Geologic and Airborne Radioactivity Studies in the Rock Corral Area San Bernardino County California

GEOLOGICAL SURVEY BULLETIN 1021-C

This report concerns work done on behalf of the U. S. Atomic Energy Commission and is published with the permission of the Commission

A CONTRIBUTION TO GENERAL GEOLOGY

GEOLOGIC AND AIRBORNE RADIOACTIVITY STUDIES IN THE ROCK CORRAL AREA, SAN BERNARDINO COUNTY, CALIFORNIA

By R. M. Moxham, G. W. Walker, and L. H. Baumgardner

ABSTRACT

The investigation in the Rock Corral area was undertaken to determine the relation between the anomalously high radioactivity recorded during an airborne survey and the distribution and mode of occurrence of radioactive material. Thorium-bearing minerals occur in relatively small, highly radioactive biotite-rich inclusions in a porphyritic quartz monzonite. Radioactive accessory minerals are also disseminated in the porphyritic quartz monzonite and in detritus derived from the porphyritic quartz monzonite. The configuration and amplitude of the major radioactivity anomalies detected from the air indicate that they have resulted chiefly from the large masses of porphyritic quartz monzonite rather than the biotite-rich inclusions. An analysis of the recorded radioactivity anomalies in the Rock Corral area and the equivalent-uranium content of the source rocks indicates that the lower limit of sensitivity of the airborne equipment, with respect to gross geologic features, is probably 0.001 percent.

INTRODUCTION

FIELDWORK

The investigation was undertaken to determine the relation between the anomalously high radioactivity detected during an airborne survey and the distribution and mode of occurrence of radioactive material in an area of about 1¾ square miles near Rock Corral, San Bernardino County, Calif. (fig. 29). A secondary objective was to determine whether the concentrations of radioactive minerals might constitute potential sources of thorium or uranium.

In 1949, prospectors discovered a number of small masses of rock containing thorium-bearing minerals in the vicinity of Rock Corral. In early 1952, preliminary reconnaissance examinations of the known occurrences and adjacent area by D. F. Hewett, G. W. Walker, and L. H. Baumgardner indicated that some biotite-rich inclusions in plutonic rocks exposed in the Rock Corral area contained concentra-

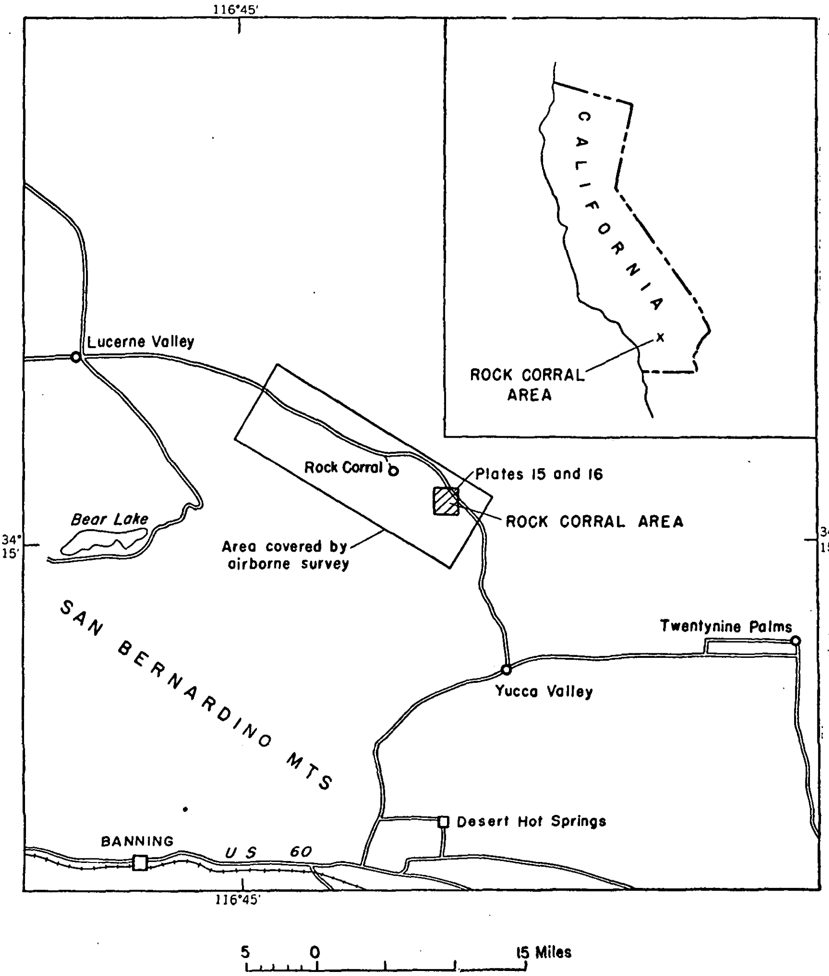

FIGURE 29.—Index map of the Rock Corral area, San Bernardino County, Calif.

tions of radioactive minerals. An airborne radioactivity survey seemed desirable to prospect for additional biotite-rich inclusions or other concentrations of the radioactive materials. In March 1952, an airborne radioactivity survey of about 80 square miles was made (Moxham, 1952) in the vicinity of Rock Corral (pl. 15). The airborne survey determined that anomalous radiation intensity, which was recorded in many parts of the area, was concentrated principally in four localities to the east and southeast of Rock Corral, and also that some of the anomalies were of the greatest amplitude recorded by the airborne equipment over natural sources. One of the four areas mentioned includes the anomaly of greatest peak intensity recorded in the Mojave Desert region, as well as several lesser anomalies, and for that reason was selected for the detailed study on the ground.

The investigation, made in June 1952, consisted of geologic reconnaissance mapping of an area of approximately 1¾ square miles, referred to as the Rock Corral area. A radioactivity survey was made on a 300-foot grid in a selected portion of the area (pl. 16), and the various rock types exposed in the area were sampled for petrographic study and for analyses of their equivalent-uranium content. This work was done in behalf of the Division of Raw Materials of the Atomic Energy Commission.

LOCATION OF THE AREA

The area is in San Bernardino County, Calif., 50 miles east-northeast of San Bernardino. The mapped portion is on the northeast flanks of the San Bernardino Mountains, on the southern edge of the Mojave Desert. Most of the area is in secs. 4 and 9, T. 2 N., R. 5 E. San Bernardino meridian, though a part extends into sec. 5 and part may extend into sec. 8. Rock Corral, which is located at one of the few permanent springs in the region, lies 5 miles northwest of the center of the mapped portion.

STRATIGRAPHY

No previous geologic mapping has been done in the area described, although reconnaissance mapping by Vaughan (1922) in an extensive area a few miles to the west and southwest has established a background adequate for a discussion of the geologic environment of the radioactive minerals. The Rock Corral area is geologically similar to the area mapped by Vaughan and to the other areas in the western Mojave Desert. In these adjacent areas the plutonic rocks, which intrude pre-Cambrian metamorphic rocks, are divided by Vaughan into "heterogeneous plutonic rocks" of undetermined age and a younger intrusive called the Cactus granite of probable Late Jurassic age. According to D. F. Hewett, U. S. Geological Survey, recent studies indicate the intrusive rocks named Cactus granite by Vaughan are probably Cretaceous rather than Late Jurassic in age (oral communication, December 1951).

PRE-CAMBRIAN ROCKS

Metamorphic rocks of pre-Cambrian age are exposed predominantly in the northeast and east part of the mapped area (pls. 15 and 16) and consist of biotite gneiss, siliceous metasedimentary rocks, and dark intercalated recrystallized metavolcanic(?) rocks. The metamorphic rocks are contorted and intricately intruded by porphyritic quartz monzonite of pre-Cretaceous age and are commonly recrystallized adjacent to contacts with the quartz monzonite. Many apophyses and small separate masses of quartz monzonite containing substantial quantities of wall rock occur in these recrystallized zones. Some of the recrystallized metamorphic rocks and the quartz monzonite containing wall rock are megascopically similar, and in many localities the various petrographic types are so intricately related as to preclude mapping as individual units. They have been grouped, therefore, into a single unit labelled "igneous and metamorphic complex" (pls. 15 and 16).

PRE-CRETACEOUS ROCKS

The pre-Cambrian rocks have been intruded by buff to gray pre-Cretaceous quartz monzonite, which in detail has a considerable range of textures and compositions; in most places the rock is porphyritic, containing alined, but erratically distributed, orthoclase phenocrysts in a medium-grained groundmass. An average sample of the quartz monzonite contains orthoclase (about 40 percent), plagioclase that ranges in composition from oligoclase to calcic andesine (about 30 percent), quartz (about 20 percent), biotite (3 to 5 percent), small amounts of magnetite, allanite, apatite, zircon, muscovite, fluorite, and minor amounts of many other accessory minerals. Chlorite, derived from biotite, is present in small amounts, and most of the feldspar has either been sericitized or saussuritized. Locally, as in the southwest part of the area, the orthoclase phenocrysts predominate over the groundmass, and the quartz monzonite contains only sparse mafic and accessory minerals. In other outcrops, the mafic and accessory minerals are abundant.

Near contacts with the pre-Cambrian metamorphic rocks, the quartz monzonite contains many metasomatically altered biotite-rich inclusions of wall rock. These inclusions range in shape and size from nearly equidimensional masses as much as 20 feet in diameter to 50-foot tabular plates, which may represent reconstituted sections of sedimentary beds. Some inclusions, or small roof pendants, are gray mica schist and others are nonfoliated black masses composed of 80 to 90 percent biotite, minor amounts of andesine, magnetite, allanite, sphene, apatite, and zircon.

Parts of the Rock Corral area are underlain by a fine-grained intrusive(?) crystalline rock with a texture and composition like the groundmass of the porphyritic quartz monzonite. The fine-grained rock contains sparse accessory minerals except biotite, no orthoclase phenocrysts, and is commonly more strongly foliated than the quartz monzonite. Locally, contacts between the quartz monzonite and the fine-grained rock are sharp, whereas in other areas, contacts appear to be gradational; probably the fine-grained rock represents an early phase of quartz monzonite intrusion, perhaps correlative with the porphyritic quartz monzonite. Small intrusive bodies of quartz-feldspar pegmatite, probably genetically related to the quartz monzonite, occur in areas underlain by the igneous and metamorphic complex and the pre-Cambrian metamorphic rocks.

CRETACEOUS ROCKS

The Cactus granite of Vaughan (1922), which is younger than the porphyritic quartz monzonite, intrudes both the pre-Cretaceous quartz monzonite and the pre-Cambrian metamorphic rocks. On the west edge of the area, in a typical exposure, the granite is uniformly coarse grained, light gray, and composed of orthoclase, andesine, quartz, and minor amounts of biotite, magnetite, chlorite, muscovite, zircon, apatite, sphene, and allanite. The plagioclase and orthoclase may be present in equal amounts, though commonly the plagioclase predominates; according to some rock classifications the rock would be a quartz monzonite rather than a granite.

Many fine-grained felsic sills and dikes extend from the main granite body into the older rocks. The texture and composition of the sills and dikes near the main intrusive mass are identical with the Cactus granite, but at localities more remote from the main mass these apophyses are commonly very fine grained, locality porphyritic, and resemble dacite. A few of the fine-grained dikes, not definitely correlated with the Cactus granite, may possibly be Tertiary volcanic intrusive rocks, but in this report all of them are grouped with the Cactus granite.

TERTIARY AND QUATERNARY ROCKS

Small remnants of a Tertiary olivine basalt flow are exposed in the southwest part of the mapped area. Areas adjacent to the dry washes are covered by Quarternary bench gravels or slope wash. The washes and valleys of the mapped area are floored with Recent alluvium.

STRUCTURE

The dominant faults trend northwest and dip at steep angles both east and west. Although the regional structure is poorly known, it is believed that some of the northwest-trending faults in the Rock Corral area are extensions of normal faults which other workers have mapped along the northeast edge of the San Bernardino Mountains. The movement on these faults has dropped the valley, or northeast block, in relation to the mountain, or southwest block. Some of the northwest-trending faults may have existed before the intrusion of the porphyritic quartz monzonite, though recurring movement along these, or later parallel faults, has displaced masses of Cactus granite of Vaughan and possibly also displaces the olivine basalt of Tertiary age. A second set of faults, which trends northeast, locally offsets the northwest-trending faults. Some of the faults, which trend northeast, are displaced by northwest-trending faults. Many of those zones of rupture are filled with intrusive Cactus granite or with a fine-grained, dacitelike rock comparable to the Cactus granite.

OCCURRENCE OF RADIOACTIVE MINERALS

Petrographic studies of 18 samples of rocks of the area indicate that several radioactive accessory minerals are present. Significant concentrations of these accessory minerals occur in metasomatically altered, biotite-rich inclusions in the quartz monzonite, in porphyritic quartz monzonite, and in detritus deposited in washes that drain outcrop areas of the porphyritic quartz monzonite. Not all outcrops of the rock types mentioned above, however, contain significant concentrations of the radioactive accessory minerals.

The minerals responsible for the radioactivity of the various rock types were for the most part identified either by means of radioactivity measurements of relatively pure fractions of a particular mineral, or by the presence of pleochroic halos around a particular mineral species. Some accessory minerals such as monazite (?) and xenotime (?) were present in such small quantities that it was not possible to separate a pure fraction for radioactivity tests nor were they found in association with biotite. Probably such minerals do contain radioactive elements and have contributed to the total radioactivity in the Rock Corral area.

The radioactive minerals that have been identified include allanite, zircon, apatite, sphene, monazite(?), and xenotime(?). Allanite is the principal source of the anomalous radioactivity in the Rock Corral area.

Eight samples representative of each of the four major lithologic types in the area were collected for determination of equivalent-uranium content. Each bedrock sample consisted of fresh chips collected at about 3-foot intervals along lines indicated on plates 15 and 16; the samples of alluvium represent surficial material collected at about 3-foot intervals along the lines indicated on the same plates.

Equivalent-uranium content determined by beta-gamma radioactivity measurements

[Analyst, B. A. McCall, U. S. Geological Survey]

Sample	Description	Equivalent uranium (percent)
1	Biotite-rich inclusion	0.032
2	Porphyritic quartz monzonite	.007
5	do	.008
6	do	.008
7	do	.007
9	Alluvium	.0023
10	Metasedimentary rocks	.0026
11	Alluvium	.0026

The heavy minerals (>3.3 specific gravity) were separated from the rest of sample 6 and further separated into magnetic-susceptibility fractions by means of an alnico magnetic and a Frantz isodynamic separator. Each magnetic fraction was analyzed for equivalent-uranium content.

Analysis of heavy-mineral portion of sample 6

[Analyst, B. A. McCall, U. S. Geological Survey]

Magnetic-susceptibility fraction	*Equivalent uranium (percent)*
Alnico magnetic (few grains)	----
Frantz, 0.3 amp	0.09
Frantz, 0.6 amp	.17
Frantz, 0.9 amp	1.00
Nonmagnetic	.24

PORPHYRITIC QUARTZ MONZONITE

Samples of various phases of porphyritic quartz monzonite collected from different localities in the area contain an unusual number of accessory minerals, and the relative abundance of the accessory minerals differs in each phase. The porphyritic quartz monzonite, in which the groundmass predominates over the orthoclase phenocrysts, invariably contains a greater abundance and probably a greater assortment of accessory minerals than the quartz monzonite in which the phenocrysts predominate. The most abundant accessory mineral identified is biotite, but the rocks also contain magnetite, ilmenite, fluorite, apatite, allanite, many varieties of zircon, two varieties of sphene, and lesser amounts of zoisite, rutile, xenotime(?), corroded hornblende, tourmaline, garnet, monazite(?), and topaz(?). Some outcrops of quartz monzonite, in which the groundmass predominates, contain appreciably more biotite and fluorite than similar-textured quartz monzonite elsewhere. An increase in the biotite and fluorite content generally indicates an increase in the content of allanite, zircon, and apatite and may indicate an increase in the monazite(?) and xenotime(?). A point-count petrographic analysis was made of a thin section of porphyritic quartz monzonite which contains fluorite, moderate amounts of biotite, and other accessory minerals. The analysis shows that locally this rock contains as much as 4.5 percent allanite and nearly 1.5 percent zircon.

In all types of porphyritic quartz monzonite, the allanite and some types of zircon are definitely radioactive; both are invariably surrounded by pleochroic halos where found in contact with biotite. Nearly pure fractions of the allanite and zircon are appreciably radioactive. Monazite(?) and xenotime(?) occur only in minute quantities and are not found in association with biotite; they have been classed, therefore, as probably radioactive. Apatite, locally abundant and commonly associated with biotite, is essentially nonradioactive; however, a few apatite grains, containing minute unidentified inclusions are surrounded by faint pleochroic halos in the enclosing biotite. Sphene, like apatite, is considered essentially nonradioactive, though one grain of sphene observed in a thin section is apparently surrounded by a faint pleochroic halo. Tests of the other accessory minerals indicate that they are not radioactive.

Porphyritic quartz monzonite, which contains concentrations of both biotite and fluorite and appreciable amounts of radioactive minerals, crops out extensively along the ridge northwest of check point 76, flight line 4*A* (pls. 15 and 16) and north to the fault contact between the quartz monzonite and the igneous and metamorphic complex. South of the ridge, to midway between flight lines 4*A* and 5, the quartz monzonite contains appreciably less fluorite; the biotite, zircon, and allanite content south of the ridge varies locally, but is commonly less than in the quartz monzonite along the crest and north of the ridge. Allanite, zircon, and probably other radioactive minerals are present in the masses of the porphyritic quartz monzonite exposed in the north and northeast part of the area. However, no attempt has been made to determine the quantity or distribution of the radioactive minerals in these masses.

Spectrographic analysis of sample 6

[Analyst, H. W. Worthing, U. S. Geological Survey]

Element	*Percent*
Al, Si	over 10
Ca, K, Na, Fe	1.0–10.0
Mg, Ba	0.1–1.0
Ce, Sr, Ti, Nd, B, Cr, La, Mn, Fr, Co	0.01–0.1
Pb, Ga, V, Cu, Sc	0.001–0.01
Yb, Be	0.0001–0.001

INCLUSIONS RICH IN BIOTITE

The mineralogic composition of the biotite-rich inclusions varies only slightly from one inclusion to another but the inclusions invariably contain not less than 60 percent of olive-green to brown biotite. A thin section of a sample from an inclusion about 15 feet in diameter was analyzed petrographically by the point-count method. The analysis shows about 74 percent biotite, about 8 percent feldspar, slightly more than 7 percent allanite, 5 to 6 percent magnetite, about 3 percent apatite, and 1 percent of each sphene and zircon. The radioactivity of the inclusion is due largely to the high content of allanite; distinct pleochroic halos surround crystals of both allanite and zircon. Other biotite-rich inclusions exposed in the area are also appreciably radioactive, probably due to the content of allanite.

Biotite-rich inclusions in the porphyritic quartz monzonite are exposed at only a few localities in the Rock Corral area. All of the appreciably radioactive inclusions occur in the south-central part of the area. The total outcrop area of all the biotite-rich inclusions is not more than a few hundred square feet in an area of nearly 1¾ square miles.

ALLUVIUM

Some of the alluvium, which fills the washes that drain areas underlain by porphyritic quartz monzonite containing significant quantities of wall rock, is nearly identical in mineralogic composition to the source rocks. The alluvium in these washes is composed of abundant quartz and feldspar, and lesser amounts of biotite and accessory minerals. Some placer concentrations of dark-colored minerals occur as thin discontinuous layers in the alluvium and, locally, on the surface of the alluvium. The principal constituents of the dark layers are quartz, feldspar, biotite, and magnetite; the content of radioactive minerals is only slightly greater than that found in typical specimens of porphyritic quartz monzonite.

RADIOACTIVITY SURVEYS

AIRBORNE SURVEY

The airborne radioactivity survey in the Rock Corral area was made with gamma-radiation detection equipment mounted in a multi-engine aircraft. A nominal flight level of 500 feet was maintained during all traverses, and the distance of the aircraft from the ground was measured with a radar altimeter and continuously recorded by a graphic milliammeter. Aerial photographs were used for pilot guidance, and the flight path of the aircraft was recorded by a 35 millimeter gyrostabilized camera using continuous-strip film (Jensen and Balsley, 1946).

The observer integrated the data by means of a synchronous circuit that simultaneously marked the radiation and altimeter records and the strip film, thereby relating the flight records to the ground.

All measurements of gamma radiation intensity were made with scintillation equipment developed by the Oak Ridge National Laboratory, Division of Health Physics, in cooperation with the Geological Survey. The components of the equipment are shown in figure 30. The equipment consists of two independent detecting and recording units operated from a common power supply. The detectors of each unit consist of three thallium-activated sodium iodide crystals 2 inches thick and 4 inches in diameter. A photomultiplier tube, mounted in direct contact with each crystal, detects the scintillations and feeds the resultant pulses into the amplification stages. The amplified pulses are fed into a count-rate recorder which is essentially similar to a scaling circuit. The incoming signal is measured over a 1-second period and is recorded in the following 1-second interval. A con-

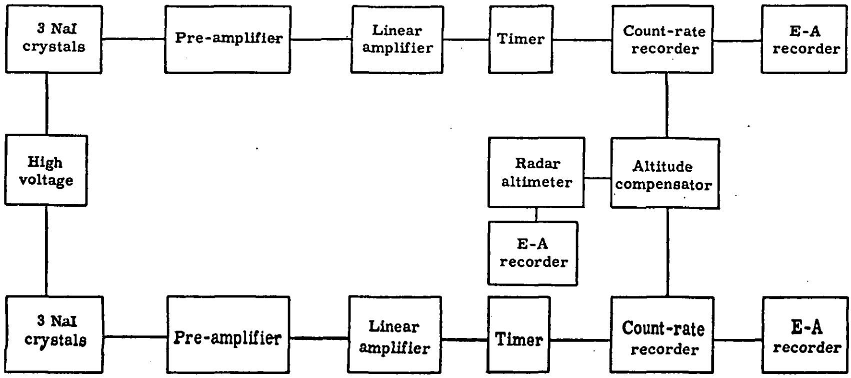

FIGURE 30.—Diagram of the scintillation detection equipment.

tinuous record is provided through the incorporation of two identical channels in each count-rate recorder which alternately measure and record the radiation intensity. A mechanical timer driven by a synchronized motor provides the necessary switching. The development of this recording technique has been described elsewhere.[1]

A d-c bucking voltage is utilized to eliminate, in effect, the cosmic component from the total counting rate so that the recorded intensity represents the net counting rate. To compensate automatically for variation in radiation intensity with variation in distance from the ground, the output of the radar altimeter is fed into the recording circuit in such a manner as to modify the sensitivity of the count-rate recorder proportional to $e^{-\mu x}$ (where μ=linear absorption coefficient of the air, and x=height of the aircraft above the ground). This function is an approximation of the relation between the distance and radiation intensity from a semi-infinite plane source.

The flight lines of the airborne survey (fig. 29) were oriented in a northwestward direction and, in the greater part of the area, were spaced at quarter-mile intervals. In the eastern part of the area, intermediate flight lines were spaced at eighth-mile intervals to provide greater detail near known occurrences of radioactive materials. Seven flight lines (2*A*, 3, 3*A*, 4, 4*A*, 5, and 5*A*), spaced at approximate eighth-mile intervals, cross the area (pls. 15 and 16).

The width of the zone on the ground from which anomalous radioactivity is measured at the nominal 500-foot flight altitude varies with the areal extent and tenor of the source rocks. However, at quarter-mile flight-line spacing the radiation from smaller areas of considerable intensity, located midway between the flight lines, probably would not be resolved. By employing an eighth-mile flight-line

[1] Stead, F. W., 1951, Airborne radioactivity survey in the vicinity of Grants, McKinley, and Valencia Counties, New Mexico: U. S. Geol. Survey, Trace Elements Memo. Rept. 161.

interval at a nominal 500-foot altitude, smaller variations of the source distribution are better delineated.

The data of the airborne radioactivity survey were compiled as an isoradioactivity contour map (pl. 15) in order to determine the relation between the measurements of radiation intensity at the 500-foot flight level and the surface distribution of source materials. The intensities shown are net values (total minus cosmic).

The maximum radiation intensity recorded at the 500-foot flight level over the middle of the mapped area is related to the main mass of quartz monzonite. On flight line 4*A* the radiation intensity exceeded the limit of the graphic recorder so that the configuration of the peak of the anomaly is not fully known. The shape of the profile of radiation intensity along this line suggests that at least one, and possibly two, additional contours would be needed to delineate the true radiation magnitude. One additional contour has been sketched on plate 15, but its location may be considerably in error. The areal extent of the principal anomaly in the central part of the area conforms in most places to the principal outcrop area of quartz monzonite. A northeastward extension of the principal anomaly conforms in general to the alluvium-filled wash that drains the northern part of the main mass of quartz monzonite. Another extension in the east-central part of the area is situated over outcrops of the igneous and metamorphic complex, which contains a considerable amount of quartz monzonite. In most localities a rather sharp decrease in the radiation intensity was recorded over the fine-grained intrusive(?) rock that borders the porphyritic quartz monzonite on the north and east.

The gneiss of pre-Cambrian age and metasedimentary and metavolcanic(?) rocks are generally low in radioactivity, as is the Cactus granite, which occupies the western part of the area. The areas of basalt of Tertiary age in the southwest and south-central part of the area are rather small and appear to have had little influence on the configuration of the radiation flux.

The typical relation between the profile of radiation intensity at the 500-foot flight level along flight line 5, and the various geologic units in the mapped area is shown in figure 31.

GROUND SURVEY

The radioactivity survey on the ground was undertaken to determine the surface distribution of radioactive materials in the Rock Corral area and to relate the surface distribution to the data obtained by measurements at the 500-foot flight level.

The survey was made by occupying stations on a 300-foot grid, with one coordinate of the grid coinciding with projections of the flight

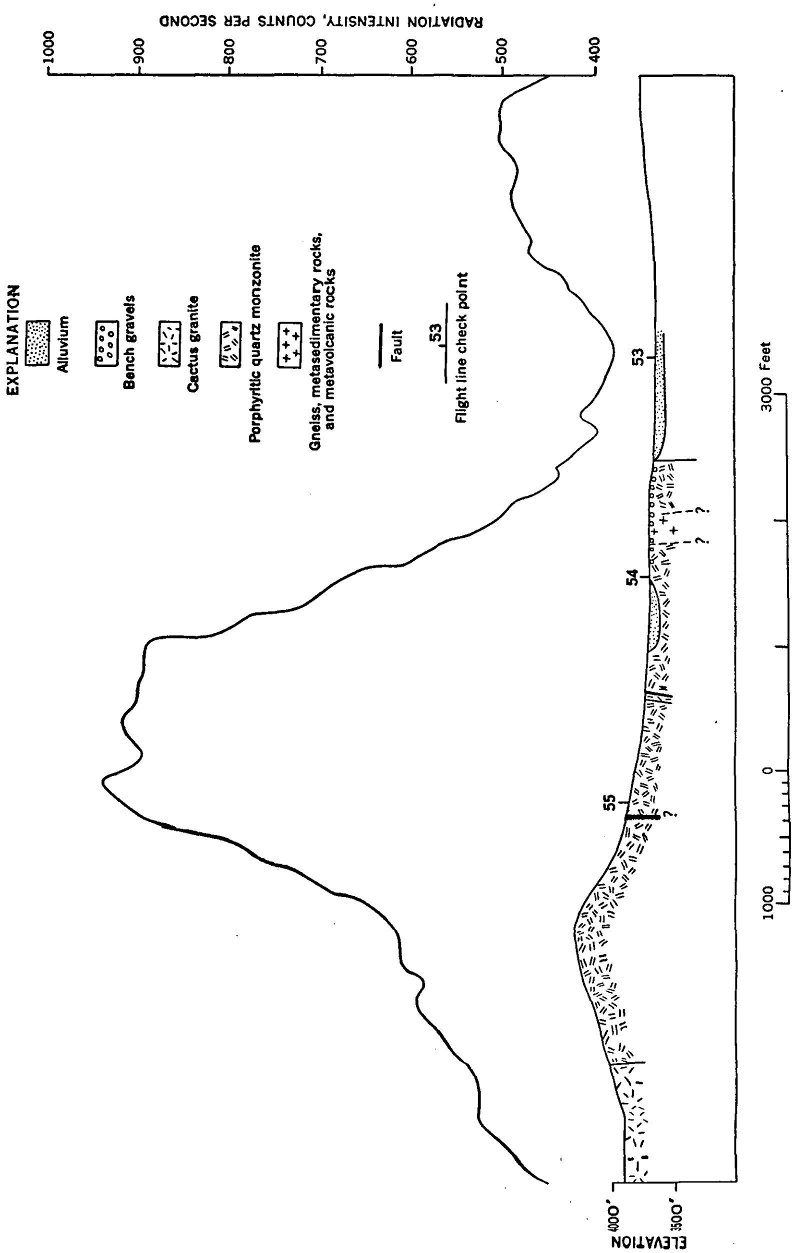

FIGURE 31.—Geologic section and radiation intensity profile along flight line 5.

lines. The data obtained were compiled as an isoradioactivity contour map (pl. 16).

All radioactivity measurements were made with a portable survey meter, equipped with a brass-walled Geiger counter 2 inches in diameter and 24 inches long. The net radioactivity was determined at each station and the results were contoured at an interval of 6 μr/hr (microroentgens per hour). The resulting isoradioactivity map presents only the gross configuration of the radioactivity field, owing to the rather wide spacing of the survey grid necessitated by the relatively large area to be covered. For instance, the felsic dikes, related to the Cactus granite, and the biotite-rich inclusions are relatively small geologic features which are quite negatively anomalous insofar as their radioactivity is concerned, but few of these small features could be resolved on the 300-foot grid.

The occurrences of radioactive materials are confined chiefly to the biotite-rich inclusions and the quartz monzonite host rock. The minerals responsible for the radioactivity have been described.

The biotite-rich inclusions in the quartz monzonite contain the most significant concentrations of radioactive minerals in the Rock Corral area. A chip sample, collected across the biotite-rich mass at sample location 1, contains 0.032 percent eU (equivalent uranium), which is the maximum radioactivity found in the area. None of the biotite-rich masses were so situated geographically or were of sufficient size or tenor to influence materially the configuration of the radiation flux.

The average equivalent-uranium content of the principal mass of quartz monzonite in the central part of the area is about 0.006 percent. The radioactivity is highest in the northeastern part of the outcrop area where the quartz monzonite is in fault contact with the igneous and metamorphic complex. In the areas of maximum radiation intensity the quartz monzonite, there moderately porphyritic, probably contains as much as 0.009 percent eU; to the southwest, the rock becomes increasingly fine grained and the equivalent-uranium content decreases to an average of 0.003 percent.

In most areas there is a sharp decrease in radioactivity from the porphyritic quartz monzonite to the foliated fine-grained intrusive(?) rock that bounds the quartz monzonite on the northeast (geologic contact shown by dashed line in pls. 15 and 16). The radioactivity of the igneous and metamorphic complex varies directly with the amount of quartz monzonite included but is generally considerably lower than that of the main mass of the quartz monzonite.

The pre-Cambrian rocks are generally low in radioactivity. Sample 10, collected from an outcrop of metasedimentary rocks in the southeastern part of the area, contains 0.0026 percent eU. Likewise, felsic dikes related to the Cretaceous Cactus granite are relatively low in radioactivity, probably containing less than 0.002 percent eU. The composition of the slope wash is essentially the same as the quartz monzonite from which it was derived and in general is comparable in radioactivity to the parent material. Two samples of alluvium (9, 11) contain 0.0023 and 0.0026 percent eU respectively. The main outcrop areas of the Tertiary olivine basalt flows are a short distance beyond the limits of the radioactivity survey on the ground. The radiation intensity measured in the airborne survey indicates that the basalt contains negligible quantities of radioactive material.

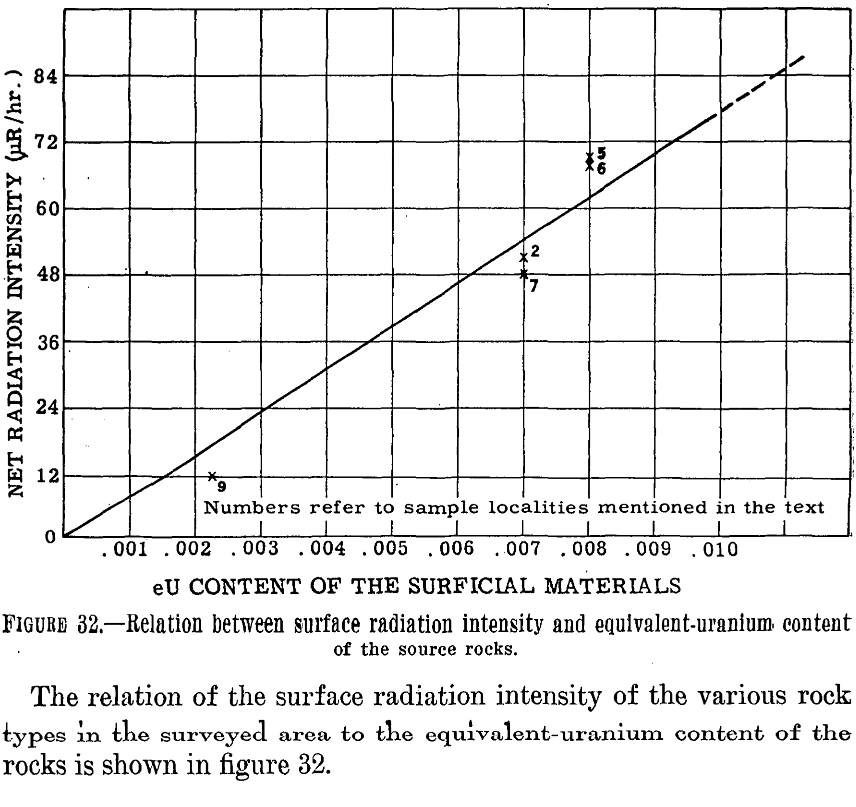

FIGURE 32.—Relation between surface radiation intensity and equivalent-uranium content of the source rocks.

The relation of the surface radiation intensity of the various rock types in the surveyed area to the equivalent-uranium content of the rocks is shown in figure 32.

RELATION OF RADIOACTIVITY OF THE ROCKS TO MEASUREMENTS FROM THE AIR

This study was undertaken to determine the relation between the distribution of radioactive materials in the rocks and measurements of the radioactivity from the air. More specifically it was desired to know whether or not the high measurements are due to biotite-rich thorium-bearing inclusions or from some other material.

The principal anomalies in the mapped area, as shown on plate 15, are symmetrically disposed in relation to the outcrop areas of the quartz monzonite of pre-Cretaceous age, the igneous and metamorphic complex containing quartz monzonite, and the alluvium containing a high percentage of quartz monzonite detritus. Assuming that the major anomalies have resulted solely from the quartz monzonite masses described above, with no contribution from the biotite-rich bodies, then the areal extent of the source materials would for the most part constitute a semi-infinite plane, with respect to the solid angle of response of the airborne detector. The behavior of the airborne equipment with respect to a semi-infinite plane source has been determined [2] as follows:

$$I_b = (kS/A_0S_0)\ (1-0.342\mu x)\, e^{\mu x} \cdot 2\pi \quad (1)$$

where I_b = response of the detector in cps (counts per second)
S = tenor of the semi-infinite source in percent eU (equivalent uranium)
S_0 = tenor of the calibration source (0.35 percent eU)
A_0 = area of the calibration source (1,600 square feet)
k = instrumental constant (3.19×10^7)
μ = linear absorption coefficient (1.4×10^{-3} ft^{-1})
x = altitude (500 ft)

At flight line 4, which crosses the northern part of the principal quartz monzonite outcrop, the peak intensity recorded (I_b) is about 1,000 cps. Solving equation (1) for S, an equivalent-uranium content of 0.0075 percent is obtained. Sample 6, collected a short distance south of the vertical projection of flight line 4, contains 0.008 percent eU.

In the eastern part of the area, flight line 4 crosses an area (between check points 34 and 35) underlain by alluvium. The average I_b over this material as shown on plate 16 is about 350 cps. From equation (1), S=0.0026 percent eU. Radiometric assay of sample 11 shows an equivalent-uranium content of 0.0026 percent.

It would appear that the gross source materials in the Rock Corral area closely follow behavior typified by semi-infinite plane sources. This fact becomes more apparent if the opposite assumption is made, that is, that the large anomalies have resulted from a point source, such as a biotite-rich body. The response of the airborne detector with respect to a point source has been determined [3] as follows:

$$I_p = (k\ ASe^{-\mu r}x/A_0S_0r^3)\ (1+\mu r-0.342[\mu r]^2) \quad (2)$$

where I_p = net response of the detector in cps above background (see below)
S = tenor of the point source (percent equivalent uranium)
S_0 = tenor of the calibration source (0.35 percent equivalent uranium)

[2] Sakakura, A. Y., 1954, U. S. Geol. Survey unpublished report.
[3] Sakakura, A. Y., idem.

A = area of the point source (square feet)
A_o = area of the calibration source (1,600 square feet)
k = instrumental constant (3.19×10^7)
μ = linear absorption coefficient (1.4×10^{-3} ft^{-1})
x = altitude (500 ft)
r = air distance from source to detector (The value of x/r will be assumed to be unity, that is, the center of the source is vertical with respect to the detector, and r=500 feet.)

In the point source equation, I_p is the net amplitude of the anomaly, that is, the peak intensity minus the intensity recorded over the adjacent "normal" rocks. The peak intensity recorded in the vicinity of the biotite-rich masses was in excess of the full-scale deflection of 1,000 cps. However, assuming that the peak value is 1,000 cps and the background intensity 350 cps (see plate 15), I_p then becomes 650 cps. Solving equation (2) for SA, the grade × area of the assumed point source must have a value of 3,770. Now, there is a total of five biotite-rich masses along line 4*A*, west of check point 76, so close together that it is conceivable that they would not be resolved individually, but would be recorded as a single anomaly. Most of the biotite-rich masses are very small, rarely exceeding a few tens of square feet in extent, so that a value of 1,000 square feet for a total A for the five biotite-rich masses would be a liberal figure. Thus, SA having a value of 3,770, S would be approximately 3.77 percent eU. A sample of one of the more radioactive of the biotite-rich masses contains 0.032 percent eU, so it seems certain that the anomalies in the Rock Corral area did not result from the small thorium-bearing masses.

Some speculation on the lower limit of sensitivity of the airborne equipment may be warranted from the flight data obtained during the Rock Corral survey. The sensitivity scale on which the equipment was operated had a full-scale deflection of 1,000 cps. Full-scale deflection was obtained over relatively broad source rocks containing about 0.007 percent eU so that a change of 0.001 percent in the equivalent-uranium content of the source rocks would result in a change of about 14 percent in the recorded radiation intensity, if a linear relationship may be assumed. The range of statistical deviation of the measurements during the Rock Corral survey was about 5 percent, so that changes on the order of 0.001 percent in the equivalent-uranium content of broad source materials should be within the detectable limit of the airborne equipment, assuming conditions of geometry and energy spectrum comparable to those existing in the Rock Corral area.

For example, consider the area of anomalous radioactivity measurements outlined by the isoradioactivity contours (pl. 16), which extends northeastward from flight line 3*A* across lines 3 and 2*A*. The peak intensity along the crest of the anomaly is somewhat in excess of

30μr/hr, and the average equivalent-uranium content of the source rocks (as determined from fig. 32) is approximately 0.004 percent. In a northwestward direction from the crest, the radiation intensity at ground level decreases to about 12μr/, indicating that the equivalent-uranium content has decreased to between 0.001 and 0.002 percent. The radioactivity anomaly detected from the air, outlined by the isoradioactivity contours (pl. 15), has therefore resulted from an overall difference in equivalent-uranium content of about 0.003 percent in source rocks occupying about 10,000 square feet. The anomaly in question is well defined by the airborne data and it seems likely that a lower sensitivity limit of 0.001 percent eU is possible for geologic units of similar extent.

CONCLUSIONS

Radioactive materials in the Rock Corral area are confined chiefly to: Quartz monzonite intrusive masses, containing as much as 0.009 percent eU—the radioactivity is attributed to disseminated thorium-bearing accessory minerals, chiefly allanite and zircon; biotite-rich inclusions in the quartz monzonite, usually less than a hundred square feet in extent, containing as much as 0.03 percent eU—the radioactivity is attributed chiefly to allanite; and alluvium composed largely of quartz monzonite detritus.

The radioactivity anomalies detected from the air resulted from the outcrops of quartz monzonite, rather than from the small biotite-rich inclusions.

As the inclusions are associated with the most radioactive geologic unit in the area, it may be possible to determine other areas of the Mojave region most favorable for the occurrence of biotite-rich inclusions by delineating the outcrops of the abnormally radioactive host rock.

Well-defined anomalies were recorded over source rocks of about 10,000 square feet in areal extent, which are anomalous only to the extent of 0.003 percent eU, with respect to contiguous rocks. It is concluded that a lower sensitivity limit of the airborne equipment is at least 0.001 percent eU for geologic units of comparable extent.

LITERATURE CITED

Jensen, Homer, and Balsley, J. R., 1946, Controlling plane position in aerial magnetic surveying: Eng. and Min. Jour., v. 147, no. 8, p. 94–95, 153–154.

Moxham, R. M., 1952, Airborne radioactivity surveys in the Mojave Desert region, Kern, Riverside, and San Bernardino counties, California: U. S. Atomic Energy Commission, Tech. Inf. Service, TEM–360.

Vaughan, F. E., 1922, Geology of the San Bernardino Mountains north of San Gorgonio Pass: Calif. Univ., Dept. Geol. Sci., Bull., v. 13, no. 9, p. 319–411.

○