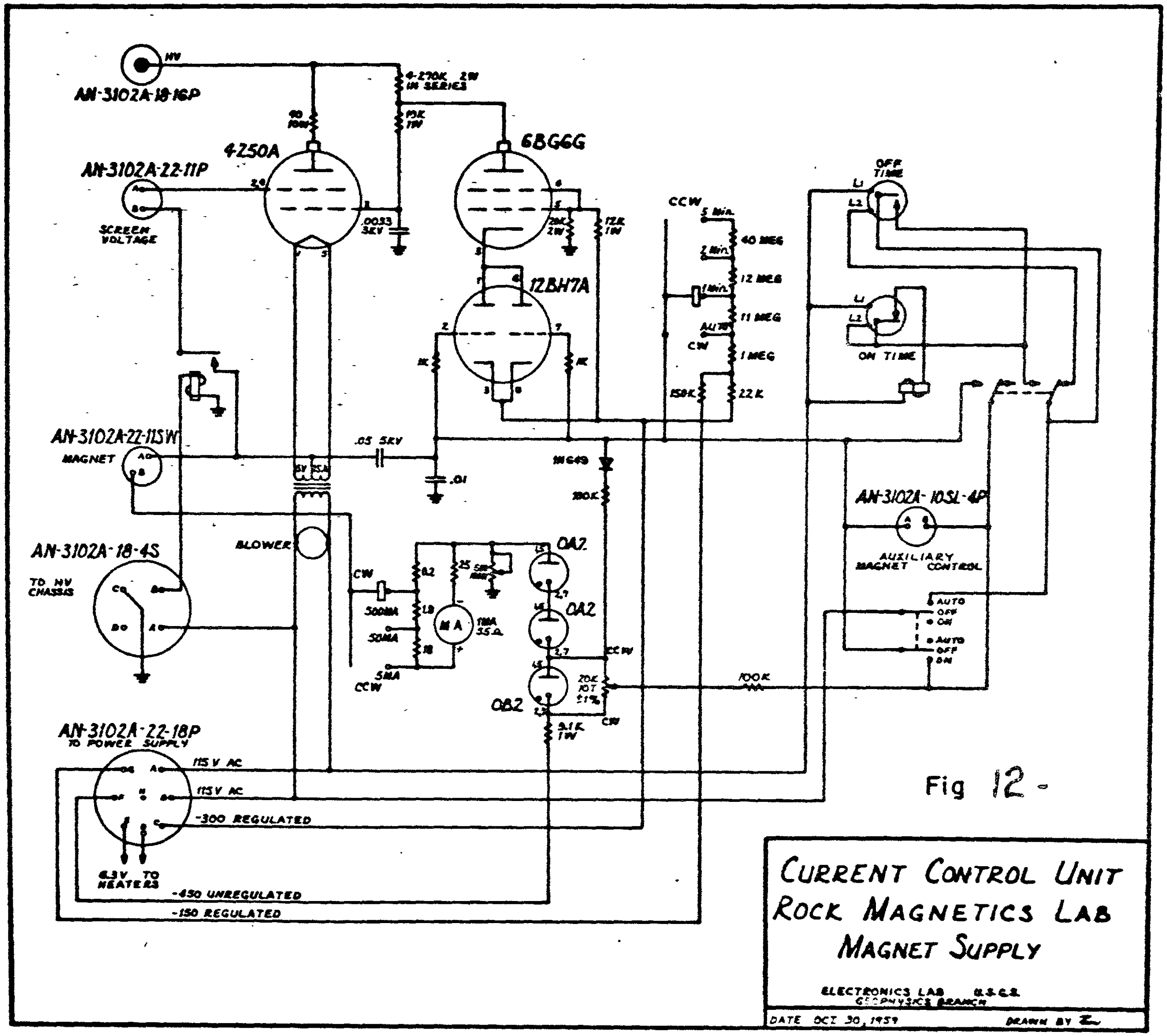


Fig 12-

CURRENT CONTROL UNIT
ROCK MAGNETICS LAB
MAGNET SUPPLY

ELECTRONICS LAB U.S.C.&G.S.
GEOPHYSICS BRANCH

DATE OCT 30, 1959 DRAWN BY

a method of heating (infrared lights or a small furnace), the mold, and a vacuum device. The total cost, in quantity, for a box 3 inches in diameter and 3/4 inch deep is 3 cents.

Several instruments for use in the national cancer research program have been constructed or are now being made. Among these are a radon collection system for an average sample of radon gas in the 1- to 6-foot interval above ground level; modified carborne scintillation counters for radiometric traverses; and condenser chambers for the freeze-out method of concentrating radon.

An apparatus for measuring the thermal conductivity of core samples was constructed for the Physical Properties Laboratory.

In view of the increased demands on the operation and application of photomultiplier tubes, a test procedure has been devised and put into operation whereby the relative sensitivity and plateau characteristics of each tube can be determined. A curve for each tube in stock is being prepared. In addition, a thermal noise factor for each run is recorded. These tests will make possible the proper replacement and availability of photomultiplier tubes to fit particular applications.

RESEARCH PROGRAMS

Physical Behavior of Radon

by

Allan B. Tanner

Condensation of radon from atmospheric air

Apparatus designed for condensation of radon from atmospheric air (TEI-751, p. 95-97) was tested during the report period but was abandoned because of operating difficulties. The emanation condensing chamber, designed to be immersed in a bath of liquid nitrogen, was so effective in removing heat from the air passing through it that oxygen and argon were condensed as fast as they could be blown into the inlet tube of the chamber. The heat transfer efficiency was cut down by encasing the chamber in a paraffin cylinder having a wall thickness of about 5/8 inch; by this means the temperature of the condensing chamber could be controlled in the range between the boiling point of oxygen, -183°C., and the condensation point of radon, -150°C. (Rutherford, 1909). Further experiments yielded the anomalous results that although radon was quantitatively removed from air when some liquid oxygen was present in the condensing chamber, there was little or no retention of radon when no oxygen was condensed in the chamber. It was discovered later that Wertenstein (1935) had found that radon is separated from mixtures of gases at liquid air temperatures by a complex process of adsorption and containment by liquid oxygen, rather than by condensation. Although the condensation method is suitable for laboratory use, where the amount of oxygen condensing can be controlled accurately, it is not believed to be suitable for field use.

Tape recording of radioactive events

Magnetic tape recording of pulses from a scintillation counter was investigated as a means of preserving as much information as possible about radioactive events that cannot be duplicated by repeating an experiment. Examples of experimental situations where such records would be of value are the measurement of radioactivity of natural gas produced from a gas well during the first day of production after a long shut-down period, of radioactivity of carrier gases passing through rock containing accumulations of radon, and of radioactivity that leads to such contamination of the detection apparatus that repetition of an experiment is impracticable because of a long period required to let the contamination reduce itself by radioactive decay.

A major difficulty in the use of the alpha scintillation flow counter (see TEI-700, p. 244) has been that the rapid change of counting rate has made optimum adjustment of the sensitivity of the counting rate meter difficult. Repetitions of the experiments have not been feasible. It has been found practicable to record changes of the high voltage on the photomultiplier of the alpha scintillation flow counter by interposing a 0.01-microfarad capacitor between the high voltage lead and the high impedance input lead of a magnetic tape recorder. Calibrated voltage and timing pulses should also be inserted in the recording. Once a tape recording has been obtained of the radioactive events, they may be reviewed by playing the tape record through a scaler, a counting rate meter, or both, depending on the range of counting rate observed during the period recorded. It is also possible to review the record through an oscilloscope to verify the absence of electronic noise and spurious pulses.

The recorder used thus far does not reproduce the scintillation pulses with fidelity sufficient for pulse height analysis. However, it is suggested that the use of a very high fidelity tape recorder and a suitable single-channel analyzer might be more satisfactory and cheaper than the use of a multi-channel analyzer, especially in field applications.

Montana earthquake

The area near West Yellowstone, Montana, was visited shortly after the earthquake of August 17, 1959 in order to determine whether radon measurements would be of assistance in the interpretation of events there.

Six spring or well water sources lying along a 9-mile east-west line of surface displacement northeast of Hebgen Lake were sampled. The radon concentrations in the water increased regularly from 340 μμc/liter at the west end to 2,000 μμc/liter at the east end. Whether this increase is related to the faulting or is a natural result of an increase of radium concentration in the ground in an easterly direction is not yet known, but should be determinable to repeat sampling and analysis.

Water samples were taken from seven of a series of earthquake-caused seeps and springs along a half mile of road at Horse Butte, on the eastern side of Hebgen Lake. A ten-fold anomaly in radon concentration was found in the samples, which were taken within an hour of each other. A ten-fold increase was also found in the radon concentration from one particular point when it was sampled and then resampled 26 hours later. Observed variations in the radon concentration and temperature of the water bore no apparent relation to each other, but suggested that the results would be quite dependent on time and on processes, such as aeration, that would tend to confuse the measurements made.

Relation between natural radioactivity and cancer

Gentry, Parkhurst, and Bulin (1959) demonstrated a greater rate of incidence of congenital malformations in areas of above-normal radioactivity from natural sources, particularly from water supplies, in upstate New York. Because congenital malformations and cancer may have similar causes, increased attention is being paid to the radioactivity of water samples in an area being investigated by the National Cancer Institute to determine relations between environmental radioactivity and cancer. During the report period, two weeks were spent in advising on the conduct of the cancer study program with respect to the sampling and analysis of natural media, particularly drinking water, for radon. Geologic environments and water supply system types tending to result in above-average radon concentrations in drinking water were named. It was also pointed out that if the study should show higher cancer incidence rates for persons drinking water of above-average radon content, an effective and simple remedy could be found in the aeration of water by means of the common type of faucet aerator. Other radio-nuclides found to be of significance could be removed by ion exchange resins such as are used in some home water softeners.

The following paper was published during the period:

Tanner, A. B., 1959, Meteorological influence on radon concentration in drill holes: Mining Engineering, 11, p. 706-708; and Am. Inst. Mining Metall. Engineers Trans., 214.

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Gentry, J. T., Parkhurst, Elizabeth, and Bulin, G. V., Jr., 1959, An epidemiological study of congenital malformations in New York State: Am. Jour. Public Health, 49, 497-513.

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

Wertenstein, L., 1935, Vapour pressure and condensation of radon at low temperatures: Royal Soc. Proc. A150, 395-410.

Geology and geochemistry of Thorium

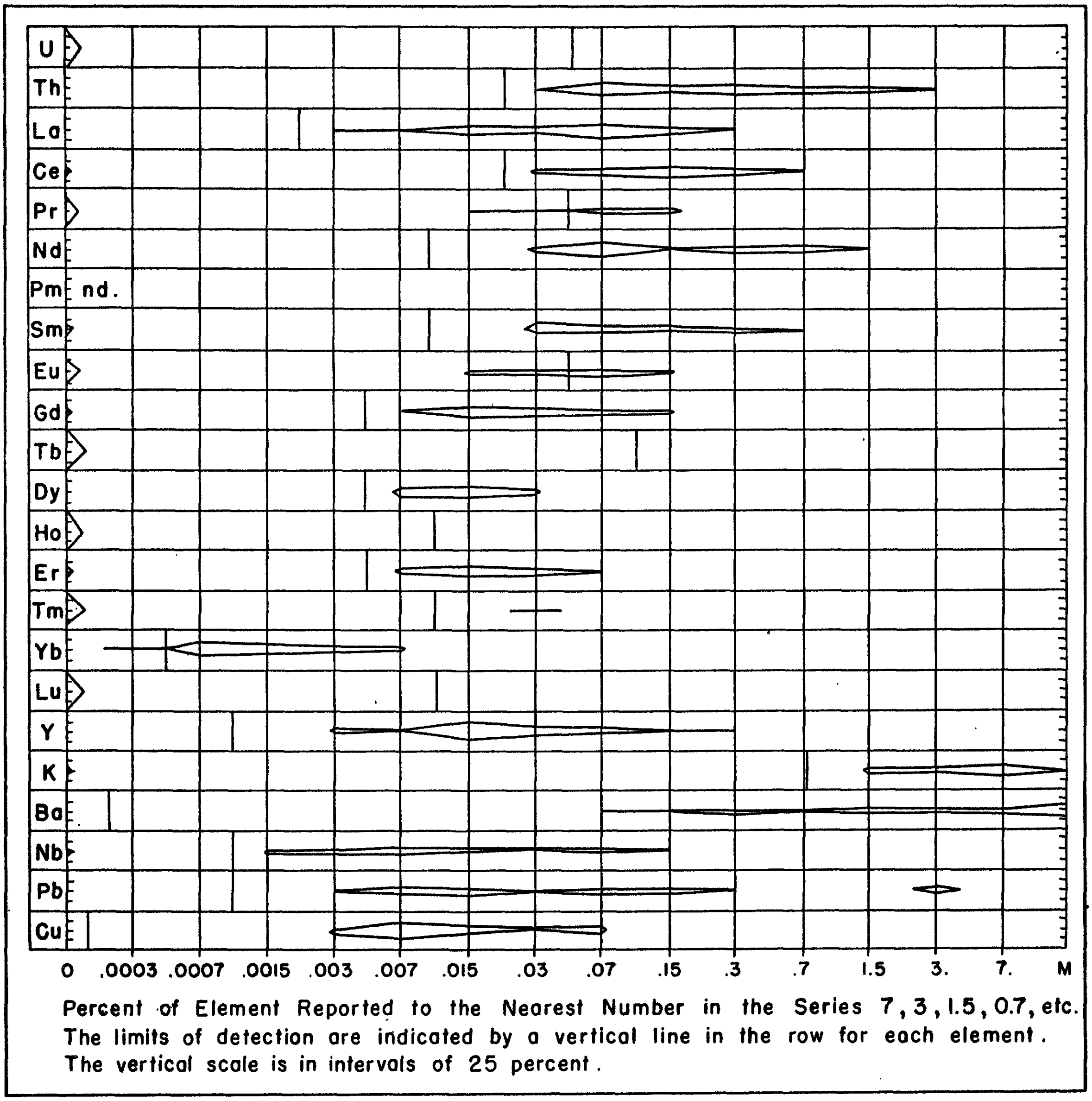
Thorium in veins, Gunnison County, Colorado

by
D. C. Hedlund and J. C. Olson

Geologic mapping of the Gateview and Cebolla quadrangles was completed at the end of the 1959 field season, and mapping was extended into the northwest corner of the Uncompahgre 1 SE quadrangle. The general geology and descriptions of thorium deposits of the Gateview and parts of the Cebolla quadrangle have been presented in TEI-640, p. 323-325; TEI-690, p. 568-569; TEI-700, p. 280-282; TEI-740, p. 311-313; and TEI-750, p. 136-138.

About 103 radioactive localities are known in the Gateview quadrangle; 48 of these have radioactivities greater than 0.1 mr/hr (background 0.01-0.02 mr/hr). Only 16 thorium-bearing veins have been found in the Cebolla quadrangle; 3 of these have radioactivities greater than 0.10 mr/hr. Of the 16 radioactive deposits known in the Cebolla quadrangle, 8 are in the 3-square-mile Wolf Creek area in which 9 small intrusive bodies of syenite and shonkinite have been mapped. From this area the number of thorium-bearing veins decreases northward to the Gunnison River. This regional distribution accords with a probable genetic relation to the syenitic and other alkalic rocks of the Powderhorn district.

The thorium-bearing minerals have been identified by X-ray diffraction. The unheated vein material has an X-ray pattern that indicates



Percent of Element Reported to the Nearest Number in the Series 7, 3, 1.5, 0.7, etc. The limits of detection are indicated by a vertical line in the row for each element. The vertical scale is in intervals of 25 percent.

FIGURE 13— A GRAPHICAL REPRESENTATION OF THE SEMI-QUANTITATIVE SPECTROGRAPHIC ANALYSES OF MATERIAL FROM 20 THORIUM VEINS IN THE POWDERHORN DISTRICT.

the presence of both thorogummite and thorite. The heated material shows strong reflections for thorite. In addition to the thorite and thorogummite, the veins contain orthoclase, specular and earthy hematite, barite, calcite, purple fluorite, and minor amounts of galena, pyrite, chalcopyrite, and sphalerite. Most of the veins are highly oxidized. Jasper, goethite, and earthy hematite are common weathering products. Orthoclase and biotite have formed in the wall rocks adjacent to many thorite veins.

Semiquantitative spectrographic analyses of samples from 20 thorium veins from various parts of the Powderhorn district are summarized in figure 13. The analytical data illustrate that there is a general decrease in quantity of rare earths with increasing atomic number from cerium to ytterbium and that the rare earths of odd atomic number are less abundant than those of even atomic number (Odds-Harkins Rule). Barium and potassium are relatively abundant, reflecting the content of barite and orthoclase in the veins. Small amounts of niobium are present, but it has not been ascertained which mineral contains the niobium.

Three plug-like bodies of intrusive breccia have been discovered during the mapping of the Cebolla quadrangle. The largest body is elliptical in general plan and is about 2900 feet long and 800 feet wide. The intrusive breccia consists of angular fragments of diverse Precambrian rocks set in a light-gray or light-green lamprophyric groundmass. Parts of these bodies of intrusive breccia have radioactivities of 2 to 3 times background.

Thorium Deposits in the Wet Mountains, Custer and Fremont Counties, Colorado

by

George Phair and Frances Gilbert

Field studies of the "veins" that cut the Precambrian rocks of the Wet Mountains, Custer and Fremont Counties, Colorado, began in 1957. Additional field work was resumed in July 1959 and continued for 5 weeks. Whereas previous field work had been directed toward the mineralogy of the thorium deposits, especially those of high grade, work done during the past summer stressed mineralogy and wall rock alteration associated with high and low grade deposits alike. As in many such studies more can be learned about the ore-forming processes from the varied low to moderate grade ores than from the mineralogically monotonous high grade ores. The associated "porphyry" dikes were specially investigated to determine the extent to which separate members ranging in composition from diabase through intermediate types to rhyolite and lamprophyre may be correlated with the somewhat similar sequence of surface flows and dikes in the Rosita-Silver Cliff District. The latter are immediately to the west of the Wet Mountains and are dated as Tertiary on the basis of plant fossils. During the past summer it was possible to date some of the dikes in the Wet Mountains area on the basis of one or more of the following criteria: 1) potassic wall rock alteration; 2) sodic wall rock alteration; and 3) barite veinlets. It is hoped that the geological age of the sequence can be established. In so doing the porphyries will be used as fixed points in a time table on which to pin point major episodes in the mineralization. The results should help to resolve the question of Tertiary versus Precambrian age for the mineralization. Isotopic Th/Pb age determinations upon the vein "thorites" so far have yielded more or less equivocal results.

A new and important development of the past summer was the recognition of the sodic pyroxene, acmite, as the chief product of sodic wall rock alteration in and around three carbonate deposits. According to the "hydrothermal" laboratory studies of Ernst (1957) magnesioriebeckite gives way to acmite as P_{H_2O} drops below 300 bars but at, and only at, the highest oxygen pressures used (magnetite-hematite buffer). These results go far toward explaining the formation of acmite instead of the more abundant magnesioriebeckite which outlines the zones of sodic alteration elsewhere in the same area. Additional facts, however, must also be considered:

1) The acmite alteration seems to be restricted to the walls of carbonate veins, and to be largely absent from the typical barite-quartz veins. This suggests that a pH control may also have been involved.

2) The magnesioriebeckite requires a source of MgO not found in the alkalic granite gneiss which it replaces. It is therefore significant that it characteristically develops within the granite gneiss along a band intermediate between the zone of maximum potassic feldspathization comprising the mineralized parts of the veins and outcrops of MgO-rich hornblende metagabbro and diabase porphyry.

The laboratory results of Julian Hemley of the Survey (personal communication, 1959) help to explain the potassic-sodic zoning about many of the ore deposits and at the same time give empirical justification to the inference that the same solutions are capable of *leaching* albite and at the same time of *depositing* potash feldspar. All that is required is a proper adjustment of the $\frac{\text{alkali}}{\text{H}}$ ratio (a measure of pH). With increasing temperature and/or pH, clay minerals give way to micas and micas to potash feldspar. Although Hemley's results are not yet completed, it now appears that the stability field of albite does not extend to as low a pH as does that of potash feldspar; hence an interval of intermediate pH exists over which potash feldspar but not albite is stable. Additional laboratory confirmation of these stability relations have been obtained by R. O. Fournier and G. W. Morey of the Survey (personal communication, 1959) in their studies of the alteration effects of hot water on perthites.

The replacement of large volumes of albite by equivalent volumes of potash feldspar requires only a substitution of K for Na_2, the Al remaining largely unaffected. This gives rise to solutions relatively high in Na_2O and low in Al_2O_3--conditions pre-requisite for the formation of sodic amphiboles and sodic pyroxenes. Such solutions migrating outward and upwards from the potassic cores of the veins are believed to have given rise to the outer sodic zones. More rarely as in the main acmite locality a later sodic alteration has replaced earlier potassium-rich microcline along a multitude of close spaced parallel fractures. Whether such a paragenesis results from a change in temperature, a change in pH or both is not known at present.

Reference

Ernst, W. G., 1957, Alkali amphiboles, in Annual Report Geophysical Laboratory, Carnegie Foundation of Washington, 1956-57, p. 228.

Distribution of Uranium and Thorium in Igneous Rocks

by

David Gottfried and E. S. Larsen, 3d.

During this report period uranium and thorium analyses were made on igneous rocks representing a wide variety of petrographic provinces. These include suites of basalts from the Hawaiian Islands; diabase-granophyre rocks from Virginia; the calc-alkalic series from the Medicine Lake highlands, the calcic series of Lassen Volanic Natural Park; the alkalic hypabyssal and extrusive rocks from Big Bend National Park and igneous rocks from the calc-alkalic Sierra Nevada and Idaho batholiths.

Hawaiian Islands

Uranium and thorium analyses were made on 35 samples of volcanic rocks believed to be fairly representative of the major rock types of the Hawaiian Islands. Olivine basalts are the predominant rock type and according to MacDonald (1949) represent the parent magma of the Hawaiian petrographic province. Powers (1955) points out that the Hawaiian olivine basalt magma is not silica deficient but is saturated with respect to silica. He suggests that the name "olivine basalt" not be applied to the magma as it suggests a magma undersaturated with silica.

The undersaturated rocks occur in considerably smaller amounts than the ordinary Hawaiian basalts and were formed during the declining stages of activity at some of the volcanoes.

Tilley (1950) showed that the ordinary basalts from the Hawaiian Islands are similar chemically to great basaltic provinces on the continents, such as the Triassic basalts from New Jersey, the Karoo dolerites, and the Deccan basalts of India.

All of the samples analyzed for uranium and thorium were made available by Howard Powers of the USGS and include samples studied by him and other workers. A chemical analysis is available for each of the samples. Table 1 lists the uranium and thorium analyses of basalts from the Koolau series of Oahu. These contain larger amounts of silica than most Hawaiian basalts. The samples are the same as those described by Wentworth and Winchell (1947). They average about 0.3 ppm uranium, 0.8 ppm thorium and have a thorium to uranium ratio of 2.6.

Table 1.--Uranium and thorium in rocks from Koolau volcano, Oahu, Hawaii

Sample No.	U(ppm)	Th(ppm)	Th/U ratio
10398	.30	.53	1.8
10404	.54	.98	1.8
9980	.30	.81	2.7
9986	.32	.61	1.9
9948	.27	.55	2.1
10396	.27	.83	3.1
11320	.27	1.2	4.5
Average	.32	.79	2.6

The data for the samples of lavas from Mauna Loa and Kilauea are given in tables 2 and 3, respectively. These samples are mostly olivine basalts. The uranium and thorium content of the samples from Mauna Loa are exceedingly uniform. They average 0.25 ppm uranium and 0.8 ppm thorium; the thorium to uranium ratio is 3.2. The samples from Kilauea also show strong uniformity in their uranium and thorium content and have nearly the same average uranium and thorium content as the samples from Mauna Loa. The average thorium to uranium ratio for the Kilauea samples is 3.1.

Table 2.--Uranium and thorium in rocks from Mauna Loa, Hawaii

Sample No.	U(ppm)	Th(ppm)	Th/U ratio
53-P-24	.25	.90	3.6
53-P-27	.28	.63	2.3
53-P-37	.28	.90	3.2
53-P-25	.24	.98	4.1
53-P-22	.21	.79	3.8
53-P-36	.23	.63	2.8
478	.26	.74	2.8
Average	.25	.80	3.2

Table 3.--Uranium and thorium in rocks from Kilauea, Hawaii

Sample No.	U(ppm)	Th(ppm)	Th/U ratio
479	.28	.84	3.0
477	.40	1.4	3.5
53-P-33	.36	.93	2.6
53-P-32	.33	1.1	3.4
P-475	.40	1.4	3.5
53-P-35	.35	.86	2.5
53-P-30	.34	1.1	3.3
53-P-12	.28	.87	3.2
53-P-9	.41	1.2	2.9
Average	.35	1.1	3.1

The samples analyzed in tables 4 and 5 are from the lavas erupted during the late, declining stage of volcanic activity which form a thin veneer over the earlier extrusives. The volume of the late-stage volcanics is insignificant as compared to the volume of the earlier formed basalts. The Honolulu basalts overlie the Koolau basalts on the island of Oahu and are separated from them by long erosion interval. They are low in silica (36-45 percent) and have a relatively high alkali content. Petrographic studies show them to be nepheline basalt, nepheline basanite and nepheline-melilite basalts (Winchell, 1947). Their average uranium (1.8 ppm) and thorium (5.4 ppm) content is higher than for any other series of volcanics from the Hawaiian Islands. The average thorium to uranium ratio, 3.1, is similar to the average for the Mauna Loa and Kilauea samples.

Table 4.--Uranium and thorium in rocks from the Honolulu series, Oahu

Sample No.	U(ppm)	Th(ppm)	Th/U ratio
9960	3.2	10.4	3.3
10402,	.98	2.9	3.0
9962	1.2	2.5	2.3
9982	.58	2.7	4.7
10400	2.4	7.1	3.0
9961	2.1	5.5	2.6
10399	2.4	6.9	2.9
Average	1.8	5.4	3.0

Table 5.--Uranium and thorium in rocks from Mauna Kea, Kohala, Hualali, and Haleakala

Sample No.	Rock type	Location	U(ppm)	Th(ppm)	Th/U ratio
473	Andesite	Mauna Kea	1.3	3.6	2.8
Ol-And	"	Kohala	1.2	5.3	4.3
444	Olivine basalt	"	.49	1.3	2.7
53-P-19	" "	Haualalai	.41	1.4	3.4
Pic-bas	Picrite basalt	Haleakala	.45	2.0	4.3
Average of 2 andesites			1.3	4.5	3.5
Average of 3 basalts			.45	1.6	3.6

Table 5 lists the uranium and thorium data for five other samples from "late" eruptions. The two andesites contain more uranium and thorium than any of the older olivine basalts. The three "late" basalts from Kohala and Hualalai on Hawaii and Haleakala on Maui contain a little over 0.4 ppm uranium and 1.6 ppm thorium, which are a little higher than the average contents of the ordinary basalts. The average thorium to uranium ratios of the two andesites is 3.5 and for the olivine basalts 3.6. More samples from these late eruptions are needed, however, before any firm conclusions can be drawn.

Fairfax County, Virginia

Twenty samples of igneous rocks from the diabase-granophyre sequence in Fairfax County, Virginia were analyzed for thorium during the report period. Uranium analyses of the same rocks were reported in TEI-751, p. 106-108. In the absence of chemical data, the rocks are grouped in three catagories based on petrographic data; (1) typical diabase, which consists essentially of monoclinic pyroxene and labradorite; (2) an intermediate phase containing amphibole, less calcic plagioclase and small amounts of quartz; (3) granophyric rocks consisting of albitic plagioclase, amphibole and quartz.

The uranium and thorium data are summarized in table 6. Uranium and thorium show nearly a five-fold enrichment in the granophyric rocks compared with typical diabase. The average thorium-uranium ratios are approximately the same for each of the rock types; 4.3 for the diabase, 3.9 for the intermediate rocks, and 4.0 for the granophyric rocks.

Table 6.--Uranium and thorium content of diabase-granophyre rocks[1] from Fairfax, Virginia

Rock type	No. of samples	Uranium range	Uranium average	Thorium range	Thorium average	Th/U ratio[2]
Typical diabase	11	0.2-0.7	0.5	0.8-3.1	2.1	4.3
Intermediate phase	5	0.8-2.0	1.4	2.6-8.5	5.4	3.9
Granophyric	4	1.9-3.3	2.5	8.2-13.1	9.6	4.0

[1] Samples supplied by E. Chao, U. S. Geological Survey

[2] These data are the averages of individual thorium/uranium ratios; not the ratio of the average uranium and average thorium content

Medicine Lake Highland, California

The Medicine Lake Highland is located approximately in the center of the Modoc lava bed quadrangle. The lavas which make up the highland represent a well-differentiated series from basalt to rhyolite. Uranium analyses on some of the older volcanics and on other samples from the Medicine Lake Highland were reported previously in TEI-740, p. 282-283 and TEI-750, p. 108-110. The samples analyzed for uranium and thorium for this report are parts of the same material studied by Anderson (1941). Chemical analyses are available for each specimen and the relation between chemical composition and uranium and thorium content is shown in table 7 and on fig. 14. Both uranium and thorium are present in greater amounts in the more siliceous rocks than in the mafic rocks. One sample of basalt (ML 295) is extremely low in uranium, containing about 0.1 ppm, and has a thorium to uranium ratio of 14. The thorium to uranium ratios in the two other basalts are 2.2 and 2.5. The rhyolites have thorium to uranium ratios from 2.7 to 3.9. Except for one basalt with the thorium to uranium ratio of 14, there appears to be a small average increase in the thorium to uranium ratios from basalt to the rhyolites. Repeat analyses on the basalt with the unusually high thorium to uranium ratio suggest that the cause of the apparently anomalous condition is not in the analytical data. It is likely that some uranium was removed from this sample by some geologic event.

Table 7.--Uranium and thorium in volcanic rocks of the Medicine Lake Highland, California

Sample No.	Rock type	Position (1/3 $SiO_2 + K_2O - CaO - FeO - MgO$)	U(ppm)	Th(ppm)	Th/U ratio
ML 295	Basalt	-13.4	.1	1.4	14
ML 61	Basalt	-2.5	.98	2.2	2.2
MF 46	Basalt	-0.5	2.0	5.0	2.5
ML 332	Andesite	+3.4	1.6	3.9	2.4
ML 56	Dacite	+14.5	4.4	10.8	2.5
ML 32	Rhyolite	+23.7	5.4	14.7	2.7
ML 105	Rhyolite	+23.8	4.9	14.1	2.9
ML 45	Rhyolite	+24.4	5.2	15.5	3.0

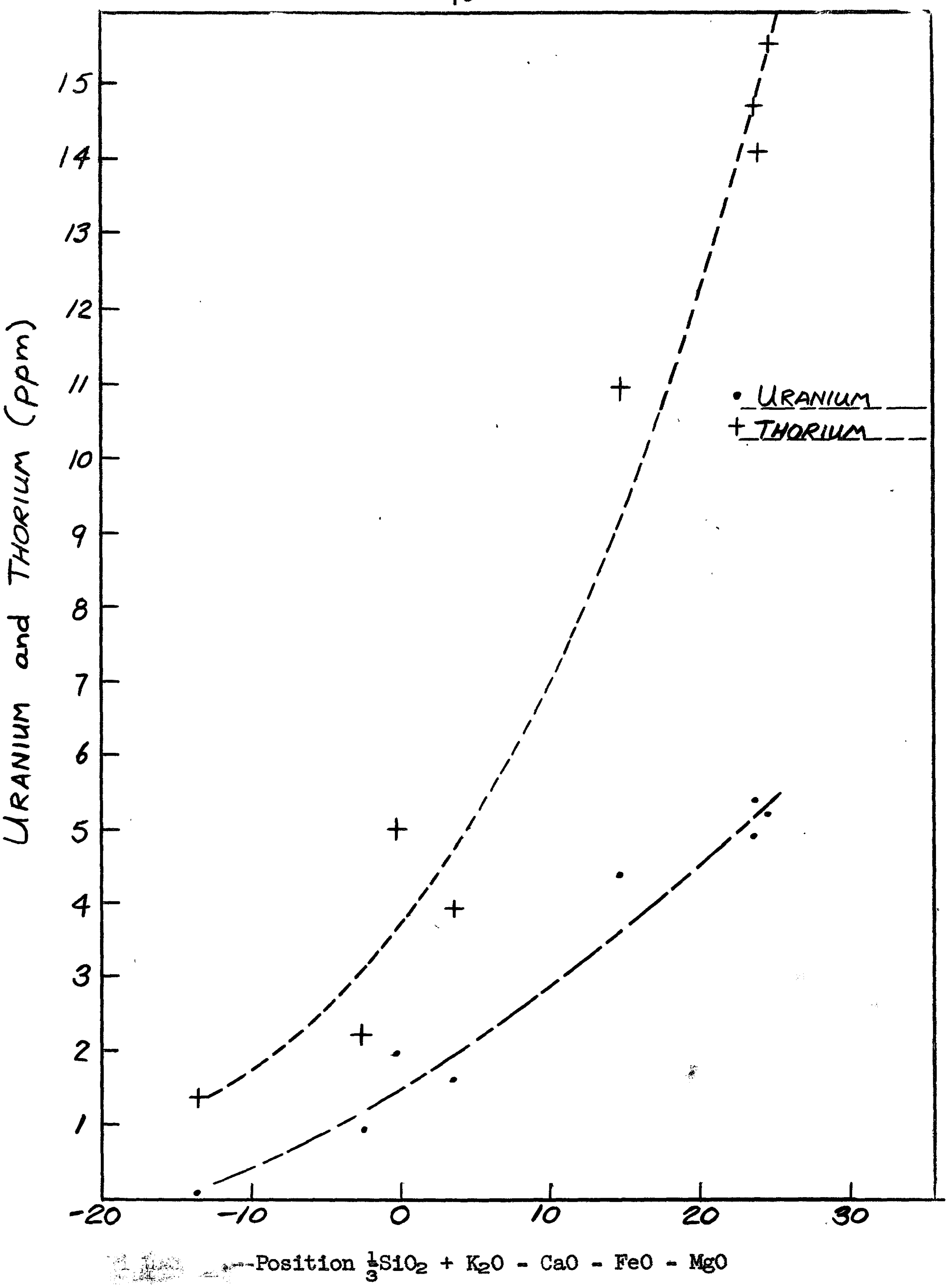


Fig. 12—Uranium and thorium in volcanic rocks of the Medicine Lake Highland.

Lassen Volcanic National Park, California

The volcanic rocks from Lassen Volcanic National Park range from basalt to dacite. Compared with the volcanic type from the Medicine Lake Highland which is regarded as a calc-alkaline series, the Lassen volcanics are regarded as a calcic suite. Uranium and thorium analyses on 9 samples of volcanic rocks studied by Williams (1932) are listed in table 8. A plot of these data on a variation diagram is given in fig. 15. There is a trend toward increasing uranium and thorium in the more siliceous rocks except for one sample of dacite which is low in both uranium and thorium. This sample of dacite, the most siliceous rock of the suite analyzed for uranium and thorium, contains only 1.0 pp uranium and 2.4 ppm thorium.

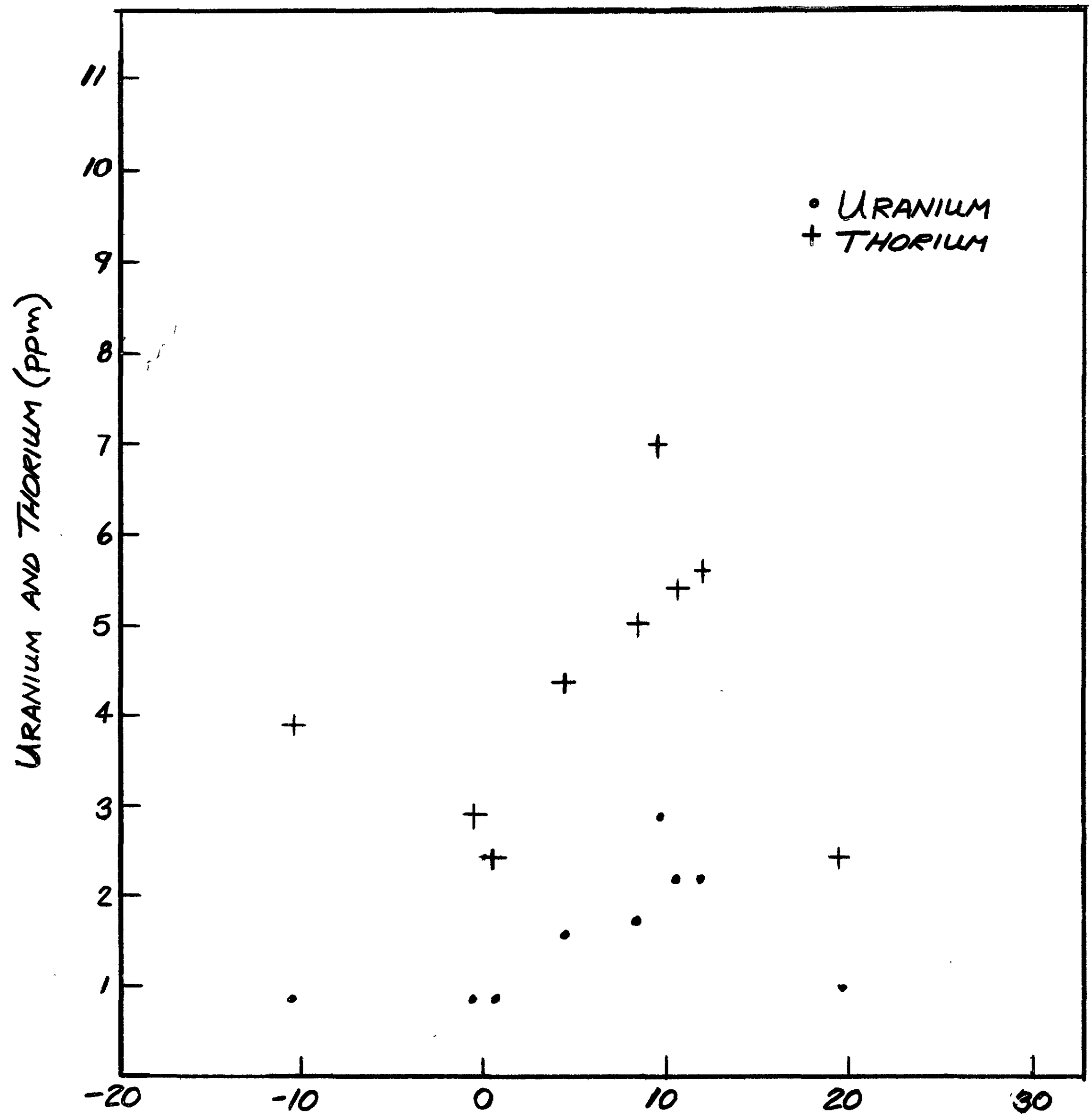
Too few samples have been analyzed to show any definite correlation of thorium to uranium ratios with rock type. However the available data indicate a decrease in the thorium to uranium ratio from basalt to dacite. The two basalts have thorium to uranium ratios of 4.0 to 3.0; the average thorium to uranium ratio of five andesites is 2.7; and in the two dacites the thorium to uranium ratio is 2.7 to 2.4.

Table 8.--Uranium and thorium in volcanic rocks from Lassen Volcanic National Park, California

Sample No.	Rock type	Position (1/3 SiO_2 + K_2O-CaO-FeO-MgO)	U(ppm)	Th(ppm)	Th/U ratio
131-73	Basalt	-10.1	0.95	3.8	4.0
131-41	Basalt	-0.4	0.92	2.8	3.0
131-240	Andesite	+ 0.2	0.93	2.4	2.6
131-303	Andesite	+ 4.6	1.6	4.4	2.8
131-199	Andesite	+ 8.2	1.7	5.0	2.9
131-129	Andesite	+ 9.8	2.9	7.0	2.5
131-79	Andesite	+10.6	2.2	5.4	2.6
131-317	Dacite	+12.0	2.1	5.6	2.7
131-237	Dacite	+19.9	1.0	2.4	2.4

Big Bend National Park, Texas

The igneous rocks from Big Bend National Park range from nepheline basalt with 41 percent silica to riebeckite rhyolites and granites containing about 76 percent silica. These rocks are one of several alkalic sub-provinces along the front of the Rocky Mountains extending from Montana to Texas. Igneous rocks from the Terlingua - Solitario region are similar to most of these rocks and have been described by Lonsdale (1940).



Position $\frac{1}{3}SiO_2 + K_2O - CaO - FeO - MgO$

Fig. 15--Uranium and thorium in volcanic rocks from Lassen Volcanic National Park

A suite of twenty seven samples of igneous rocks from Big Bend National Park obtained from Prof. Lonsdale were analyzed for uranium. The data are listed in table 9 and plotted on fig. 16. The complete suite of rocks is higher in uranium than any known ordinary calc-alkaline suite. None of the mafic rocks contain less than 1.0 ppm uranium and the highly silicious rocks range from 9 to 45 ppm. Thorium analyses on these samples will be completed at a later date.

Table 9.--Uranium content of igneous rocks from Big Bend National Park, Texas

Sample No.	Rock Type	Uranium (ppm)
Ch 689 F-2	Quartz, sanidine porphyry, intrusive	9.2
Ch 234	Riebeckite soda granophyre, intrusive	16.4
Ch 203	Riebeckite soda microgranite porphyry, extrusive	9.8
Ch 232 D	Riebeckite granophyre, intrusive	9.0
Ch 162 B	Riebeckite granite, intrusive	45.5
Ch 746 F	Riebeckite rhyolite, extrusive	16.4
Ch 767 A-3	Pyroxene microgranite porphyry, intrusive	7.0
Ch 668 F	Riebeckite trachyte, extrusive	19.4
Ch 340 B	Aegiriteaugite trachyte, intrusive	2.0
Ch 61 B	Augite soda trachyte, intrusive	3.4
Ch 747 C	Trachyandesite porphyry, extrusive	6.2
Ch 577 B	Trachyandesite porphyry, extrusive	3.3
Ch 47 B	Analcite syenite, intrusive	3.4
Ch 726 F	Trachyandesite transitional to andesite, extrusive	4.3
Ch 258	Olivine syenodiorite, intrusive	4.4
Ch 727 D	Basalt porphyry (?) extrusive	4.0
Ch 176 A	Analcite andesine syenite, intrusive	2.7
Ch 47 A	Syenogabbro, intrusive	1.6
Ch 724	Porphyritic olivine basalt, intrusive	1.6
Ch 179	Analcite syenogabbro	1.6
Ch 148	Olivine basalt, intrusive	1.2
Ch 386	Olivine basalt, intrusive	1.1
Ch 69 D	Analcite labradorite syenite, intrusive	1.6
Ch 589	Olivine basalt porphyry, extrusive	1.2
Ch 840	Metabasalt, intrusive	1.9
Ch 243 D	Nepheline basalt, intrusive	2.2
Ch 1	Porphyritic olivine basalt	2.5

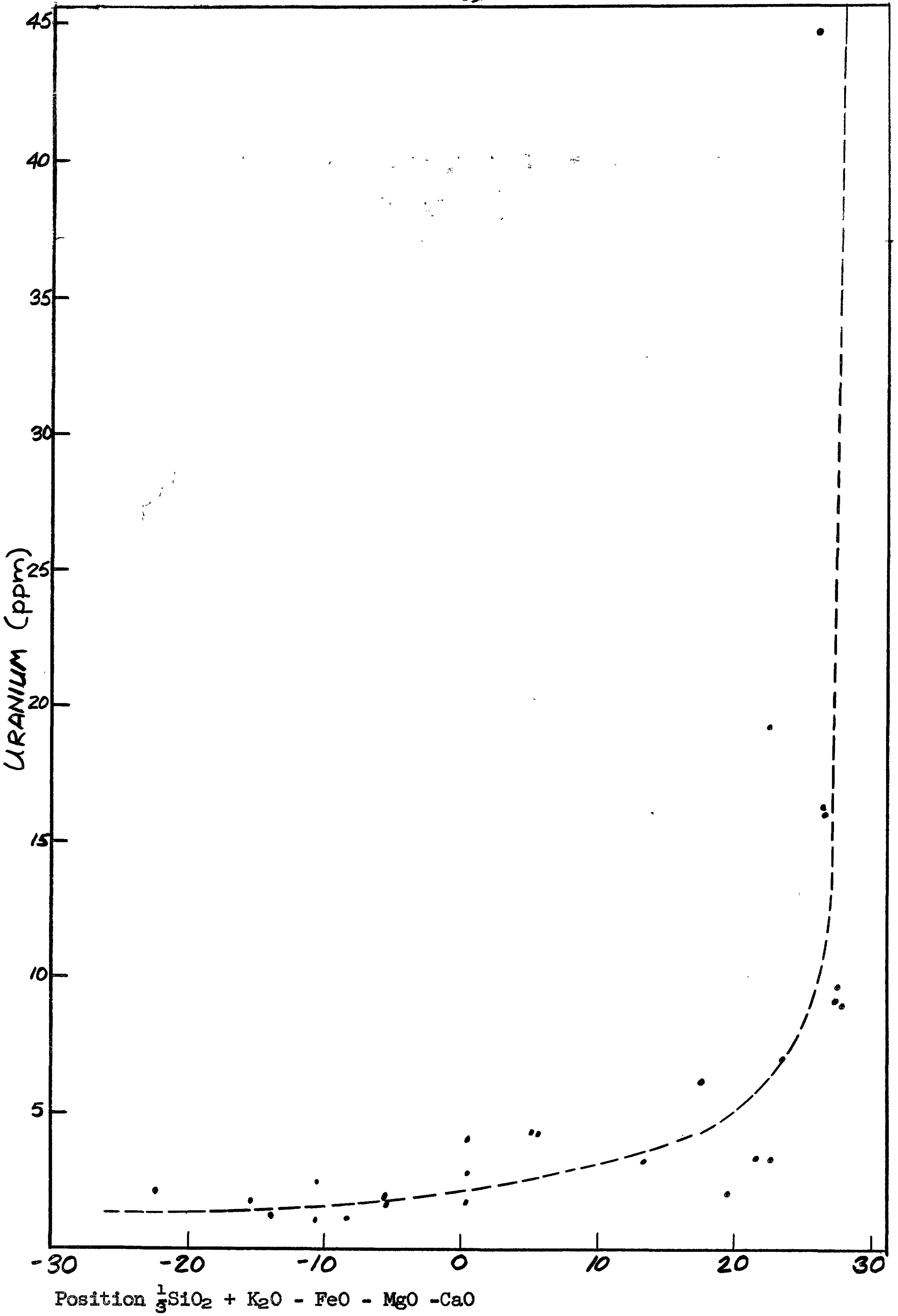


Fig. 16—Distribution of uranium in igneous rocks from Big Bend National Park, Texas

Sierra Nevada and Idaho Batholiths

Eight igneous rocks from the eastern part of the Sierra Nevada batholith and 27 igneous rocks from the Idaho batholith were analyzed for thorium and uranium.

The granitic rocks from the Sierra Nevada are from the Bishop area and range in composition from granodiorite to albite granite. These rocks are being studied in the field and laboratory by Paul Bateman of the USGS. Table 10 lists the rock types and uranium and thorium analyses. Neither uranium nor thorium show any systematic correlation with rock types and a plot of the data in fig. 17 shows considerable scatter in the thorium-uranium ratios for these rocks, which range from 2.8 to 5.0. The most siliceous rock, an albite granite, is relatively low in uranium (2.0 ppm) and thorium (914 ppm) but has a thorium-uranium ratio similar to the thorium and uranium ratios of most of the other samples.

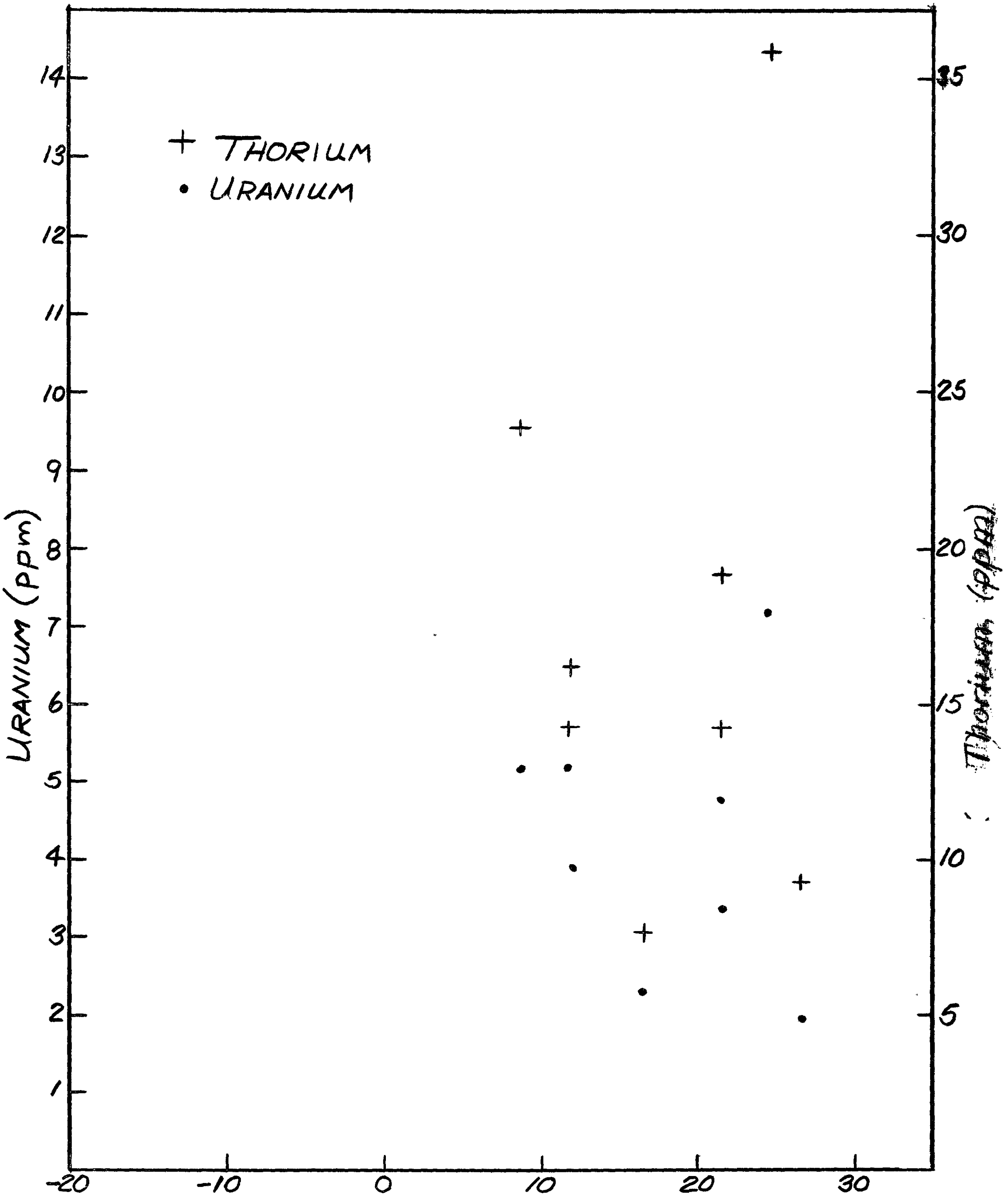
Table 11 summarizes the uranium and thorium content and the thorium to uranium ratios for 27 igneous rocks from the Idaho batholith. The rocks range from tonalite to muscovite-quartz monzonite. Uranium increases on the average from 1.9 ppm in the tonalites to 2.4 ppm in the granodiorite to 4.4 ppm in the quartz monzonite and granite. There is a significant decrease of uranium in the muscovite-quartz monzonites which average 1.5 ppm.

Table 10.--Uranium and thorium in granitic rocks of the Sierra Nevada near Bishop, California

Sample No.	Rock type	Position ($1/3$ SiO_2+ K_2O-CaO-FeO-MgO)	U(ppm)	Th(ppm)	Th/U ratio
6-119-2	Granodiorite	+8.9	5.2	24.0	4.7
6-51-2	Granodiorite	+11.8	5.2	14.3	2.8
6-151-5	Quartz monzonite	+11.9	3.9	16.4	4.2
11-174-2	Quartz monzonite	+16.3	2.3	7.6	3.3
95-43-1	Quartz monzonite	+21.3	4.8	19.3	4.1
98-66-2	Quartz monzonite	+21.3	3.4	14.3	4.2
95-83-5	Quartz monzonite	+24.4	7.2	36.0	5.0
6-140-5	Albite-granite	+26.7	2.0	9.4	4.8

Table 11.--Uranium and thorium content of igneous rocks from the Idaho Batholith

Rock type	No. of samples	Average U(ppm)	Average Th(ppm)	Average Th/U ratio
Tonalite	5	1.9	11.3	5.8
Granodiorite	12	2.4	10.3	4.8
Quartz monzonite and granite	5	4.4	14.2	4.7
Muscovite quartz-monzonite	5	1.5	6.5	5.3



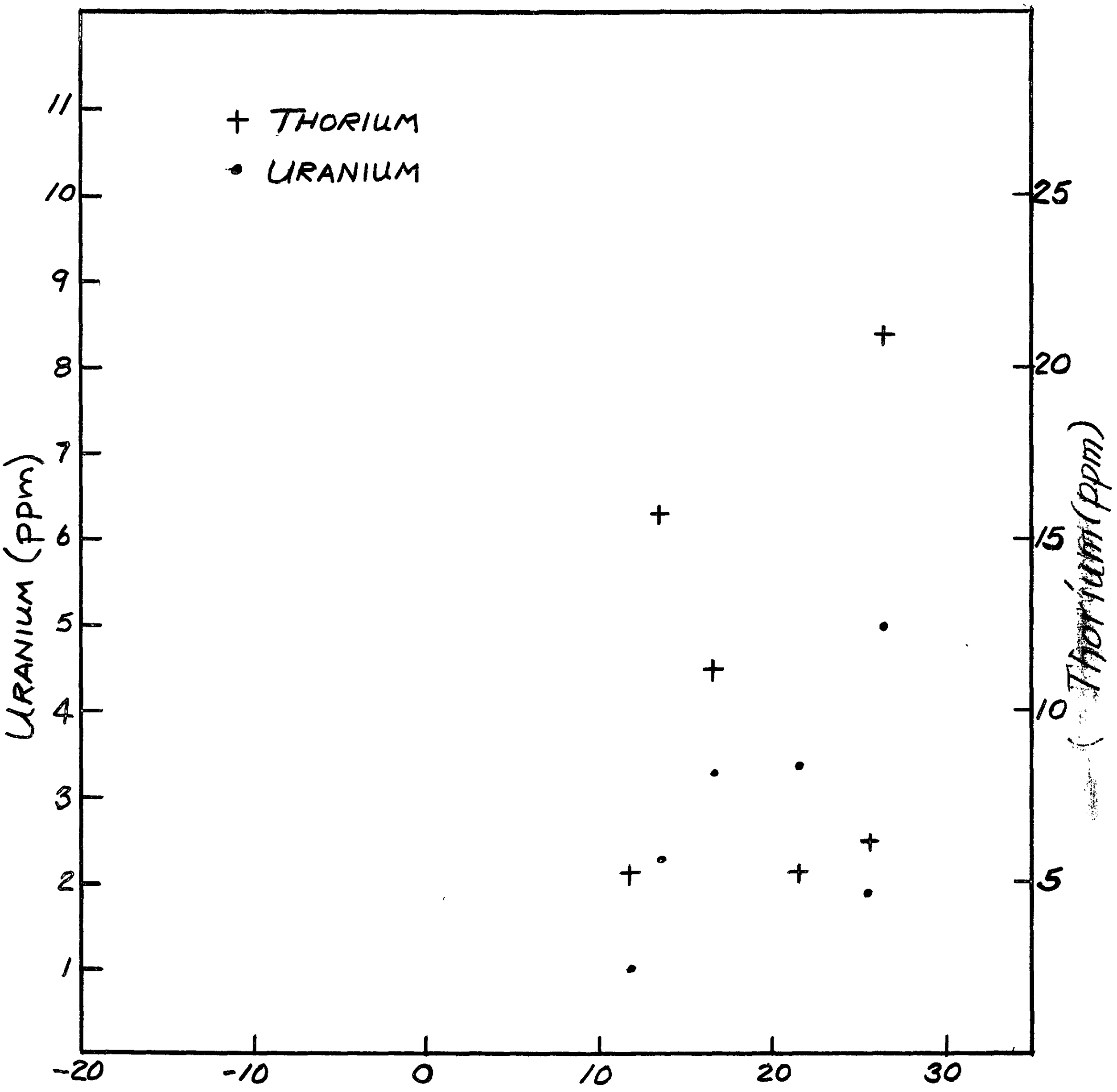
Position $\frac{1}{3}SiO_2 + K_2O - CaO - FeO - MgO$

Fig. 17—Distribution of uranium and thorium in igneous rocks from the Sierra Nevada, California

The thorium content of the tonalites averages 11.3 ppm and the granodiorites average 10.3 ppm. The average thorium content then increases to 14.2 ppm in quartz monzonite and granite. The muscovite quartz monzonites show a sharp decrease in thorium as well as uranium. They average 6.5 ppm thorium. The average thorium to uranium ratios does not differ greatly from one rock type to the next. Average thorium to uranium ratios of the rock types are as follows: Tonalites, 5.8, granodiorites, 4.8; quartz monzonite and granite, 4.7; and muscovite quartz-monzonites, 5.3. These thorium to uranium ratios are somewhat higher than those obtained on equivalent rock types from the batholith of southern California (E. L. Larsen, 3rd, TEI-740, p. 308-309).

A plot of the uranium and thorium data for six chemically analyzed rocks from the Idaho batholith is shown in fig. 18. The individual thorium and uranium values show a wide scatter, as was the case for the Sierra Nevada granitic rocks.

The decrease of both uranium and thorium in the muscovite quartz monzonites is not readily explained. Neither uranium nor thorium were selectively removed because the thorium to uranium ratios of these rocks are not significantly different than those obtained on other rock types of the batholith.



Position $\frac{1}{3}SiO_2 + K_2O - CaO - FeO - MgO$

Fig. 18—Distribution of uranium and thorium in igneous rocks of the Idaho batholith

In general both uranium and thorium are more systematically distributed in extrusive and hypabyssal suites of rocks than those from the great batholiths. This is especially true for the more siliceous rocks generally ranging in composition from granodiorite to extreme monzonites and granites. Most suites of volcanic rocks and their associated intrusives yield smoother variation curves for uranium and thorium than those obtained on the batholithic suites of rocks thus far. This may in part be from (1) problems in sampling the large batholiths, (2) differences in the distribution of uranium between extrusive and deep-seated rocks, or (3) differences in the origin and geologic history of the volcanic and batholithic rocks.

Table 12.--Uranium and thorium in chemically analyzed rocks from the Idaho Batholith

Sample No.	Rock type	Position (1/3 $SiO_2 + K_2O-CaO-FeO-MgO$)	U(ppm)	Th(ppm)	Th/U ratio
L-227	Tonalite	+11.9	1.0	5.4	5.4
L-81	Tonalite	+13.2	2.3	15.7	6.8
L-70	Granodiorite	+16.9	3.3	11.1	3.4
L-288	Granodiorite	+21.5	3.4	5.4	1.6
L-219	Quartz monzonite	+26.1	5.0	22.0	4.4
L-272	Muscovite-quartz monzonite	+25.5	1.9	6.2	3.3

The following papers were published during the period:

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Stable Isotopes

by

Irving Friedman

The tritium and deuterium content of 24 samples of atmospheric hydrogen collected at ground level near Buffalo, New York, Hamburg, Germany, and Nurnberg, Germany during 1954-1956 was measured.

At the beginning of 1954 the tritium content was found to be higher by about a factor of ten than in 1949 (Faltings and Harteck, 1950) and 1951 (Grosse and others, 1954). This probably resulted from the first explosion of a thermonuclear device in November 1952.

During 1954 and 1955 no further increase was found in the tritium content, which shows instead a seasonal variation with high tritium content in winter and about a three fold decrease in summer. Simultaneously, there is good correlation between the tritium and deuterium concentrations.

Since 1956 a noticeable increase in the tritium content from more man-made HT produced or released by thermonuclear devices into the atmosphere was found, in agreement with measurements by Gonsior (1959).

A possible explanation of the experimental results as well as a method to test the validity of the model suggested follows:

The deuterium concentrations of the samples analyzed vary between 7 and -17 percent, compared to standard Lake Michigan water with a ratio, D/H 0.0148 ± 0.0002 mole percent. Although, from these results only a correlation factor between the tritium and deuterium content of "mean atmospheric hydrogen" and not their absolute values can be derived, it is obvious that atmospheric hydrogen and the water vapor of the atmosphere are not in thermodynamic equilibrium. This has been pointed out before by Harteck and Suess (1949).

The tritium analyses were made by Dr. Fred Begemann, Max Planck Institut fur Chemie, Mainz, Germany, while the deuterium analyses were made in the Survey laboratories.

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Nuclear Geology

by

F. E. Senftle

Absolute thick source alpha counting technique

An ion chamber or scintillation counter with the usual counting circuitry is generally used when making alpha counts from thick sources (as in the alpha-lead age method). As alpha particles produce high intensity pulses, it is customary to eliminate noise and high energy beta pulses by setting the discriminator voltage just above the largest pulses coming from these two sources. However, the total alpha count obtained by this method necessarily must be less than the true alpha count because from an infinitely thick source, a continuous distribution of alpha particle energies ranging from maximum to zero is obtained. A certain fraction of the alpha particles will be emitted at energies lower than the discriminator bias voltage, and these will not be counted. To obtain the true thick source alpha count a theoretical correction factor was worked out which can be applied to the normal alpha counting technique. The correction, Fe, amounts to about 10 percent of the total count and is therefore significant. Table 13 shows the corrected experimental results compared to the count calculated from the known thorium and uranium content.

Effect of crystal thickness on the resolution of alpha scintillations in CsI(Tl)

CsI(Tl) is becoming an increasingly popular tool for alpha scintillation counting mainly because of its non-hygroscopic properties. It is common practice to use thin crystals ranging from 90 microns to 0.5 cm, but there seems to be no compelling reason for using one particular thickness in preference to another. A change in resolution with crystal thickness can be noted, however, and in view of the importance of resolution in studying

Table 13.--Comparison of experimental and calculated thick source alpha counts

No.	Material	Uranium (percent)	Thorium (percent)	$\mu d \times 10^3$ (gm/cm^3)	F_c	E(calculated) $\alpha/cm^2/hr.$	E experimental $\alpha/cm^2/hr.$
FC-1	Freshly precipitated U_3O_8	84.79	None	4.37	1.10_2	199,641	201,653
GS-64	Uraninite, Happy Jack mine, Colorado	73.46	None	3.99	1.09_4	939,780	934,387
SQ-81	Monazite, Mountain Pass, California	0.002	2.65	2.91	1.09_6	7,128	7,097
R-8109	Monazite, Ferros, Minas Gerais, Brazil	0.14	7.05	2.95	1.09_6	20,500	20,410

spectra a systematic investigation was made. Figure 19 shows the effect of thickness on resolution, and indicates that the best resolution can be obtained for crystals of the order of 0.5 mm in thickness. A resolution as low as 2.5 percent for Po^{210} alpha particles was obtained. This is adequate for most spectra problems. Among other uses, it is hoped that this technique may be applied to the study of thin sections of uranium minerals.

Miscellaneous scintillation counter studies

Work also was done on the solid state phenomenon in CsI(Tl) crystals. Measurements are being made on the rise time, pulse amplitude, and other factors at various temperatures and an attempt is being made to correlate these with radiation damage and thermoluminescence.

Along with these studies an attempt also is being made to improve the alpha counting techniques of mineral powders and solid polished mineral sections.

Magnetic susceptibility of TiO_2

Although it was planned to terminate the magnetic studies of TiO_2 at the end of the last report period, a small amount of work was done to extend the measurements below liquid nitrogen temperatures to liquid helium temperature (4.2°K). This decision was made because of the importance of

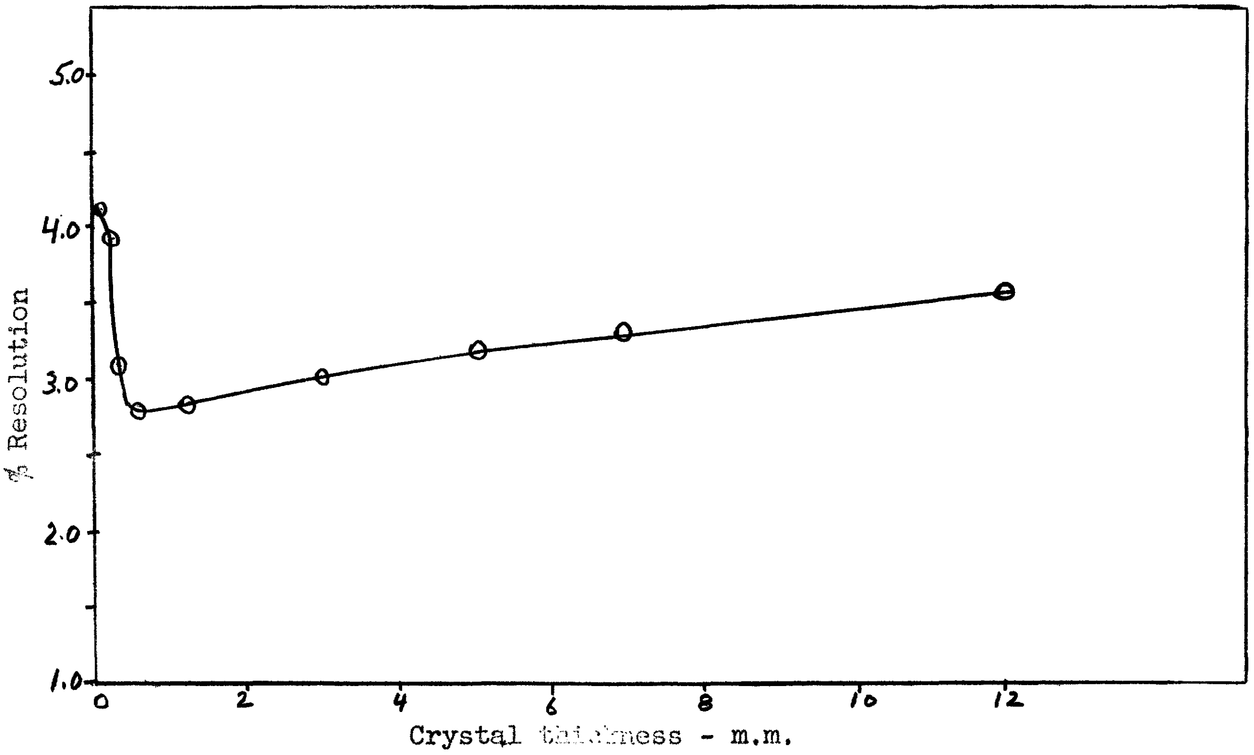


Fig. 19. Effect of crystal thickness on resolution of alpha scintillations.

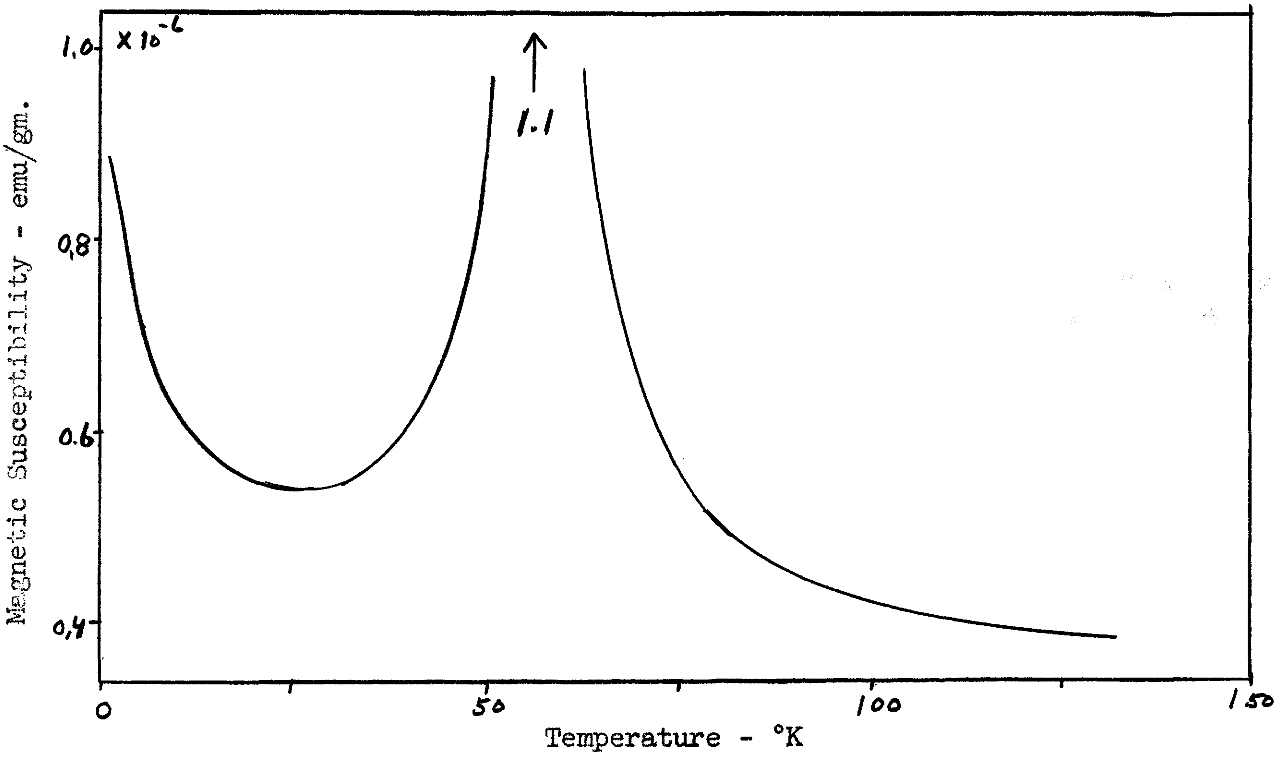


Fig. 20. Magnetic susceptibility of anatase.

the low temperature data in interpreting the magnetic effects at higher temperatures. The rutile form of TiO_2 was found to be temperature-independent down to about 10°K. It is thought that the slight rise in this region is caused by impurities. The anatase form, however, showed a large maximum in the susceptibility at about 70°K. As this could not be connected with any of the known impurities, field measurements and area measurements are being made as further studies to explain the anomaly. The results of the tests on anatase are shown in fig. 20.

Magnetic measurements on cancerous tissue

A few preliminary magnetic measurements were made on several cancerous tissue specimens for the National Institute of Health. The results are preliminary only but are significant enough to warrant further work.

Two rats of the same species were chosen for the experiment. One was injected in the hip and a cancer was allowed to grow for about four weeks. Before the cancer was allowed to affect the normal activity of the animal, the livers of both animals were removed as well as some of the cancerous tissue. Immediately on removal the tissue was quick frozen in liquid nitrogen to prevent decay of the cells. The equipment was set up in a special cold room which was kept at -10°C at all times. When ready for the measurement the specimen was removed from the liquid nitrogen, a piece removed with a glass knife and loaded onto the balance. At no time was the specimen allowed to thaw.

The magnetic measurements were at liquid nitrogen temperatures so that the sample might be preserved throughout the measuring period and also to enhance if possible the magnetic susceptibility. The results are shown in fig. 21. All the samples were diamagnetic. When the magnetic susceptibility, χ, is plotted against the reciprocal of the magnetic field, $1/H$, the slope indicates a ferromagnetic component. The liver from the normal rat shows no ferromagnetic component while that from the cancerous rat shows a definite ferro-magnetic effect. The cancerous tissue itself, however, is non-ferromagnetic and more diamagnetic, which seems to indicate a depletion of iron.

These preliminary tests appear to indicate that the liver in the cancerous rat took up significant quantities of iron and that this iron agglomerated in localized areas in the liver (probably as a fixed iron compound) in order to form ferromagnetic domains. It is possible that this iron was obtained at the expense of the cancerous tissue itself as shown by its strong diamagnetism.

No further work is planned unless so requested by the National Institute of Health.

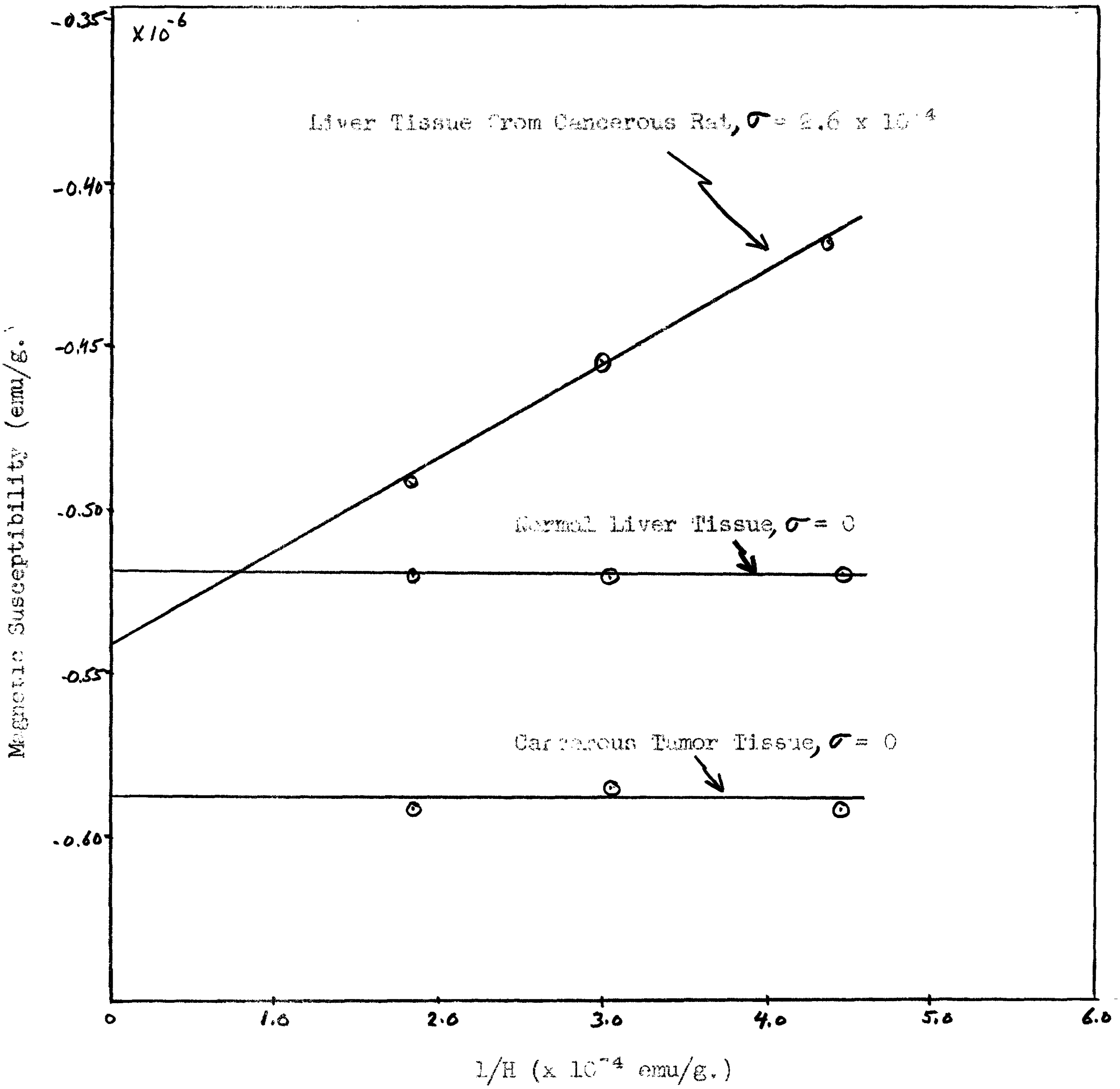


Fig. 21. Magnetic susceptibility measurements on cancerous tissues.

Magnetic Susceptibility of Zircon and Sphene

An attempt is being made to use the magnetic susceptibility and the intensity of magnetization of zircon and sphene as an indicator of geologic age. Contamination iron which exists naturally in both minerals is being used as a tracer. In sphene the diffusion coefficient of iron is relatively high at normal earth temperatures, and the iron is free to move and form domains. The diffusion coefficient in fresh zircon is low, but increases significantly in metamict zircon. By comparing these three conditions and by heating the zircon it is possible to obtain a function which seems to be proportional to the geologic age. Further work is being done to understand more fully the mechanism involved.

Miscellaneous Investigations

Work is being done on the identification of a new thorium-bearing mineral. After separating a small amount from about 30 libs. of limestone, X-ray analysis showed the mineral to be of a hydrous nature, changing to a monazite-type structure upon heating. Further work will be done in a attempt to complete the identification.

A correlation study is also being made between the color of sphenes, the total alpha dose, and the geologic age. About forty sphenes were separated and are being handpicked for this purpose.

Radiochemical work, formerly done in Denver, was relocated at the Marine Laboratory, University of Miami. Application of the techniques discussed in the preceding paragraph are being made in an attempt to date deep sea cores.

Nuclear Irradiation Studies

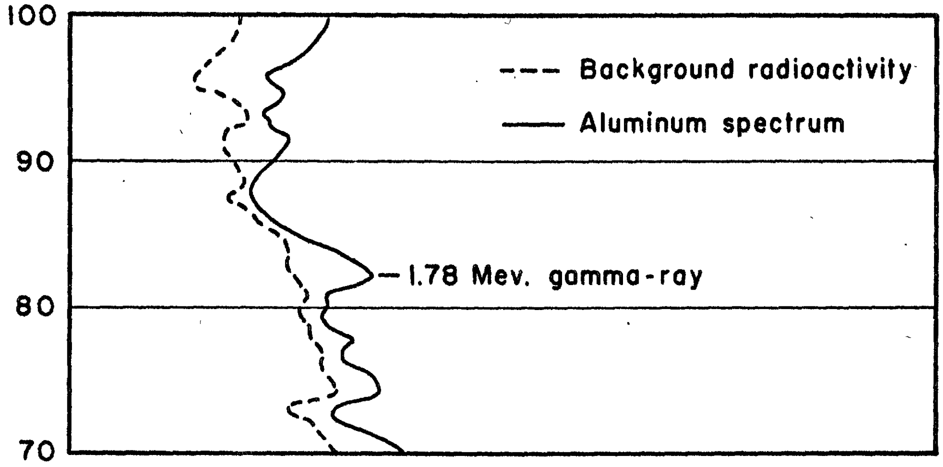
by

C. M. Bunker

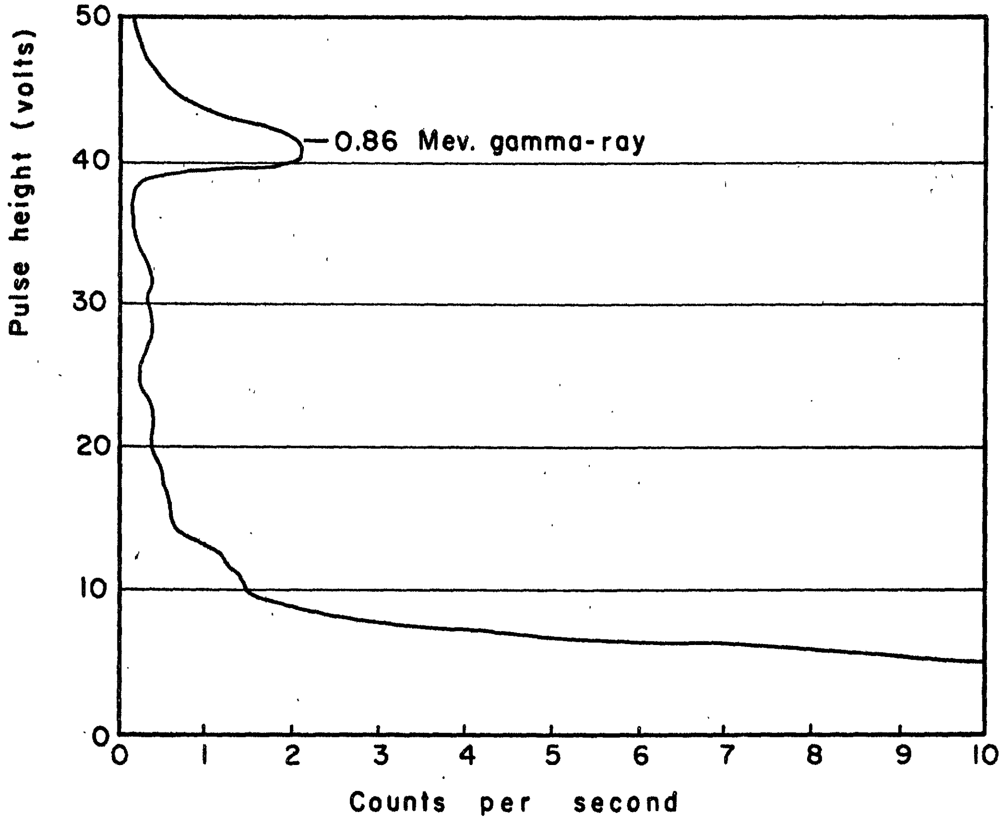
The objective of the nuclear irradiation studies is the development of equipment and techniques for measuring density, water content, and the content of various elements in rocks. Measurements are made by irradiating samples or formations with gamma rays or neutrons, and the resulting radioactivity is then related to the physical and chemical properties of the rocks.

In the preceding report period preliminary calibration of a density logging unit was completed (TEI-751, p. 117-119). Although results obtained from the unit were promising, radioactivity from radioisotopes in an adjacent storage area created an undesirably high background. For that reason the investigations have been recessed temporarily until the laboratory can be separated from the radioisotope space.

During the report period research was started on development of a field method for using neutron activation for determining semiquantatively the presence of certain elements in soil samples. Laboratory experiments to date indicate that manganese and aluminum can be identified by their secondary gamma-ray spectra (see fig. 22). Results of this study would be improved by using a larger neutron source, and a 10-curie plutonium-beryllium source that emits about 1.6×10^7 neutrons per second will be obtained for that purpose.



Gamma-ray spectrum of aluminum during irradiation with plutonium-beryllium neutron source



Gamma-ray spectrum of manganese after neutron irradiation

FIGURE 22 .NEUTRON ACTIVATION ANALYSES OF ALUMINUM AND MANGANESE

An irradiation chamber for irradiating samples with neutrons for activation analysis and for investigation of the effect of neutron flux on the thermoluminescence of various rocks has been constructed and put into operation. With this chamber sixteen samples can be irradiated simultaneously in essentially equal amounts of neutron flux.

Geochronology, Pb-U Method

by

L. R. Stieff

During the report period 44 samples of radioactive minerals and galena were prepared for chemical and isotopic analysis. Analytical work was completed on approximately 20 samples. In addition, modifications in the sample loading procedure and the mass spectrometer source resulted in further reductions in the amount of sample required for a lead isotope analysis. Isotopic analyses are now being made on approximately 10 micrograms of lead.

The work on the mathematical procedures for the evaluation of discordant lead-uranium ages was completed. Extending Wetherill's graphical method for the calculation of discordant lead isotope ages, concordant ages corrected for common lead can be obtained on plots of mole ratios of total Pb^{206}/U^{238} versus total Pb^{207}/U^{235} using only the Pb^{207}/Pb^{206} ratio of the contaminating common lead.

If isotopic age data are available for two samples, a and b, from the same or equivalent deposits or outcrops whose ages are assumed equal, plots of $\frac{Pb_a^{206}/Pb_a^{208}-Pb_b^{206}/Pb_b^{208}}{U_a^{238}/Pb_a^{208}-U_b^{238}/Pb_b^{208}}$ versus $\frac{Pb_a^{207}/Pb_a^{208}-Pb_b^{207}/Pb_b^{208}}{U_a^{235}/Pb_a^{208}-U_b^{235}/Pb_b^{208}}$ (or normalized with Pb^{204} if Th is present) can give concordant ages corrected for unknown amounts and ratios of common lead. Data on three related samples will give concordant ages corrected in addition for one unknown period of alteration or the presence of an older radiogenic lead of unknown Pb^{207}/Pb^{206} ratio. Algebraic solutions equivalent to the graphical methods have also been derived.

The validity of these concordant age solutions may be evaluated in terms of the geologic history of the area, geologic age relations of the enclosing rock, probable sources of the lead and uranium, and the isotopic composition of the lead in associated nonradioactive minerals.

These graphical methods were applied to the isotopic age study of uranium ores from two uranium deposits in Carbon County, Pennsylvania. Lead isotope age determinations (see table 14) were made on two samples of uraninite (nos. 346, 538) from the Mt. Pisgah deposit in the basal sandstone and conglomerate member of the Pottsville formation (Pennsylvanian) near Jim Thorpe (Mauch Chunk). Two samples of uraninite (403, 586) also were studied. They were from a uranium occurrence in the upper part of the Catskill formation (Devonian) near Penn Haven Junction. In addition

Table 14.--Chemical and isotopic data on uranium ores from Carbon County, Pennsylvania

No.	Percent Pb*	Percent U*	Atom ratios Pb^{204}/Pb^{208}	Pb^{207}/Pb^{206}	Pb^{207}/Pb^{208}
346	0.65	14.4	0.029 ± 0.003	0.0568_1 ± 0.0003	10.5_4 ± 0.05
538	0.21	4.34	0.027 ± .001	0.0564_1 ± .0003	11.1_5 ± 0.04
586	3.30	12.4	0.0260_5 ± 0.0001	0.412_7 ± 0.0009	0.438_7 ± 0.0002
403	0.055	0.50	0.0259_5 ± 0.0002	0.344_4 ± 0.0015	0.450_7 ± 0.0018
512	48.6	4.0	0.0262_7 ± 0.0002	0.783_7 ± 0.002	0.409_9 ± 0.0008
529	83.9	0.0007	0.0260_6 ± 0.0002	0.846_4 ± 0.0015	0.4092 ± 0.0013
584	79.3	0.003	0.0263_1 ± 0.00007	0.827_3 ± 0.0003	0.408_1 ± 0.0003

*Analysts: Grafton J. Daniels and J. J. Warr

Using the Nesquehoning galena and Pb^{208} as the common lead index the approximate, discordant trial ages in millions of years were obtained. These are shown in Table 15.

Table 15.--Chemical and isotopic data on uranium ores from Carbon County, Pennsylvania

		Approximate trial ages. m.y.		
No.	Locality	Pb^{206}/U^{238}	Pb^{207}/U^{235}	Pb^{207}/Pb^{206}
403	Penn Haven Jct.	220	245	305
586	Penn Haven Jct.	438	428	368
346	Mt. Pisgah	314	325	413
538	Mt. Pisgah	300	312	402

isotopic analyses were made on the lead in a sample of clausthalite (512) from Penn Haven Junction, from a specimen of galena (584) collected from Nesquehoning (Allegheny formation?, Pennsylvania) and from galena (529) in tension fractures in the Portage formation (Devonian) near Walcksville.

A possible evaluation of this discordant age data using new graphical methods suggests that the Penn Haven Junction and Mt. Pisgah uranium deposits were formed at approximately the same time, about 120 m.y. ago.

The following papers were presented at the annual meeting of the Geological Society of America, Pittsburgh, Pennsylvania, November 1, 1959:

Stieff, L. R., and Stern, T. W., New graphical and algebraic methods for the evaluation of discordant lead-uranium ages.

Stern, T. W., Stieff, L. R., Klemic, H., and Delevaux, M. H., Lead isotope age studies in Carbon County, Pennsylvania

Isotope Geology of Lead

by

R. S. Cannon, Jr., A. P. Pierce, J. C. Antweiler, and K. L. Buck

Evidence concerning the origins of ore deposits provided by lead-isotope studies is essentially threefold: indications of (1) the sources from which ore metals originate, (2) the processes that bring them hence, and (3) the chronology of mineralizing events. Evidence on these matters is recorded by variations in the isotopic composition of lead--variations that originate as newly formed atoms of radiogenic lead gradually accumulate over long spans of time, or when several different leads are mixed geochemically to form a new product. The general nature of isotopic variation of lead during geologic time is shown diagrammatically in figure 23a, in which heights of bars represent atomic proportions in the earth's crust of stable isotopes of lead (bottom row) versus radioactive parents (top row). The diagram shows that Th^{232} gives birth to new atoms of Pb^{208}, U^{235} to Pb^{207}, and U^{238} to Pb^{206}, whereas for Pb^{204} no new atoms are thus formed in earth material. The black bars at the bottom show what primeval earth-lead may have been like, based on analyses of lead from sulfide phase of iron meteorites (Patterson, 1956). The gray portions represent decay of radioactive parents to radiogenic daughters during some $4\frac{1}{2}$ billion years, and the white bars at top represent atoms of parents that remain today. According to this model, two-thirds of the lead now present in the earth's crust was original (primeval); the other third produced by accumulation of radiogenic daughters.

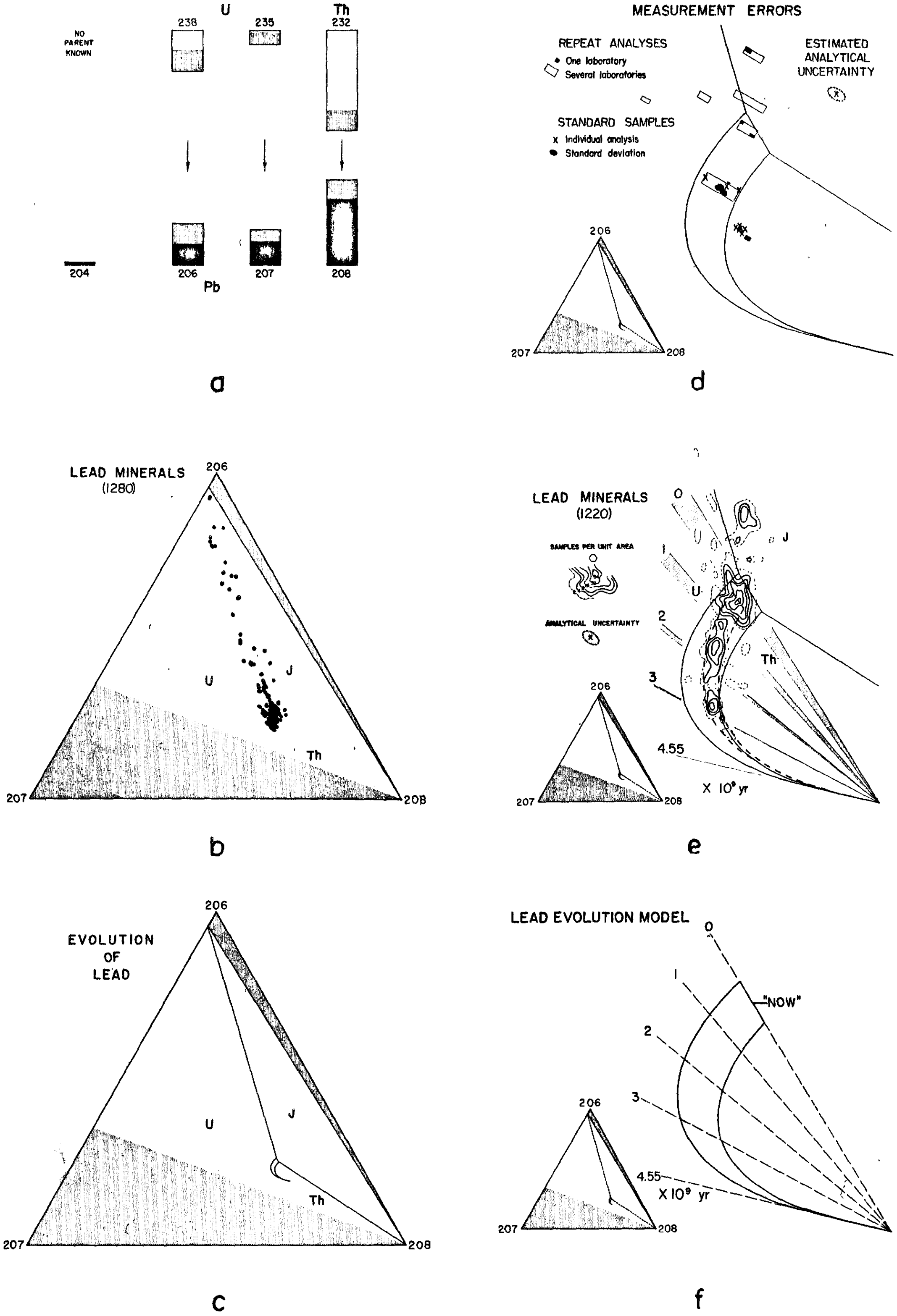


Figure 23 .-Isotopic composition and evolution of lead.

Our interest is in interpreting variations produced by the three radiogenic daughters accumulating differently in different situations in the earth's crust in the course of geologic time. In theory, because Pb^{204} is invariant, it is the best yardstick for measuring variations in the other isotopes. In practice, however, because its abundance is so small (less than 1-2/3 percent in earth-leads studied to date), Pb^{204} is difficult to measure precisely. Abundances of Pb^{206}, Pb^{207}, and Pb^{208}, on the other hand, tend to be large and measurable with better precision. For this reason only variations in atomic abundances of Pb^{206}, Pb^{207}, and Pb^{208} are presented here, recalculated to 100 percent and plotted on trilinear coordinates (fig. 23b).

The shaded areas of figure 23b represent compositions of lead that (in theory at least) do not exist on earth; the white area represents compositions that do exist, or may have existed in the past. The lower left-hand edge of the white area represents all mixtures of radiogenic lead that were being generated 4½ billion years ago. At that time uranium was giving birth to Pb^{206} and Pb^{207} in the ratio represented by the left-hand apex of the white area. Lead being generated by uranium has changed progressively in Pb^{206}/Pb^{207} ratio from that composition 4½ billion years ago to the top apex of the white area now. The upper right-hand edge of the white area thus represente all possible compositions of radiogenic lead being formed today by decay of uranium and thorium, and the gray area above represents all radiogenic lead to be formed in future geologic time.

Our present knowledge of variations in ore-lead is summed up by the data on figure 23b, each dot representing an isotopic analysis of lead from galena or other ore-mineral, for a total of 1280 samples. Most of these data are concentrated within a very small part of the diagram.

These observed variations in composition can be tested against wholly hypothetical, calculated models. The small horn-shaped area in figure 23c is a hypothetical model that encompasses nearly 75 percent of all the data. In figure 23f this model has been enlarged 10 times for more detailed study. Each of the boundary curves is, in fact, a hypothetical model, representing a system that 4.55 billion years ago contained the kind of lead that Patterson (1956) found preserved in troilite from iron meteorites. The two curves represent minor differences in relative abundances of thorium, uranium, and lead. The Th/U weight-ratio is 4.6 for both curves, but the Pb/U weight-ratio is 6.0 for the outer curve, 7.3 for the inner. These curves then represent mathematically calculated evolution of lead, by additions of radiogenic Pb^{206}, Pb^{207}, and Pb^{208} to preexisting primeval lead, within closed systems, during 5.44 billion years of time. Any sample of lead extracted from such a system and preserved as galena 3 billion years ago should have an isotopic composition--then and now--somewhere on the 3 b.y. isochron. Or any sample of lead extracted now from such a system should fall somewhere on the zero isochron. This is the essence of what has been called "galena dating".

The compositions of lead actually observed in 95 percent of the 1280 samples of lead minerals plot within the limits of figure 23e. To compare the observed data with hypothetical models the frequency distribution of these samples is shown by contouring the number of samples that fall within each unit area like the hexagon shown in the explanation. Within the innermost contour the maximum concentration is 69 points per unit area, a concentration 5000 times greater than homogeneous distribution. Unit areas containing only 1 point, or none, lie outside the outermost (dotted) contour. Nearly 75 percent of all ore-lead samples fall in the area between the two evolution curves of figure 23f--a remarkable coincidence between experimental data and hypothetical models.

Other evolution curves can be calculated to fit the data even more closely, however. The two inner curves of figure 23e represent similar hypothetical systems in which Th/U weight-ratio is 3.9 and Pb/U weight-ratios are 7.1 and 7.7. In the narrow crescent between these two curves fall 43 percent of all analyzed lead minerals. This coincidence suggests that many ore-leads were indeed evolved within some such simple system that must have remained virtually unaltered by geochemical change during much of geologic time. A model earth consistent with these ratios might contain, for example, 3 ppm U, 12.3 ppm Th, and 22 ppm Pb.

The confidence that can be placed in the measurements must be kept in mind if we are to discriminate real variations from analytical errors. Figure 23d shows a representative sampling of comparative analytical results.

When a single sample is reanalyzed, variations between different laboratories are generally several times as large as the precision of a single laboratory. In comparative studies of data from many laboratories we judge the reliability of any one analysis to be 0.5 percent--the gray ellipse on figure 23d--or ±150 million years in model age. Severalfold improvement could result if all laboratories related their analyses to a common reference lead sample such as National Bureau of Standards Sample 200 (Mohler, 1957). An additional, more fundamental improvement will be possible when the accuracy of measurements can be checked against "absolute" standards prepared from purified isotopes.

Figure 24a is a synthesis of data from only the big mineral deposits, capable of producing, say, $25,000,000 or more of raw materials such as lead, copper, zinc, nickel, gold, or rare earths. Most of these data represent major lead producers, but about a fifth of them are from deposits in which lead is not a major constituent. Here correspondence to our hypothetical model is even closer, possibly because a large ore deposit is simply a better geochemical sample. Excepting area J, all data from major sulfide deposits fall in a narrow band whose width scarcely exceedes the analytical uncertainty. These data indicate that any mineral prospect having lead of composition to right or left of this band has little chance of developing into a major metal mine. Various limiting factors make it difficult to evaluate this practical observation at present in more detail. We have other scraps of evidence implying that with better analyses we will find additional correlations of isotopic composition with size of deposit.

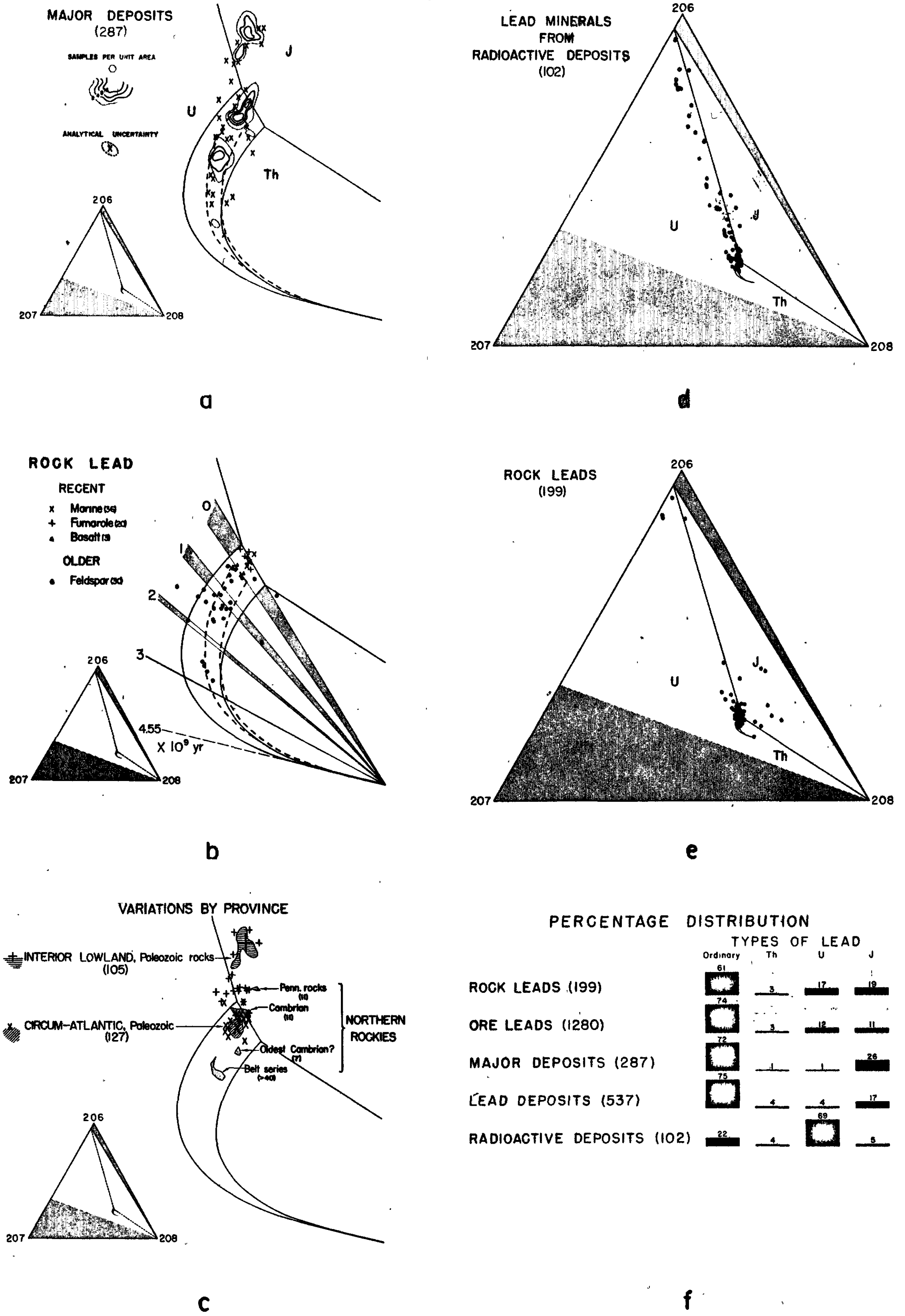


Figure 24. Lead isotope variations in relation to geologic factors.

Another practical application for lead-isotope techniques is their potential application in prospecting for radioactive deposits (Cannon, Stieff, and Stern, 1958). Figure 24d is a synthesis of data from such deposits and shows that nearly 70 percent of lead minerals from radioactive deposits have compositions in area U. For the uranium prospector who discovers galena made of U-type lead the odds are 50-50 that he is on the trail of a uranium deposit. For this application present-day analyses are adequate but costly.

Epochs of mineralization and metallogenetic provinces are intertwined concepts that have fundamental as well as practical importance. Figures 23e, 24a, and 24c illustrate how lead-isotope studies will help define and solve the problems inherent in these concepts. Some of the contoured maxima (fig. 23e) may be products of major epochs of mineralization, or they may represent some kind of dependence of composition of lead in ore deposits upon age of enclosing rocks. The "oldest" maximum, near the 3 b.y. isochron, represents deposits in Precambrian rocks, some of which are known to be extremely old; the next maximum, in the isochron interval 1.5-2.0 b.y. includes deposits in Precambrian rocks, none of which are known to be extremely old; and a third maximum around 0 to 0.5 b.y., includes deposits known to be younger than Precambrian because they are emplaced in rocks of Paleozoic, Mesozoic, or Tertiary age.

A fourth maximum, in area J beyond the zero isochron, may represent some kind of provincial rather than time-dependent phenomenon. J-type leads are a problem still unsolved, but lead-isotope studies will eventually suggest a solution just as they gave us our first intimation, only a few years ago, that lead deposits in the interior U. S. contain a more or less unique kind of lead and therefore represent a special problem in ore genesis. Lead deposits in Paleozoic rocks (chiefly marine limestones and dolomites) in the Mississippi Valley are composed overwhelmingly of this J-type lead. On the other hand (fig. 24c) nearly all deposits in Paleozoic environments around the perimeter of the North Atlantic, including a great many "Mississippi-Valley-type" lead-zinc deposits in Northern Europe, contain ordinary lead near the zero isochron of our model. Whereas lead tends to be of nearly uniform composition within each of the above provinces, it varies widely in the Northern Rocky Mountain province. There, the younger the sedimentary host rock, the more radiogenic the lead in the ore deposit, a generalization that doubtless will become less tidy as more data are obtained.

Is lead in ore-deposits isotopically like or unlike that in the ordinary rocks of the earth's crust? The variation pattern on figure 24e (199 rock-leads) is much like that on figure 1b (1280 lead minerals). The similarity apparent on these graphs is verified by the percentage distribution summaries in figure 24f. Only the samples from lead minerals in radioactive deposits are strikingly unique. On figure 24b two kinds of rock-lead are shown in more detail--rock-leads of zero age, and older rock-leads, frozen into feldspars when they crystallized. Note how closely these two categories of rock-lead resemble in composition their counterparts among ore-leads. Implicit in this similarity is a strong possibility that ordinary rocks of the earth's crust may have spawned many ore deposits.

The authors presented a fuller version of this review at a Symposium on the Role of Stable Isotope Research in the Field of Ore Deposits, held by the Society of Economic Geologists at Pittsburgh, November 1, 1959. The Society proposes to publish the proceedings of the Symposium.

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Crystallography of Uranium and Associated Minerals

by

Howard T. Evans

Work on the crystal chemical study of the vanadium oxide minerals häggite and doloresite was completed during the report period. The results of the least squares analysis of the structures of häggite ($V_2O_3 \cdot V_2O_4 \cdot 3H_2O$), "phase B" ($V_2O_3 \cdot 2V_2O_4 \cdot 5H_2O$) and doloresite ($3V_2O_4 \cdot 4H_2O$), were interpreted in terms of their mode of formation and their geochemical interrelationships. Häggite, phase B and duttonite ($V_2O_4 \cdot 2H_2O$) are found to form a thermodynamically stable series of the type $H_{2n-2}V_nO_{3n-2}$, with $n = 4.6$ and ∞ respectively. A common weathering phenomenon is the reconstructive replacement of orthorhombic montroseite by monoclinic phase B. A submicroscopically twinned aggregate results from the structural control of the montroseite. This process is followed on exposure to air by oxidation of phase B to the metastable doloresite (without change in structure) and the remnant montroseite to paramontroseite, giving rise to the bronzy, impure doloresite commonly found in the Colorado Plateau vanadium-uranium ore deposits.

Work continued on the crystal chemistry of the autunite group of minerals, which began with the structure analysis of abernathyite. The crystal structure study revealed all of the oxygen atoms but showed no evidence of potassium atoms. Synthetic and analytical chemical studies by Grimaldi and Meyrowitz of the Geological Survey (personal communication) proved the presence of the alkali cation in this and analogous structures. It was found that the potassium ion could be accounted for in the X-ray study if it is assumed to replace at random 4 of the 16 crystallographically equivalent water molecules in the unit cell. This means that the correct formula for abernathyite would be $KUO_2AsO_4 \cdot 3H_2O$. Abernathyite itself was not synthesized, but the synthetic compounds $KH(UO_2AsO_4)_2 \cdot 7H_2O$, $NH_4UO_2AsO_4 \cdot 3H_2O$ and $KUO_2PO_4 \cdot 3H_2O$ have closely analogous crystal structures. Careful chemical analyses confirmed that the cation and water must be lumped together to make a ratio to uranium of 4:1. The random replacement of water molecules by cations in interstitial structural arrangements of this type is not believed to have been proven previously in this manner, but it may be a major crystal chemical principle of structure in such minerals as the clays and zeolites.

Infrared and ultraviolet radiation studies

by

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The ability of certain materials to luminesce in the infrared part of the spectrum has been known for many years, but quantitative studies of the problem were not made practical until the advent of the infrared image converter tube.

Barnes (1958) examined with this instrument a large suite of minerals and found that a substantial number exhibited infrared luminescence when examined visually. He reported that none showed visible phosphorescence.

(Luminescence, a generic term, usually applies to radiation emission of sub-atomic origin in excess of thermal radiation; phosphorescence is generally applied to afterglow duration $>10^{-8}$ sec., while fluorescence denotes afterglow duration $<10^{-8}$ sec.).

It seemed reasonable to expect that among such a wide variety of minerals, at least some should phosphoresce. It was desired to verify this experimentally and further, to examine some of the phosphorescent properties.

A pulsed excitation technique somewhat similar to that of Skarsvåg (1955) was adopted. By this means a mineral specimen could be excited for a period of $\sim 10^{-5}$ sec. and the phosphorescence observed and recorded electronically. The general principal of operation was described in the previous semiannual report (TEI-751, p. 131-133). Since that time some changes have been made in instrumentation. Figure 25 is a block diagram of the instruments used in obtaining the data described below. The time relationship between the events is shown in figure 26.

The flash tube was covered with a 5 percent $CuSO_4$ filter to decrease infrared emission from the exciting source; a Kodak 89 B filter, which transmits only infrared, covered the photomultiplier. This filter system was designed to eliminate detection of reflected energy. It was only

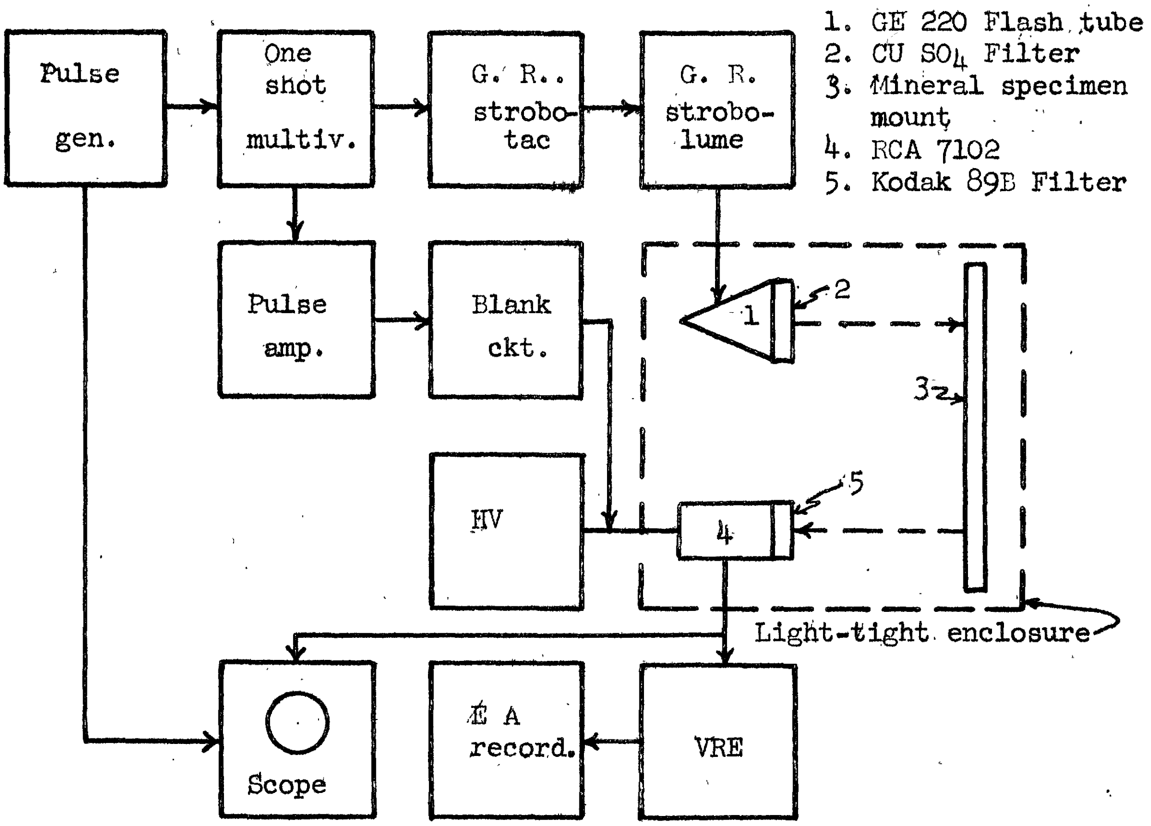

Fig. 25.—Block diagram of phosphorescence detector

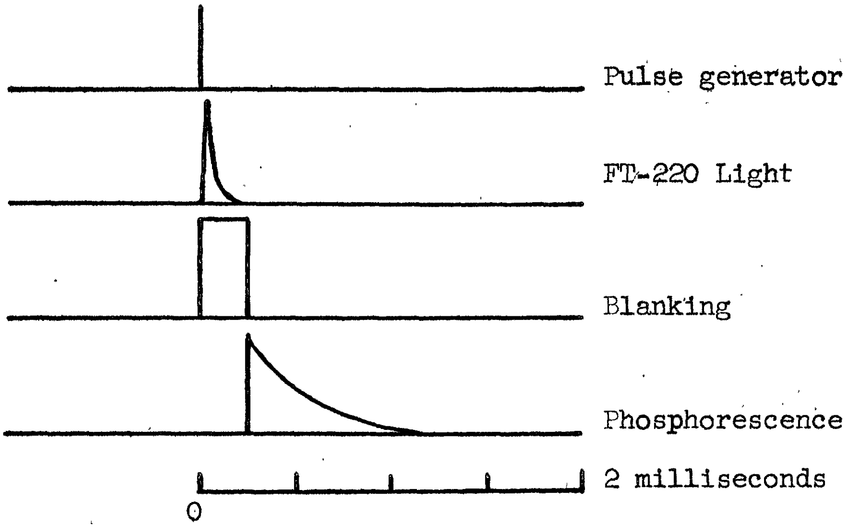

Fig. 26. Time relationships

partially effective, as light reflected from the exciting source had a detectable duration of about 450 μs which required that the photomultiplier be blanked for at least that period. In essence this limited our observations to afterglow $>$450 μsec. It is apparent from the results below that the majority of the minerals involved have afterglow durations considerably shorter than 450 μsec.

The following minerals were examined:

Mineral	Location	Mineral	Location
Asbestos	Arizona	Corundum	Jefferson Co., Mont.
Wulfenite	Miess, Jugoslavia	Scheelite	Cochise Co., Arizona
Crysoberyl	Jefferson Co., Mont.	Beryl	Golden Gate Canyon, Colo.
Kyanite	Minas Gerais, Brazil	Beryl	Lake George, Colo.
Cerussite	Tiger, Arizona	Barite	Stoneham, Colo.
Fluorite	Rosiclare, Ill.	Sphalerite	Crystal City, Colo.

Three of the mineral specimens - scheelite, kyanite and fluorite - had phosphorescence duration sufficiently long to be easily observed on the oscilloscope (figure 27). A very short afterglow from beryl was recorded by the VRE but could not be resolved on the oscilloscope.

Decay of phosphorescence from most substances obeys either an exponential e^{-at} or power law t^{-n}, or a combination of both. A plot of the observed data (fig. 28) indicates that fluorite has simple exponential decay; kyanite and scheelite are nearly exponential.

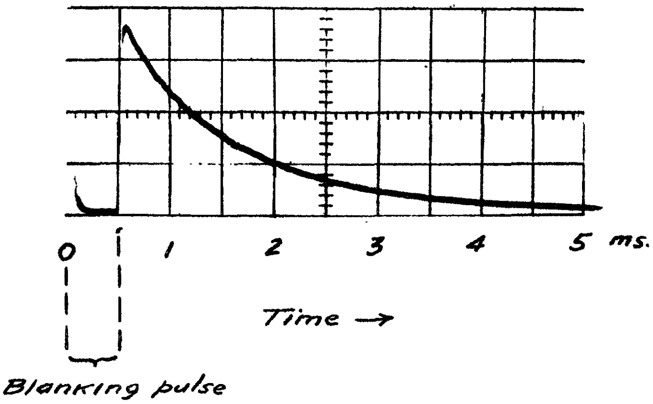

Fig. 27.—Oscilloscope photograph showing infrared phosphorescence decay of fluorite

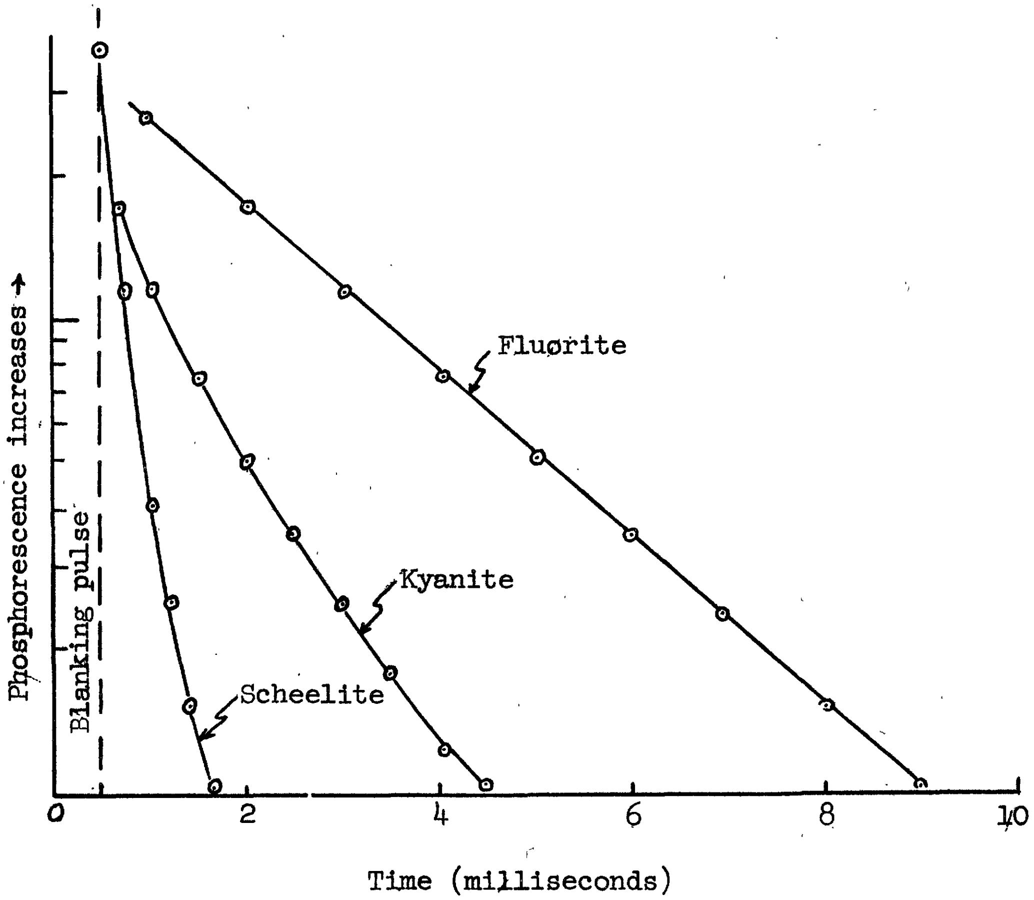

Fig. 28.—Infrared phosphorescence decay of fluorite, scheelite, and kyanite

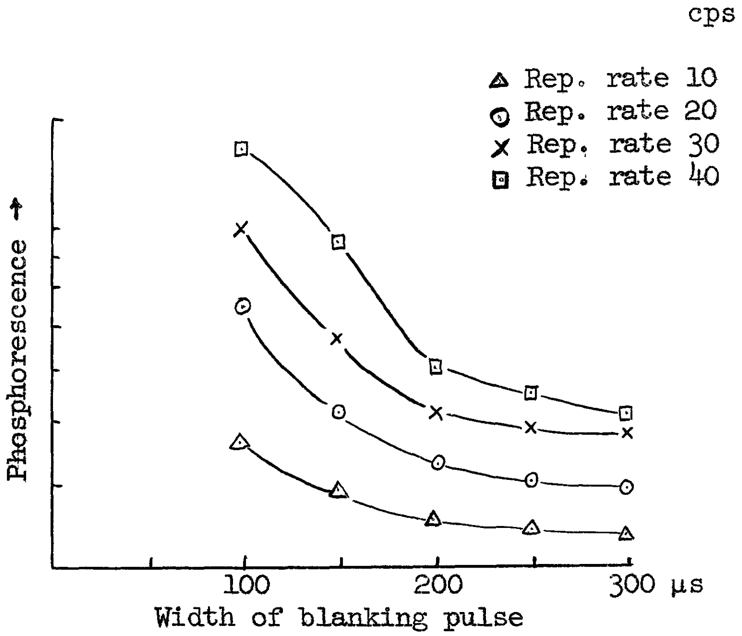

Fig. 29 Relation of phosphorescence output to pulse repetition rate

The effect of pulse repetition rate is shown in figure 29. Intermittent flash tube firing was experienced at rep rates >40 per second. Presumably the phosphorescence output will build up to some "saturation" value as the rep rate increases.

The FT-220 flash tube will be replaced by an EGG FX-12 in an effort to reduce the excitation period and to increase the rep rate capacity so that the output of the fast phosphors can be examined and the optimum rep rate for maximum phosphorescence output can be established.

References

Barnes, D. F., 1958, Infrared luminescence of minerals: U. S. Geol. Survey Bull. 1052-C.

Skarsvåg, Kristian, 1955, Method of recording the decay of phosphorescence: Rev. Sci. Instrumento, Vol. 26, no. 4.