Thorium Resources of the Mountain Pass District, San Bernardino County, California

By D. R. Shawe

Trace Elements Investigations Report 251

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Geology and Mineralogy

This document consists of 73 pages, plus 4 figures.
Series A

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

THORIUM RESOURCES OF THE MOUNTAIN PASS DISTRICT SAN BERNARDINO COUNTY, CALIFORNIA *

By

Daniel R. Shawe

March 1953

Trace Elements Investigations Report 251

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

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THORIUM RESOURCES OF THE MOUNTAIN PASS DISTRICT, SAN BERNARDINO COUNTY, CALIFORNIA

By Daniel R. Shawe

ABSTRACT

Rare earths and thorium deposits are found in a belt six miles long of pre-Cambrian carbonate rocks associated with potash-rich igneous rocks of probable pre-Cambrian age in the Mountain Pass district, San Bernardino County, California. Andesitic dikes of possibly early Tertiary age cut all the other rocks.

The thorium-bearing deposits studied during this investigation were the large Sulphide Queen carbonate body, which contains a small amount of monazite of probable pre-Cambrian age, and thorium-bearing shear zones on the Ray-Welch-Willmore and Windy groups, and other claims, in which thorite is the chief thorium mineral. The Sulphide Queen carbonate body is 2400 feet long and as much as 700 feet wide. Mineralized zones in the Ray-Welch-Willmore and Windy claims are about 3000 and 2000 feet long respectively, and as much as 100 feet wide. One vein in the Windy group is 300 feet long and 5 feet wide. Assays of samples show that the grade of the deposits ranges between 0.02 and 0.5 percent ThO_2; local concentrations contain as much as 6 percent ThO_2.

Thorite, monazite, allanite, and bastnaesite occur with chlorite, sericite, phlogopite, crocidolite, carbonates, barite, fluorite, quartz, hematite, magnetite, hydrated iron oxides, galena, and pyrite in the veins.

The andesitic dikes apparently have been instrumental in redistributing and concentrating thorium which was already in the intruded rocks. This is suggested by concentrations of thorite near many of the andesitic dikes where the dikes cut the belt of rare earths and thorium deposits, by the late development of thorite, and by hydrothermal alteration along faults that cut the carbonate rock.

INTRODUCTION

Location of the Mountain Pass district

The Mountain Pass district is in the northeastern corner of San Bernardino County, California, near the eastern edge of the Mojave Desert. U. S. Highway 91 passes through the district about 200 miles northeast of San Bernardino, California, and about 60 miles south-southwest of Las Vegas, Nevada (fig. 1).

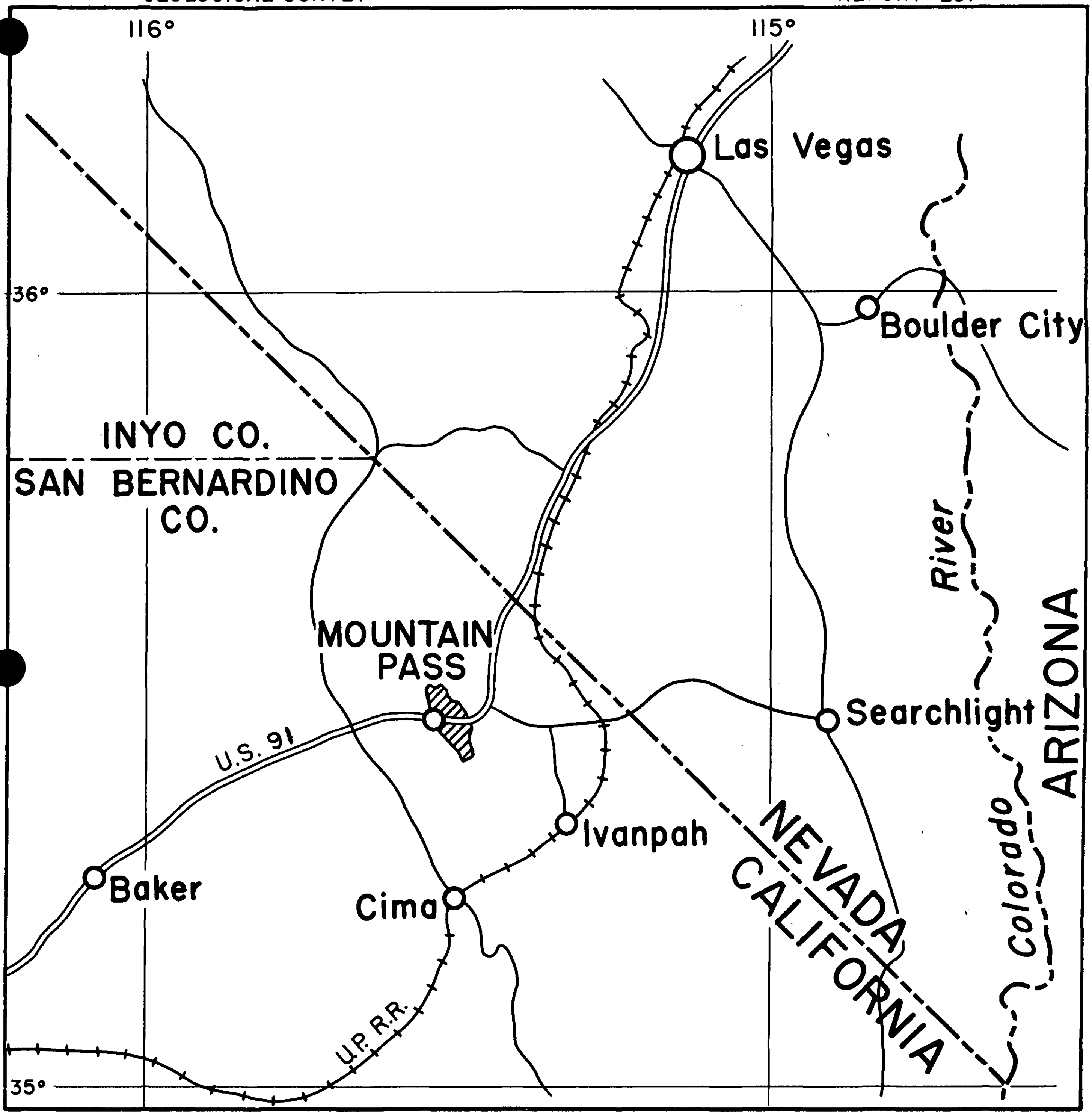


FIG. 1.-MAP SHOWING LOCATION OF MOUNTAIN PASS DISTRICT

15 0 30 Miles

GPO 830588

Previous work

The rare earths deposits of the Mountain Pass district were studied during the period 1949 to 1952 by several geologists of the U. S. Geological Survey. Late in 1949, L. C. Pray and W. N. Sharp mapped the Birthday area, the site of the original rare earths discovery, on a scale of 1 inch to 50 feet and Sharp made a preliminary examination of the radioactivity in the Birthday area (Sharp, 1950). Late in 1950 the Mountain Pass district was mapped on a scale of 1:15,000 by J. C. Olson who was assisted part of the time by E. D. Jackson. Also late in 1950, W. N. Sharp mapped, on a scale of 1 inch to 100 feet, the large Sulphide Queen carbonate body, now the site of mining operations by Molybdenum Corporation of America. The Sulphide Queen carbonate body was discovered during the course of the district mapping. Late in 1951, D. R. Shawe added details to the map of the Sulphide Queen carbonate body made by Sharp, and mapped the area between the Sulphide Queen carbonate and the Birthday area on a scale of 1 inch to 200 feet.

Field work and acknowledgments

Detailed investigation of the thorium resources of the district was made by Shawe between May 13 and June 17, 1952. Field work consisted of the mapping of several properties by plane-table and compass-and-pace methods and sampling for analytical and petrographic study. Sharp assisted in the field from May 19 to June 4, 1952. The work was done under the supervision of L. R. Page and J. C. Olson, of the Geological Survey on behalf of the Division of Raw Materials of the Atomic Energy Commission.

Radioactivity was measured in the field with a Geiger-Mueller type beta-gamma survey meter. Readings were taken with an open probe held against the outcrop and were recorded in milliroentgens per hour (mr/hr). A background radioactivity between 0.03 and 0.04 mr/hr was established for the rocks exposed in the area.

Acknowledgment is made of analyses, thin sections, and autoradiographs of thin sections made by Geological Survey's Trace Elements Section Denver Laboratory, and mineralogic work of radioactive age determinations on monazite, made by the Geochemistry and Petrology Laboratory of the Geological Survey in Washington, D. C.

GENERAL GEOLOGY

The geology of the Mountain Pass district has been described by Olson, et al. (in preparation) and accordingly only a brief summary is given in this report. The district is in an area of pre-Cambrian metamorphic rocks bounded on the west by Paleozoic and Mesozoic volcanic and sedimentary rocks and on the east by the alluvium of Ivanpah Valley (fig. 2).. The Clark Mountain normal fault separates the Paleozoic and Mesozoic rocks from the pre-Cambrian rocks. Movement on this fault probably originated during late Cretaceous time. Potash-rich igneous rocks and associated rare earths- and thorium-bearing carbonate rocks occur in a northwest-striking belt six miles long in the pre-Cambrian rocks. A tentative radioactive age determination on monazite from the carbonate rock by the Geochemistry and Petrology Branch of the Geological Survey indicates an age of 770 to 1100 million years. Field evidence indicates that the potash-rich igneous rocks are older than the carbonate rocks, and both are considered to be pre-Cambrian in age.

The potash-rich rocks, which in order of emplacement are shonkinite, syenite, granite, and shonkinitic dike rocks, and the associated carbonate rocks intrude the pre-Cambrian metamorphic rocks; all are cut by east-trending andesitic dikes of probably late Mesozoic or early Tertiary age. The east-trending dikes range in composition from dacite to basalt, but for convenience of reference they are called andesitic. The andesitic dikes are truncated by the Clark Mountain fault along which movement has recurred since its inception.

Thorite and monazite account for the largest part of the radioactivity. Except for concentrations of monazite in and near the large Sulphide Queen carbonate body (fig. 3), the strongest radioactivity is attributable to thorite concentrated in the belt of rare earths mineralization, particularly near some andesitic dike rocks.

Lead and zinc have been mined in veins in the sedimentary rocks west of the Clark Mountain fault (fig. 2). Many pits have been dug in the district on showings of copper, gold, lead, and zinc, and two lead prospects have been found adjacent to andesitic dike rocks in the pre-Cambrian metamorphic rocks near the south edge of the district (fig. 2). A copper prospect near the lead prospects may be on the projection of the andesitic dike which is exposed in the canyon east of the copper prospect.

MINERALOGY

Wall rock minerals

The minerals in the country rocks of the thorium deposits--schists and gneisses, shonkonite, and "syenitized" gneisses--are described briefly below.

Orthoclase and microcline.--Orthoclase and microcline, both locally perthitic, are abundant in the metamorphic rocks. Orthoclase, microcline, and quartz are the major constituents of most gneisses exposed in the area and some of the gneisses contain both grid-twinned microcline and untwinned orthoclase.

Quartz.--Quartz is an abundant original constituent of the metamorphic wall rocks. The quartz is broken, and individual quartz fragments a half millimeter and less in diameter show rounded outlines in many places near the veins. Quartz and feldspars, in some of the mylonitized shear zones are milled to grains of microscopic size which form an indurated matrix containing larger grains of quartz and feldspars. Lines of dusty inclusions in quartz, parallel to fractures in adjacent potash feldspar, suggest that quartz recrystallizes more readily than feldspar under stress. Moreover, where quartz is recrystallized along shear planes, the adjacent potash feldspar shows only parallel lines of dusty inclusions. Fine-grained recrystallized quartz and strain shadows along shear planes in some of the rock, and the mylonitization, attest to the extreme stress involved in the development of the shear zone along which rare earths, thorium, and other materials were subsequently introduced. Some vein minerals have replaced quartz.

Albite.--Rounded grains of albite as large as 1 mm in diameter are seen in a thin section from 190 S-205 E on the map grid of the Windy group of claims (fig. 6.) The albite is surrounded by microscopic grains of other minerals crushed during the shearing which preceded introduction of vein minerals.

Other minerals.--Other minerals in the wall rocks of schists and gneisses, shonkinite, and "syenitized" gneisses, include plagioclase, hornblende, soda amphibole, acmite (aegirite), garnet, biotite, muscovite, phlogopite, sphene, zircon, apatite, and magnetite. Alteration products that are at least in part associated with the formation of the veins include epidote, prehnite, sericite, chlorite, carbonates, leucoxene(?), hematite, hydrated iron oxides, and probably clay minerals. Epidote, prehnite, sericite, carbonates, and chlorite are abundant far from the thorium-bearing veins, and may have developed through processes independent of those forming the veins.

The ferromagnesian minerals in the veins, unlike the relatively unaltered quartz and feldspars, have been commonly replaced by chlorite, hematite, hydrated iron oxides, and other vein minerals.

Vein minerals

The vein minerals, grouped according to chemical composition, are listed in the following table.

I. Sulfides and fluorides
   1) Galena
   2) Pyrite
   3) Copper-bearing sulfides
   4) Fluorite

II. Oxides
   1) Quartz
   2) Hematite
   3) Magnetite
   4) Hydrated iron oxides
   5) Melaconite

III. Carbonates and fluocarbonates
   1) Calcite
   2) Dolomite
   3) Ankerite
   4) Siderite
   5) Bastnaesite (and parisite?)

IV. Sulfates and phosphates
   1) Barite
   2) Monazite

V. Silicates
   1) Thorite
   2) Allanite
   3) Sericite
   4) Phlogopite
   5) Crocidolite
   6) Chlorite

Galena.--Scattered blebs and crystals of galena are seen in much of the vein material, and galena is locally sufficiently abundant that several of the galena-bearing veins have been prospected by shallow pits.

Pyrite.--Pyrite can be observed underground at the Birthday and Sulphide Queen shafts, and sparse hematite pseudomorphous after pyrite occurs in carbonate rock at the surface.

Copper-bearing sulfides.--Bright green specks of copper stain in some of the thorium-bearing veins attest to the probable original presence of copper sulfides. Chalcopyrite and bornite have been identified at the copper prospect shown near the south edge of the Mountain Pass district map (fig. 2). Chalcopyrite is found associated with melaconite underground in the recent workings at the Ray-Welch-Willmore group of claims, near 975 S-490 E on the map grid (fig. 6).

Fluorite.--Fluorite is not common in the Mountain Pass veins, but near 485 S - 420 E on the map grid of the Windy group of claims (fig. 6), one weakly radioactive vein contains several percent fluorite. Part of the fluorite is purple, the color being most intense along cleavages and fractures. Some masses of almost pure fluorite are several centimeters large, and small euhedra are enclosed in siderite (?) of the vein.

Quartz.--Vein quartz, constituting up to 50 percent of the thorium-bearing veins but averaging much less, is a late mineral and is found in irregular veinlets cutting earlier minerals, as euhedra--sometimes zoned with dusty opaque material--in barite, and as euhedral crystals lining vugs. Quartz is also found as interlocking anhedral crystals in patches in broken mineralized gneisses, and may have recrytallized from the original quartz of the gneisses.

Late quartz occurs in radioactive granite at 2165S - 111W on the map grid of the Birthday-Sulphide Queen area (fig. 3). Stained joint surfaces in the granite show radioactivity up to 0.9 mr/hr. In thin section the joint surfaces are seen to be impregnated with hematite and probably thorite, and dilation veinlets of hematite, thorite, hydrated iron oxides, and possibly manganese oxides occur in the granite. Quartz grains have replaced feldspar and quartz of the granite and have replaced the thorite-bearing veinlets. Quartz crystals extend unbroken through the veinlets along some of which movement has occurred; there are shadowy remnants of the veinlets in the quartz in line with segments of the veinlets on either side of the quartz. This suggests that quartz metasomatism post-dates the thorium mineralization. The quartz which crosscuts the veinlets cannot be distinguished from quartz presumed to be primary in the granite.

Hematite.--Hematite is seen in thin sections as minute, anistropic, bright orange red hexagonal plates with high relief, and larger opaque plates. The plates range from a small fraction of a millimeter to several millimeters across, and deepen in color with size increase. The ubiquitous occurrences of hematite with thorite is notable. Hematite locally constitutes 25 percent of the thorium-bearing veins. Irregular grains of hematite are scattered through all of the thorite-bearing veins, and dusty hematite is developed in thorite and is developed as skeletons of earlier ferromagnesian minerals in the altered gneisses. Plates of hematite developed preferentially around the edges of masses of fluorite in the vein near 485S - 420E on the map grid of the Windy group of claims (fig. 6).

Magnetite.--Magnetite is associated with thorium-bearing minerals locally in carbonate rock such as at 3523S - 290E on the map grid of the Birthday-Sulfide Queen area (fig. 3). Shiny black magnetite octahedra up to a millimeter in size are embedded in carbonate.

Hydrated iron oxides.--Virtually all the thorite-bearing rock contains several percent hydrated iron oxides. Irregular grains and masses of a mineral which is probably lepidocrocite were observed in a thin section from 1070S - 865E on the map grid of the Windy group of claims, (fig. 6). This mineral is reddish- to yellowish-brown, pleochroic, and lacks the strong dispersion of goethite. Lepidocrocite is pseudomorphous after hematite and has concentric rhomb-shaped outlines where it has probably altered from siderite. Other hydrated iron oxides and manganese oxides are probably present in the veins.

Melaconite.--Melaconite is found with chalcopyrite underground in the recent workings at the Ray-Welch-Willmore group of claims, near 975S - 490E on the map grid (fig. 6).

Calcite.--Calcite is the most abundant carbonate mineral in the veins at Mountain Pass. It is found as anhedral interlocking grains ranging from less than 0.01 mm to several millimeters in size. The calcite content of the veins ranges from less than 1 percent to over 50 percent. Streaks of fine-grained calcite along parallel shears are seen in thin sections, and in many of the larger grains. The twin lamellae and gliding planes are alined. Calcite replaces other carbonates, barite, quartz, and feldspars. It is also found as scattered blebs in vein material, filling interstices between broken and milled grains of quartz and feldspars and along cleavages in the feldspars of the altered gneisses. Some calcite fills vugs which have been lined by late quartz, and some fills fractures in the veins.

Dolomite.--Although dolomite has not been identified in the investigation of the thorium-bearing veins, earlier work/ indicates that it is

/ Jaffee, H. W., 1952, Personal communications in references to work done on samples from the Mountain Pass district, California.

a common mineral in the carbonate rocks.

Ankerite.--Much of the carbonate of the veins is evenly iron-stained and occurs as anhedral grains replacing siderite rhombs, or quartz and feldspar of the gneiss, and is probably ankerite. The vein at 2000S - 630W on the map grid of the Birthday-Sulphide Queen area (fig. 3), contains a carbonate with nZ equal to 1.70 ± 0.005. The index is that of parankerite (Mg: Fe:: 2:1) and of a manganese carbonate (Winchell, 1951) but the reddish stain on weathered surfaces of this carbonate suggests that it is not the manganese carbonate.

Siderite(?).--Iron-stained rhombs of siderite(?) appear to have replaced quartz and feldspar of the gneisses and form irregular veinlets in altered gneiss. Locally the rhombs contain hydrated iron oxides as concentric zones and some of the rhombs have been replaced by clear calcite and quartz so that zoning shown by the iron oxides is incomplete.

Bastnaesite (and parisite?).--Bastnaesite, probably with parisite, is present in amounts up to several percent in many of the thorium-bearing veins of the district. In places it is concentrated along shears that are iron-stained or filled with sericite, chlorite, and crocidolite. Bastnaesite is found in and adjacent to late veinlets of quartz, iron oxides, and calcite. The bastnaesite occurs as subhedral platy or prismatic hexagonal crystals.

Autoradiographs of four thin sections of thorium-rich veins, after an exposure of 41 days, show the bastnaesite to be radioactive. Some clusters of unoriented alpha tracks in the photographic emulsion immediately over clear grains of bastnaesite indicate that the mineral is radioactive and, on the basis of analyses of samples from these veins, probably thorium-bearing. However, not all the bastnaesite in the Mountain Pass district is believed to be radioactive, because an autoradiograph exposed for 19 days shows that bastnaesite from the discovery vein in the Birthday area, although containing a radioactive mineral in cracks, is not appreciably radioactive. The thorium content of the radioactive bastnaesite is probably only a fraction of a percent.

Barite.--Barite is found in most of the veins in the district in amounts rarely more than 40 percent, and it is scarce in some of the thorium-rich veins. At 800S - 750E on the map grid of the Windy group of claims (fig. 6) a small vein 4 inches wide is almost entirely barite which occurs in crystals up to a centimeter wide. The barite in the thorium-bearing veins is anhedral, and grains range up to several centimeters in diameter. It is an early vein mineral in most places, but barite veinlets cut barite; veinlets of barite and late quartz cut earlier quartz, feldspars, and other minerals; and barite and calcite fill quartz-lined vugs.

Monazite.--Monazite has not been found in the highly radioactive veins which contain abundant thorite. It is found locally in amounts of a few percent as scattered prismatic grains in the carbonate rock of the Sulphide Queen carbonate body and nearby satellitic veins. In a vein west of the north end of the carbonate body, monazite crystals several millimeters in size occur in a veinlet of calcite in rock composed of barite and brown-weathering carbonate.

Monazite is most abundant in the large Sulphide Queen carbonate body; local concentrations have radioactivity up to 0.8 mr/hr. Slight radioactivity of the monazite is confirmed by one thin section autoradiograph exposed for 41 days. Analyses of monazite collected near 4275S - 230E on the map grid of the Birthday-Sulphide Queen area (fig. 3), indicate a range in ThO_2 content between 1 and 3 percent. Radioactive age determinations on this monazite indicate a tentative age of 770 to 1100 million years.

Thorite.--Lustrous, hematite-colored reddish grains of thorite in the thorium-rich veins range in size up to 3 mm. Thin sections show that much of the thorite is crowded with minute specks of hematite and hydrated iron oxides. In many thorite crystals the iron oxides are chiefly near the edges of the thorite and, in other crystals, they are in concentric zones. Some thorite is irregularly crowded with inclusions, and some thorite contains so much hematitic dust as to be almost opaque. Most of the thorite is anistropic, with low and mottled birefringence, and some contains irregular isotropic patches; and some is wholly isotropic. Anisotropic crystals are uniaxial positive.

The crystal structure of the isotropic thorite contains water and the mineral may be hydrothorite but in this report it will be called thorite. Many grains of thorite are surrounded by radiating and anastomosing cracks, in the host quartz and feldspar, which have developed by expansion of the thorite during its hydration. Examination in index oils of some isotropic thorite from 190S - 205E on the map grid of the Windy group of claims, (fig. 6), indicates that the refractive index is close to 1.71. There is doubtless a range in water content and refractive index of the thorite.

Much of the thorite is square or octagonal in cross section, and sections cut along the crystallographic axis of a crystal show typical elongate prisms doubly terminated with pyramids whose apices have several obtuse and acute angles. Many grains are terminated with an obtuse pyramid on one end and an acute pyramid on the other. Length to width ratios of the thorite crystals range from about 3:2 to 7:2.

Thorite from the galena-rich vein at 2482S - 238E on the map grid of the Birthday-Sulphide Queen area (fig. 3), is found as minute, yellowish, almost isotropic, tetragonal crystals about 0.05 mm in size. Most of the thorite crystals are in small spheres of quartz two to four times the diameter of the thorite crytals. The spheres are in a mass of irregular hematite grains, hydrated iron oxides, and small quartz anhedra. Almost all the thorite observed in thin sections is in iron oxide filled shears, or in areas of broken gneiss. The thorite-bearing areas are connected by sinuous shears and veinlets of iron oxides, sericite, chlorite, quartz, and carbonates. Elongate yellowish-brown prisms of thorite up to 0.5 mm long occur with bastnaesite, hematite, and magnetite, scattered in very fine-grained carbonate in a narrow vein at 3523S - 1090E on the map grid of the Birthday-Sulphide Queen area (fig. 3).

In four thin sections the thorite ranges from clear yellowish-brown prismatic crystals to almost opaque hematite-crowded blebs. In autoradiographs of these thin sections exposed 41 days the thorite is surrounded by numerous radiating alpha tracks in the emulsion above the thorite crystals. Analyses of thorium-rich vein material are as much as 6 percent ThO_2.

Most thorites require ignition before showing thorite patterns in X-ray powder photographs. An X-ray powder photograph of a thorite-rich sample from the vein at 190S - 205E on the map grid of the Windy group of claims (fig. 6), shows a thorite pattern without pre-heating.

Allanite.--Minor amounts of allanite are scattered in coarse- and fine-grained carbonate minerals, and in late shears in several of the carbonate veins in the Mountain Pass district. The allanite is strongly pleochroic from light greenish-brown to dark reddish-brown and is prismatic. Near 1335S - 990E on the map grid of the Windy group of claims (fig. 6), allanite in a thorium-mineralized altered gneiss is irregularly colored and appears gradational to epidote in single crystals. Several percent epidote is present in the rock, and aggregates of epidote, allanite, hematite, chlorite, quartz, and hydrated iron oxides are alteration products of ferromagnesian minerals of the gneiss. A prismatic mineral, pleochroic from yellowish- and greenish-brown to dark reddish-brown, tentatively identified as allanite, is seen sparsely in a thin section from an andesitic dike near the south edge of the Mountain Pass district. The allanite is invariably associated with carbonate which has replaced phenocrysts in the altered andesitic rock, and it is undoubtedly not an original constituent of the dike.

Much of the allanite of the veins is only weakly radioactive and probably contains less than one percent thorium.

Sericite.--Sericite has developed along sinuous shears locally in mineralized granite gneiss, as at the unnamed prospect No. 4 (fig. 2). Sericite also is found sparsely in feldspars in fragments of gneiss in the veins.

Phlogopite.--Phlogopite is found in shonkinite in several places along thorium-bearing veins and locally in the veins themselves. Commonly phlogopite is found along or near shears in the carbonate rocks, but it occurs also as scattered isolated flakes in calcite. Northwest of the large Sulphide Queen carbonate body, at 3826S - 14W on the map grid of the Birthday-Sulphide Queen area (fig. 3), phlogopite is found in "syenitized gneiss". The gneiss has abnormal radioactivity due probably to thorite associated with the hydrated iron and manganese oxides and hematite in the rock. Near 1334S - 990E on the map grid of the Windy group of claims (fig. 6) altered gneiss containing allanite and thorite also has some pale greenish-brown phlogopite.

Some of the phlogopite has anomalous absorption, X bright orange to light brown and Y and Z pale to bright green; the colors vary in single crystals.

Crocidolite.--A fibrous pale green to pale bluish-green mineral of moderate to low birefringence and anomalous interference colors, found in the altered gneisses and the shonkinite is probably crocidolite; the crocidolite may be locally intimately mixed with chlorite.

Chlorite.--Chlorite is found in irregular fractures, in shears, and is interstitial to breccia fragments in crushed gneisses in the mineralized shear zones. Chlorite also occurs with hematite and hydrated iron oxides as skeletal remnants of earlier ferromagnesian minerals in mineralized gneisses. Pale green chlorite with anomalous interference colors and strong dispersion, $v > r$, biaxial (-), 2V approximately 40°, is found abundantly at the unnamed prospect No. 4 (fig. 2).

DESCRIPTIONS OF THE INDIVIDUAL PROPERTIES AND DETAILS OF THE GEOLOGY

The three largest areas of thorium occurrence in the Mountain Pass district are the Sulphide Queen carbonate body, the Ray-Welch-Willmore group of claims, and the Windy group of claims (fig. 2). The Sulphide Queen carbonate body is 2,400 feet long and as much as 700 feet wide, of heterogeneous mineralogy, and it contains local concentrations of thorium-bearing minerals. The Ray-Welch-Willmore group of claims is in a zone of mineralized shears which is about 3,000 feet long and as much as 100 feet wide. Some of the individual shears contain small thorium-bearing veins. The Windy group of claims, in a zone which is about 2,000 feet long and locally more than 100 feet wide, is similar to the Ray-Welch-Willmore group, but the shear zone in the Windy group contains more and larger veins. The veins are probably developed in braided shears of the zone. Most of the other thorium occurrences in the district (fig. 2) are similar in geology and mineralogy to the Ray-Welch-Willmore group of claims and the Windy group of claims.

Birthday-Sulphide Queen area

The thorium-bearing minerals known to occur in the Birthday-Sulphide Queen area (fig. 3) are monazite and thorite. Monazite of probable pre-Cambrian age is disseminated locally in the carbonate rock of the large Sulphide Queen carbonate body. Thorite is associated with hematite and hydrated iron oxides as fissure and shear fillings in shear zones and as impregnations of fracture walls.

North of the Sulphide Queen carbonate body a few veins, where shearing and hematitic staining is apparent, have radioactivity as much as 0.8 mr/hr in one and vein and 1.3 mr/hr in another, due largely to thorite. These include the Birthday discovery vein near 1250S - 230W, on the map grid of the Birthday-Sulphide Queen area (fig. 3), the vein near 1240S - 500W on the same map grid, and smaller veins with local high radioactivity. The area of abnormal radioactivity along the shear zone between 2450S and 2800S - 100W and 150E on the map grid of the Birthday-Sulphide Queen area (fig. 3), is in line with the andesitic dike exposed in the gneiss about 500 feet west-southwest, (fig. 2.) Many other carbonate veins in the Birthday-Sulphide Queen area have abnormal but low radioactivity.

Much of the radioactivity of the Sulphide Queen carbonate body is due to monazite, locally present in amounts of several percent, but thorite has been tentatively identified in the rock. Average radioactivity of the large carbonate body ranges from 0.06 to 0.10 mr/hr. Because the large carbonate body is now being worked for its rare earths content, the thorium is a potential byproduct, although the thorium grade is much lower than in several other deposits in the district.

Radioactivity in the Sulphide Queen gold mine is several times surface background due largely to the mass effect of the surrounding wall rock.

The tailings pond about 300 feet east of the Sulphide Queen gold mine (fig. 2) is radioactive (0.15 to 0.20 mr/hr).

Candy and Cake No. 3 claim

The Candy and Cake No. 3 claim is on a northwest-striking shear zone in the pre-Cambrian metamorphic rocks (fig. 2). The workings consist of a pit 6 feet deep in red-stained radioactive rock in a segment of the shear zone. Hematite and thorite occur in the sheared gneiss which contains abundant yellow-brown hydrated iron oxides. Radioactivity of the shear zone in the pit is as much as 0.25 mr/hr, and radioactivity extends 15 feet northwest of the pit where it is 0.2 mr/hr, and 10 feet southeast where it is 0.1 mr/hr. The counter readings average 0.07 mr/hr for 90 feet southeast of this to a point where a scraped area 25 feet long exposes a mineralized strip 3 feet wide, in line with the shear zone at the prospect pit. Radioactivity in the scraped area is as much as 0.27 mr/hr. About 350 feet S. 20° E. from the Candy and Cake No. 3 pit, a small area shows local radioactivity up to 0.08 mr/hr.

Radioactivity up to about 0.1 mr/hr occurs locally in yellow-brown stained, sheared gneiss east of the wash which lies east of the Candy and Cake No. 3 claim.

Alice claim

A carbonate vein 8 feet long in an altered shear zone at the Alice claim (fig. 2) is explored by one prospect pit 8 feet deep. The vein strikes N. 45° E., dips 65° NW., and is apparently a faulted segment of a longer vein. The exposed vein tapers from a width of 2 feet at the southwest end to about 6 inches at the northeast end. Laminations in the vein are manifested by concentrations of hematite and hydrated iron oxides parallel to the contacts. The hematite-rich and most radioactive part, in which radioactivity ranges up to 0.9 mr/hr, probably represents less than 5 percent of the vein. A thin section of this radioactive material contains about 30 percent thorite and hematite, 40 percent barite, 10 percent quartz, and 20 percent hydrated iron oxides.

Unnamed prospect No. 1

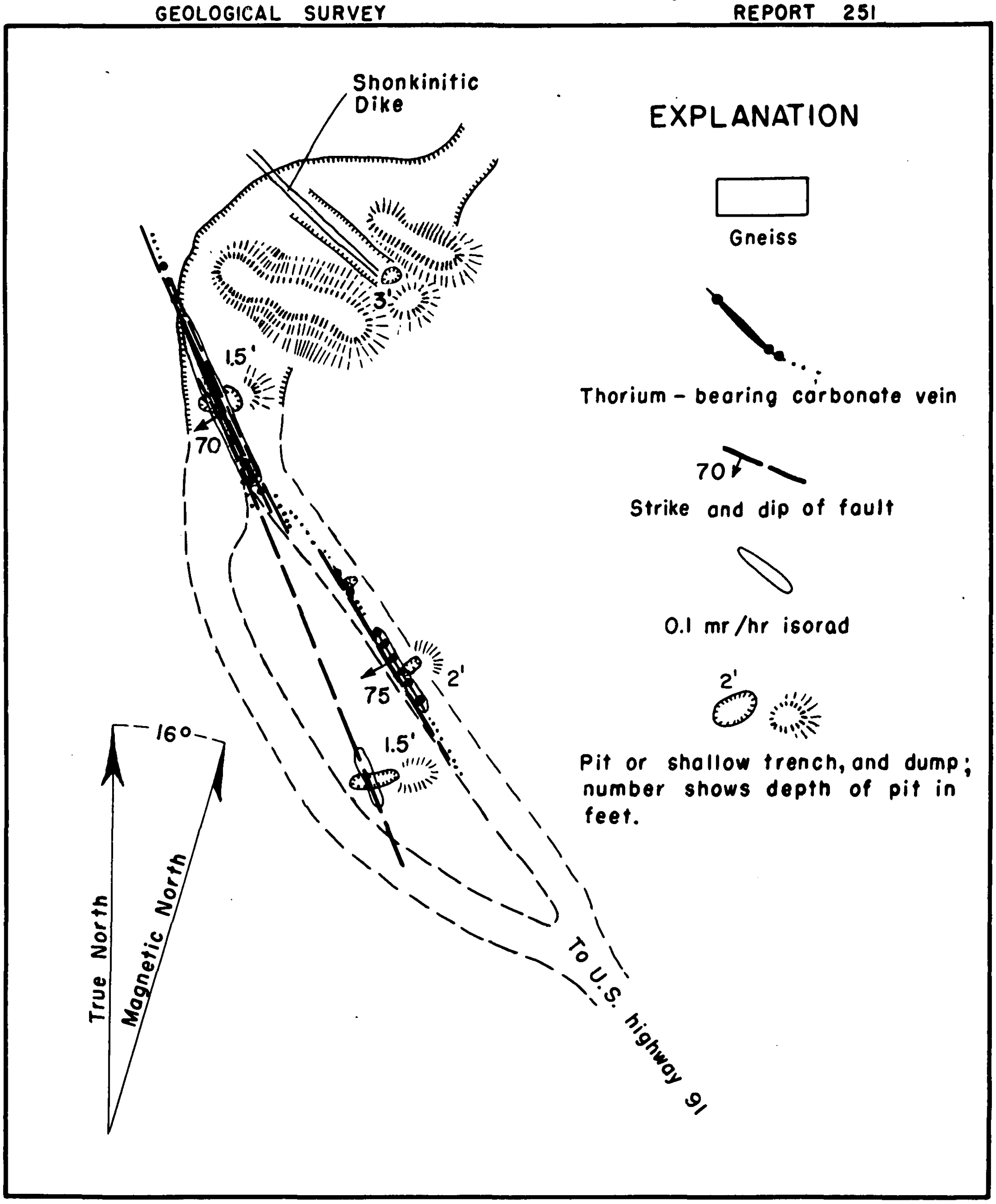
At the unnamed prospect No. 1 (fig. 2), a silicified carbonate vein, striking slightly north of west, intersects a reddened shear zone which strikes northwest in pre-Cambrian metamorphic rocks. The silicified vein is exposed for about 50 feet west of the shear. The vein has radioactivity about 0.06 mr/hr which is slightly higher than the 0.04 mr/hr background. An area about 50 feet long and 3 to 10 feet wide along the shear zone in hematitic, thorite-bearing rock has radioactivity ranging from 0.1 to 0.2 mr/hr.

Bullsnake claim

A map of the Bullsnake claim and prospect pits is shown in figure 4. At the north end of the workings a shonkinitic dike two feet wide striking northwest is exposed in a trench. The radioactivity of this dike is about twice background. South of the dike, carbonate vein material in a branching shear zone is exposed in several small pits. The largest pit has been dug on a vein of silicified, hematitic carbonate rock four feet wide and dipping 70° W. The vein narrows to an inch or two in width about 30 feet both north and south of the pit. Thin lenses of similar rock occur southward along both branches of the shear zone. Thorite and hematite make up about 10 percent of the vein, quartz about 45 percent, calcite about 35 percent, and bastnaesite about 10 percent.

Reynolds Robbins prospect A

The Reynolds Robbins prospect north of Highway 91, (A in fig. 2) consists of two silicified carbonate veins containing rare earths and minor thorium. The west vein is about 30 feet long and 4 feet wide in outcrop but pinches out at each end. It strikes north and dips about 60° W. A shear zone that contains small lenses of shonkinite is exposed in a pit 7 feet deep which has been dug on the vein. The east vein is 80 feet long, 2 feet in maximum width, strikes N. 20° W., and dips 70° W. Radioactivity of the west vein is two to three times background, but radioactivity of the east vein does not exceed twice background.



Mapped by compass and pace
by D.R. Shawe, May 1952

Geology by D.R. Shawe
May 1952

FIGURE 4.-MAP OF BULLSNAKE CLAIM,
MOUNTAIN PASS DISTRICT, CALIFORNIA

Reynolds Robbins prospect B

The prospect pit at B (fig. 2) exposes red altered gneiss in a shear zone in which a small lens of shonkinite are visible. This altered gneiss has a maximum radioactivity of about 0.6 mr/hr. Radioactivity dies out within 100 feet south along the shear zone, and ranges from 0.1 to 0.15 mr/hr northward along the shear zone 100 feet to a pit where radioactivity is about 0.2 mr/hr. Within 50 feet north of the pit the radioactivity drops to that of the average gneiss.

Reynolds Robbins prospect C

The Reynolds Robbins prospect C (fig. 2) consists of a pit 4 to 7 feet deep and 15 feet long, across a mineralized north-striking shear zone in the pre-Cambrian gneisses. In the pit the shears dip 72° - 80° W., and some of them are mineralized. At the west end of the pit is three feet of crushed gray gneiss separated by a shear from 3 feet of red-brown stained gneiss to the east. An inch-thick reddish vein in a shear lies between the three feet of red-brown stained gneiss and 2.5 feet of similar gneiss to the east. East of this stained gneiss is 1.5 feet of thoroughly sheared and altered gneiss. Between the pronounced shear zone and six inches of clayey gouge at the east end of the pit is 3.5 feet of mineralized gneiss.

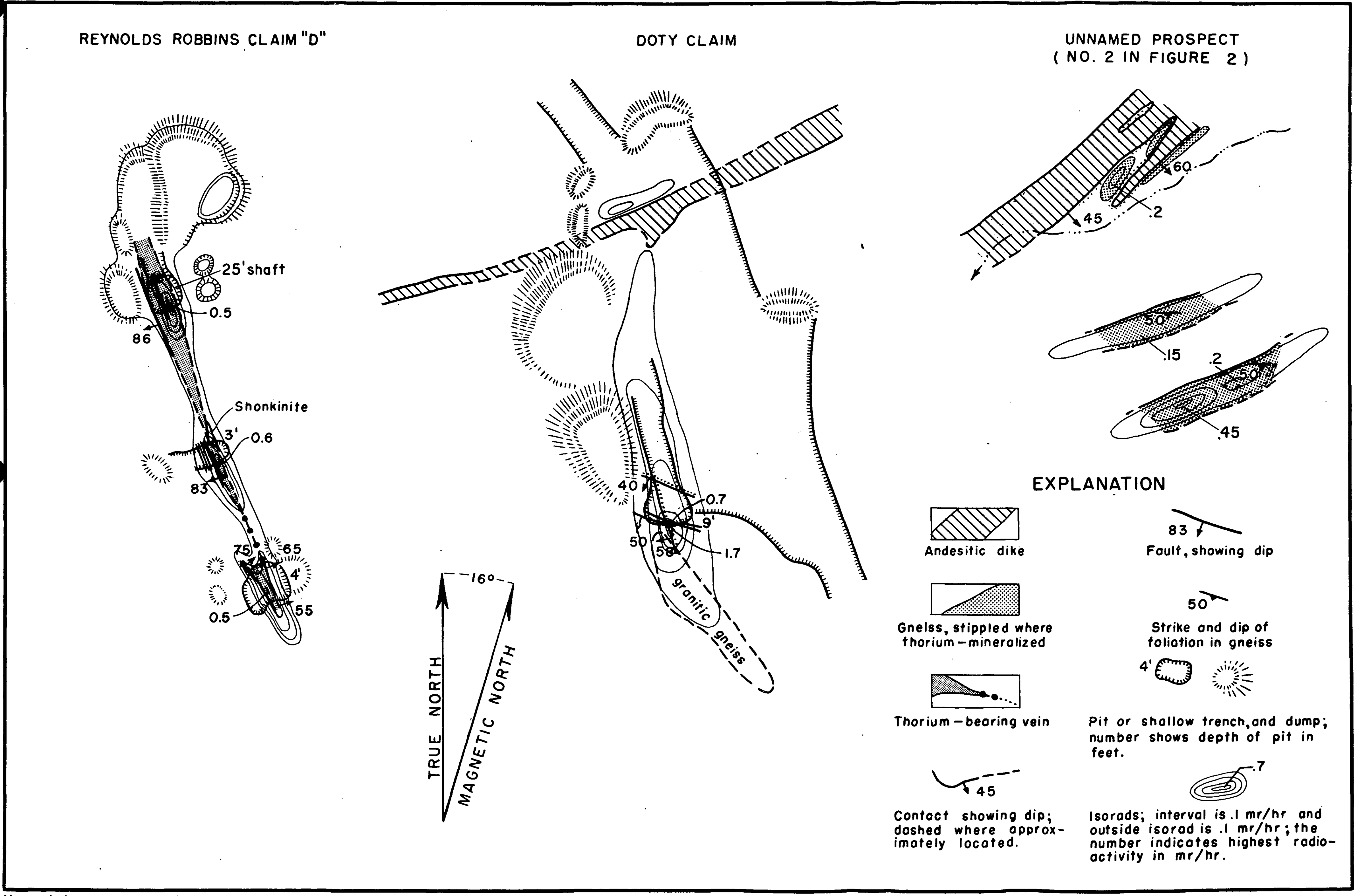
Radioactivity of the crushed gray gneiss at the west end of the pit is about 0.1 mr/hr, and that of the red-brown stained gneiss to the east is 0.2 mr/hr. The inch-thick reddish vein in the shear separating the red-brown gneiss to the west from similar gneiss to the east with radioactivity of about 0.5 mr/hr, has radioactivity of about 1.2 mr/hr. The pronounced shear zone has radioactivity of 0.7 mr/hr; the mineralized gneiss to the east has radioactivity between 1.2 and 2.0 mr/hr, and the clayey gouge at the east end of the pit has radioactivity of 0.5 mr/hr. Two to three feet east of the pit, 50 feet north along the strike of the shear zone, and 100 feet south along the strike, the radioactivity is normal background.

Reynolds Robbins prospect D

At the Reynolds Robbins prospect D (figs. 2 and 5), a carbonate vein in altered gneiss is exposed for 155 feet along its strike in three pits and a shaft 25 feet deep; the map (fig. 5) does not show the southernmost pit and 95 feet of the vein at the south end. Shonkinite was found in two places along the vein. The vein has been sheared by recurrent movement along the fracture in which it was emplaced. The vein pinches out to the south and is hidden under a dry wash to the north. The amount of radioactivity is indicated on the map (fig. 5).

Simon-Ray claim

A vein on the Simon-Ray claim (figs. 2 and 6) was being worked for its rare-earths content in June 1952.



Mapped by compass and pace by D.R. Shawe, June 1952

Geology by D.R. Shawe June 1952

FIGURE 5.—MAPS OF THREE THORIUM OCCURRENCES IN THE MOUNTAIN PASS DISTRICT, CALIFORNIA

20 0 40 Feet

GPO 830588

Tabular bodies of carbonate-barite-bastnaesite rock occur in a north-striking shear zone in pre-Cambrian metamorphic rocks just south of two parallel east-trending andesitic dikes and a cross-fault which has cut the mineralized zone. Vein material constitutes no more than 25 percent of the shear zone, near 225S - 50E on the Simon-Ray claim map grid (fig. 6). The vein is disseminated in broken and altered gneiss containing crocidolite and phlogopite. Near 50S - 25W and 350S - 50E on the Simon-Ray claim map grid (fig. 6), coarse-grained shonkinite a few inches thick occurs at the edge of the vein, and fragments of shonkinite are seen in places in the carbonate rock. A lens of shonkinite in the gneiss parallel to the vein is found a few feet east of the vein at 350S - 50E. Radioactivity of the reddish vein material is about 0.1 to 0.15 mr/hr, and the radioactivity of a few streaks of yellow-brown material one or two inches wide and up to a foot long ranges up to 0.35 mr/hr.

Ray-Welch-Willmore group of claims

The Ray-Welch-Willmore group of claims was mapped in a strip 3200 feet long and averaging 250 feet wide (fig. 6). Pre-Cambrian metamorphic rocks exposed in the area consist of mafic hornblende and pyroxene-rich gneisses, felsic and chloritized mafic augen gneisses, chloritized mafic schists, laminated granitic gneiss, and pegmatitic granitic gneiss. These rocks are cut by a shear zone in which carbonate rocks, containing thorium have been introduced. Along a mineralized part of the shear zone shonkinite is found near 1200S - 600E on the map grid of the Ray-Welch-Willmore group of claims (fig. 6). Altered gneiss containing crocidolite and abundant phlogopite occurs near 150S - 175W and near 975S - 500E on the map grid.

The shear zone contains hematite, quartz, hydrated iron oxides, thorite, barite, bastnaesite, possibly other rare earths minerals, and carbonates. Where these minerals are disseminated in the shear zone, the radioactivity is low, whereas higher radioactivity is commonly associated with well-defined thorium- and rare earths-bearing carbonate-barite veins. Such veins occur near 300S - 100W, 950S - 500E, 1400S - 675E, 2300S - 850E, and 2650S - 975E on the map grid of the Ray-Welch-Willmore group of claims (fig. 6).

Several andesitic dikes, striking generally west, transect the shear zone. One dike, (near 250S - 60W on the map grid) which intersects but does not cross the shear zone, possibly has been displaced along the shear zone. Movement along the zone possibly occurred during the period of emplacement of the andesitic dikes. The dike at 1350S - 675E on the map grid bends at the point where it crosses the shear zone, and inasmuch as it is apparently not sheared at that point, the influence of the shear zone during time of emplacement of the dike is inferred.

A rapid chemical analysis of a basalt from 800S - 265E on the map grid of the Ray-Welch-Willmore group of claims is shown (table 1). The basalt is similar to those described in table 2.

Radioactivity of the deposits in the Ray-Welch-Willmore group of claims is shown in figure 7. The high radioactivity is near the andesitic dikes. Radioactivity may extend closer to the dike near 2450S - 800 to 1000E than is indicated, but the shear zone is covered.

Table 1.--Rapid chemical analysis of basalt from 800S - 265E, Ray-Welch-Willmore group of claims. 1/

	Percent
SiO_2	46.8
Al_2O_3	15.8
Total Fe as Fe_2O_3	7.8
MgO	7.6
CaO	6.9
Na_2O	3.9
K_2O	1.3
TiO_2	1.0
P_2O_5	.16
MnO	.13
BaO	.05
Ignition 2/	9.1
Sum	100.5
FeO	5.0
Fe_2O_3	2.3

1/ Trace Elements Section Denver Laboratory

2/ Includes gain due to oxidation of FeO

Table 2.--Estimated percentages of minerals in four thin sections of "andesitic" dikes in the Mountain Pass district, California.

	Hornblende basalt Windy claims 765S - 575E	Hornblende basalt Windy claims 765S - 575E	Hornblende andesite Unnamed prospect No. 2	Hornblende dacite Windy claims 130N - 50W
Plagioclase	40 (labradorite?)	45 (labradorite)	50 (andesine)	48 (andesine)
Augite	10	10	-	1
Hornblende	40	37	42	35
Magnetite	5	5	5	4
Quartz	-	1	-	12
Others, including chlorite, epidote, carbonates, hydrated iron oxides.	5	2	3	-
Total	100	100	100	100

A pit at 310S - 100W exposes mineralized gneiss with abnormal radioactivity. On the east side of the pit a breccia vein up to a foot wide contains numerous gneiss fragments in reddish vein material. West of the breccia vein in the pit fractured gneiss 5 feet thick has thin coatings of reddish vein material in the fractures. Radioactivity of the breccia vein in the pit ranges from 0.9 to 1.3 mr/hr and radioactivity of the fractured gneiss averages about 0.6 mr/hr. Radioactivity 10 feet south of the pit and 50 feet north of the pit is less than 0.2 mr/hr, and within 5 feet east and west of the pit radioactivity is normal for the gneiss.

Disseminated thorium minerals in the shear zone are present near 2160S - 810E on the map grid, across 8 feet of reddish-brown altered gneiss and 3 feet of yellow-brown altered and intensely sheared gneiss. Radioactivity of the reddish-brown and yellow-brown gneiss averages 0.5 mr/hr. Radioactivity 30 feet north of this point is negligible, and to the south radioactivity diminishes and then increases to another high at 2230S - 820E on the map grid. At this point the shear zone is exposed in a prospect pit. At the west end of the pit is a manganese oxide-stained shear dipping about 60° west; red-brown stained, chloritized gneiss extends 8 feet farther east. A strongly sheared and reddened zone averaging 6 inches wide separates the chloritized gneiss from about 6 feet of yellow-brown and red-brown sheared gneiss to the east. Radioactivity of the chloritized gneiss increases from 0.35 mr/hr at the west end of the pit to 0.9 mr/hr at the sheared and reddened zone in which radioactivity ranges from 0.4 to 1.5 mr/hr. In the yellow-brown and red-brown sheared gneiss east of this, radioactivity is as much as 0.25 mr/hr. Radioactivity is normal a few feet east and west of the pit.

A cut, 100 feet south of the pit just described, exposes a sheared thorium-bearing carbonate vein about a foot thick, on both sides of which is intensely sheared and altered gneiss. Radioactivity of the thorium-bearing vein is as much as 1.9 mr/hr and the sheared and altered gneiss on either side is less radioactive. Radioactivity diminishes to about 0.2 mr/hr in chloritized gneiss 10 feet to the west and 5 feet to the east of the carbonate vein. Farther west and east the radioactivity is normal.

Smaller areas of lower radioactivity along the shear zone in the Ray-Welch-Willmore group of claims are shown on figure 7.

Goulder Goulch claim

At the Goulder Goulch claim radioactive veins are exposed in six pits and trenches (fig. 6). The veins are in sheared and altered gneiss which contains abundant hydrated iron oxides and questionably identified clay minerals. Mafic gneiss is cut by pegmatitic granite gneiss just south of the veins. West and north of the veins are faults striking about N. 25° W. and west, respectively; both faults are expressed topographically by canyons. The west-striking cross faults offsets the shear zone in which the thorium deposits are found (fig. 2).

The veins consist of carbonate materials, some barite, some quartz, and abundant hematite and hydrated iron oxides. Masses of radioactive material, crowded with fine-grained hematite, are probably thorite. Skeletons of older minerals that have been replaced by dusty aggregates or parallel streaks of hematite and hydrated iron oxides are seen in thin section. Some veins contain fragments of gneiss whose quartz and microcline appear in thin sections to be broken and milled. The gneiss has been replaced by carbonate, hematite, probably thorite, and late quartz containing minute needles of rutile(?). Radioactivity of the veins ranges up to 4.0 mr/hr.

Unnamed prospect No. 2

In the canyon just south of the Goulder Goulch claim and north of the Doty claim (fig. 2) is a small area of abnormal radioactivity adjacent to an andesite dike (fig. 5). As seen in thin section, the andesite has phenocrysts of hornblende, pleochroic from pale yellow to light greenish-brown, and andesine, up to 2 mm long, which together make up 20 percent of the rock. Fine-grained hornblende, andesine, and magnetite, less than 0.25 mm in size, constitute most of the groundmass. Percentages of the minerals in the thin section of the hornblende andesite are given in table 2.

The andesite lies in hydrothermally altered gneiss. A thin section of the gneiss shows hydrated iron oxides, fine-grained calcite, and siderite in fractures and replacing the gneiss. The quartz of the gneiss exhibits strain shadows. Parts of the gneiss adjacent to the andesite and two lenticular areas southeast of the andesite are sheared and reddened by hematite associated with carbonate and thorite, and these parts are radioactive up to about 0.45 mr/hr.

Doty claim

The Doty claim lies between the Windy group of claims and the Goulder Goulch claim (fig. 2), probably in the same shear zone exposed on the Goulder Goulch and Windy claims. This zone, although shown as continuous on figure 2, is probably faulted within a few hundred feet of the major cross fault just north of the Goulder Goulch claim; the northern segment or segments of the thorium-bearing shear zone are offset to the west.

A trench 9 feet deep in the side of the hill at the Doty claim (fig. 5) exposes several mineralized shears which are radioactive, one up to 1.7 mr/hr. Abnormal radioactivity extends from a lenticular reddened granitic gneiss outcrop northward along the trend of the north striking mineralized shear to an andesitic dike which strikes about N. 60° E. The dike is not abnormally radioactive. A small spot of abnormal radioactivity occurs just north of the dike in line with the radioactive area to the south. An apophysis extends from the dike at the point of intersection of the dike with the radioactive zone. The apophysis may have resulted from concurrent intrusion of the dike into a cross fracture, and this fracture may have also controlled the thorium mineralization.

A thin section of the radioactive granitic gneiss shows some mylonitization, and hematite with probable thorite as impregnations along a fracture. Abundant hematite and some thorite occur in thin lenses a half an inch thick or less in the mineralized shears.

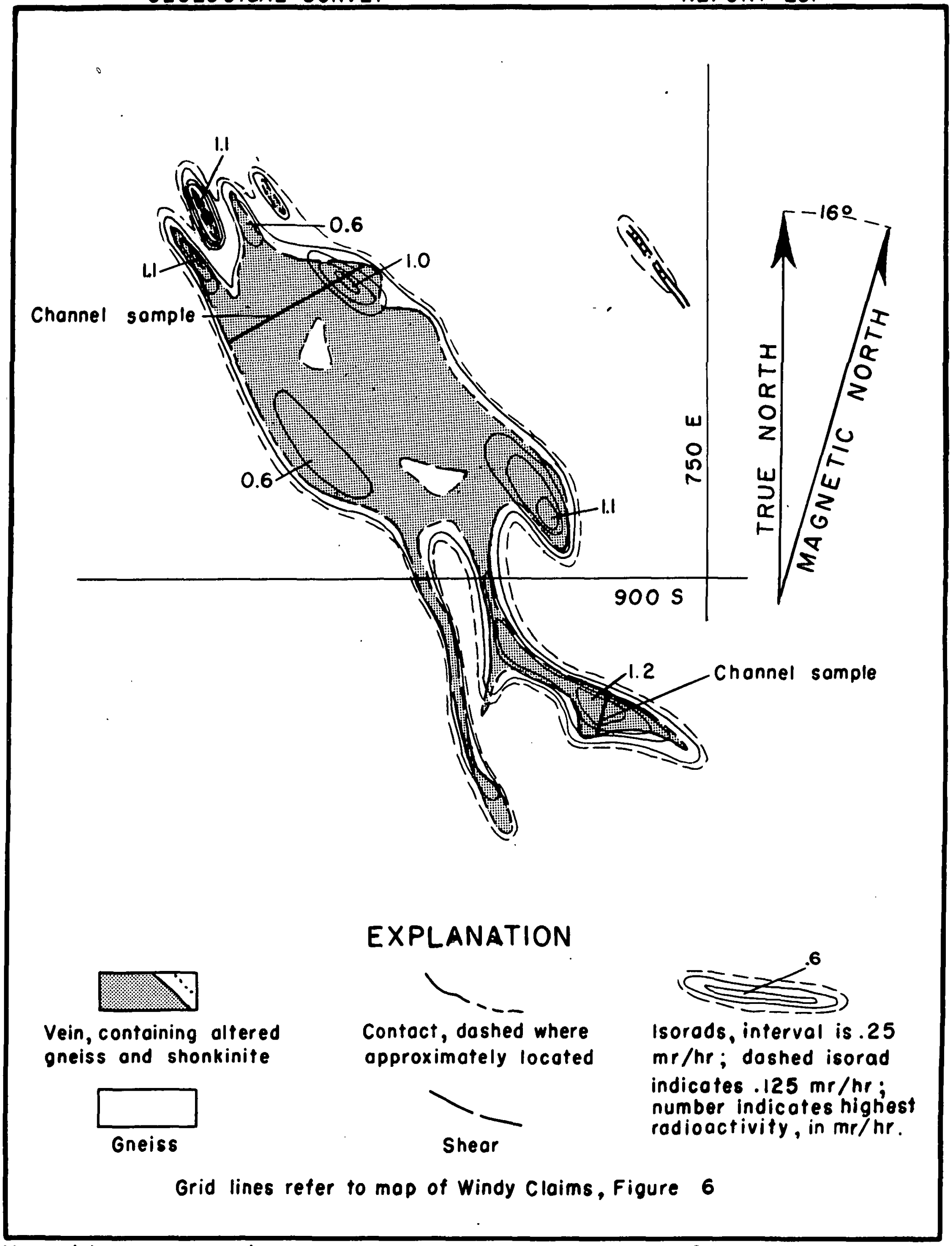
Windy group of claims

The mineralized shear zone upon which the Windy group of claims has been located was mapped in a strip about 2000 feet long and averaging 300 feet wide (fig. 6). The shear zone cuts interlayered laminated granitic gneiss, granitic augen gneiss, chloritized mafic augen gneiss, quartz-hornblende plagioclase gneiss, and schists. The schists are gradational in texture to the chloritized mafic augen gneiss. The gneisses crop out, whereas the schists are more deeply weathered and are obscured by float from the outcrops. Blank areas on the map are probably underlain largely by schist or easily weathered gneiss such as the chloritized mafic augen gneiss.

The shear zone is cut by several andesitic dikes that strike northeast and dip steeply or are vertical. Two thin sections of a hornblende basalt dike near 765S - 575E show phenocrysts of pleochroic hornblende, pale yellow to pale greenish-brown and pale green, and augite phenocrysts, up to 3 mm long, in a fine-grained (0.25 mm and less) groundmass of hornblende needles, plagioclase laths, and minute octahedra of magnetite (commonly less than 0.01 mm in size). A thin section of a hornblende dacite dike near 130N - 50W shows abundant hornblende, phenocrysts, pleochroic from pale yellow to pale greenish-brown, and sparse augite phenocrysts in a groundmass of fine-grained hornblende, plagioclase, quartz, and magnetite. Percentages of the minerals in the hornblende basalt and hornblende dacite are shown in table 2.

Movement along the shear zone may have occurred during emplacement of the andesitic dikes, as suggested by the narrow dikes, near 350S - 400E and 750S - 600E of the map grid (fig. 6), which intersect the shear zone but which do not cross it. The narrow dike near 00-00 bends but is not sheared at the point where it crosses the shear zone.

Shonkinite is found as lenses in the shear zone, associated with thorium-bearing carbonate rock. In places, such as illustrated (fig. 8) and near 350S - 350E, the vein contains considerable altered gneiss with fragments of crocidolite and phlogopite and shonkinite. In places vein material is disseminated in the shonkinite, and the contact between shonkinite and vein material of carbonates, barite, and various rare earths-, thorium-, and fluorine-bearing minerals is apparently gradational.



Mapped by compass and pace by D.R. Shawe, June 1952

Geology by D.R. Shawe May 1952

FIGURE 8.—DETAIL OF VEIN AT WINDY CLAIMS, MOUNTAIN PASS DISTRICT, CALIFORNIA

Near 425E - 500E, fluorite is abundant in a silicified carbonate vein showing low radioactivity.

Well-defined tabular thorium-bearing veins occur in the shear zone as near 100N - 00, and in irregular forms as at 425S - 400E, and at 900S - 750E (fig. 8). The veins consist of abundant hematite, hydrated iron oxides, carbonates, barite, quartz, some thorite, and minor bastnaesite.

The vein at the north end of the Windy claims is cut by a thick andesitic dike. The vein where exposed in a pit 8 feet deep just south of the dike, at 130N - 20W, is 5 feet wide, and the vein is 300 feet long. The vein is locally brecciated as at a pit one foot deep across the vein at 110N - 00. The vein, four feet wide here, contains numerous fragments of shonkinite and gneiss; brecciated gneiss forms the east wall of the vein at the pit, and a lens of shonkinite forms the west wall.

Within 25 feet north of the thick dike which cuts the vein at the north end of the Windy claims, the vein has 2 radioactive highs (1.2 mr/hr); and 30 feet south of the dike the vein has another radioactive high (4.5 mr/hr). Just south of the dike in the 8 feet deep pit, radioactivity of the vein varies from 1.2 to 1.5 mr/hr across the vein. The walls of the vein here are radioactive (0.15 and 0.2 mr/hr); within two feet of the vein radioactivity is equal to background. Radioactivity of the vein at 110N - 00 ranges from 3.5 to 4.5 mr/hr. The gneiss in the east wall here has radioactivity of 1.1, and shonkinite in the west wall has radioactivity of 0.7 mr/hr. Radioactivity 2 or 3 feet from the well-defined vein is normal.

The small vein north of the thick dike near 200S - 250E is abnormally radioactive (6.0 mr/hr) 50 feet north of the dike. A set of parallel closely-spaced veins 100 feet south of the dike has radioactivity as high as 1.1 mr/hr. Comparable radioactivity is found farther south in veins near the small dikes in the vicinity of 800S - 700E on the map grid. The small parallel closely-spaced veins 300 feet southeast of these dikes show a maximum radioactivity of 1.5 mr/hr, and no andesitic dike is exposed in their immediately vicinity.

Unnamed prospect No. 3

At the unnamed prospect No. 3 (fig. 2), two andesitic dikes transect the north-trending shear zone in the gneisses on the west side of a large canyon. Near both dikes, in the sheared gneisses, radioactivity of purplish stained and coated joint and shear surfaces ranges as high as 0.7 mr/hr. The radioactivity is probably due to thorite associated with the hematite which imparts the purplish color to the joint and shear surfaces. Average radioactivity across the shear zone 10 feet wide between the andesitic dikes is probably no more than 0.1 mr/hr.

The andesitic dike exposed in the canyon approximately 1000 feet south of the unnamed prospect No. 3 crosses the shear zone (fig. 2) where radioactivity locally is as high as 0.15 mr/hr.

Unnamed prospect No. 4

The vein at the unnamed prospect No. 4 (fig. 2) is in granitic gneiss and chloritized augen gneiss. The vein strikes about N. 40°W. and it is exposed by a small pit on the north side of the gully which crosses the vein. The vein ranges in width from a fraction of an inch, where it fills a fracture in the gneiss, to a few feet, where the vein material is disseminated in gneiss.

Two thin sections of radioactive rock from the vein show that the vein is along a shear zone. Rounded grains of quartz and microcline are found in a matrix of microscopic granules of the milled quartz and microcline. Part of the matrix has been replaced and intruded by veins of quartz. The rock contains as much as 10 percent chlorite in irregular fractures and shears and interstitial to broken quartz and feldspar. Thorite, sericite, bastnaesite(?), hematite, and hydrated iron oxides occur along sinuous shears. The iron oxides may have been formed by hydrothermal alteration of ferromagnesian minerals, as suggested by selvages of hematite and hydrated iron oxides occurring within boundaries of minerals which have been replaced by quartz and chlorite.

About 100 feet east of the prospect pit at the unnamed prospect No. 4, is the irregularly branching end of an andesitic dike which extends across the large canyon east of the prospect.

Radioactivity of the vein is as high as 1.3 mr/hr where the vein is thin, but where the vein material is disseminated in gneiss, radioactivity is lower. Radioactivity of the vein is as much as 0.7 mr/hr, 100 feet up the slope northwest of the prospect pit; radioactivity dies out within a few feet to the northwest. Halfway to the top of the ridge northwest of the pit there is another radioactive high of 0.6 mr/hr in line with the northwest-striking vein, and at the ridge crest 300 or 400 feet northwest of the prospect pit the radioactivity is 0.06 mr/hr. Disseminated material in the vein 150 feet southeast of the prospect pit has radioactivity up to 0.9 mr/hr, and radioactivity up to several times background is detected along the vein locally for a distance of 200 feet southeast of the pit.

DETERMINATION OF GRADE OF THE DEPOSITS

Three measurements were used in determining the grade of the deposits: (1) a Geiger-Mueller type counter was used in the field to map the distribution of radioactivity, (2) representative samples collected in the field were analyzed for radioactivity, (3) 101 of the samples were analyzed chemically for thoria (tables 3 and 4).

The chemical analyses in general substantiate the thoria percentages calculated from the radioactivity analyses. Because of the difficulty of chemical analysis for thorium in the presence of abundant rare earths and barium, particularly where the thorium content is less than 0.10 percent or the rare earth content greatly exceeds the amount of thorium present, the thoria calculated from radioactivity analyses is considered a more reliable figure for reserve calculations, once it has been established that the radioactivity is due to thorium. It has been determined that in general a factor of 4.9 times the difference between eU and U (eU-U) gives the approximate Th content, and a factor of 5.6 applied to this difference (eU-U) gives the approximate ThO_2 content.

These factors were determined by the Trace Elements Section Denver Laboratory, using the series of thorium standards from the National Bureau of Standards. Twenty-five separate eU determinations (5 each of 1.0 percent Th, 0.1 percent Th, 0.05 percent Th, 0.02 percent Th, and 0.01 percent Th) give a value of 0.204 percent eU/percent Th, or 4.9 percent Th/percent eU, which corresponds to 5.6 percent ThO_2/percent eU.

Nineteen samples (table 3) were investigated to determine if any elements other than uranium and thorium are responsible for the radioactivity of the samples. The data show that the disagreement between eU and U values is due chiefly to thorium.

SUMMARY AND CONCLUSIONS

The rare earths and thorium are found in carbonate rock bodies in a narrow belt in the pre-Cambrian metamorphic rocks. The belt follows a fracture zone in the pre-Cambrian metamorphic rocks in which the carbonate rocks and potash-rich igneous rocks were formed. The potash-rich rocks and the carbonate rocks were faulted and offset subsequent to emplacement probably during Laramide (late Cretaceous) time (fig. 2). The carbonate rocks were later hydrothermally altered along the offsetting faults. (Olson, et al., in preparation).

The monazite in the carbonate rock is probably pre-Cambrian in age. The andesitic dikes were injected after much of the faulting. Because the thorite was formed late, and the thorite deposits are spatially associated with many of the andesitic dike rocks where the dikes cut the belt of rare earth deposits, it is considered probable that the hydrothermal alteration of the carbonate rock and the thorite mineralization were results of the andesitic dike injections. Many andesitic dikes do not have thorium deposits near them, and it is not considered that the thorite was derived from the dikes. It is postulated that aqueous emanations accompanying the andesitic magmas served as vehicles of redistribution of the thorium already in the invaded carbonate rock. The mobilized thorium moved in the aqueous emanations along the edges of the dikes or along connecting fractures and was deposited as thorite in favorable structural traps in the carbonate rock and altered gneiss.

Table 3.--Analyses of samples (in percent) from the Mountain Pass district, California, showing thorium as the chief radioactive element.

Sample number or location	eU1/	U2/	$ThO_2$3/ (chem.)	$ThO_2$4/ (ra-ch.)	$ThO_2$5/ (calc.)
12C, table 4	0.08	0.004	0.41	0.46	0.43
31C, table 4	0.23	0.007	1.19	1.2	1.25
32C, table 4	0.39	0.003	2.07	2.1	2.2
33C, table 4	0.058	0.007	0.25	0.25	0.29
35C, table 4	0.20	0.007	0.96	0.95	1.1
37C, table 4	0.14	0.007	0.54	0.56	0.74
38C, table 4	0.55	0.005	2.39	2.54	3.1
40C, table 4	0.37	0.020	2.00	2.	2.0
6B, table 4	0.013	0.002		0.076	0.06
64C, table 4	0.018	0.002		0.081	0.09
5C, table 4	0.13	0.002	0.26	0.70	0.72
6C, table 4	0.076	0.002	0.20	0.33	0.41
27C, table 4	0.11	0.009	0.37	0.36	0.57
Sulphide Queen, fig. 3, 3785S-75W	0.049	0.001		0.24	0.27
Windy claims, fig. 6, 290S-305E.	0.033	<0.001	0.07	0.14	0.18
Windy claims, fig. 6, 125N-10W.	0.085	0.026	0.54	0.36	0.33
Ray-Welch-Willmore, fig. 6, 310S - 100W.	0.065	0.009	0.52	0.32	0.31
Goulder Goulch, fig. 6, 200S-40W.	0.052	0.001	0.17	0.25	0.29
Goulder Goulch, fig. 6, 240S-130W.	0.14	0.002	0.74	0.76	0.76

1/ Equivalent uranium

2/ Chemical uranium

3/ Chemical thorium oxide

4/ Thorium oxide determined by radiochemical methods

5/ Thorium oxide calculated from eU-U

Table 4.--Analyses of samples from the Mountain Pass district

Locations shown on map of Birthday-Sulphide Queen area, (fig. 3):

Location	eU	U	ThO_2	ThO_2(calc.)	Remarks
1600S - 390W	0.013	0.002	< 0.1	0.06	Grab, granite.
1580S - 630W	0.022	0.002		0.11	Grab, vein.
2030S - 605W	0.012	0.002	< 0.1	0.05	Grab, vein.
1985S - 180W	0.017	0.001	< 0.1	0.09	Grab, vein.
2035S - 145W	0.031	0.005		0.15	Grab, vein.
2135S - 65W	0.020	0.003	< 0.1	0.09	Across 6" vein.
2685S - 680W	0.095	<0.001	0.42	0.53	Grab, vein.
2640S - 710W	0.63	0.012	2.71	3.46	Grab, vein.
3575S - 305E	0.045	0.003	0.17	0.23	Seam in vein.
3785S - 75W	0.049	0.001	0.24	0.27	Grab, gneiss.
3090S - 285E	0.013	0.006	< 0.1	0.04	Across 4' vein.
2880S - 260W	0.060	0.002	0.34	0.33	Grab, vein.
5215S - 1590E	0.006	0.003	< 0.1	0.02	Across 4' vein.
Candy and Cake no. 3 claim	0.008	0.001		0.04	Across 3' sheared gneiss.
2000 ft south of Highway Maintn. Sta.	0.005	0.001		0.02	Fine-grained shonkinite.
Locations shown on map of Goulder Goulch claim. (fig. 6):					
200S - 40W	0.052	0.001	0.17	0.29	Across 1' vein.
220S - 70W	0.020	0.001	< 0.1	0.10	Across 12' sheared gneiss.
235S - 90W	0.021	0.003	< 0.1	0.10	Across 1' vein.
240S - 130W	0.14	0.002	0.74	0.76	Across 2.5' vein.

Table 4.--Analyses of samples from the Mountain Pass district--Continued.

Location	eU	U	ThO_2	ThO_2(calc.)	Remarks
Bullsnake claim	0.016	0.001		0.08	Across 4' vein.
Reynolds Robbins claim A	0.011	0.002		0.05	Across 1.5' vein.
Reynolds Robbins claim C	0.051	0.001	0.24	0.28	Across 15' sheared gneiss.
Locations shown on map of Windy group of claims (fig. 6):					
1260S - 935E	0.008	0.001	<0.1	0.04	Across 4' reddened gneiss.
1330S - 970E	0.034	0.002	0.14	0.18	Reddened gneiss.
1335S - 990E	0.021	0.001	0.06	0.11	Do.
1070S - 865E	0.076	0.003	0.48	0.41	Across 10" vein.
900S - 730E	0.048	0.001	0.19	0.26	Across 3' vein.
900S - 730E	0.042	0.002	0.19	0.22	Across 10' vein.
690S - 605E	0.23	0.005	1.12	1.26	Across 1' Mn-stained gneiss.
290S - 305E	0.050	0.003	0.21	0.26	Across 5' vein with shonkinite.
290S - 305E	0.033	<0.001	0.14	0.18	Across 2' vein.
190S - 205E	1.1	0.030	5.92	6.00	Across 8' vein.
110N - 00	0.21	0.010	1.01	1.12	Across 5' breccia vein.
125N - 10W	0.085	0.026	0.36	0.33	Across 5' vein.

Locations shown on map of Ray-Welch-Willmore group of claims (fig. 6)

2155S - 810E	0.014	0.002	0.04	0.07	Across 3' sheared gneiss.
2155S - 810E	0.013	0.002	0.07	0.06	Across 8' reddened gneiss.
2220S - 810E	0.031	0.003	0.12	0.15	Across 8' reddened gneiss.
2220S - 815E	0.026	0.003		0.13	Across 1' sheared gneiss.
2220S - 820E	0.005	0.001	< 0.1	0.02	Across 5' gneiss.
310S - 100W	0.065	0.009	0.32	0.31	Across 1' breccia vein.
310S - 100W	0.031	0.002	0.20	0.16	Across 6' reddened gneiss.

Location shown on map of Simon-Ray claim (fig. 6):

60S - 10W_/	0.010	0.001	< 0.1	0.05	Across 3' vein.

_/ This and previous samples were collected by D. R. Shawe. The following samples were collected by W. N. Sharp.

Table 4.--Analyses of samples from the Mountain Pass district--Continued.

Locations showns on map grid of Birthday-Sulphide Queen area (fig. 3):

Location		eU	U	ThO_2	ThO_2(calc.)	Remarks
1B	3430S-600E	0.009	0.007	<0.1	0.01	Sulphide-Queen carbonate body.
2B	3570S-490E	0.014	0.007	<0.1	0.04	Do.
3B	4335S-355E	0.004		<0.1	0.02	Do.
4B	5360S-770E	0.005		<0.1	0.02	Do.
5B	4880S-725E	0.006		<0.1	0.03	Do.
6B	5685S-275E	0.013	0.002	<0.1	0.06	Do.
8B	3405S-580E	0.007		<0.1	0.03	Do.
9B		0.003		<0.1	0.01	Do.
10B		0.003		<0.1	0.01	Do.
11B		0.004		<0.1	0.02	Do.
12B	Between	0.004			0.02	Do.
13B	500-1000E	0.011			0.05	Do.
14B	5000-5800S	0.001		<0.1	0.01	Do.
15B		0.007			0.03	Do.
16B		0.005			0.02	Do.
17B		0.003			0.01	Do.
18B		0.009		<0.1	0.04	Do.
19B		0.004		<0.1	0.02	Do.
20B		0.007			0.03	Do.
25B	3555S-520E	0.005		<0.1	0.02	Do.
26B	4205S-325E	0.004		<0.1	0.02	Do.
27B	4515S-420E	0.008		<0.1	0.04	Do.
28B	4100S-490E	0.005		<0.1	0.02	Do.
29B	4840S-490E	0.001		<0.1	0.01	Do.
30B	5045S-790E	0.008		<0.1	0.04	Do.
31B	5355S-585E	0.005		<0.1	0.02	Do.
32B	5170S-1050E	0.003		<0.1	0.01	Do.
33B	5510S-715E	0.004		<0.1	0.02	Do.
34B	5660S-625E	0.016		<0.1	0.08	Do.

Locations in Sulphide Queen gold mine (3820S-970E):

41C	3d level	0.014	0.006		0.04	Altered rock in shear zone.
42C	4th level	0.045	0.013	0.23	0.18	Carbonate-barite vein.
43C	3d level	0.021	0.007		0.08	Altered rock in shear zone.
44C	2d level	0.025	0.006	<0.1	0.10	Sulfide-rich lens 2" thick.

Table 4.--Analyses of samples from the Mountain Pass district--Continued.

Locations shown on the map grid of the Birthday-Sulphide Queen area (fig. 3 unless otherwise noted in remarks):

Location		eU	U	ThO_2	ThO_2(calc.)	Remarks
1A	1240S-1025W	0.009	0.002	< 0.1	0.04	Shonkinite, east wall of Birthday discovery vein.
2A	1820S-645W	0.007	0.003		0.02	Shonkinite.
3A		0.007	0.002		0.03	Shonkinite, composite body, 4000 ft S. of Hwy. Maintn. Sta.
4A		0.012	0.005	< 0.1	0.04	Do.
5A		0.012	0.003	< 0.1	0.05	Do. (Pegmatitic part).
6A		0.007	0.002		0.03	Do. (Mafic syenite).
7A		0.012	0.003	< 0.1	0.05	Do. (Shonkinite dike).
8A	1755S-755W	0.006	0.002		0.02	Shonkinite.
9A	1580S-885W	0.007	0.002		0.03	Do.
10A	1945S-1265W	0.008	0.002	< 0.1	0.03	Mafic syenite.
11A	1840S-980W	0.008	0.004		0.02	Shonkinitic dike.
12A		0.013	0.013	< 0.1	0.00	Granite, 3000 ft WSW. of Hwy. Maintn. Sta.
13A	2012S-945W	0.005	0.003		0.01	Fine-grained granite dike.
14A	1490S-795W	0.008	0.004		0.02	Do.
15A	1290S-1050W	0.010	0.003		0.04	Do.
16A	1030S-1425W	0.006	0.003		0.02	Do.
17A		0.013	0.002	< 0.1	0.006	Metadiorite, W. of Birthday area.

Table 4.--Analyses of samples from the Mountain Pass district--Continued.

Locations shown on the map grid of the Birthday-Sulphide Queen area (fig. 3 unless otherwise noted in remarks):

Location		eU	U	ThO_2	ThO_2(calc.)	Remarks
1C	2010S-620W	0.086		0.58	0.48	Across 10' vein.
2C	2120S-580W	0.026		0.13	0.14	Across 4' vein.
3C	2200S-525W	0.016		<0.1	0.08	Across 4' vein.
4C		0.031		0.23	0.17	Reynolds Robbins claim D.
5C		0.13	0.002	0.70	0.72	Reynolds Robbins claim C.
6C		0.061	0.002	0.33	0.33	Reynolds Robbins claim B.
7C	1445S-800W	0.005	0.006		0.00	Grab, vein, west wall of pit.
8C	1445S-800W	0.005	0.004		0.01	Do.
9C	1685S-1035W	0.021	0.003		0.10	Carbonate-barite limonite vein in pit.
10C	1685S-1035W	0.011	0.004		0.04	Do.
11C	1550W-1150W	0.076	0.003	0.30	0.41	Carbonate-bastnaesite-barite vein in pit.
12C	1550S-1150W	0.080	0.004	0.41	0.43	Do.
13C	990S-1290W	0.080	0.002	0.37	0.44	Limonite-rich vein in pit.
14C	1240S-1025W	0.092	0.006	0.39	0.48	16' drift from Birthday pit, chip sample of vein.
15C	1240S-1025W	0.097	0.001	0.39	0.54	Do.
16C	1190S-1460W	0.047	0.008		0.22	Grab, vein in pit.
17C	1180S-1435W	0.032	0.005		0.15	Composite sample, veins and wall rock.
18C	1680S-1660W	0.29	0.001	1.31	1.53	Limonite-rich carbonate vein.
19C	950S-2160W	0.004	0.001		0.02	Quartz vein with minor barite.
20C		0.029	0.005		0.13	Alice claim.
21C	5000S-1450E	0.008		<0.1	0.04	Chip sample of vein.

Table 4.--Analyses of samples from the Mountain Pass district--Continued.

Location		eU	U	ThO_2	ThO_2(calc.)	Remarks
22C	4430S-1220E	0.005		<0.1	0.03	Chip sample of vein.
23C	4340S-1150E	0.006		<0.1	0.03	Do.
24C	4170S-1120E	0.004		<0.1	0.02	Do
25C	4100S-1085E	0.008		<0.1	0.04	Do.
26C		0.006		<0.1	0.03	650'N. of Sulphide Queen shaft.
27C	125N-10W	0.11	0.009	0.37	0.57	Chip sample across 40" vein.
28C	Windy claims	0.019		<0.1	0.10	Across 4' sheared gneiss.
29C	Windy claims	0.13		<0.34	0.73	Chip sample, fluorite bearing carbonate vein.
30C	Doty claim.	0.018		<0.1	0.10	Across 3' sheared gneiss.

Locations shown on map of Birthday-Sulphide Queen area (fig. 3):

Location		eU	U	ThO_2	ThO_2(calc.)	Remarks
31C		0.23	0.007	1.19	1.25	Rich in hematite face of drift.
32C		0.39	0.003	2.07	2.17	Soft weathered limonite-rich west wall of drift.
33C		0.058	0.007	0.25	0.28	Hard, massive limonite-rich drift.
34C		0.19	0.005	1.03	1.04	Do.
35C	1240S-1025W Birthday discovery vein. (31C–40C)	0.20	0.007	0.96	1.08	Soft material from shear.
36C		0.023	0.008		0.08	Hard, massive limonite-rich face of drift.
37C		0.14	0.007	0.54	0.76	Soft material from shear.
38C		0.55	0.005	2.39	3.05	Limonite-rich, near surface.
39C		0.085	0.010	0.25	0.42	Hard, massive material.
40C		0.37	0.020	2.00	1.96	Prospect pit.

Table 4.--Analyses of samples from the Mountain Pass district--Continued.

Location		eU	U	ThO_2	ThO_2(calc.)	Remarks
45C	West of Birthday area	0.014	0.001		0.07	Quartz vein.
46C	1395S-1850W	0.008	0.006	<0.1	0.01	Siliceous vein.
47C	990S-1290W	0.13		0.62	0.73	Carbonate vein with thorite(?).
48C	1080S-1365W	0.12		0.59	0.67	Limonitic carbonate vein.

The occurrence of the two lead prospects (fig. 2) adjacent to an andesitic dike is further suggestion that the andesitic dike rocks may have played a role in the development of the ore deposits. This andesitic dike does not cut the rare earths belt. The proximity of ore deposits to the andesitic dikes implies a genetic association of deposits to the dikes. That different ore deposits near andesitic dikes which were injected during the same geologic episode are of different elements, i.e., lead and thorium, implies a wall rock influence on the ore forming properties of the andesitic magmas. It is also suggested that preexistent thorium and lead in the host rocks were the source of those elements in the ore deposits.

LITERATURE CITED

Winchell, A. N., 1951, Elements of optical mineralogy, John Wiley and Sons, Inc., New York.

UNPUBLISHED REPORTS

Olson, J. C., Shawe, D. R., Pray, L. C., and Sharpe, W. N., Rare earth mineral deposits of the Mountain Pass district, San Bernardino County, California, in preparation.

Sharp, W. N., 1950, Analyses of radioactivity of the cerium-lanthanum deposits, San Bernardino County, Calif.: U. S. Geol. Survey unpublished report, in Trace Elements files, Denver.