Geology and Ore Deposits of the Kern River Uranium Area, California

By E. M. MacKEVETT, Jr.

CONTRIBUTIONS TO THE GEOLOGY OF URANIUM

GEOLOGICAL SURVEY BULLETIN 1087-F

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1960

UNITED STATES DEPARTMENT OF THE INTERIOR

FRED A. SEATON, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C.

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GEOLOGY AND ORE DEPOSITS OF THE KERN RIVER URANIUM AREA, CALIFORNIA

By E. M. MacKevett, Jr.

ABSTRACT

In the Kern River uranium area, an area of about 30 square miles in northeastern Kern County, Calif., small uranium deposits are erratically distributed along fractures, most of them within the Isabella granodiorite of Miller (1931). The deposits probably are too small and of too low grade to be worth mining on a large scale, but they contain local concentrations of ore. Uranium was first discovered in the area in January 1954 at the Miracle mine. Four shipments of uranium ore, totaling about 189 tons, were made in 1954 and 1955; 2 were from the Miracle mine and 2 from the Kergon mine. The most valuable shipment was the first one from the Miracle mine, which consisted of 46 tons of ore containing 0.53 percent uranium. The other shipments contained, respectively, 0.14 percent, 0.18 percent, and 0.16 percent uranium.

The principal ore mineral is autunite, but minor amounts of sooty pitchblende, carnotite, and metazeunerite have been found. Common gangue minerals are scarce or altogether lacking in most of the deposits, and wallrock alteration is generally weak or absent.

Most of the deposits probably formed in low-temperature near-surface environments and are epithermal. Some of the numerous hot springs in the area and nearby may have influenced uranium deposition. A possible alternative explanation for the origin of some of the deposits is that the uranium was derived from the Isabella granodiorite. This rock locally contains abnormal amounts of uranium, and it is conceivable that some uranium was leached from it and subsequently deposited in fractures.

Minor gold deposits, in both lodes and placers, and small tungsten deposits associated with quartz veins or disseminated in tactite also occur in the area.

INTRODUCTION

LOCATION AND ACCESSIBILITY

The Kern River uranium area includes about 30 square miles in Tps. 26 and 27 S., Rs. 31 and 32 E., Mount Diablo base line and meridian, in northeastern Kern County, Calif. (fig. 21). The area is in the highly dissected southern Sierra Nevada and is included in the Sequoia National Forest. The center of the area is about 30 miles northeast of Bakersfield, from which it is accessible by State

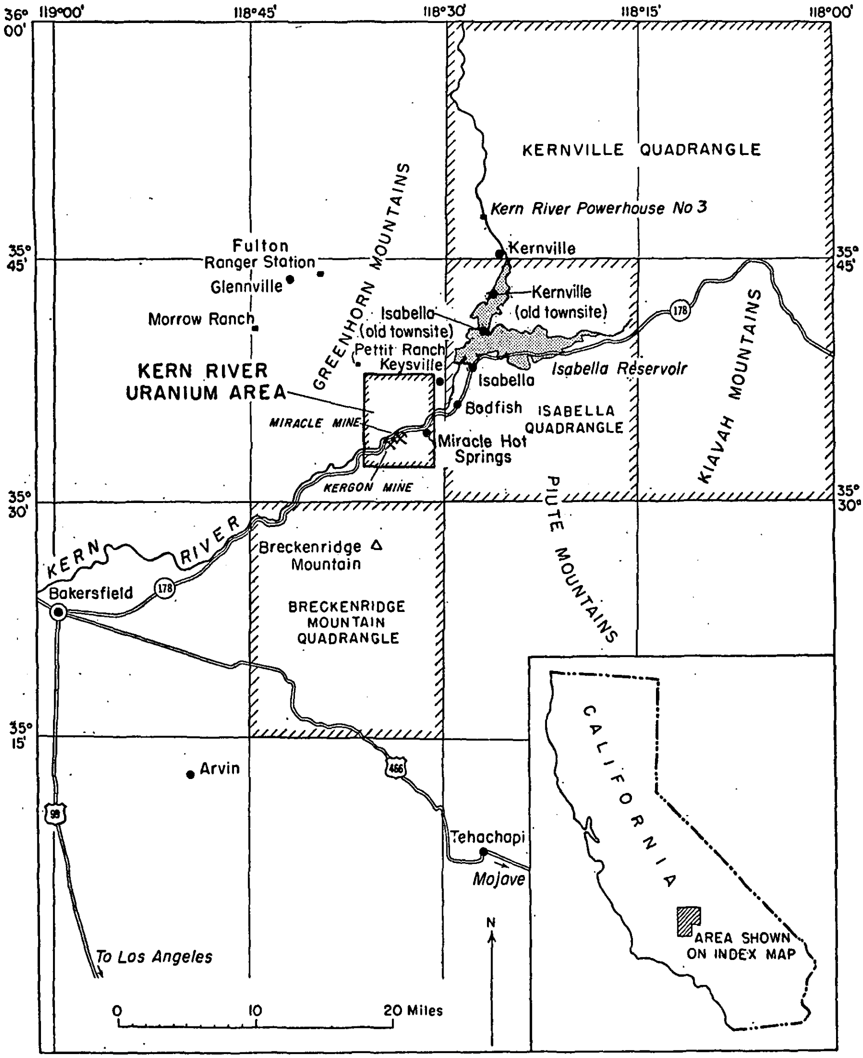


FIGURE 21.—Index map showing the location of the Kern River uranium area and nearby geologically mapped quadrangles.

Highway 178. Its northern part is penetrated by a number of dirt roads but most of these are very rough. The nearest railroad shipping point and major supply source is Bakersfield, which is served by both the Santa Fe and Southern Pacific railways. The only settlement in the area is Miracle (formerly Hobo) Hot Springs, whose population is small.

HISTORY OF MINING

Mining activity in the Kern River uranium area is divisible into three phases: gold prospecting, probably resulting from successful mining in the nearby Cove, Keyes, and Clear Creek (Havilah) districts between 1850 and 1880; tungsten prospecting, which began during World War I and was stimulated by the demand for tungsten during World War II; and uranium prospecting, impelled by the discovery of the Miracle mine deposit in January 1954. Despite considerable prospecting, attested by numerous shallow exploratory workings, the area has yielded only small quantities of ore. Parts of the Clear Creek, Keyes, Greenhorn Mountain, and Pioneer mining districts are in the area.

The uranium deposits, with a few exceptions, are localized in regional secondary fractures in Miller's Isabella granodiorite. Tungsten occurs both in quartz veins and in tactite in rocks of the Kernville series in the southeastern part of the area. Gold, exclusive of placer deposits, is found chiefly in quartz pods and veins cutting the more light-colored parts of the Isabella granodiorite in the northern part of the area. The tungsten and gold deposits were little studied during the present investigation, and the brief descriptions included here are largely abstracted from reports of the California State Division of Mines.

PREVIOUS WORK

Published geologic data on the Kern River uranium area consist of descriptions of the uranium mines and prospects by Walker, Lovering, and Stephens (1956), and brief descriptions of some gold and tungsten mines by the California State Division of Mines (Brown, 1915; Tucker and Sampson, 1940; Tucker, Sampson, and Oakeshott, 1949). W. A. Bowes and other geologists of the U.S. Atomic Energy Commission have investigated the Miracle and Kergon mines and the uranium prospects in the area, but the results of their work have not been published.

Several geologic reports on areas near the one here described have been published. Miller (1931) constructed two geologic sections across the southern Sierra Nevada on the basis of reconnaissance mapping, Miller and Webb (1940) mapped the 30-minute Kernville quadrangle, and Dibblee and Chesterman (1953) have mapped the 15-minute Breckenridge Mountain quadrangle.

PURPOSE AND SCOPE OF PRESENT WORK

The purpose of this investigation was to determine the mode of occurrence, origin, and probable extent of the uranium deposits, to relate them to the regional geology, and to learn by a study of the geology of the area if it is likely to contain other uranium deposits, and if so where to seek them. The work was on behalf of the U.S. Atomic Energy Commission.

During 3 months allotted to field studies, the geology of the entire area was mapped on a scale of 1:20,000 on National Forest Service aerial photographs, the geology of the areas around the Miracle and Kergon mines on a scale of 200 feet to the inch by planetable methods, and the geology of the workings in the Miracle and Kergon mine areas on a scale of 20 feet to the inch by means of Brunton compass and tape. A scintillation counter was used to make detailed radioactivity surveys in the mine areas and reconnaissance surveys throughout the remainder of the area.

Geologic data from the aerial photographs were compiled on a 1:20,000 topographic base prepared by the U.S. Geological Survey from the Glennville 15-minute quadrangle (1956). Laboratory work included petrographic studies of thin sections and mineralogic investigations by means of heavy-media separations, oil immersion methods, and X-ray diffraction. An X-ray spectrometer was used for determining some of the characteristic assemblages of elements in many ores and rocks, and semiquantitative spectrographic analyses, uranium assays, and age determinations were made on selected samples.

ACKNOWLEDGMENTS

W. A. Bowes and other Atomic Energy Commission geologists stationed at Bakersfield were extremely cooperative, both in discussing the geology of the uranium deposits and in making available the results of their investigations. Unpublished reports by the U.S. Corps of Engineers on the Isabella Dam site and the Isabella quadrangle (see fig. 21) were made available to the author. Valuable help was given by mining people, especially C. S. Hale, president of the Great Lakes Oil and Gas Co., which owns the Kergon mine; R. L. Steele, formerly superintendent of the Kergon mine; and M. S. Patterson and John Yonke of the Miracle Mining Co. U.S. Geological Survey members L. J. White assisted on the project for 2½ months and H. G. Stephens for 2 weeks, and H. W. Jaffe made lead-alpha age determinations.

GEOGRAPHY

The southern Sierra Nevada comprises several distinct ranges whose general trend is north. Their altitudes generally diminish from north to south, and at their south ends the ranges curve southwestward and merge into the Tehachapi Mountains. This part of the Sierra presents a marked contrast to much of the central part, with its prominent crest, steep east escarpment, and long moderate west slope.

In the Kern River uranium area, the Kern River cuts across the general trend of the ranges in a deep gorge. Altitudes in the area range from about 2,100 feet in the Kern River canyon to about 6,100 feet on the eastern slopes of the Greenhorn Mountains, one of the ranges in the southern Sierra Nevada. The Kern River is the master drainage artery. Several tributary streams, including Clear Creek, Greenhorn Creek, the stream occupying Black Gulch, and smaller unnamed streams are permanent, although their flow may be reduced to mere trickles by late summer. Springs, including some hot springs, are abundant in the general region, and several are within the mapped area.

The summers in the Kern River uranium area are hot and dry and the winters moderately cold. The annual precipitation probably ranges from about 5 inches in the lowest parts of the area to about 15 inches at the highest altitudes. Most of the precipitation occurs during winter storms, which generally deposit snow on the higher ground. In the summers, thunderstorms produce a moderate amount of rain. Data from nearby weather stations, whose locations are shown in figure 21, are summarized in table 1.

TABLE 1.—*Data*[1] *from weather stations near the Kern River uranium area*

Station	Altitude (feet)	Average annual temperature		Maximum temperature		Minimum temperature		Annual precipitation	
		°F	Number of years recorded	°F	Number of years recorded	°F	Number of years recorded	Inches	Number of years recorded
Glennville:									
Fulton Ranger Station	3, 540	-----	-----	----	-----	----	-----	12. 64	8
Morrow Ranch	3, 270	52	37	99	37	10	37	13. 56	38
Kernville:									
Kern River Power House No. 3	2, 701	58. 8	1	106	1	14	1	5. 63	1
Old townsite	2, 565	-----	-----	----	-----	----	-----	4. 45	54

[1] Data from U.S. Weather Bureau, 1948, p. 351, 352, 355, 356, 365, 366.

The vegetation is controlled mainly by altitude and rainfall, and to a lesser extent by the character of the rocks. The commonest trees at moderate altitudes are Digger pine, buckeye, and scrub oak, which characterize the greater part of the landscape. Conifers of several species grow at the higher altitudes, and sagebrush and cactuses predominate at the lower altitudes. Brush of various kinds, some forming dense thickets, abounds at intermediate and high altitudes. Willow, sycamore, cottonwood, and poison-oak are common along streams.

GEOLOGY

GENERAL GEOLOGIC SETTING

The southern Sierra Nevada, in which the Kern River uranium area lies, consists predominantly of granitic rocks with local roof pendants of metamorphic rocks. The metamorphic rocks are remnants of a thick geosynclinal sequence and consist mainly of mica schist and phyllite but include some quartzite, marble, and metavolcanic rock. Miller and Webb (1940, p. 350) estimate that these rocks are more than 12,000 feet thick in the Kernville quadrangle, and Dibblee and Chesterman (1953, p. 19) believe that the thickest metasedimentary rock unit in the Breckenridge Mountain quadrangle is about 20,000 feet thick. Most contacts between metamorphic and granitic rocks are sharp, but in places they are gradational.

The batholithic rocks range from gabbro to granite but are preponderantly quartz monzonite, granodiorite, and quartz diorite. The most mafic plutonic rocks—gabbro, diorite, and related types—are the oldest and were intruded and partly assimilated by later magmas. They occur chiefly in small isolated bodies or in zones of mixed rock. Dikes of pegmatite and aplite cut the batholithic rocks and the metamorphic rocks. Tertiary and Quaternary rocks, chiefly terrestrial sedimentary deposits, locally flank the range.

The region is tectonically active and the site of many recorded earthquakes (Townley and Allen, 1939; Dibblee and Chesterman, 1953, p. 50; Oakeshott, 1955). Dibblee and Chesterman (1953, p. 50, 51) divide the southern Sierra Nevada into four fault-bounded structural blocks. In general, post-Nevadan structures conform to the hypothesis of Hill (1954, p. 9), who regards regional north-south shortening and east-west extension as the primary tectonic strain pattern for most of southern California. The major systems of shears are exemplified by the left-lateral northeast-trending Garlock and similar faults, and the right-lateral northwest-trending San Andreas and related faults.

The Havilah Valley fault, which is believed to be a segment of the Kern Canyon fault zone,[1] the most important structural feature the general region, passes about a quarter of a mile southeast of the southeastern corner of the Kern River uranium area. According to Webb (1955, p. 35) the Kern Canyon lineament extends from the Tejon Hills in the southern San Joaquin Valley northeastward and northward for more than 100 miles and includes the White Wolf, Breckenridge, Havilah Valley, Hot Springs Valley, and Kern Canyon faults, probably as distinct segments (fig. 22).

[1] The Kern Canyon fault zone and its probable southwesterly extensions and intersegments have been termed the Kern Canyon lineament by Webb (1955, p. 35).

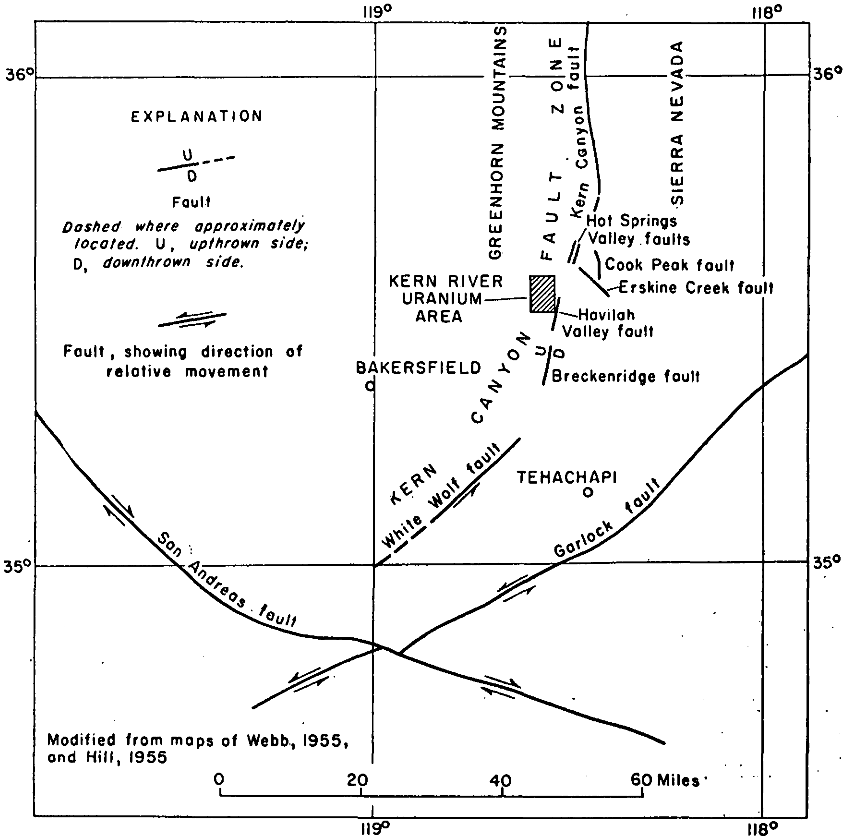


FIGURE 22.—Map showing segments of the Kern Canyon fault zone and nearby major faults.

The nature of the displacement has been established for some faults of this fault zone but is conjectural for others. Movement on the recently active White Wolf fault is mainly left lateral (Hill, 1955, p. 40). The movement on the Breckenridge fault is believed to have been mainly or entirely vertical, the west block having been elevated at least 4,000 feet (Dibblee and Chesterman, 1953, p. 46). Treasher (1949b, p. 1957–1958) believes that the north-striking Kern Canyon fault is a high-angle west-dipping thrust fault north of Bodfish, and a high-angle east-dipping normal fault south of Bodfish. Near the Isabella Dam site the crushed rock along the Kern Canyon fault is 800 feet wide (Treasher, 1949a, p. 1946). Webb (1946, p. 362) believes that the Kern Canyon fault was probably developed during the Nevadan orogeny and that only its roots are now visible.

Treasher (1949b) has described other major faults in the Isabella quadrangle, including the Cook Peak fault, which is a south-trending split from the main Kern Canyon fault, and the northwest-trending Erskine Creek fault (fig. 22). Miller (1931, p. 335) and Hake (1928, p. 1028) believe there is a major north-trending fault along the west flank of the Greenhorn Mountains.

GEOLOGIC FORMATIONS

PRE-CRETACEOUS METAMORPHIC ROCKS

KERNVILLE SERIES OF MILLER (1931)

NAME AND DISTRIBUTION

The name Kernville series was proposed by Miller (1931, p. 335) for metasedimentary rocks near Kernville. Miller and Webb (1940, p. 349, 350) subsequently extended their usage of the name to include the subordinate amount of metavolcanic rocks associated with the metasedimentary sequence in the Kernville quadrangle. Dibblee and Chesterman (1953, p. 13) use the name for metasedimentary rocks in the eastern part of the Breckenridge Mountain quadrangle.

Rocks of Miller's Kernville series crop out in secs. 15, 22, and 27, T. 27 S., R. 32 E., and are the dominant rocks between Clear Creek and the east border of the area (pl. 21). Inclusions of schist as much as 7 feet wide and about 30 feet in outcrop length are enclosed in pegmatite near the Miracle mine (pl. 23). Some partly assimilated rocks of the Kernville series may have been mapped as diorite and related rocks (pl. 21).

GENERAL DESCRIPTION

The metamorphic rocks, which are undifferentiated in plate 2, are chiefly in roof pendants which strike northward and dip from 45° W. to vertical (pl. 21). The beds range from a few inches to about 2 feet in thickness, but in most places the bedding is obscured by metamorphic effects. Foliation is well developed and is generally parallel to the bedding. In places there are minor steep fractures, closely spaced, and on some of these there have been displacements of 1 or 2 feet. Neither the base nor the top of Miller's Kernville series is exposed. Disregarding the effects, probably minor, of the many small drag folds and faults, the apparent thickness of the partial section of the Kernville series in the area is 3,700 feet. The contacts of the Kernville with intrusive rocks are commonly accordant and in places gradational for several tens of feet across their strike. Throughout the metamorphic areas the pegmatites, which commonly strike parallel with the bedding and schistosity, do not produce visible metamorphic changes. Weathering of the metamorphic rocks produces moderately smooth bare or grass-covered slopes, broken in places by knobs of pegmatite or resistant metamorphic rocks.

LITHOLOGY

The Kernville series of Miller consists mainly of mica schist and impure quartzite but includes a little calc-hornfels and marble. The quartzite and schist are commonly medium gray on fresh surfaces, and various shades of brown where weathered. The calc-hornfels is tan, light brown, or buff, with alternating color bands, and weathers medium or dark brown. The marble is bluish white to light gray and weathers to a light-gray rock with pitted surfaces.

The metamorphic rocks were probably derived for the most part from muddy sediments deposited in a geosyncline, but they have been subjected to both regional and thermal metamorphism. They are commonly fine grained, but near contacts with intrusive rocks they are coarser grained and closely resemble some inclusions found in the granodiorite. Gradations between schist and quartzite are common. Most of the metamorphic rocks are in the amphibolite facies (Turner and Verhoogen, 1951, p. 446), but some of those near contacts with the Isabella granodiorite of Miller (1931) may be in the pyroxene-hornfels facies (Turner and Verhoogen, 1951, p. 441).

PETROGRAPHY

SCHIST

The schist is characterized by the strong parallelism of mica, and commonly by parallel or subparallel orientation of plagioclase and quartz. Some of the schist is locally gneissic, containing alternating biotite-rich and felsic bands, each about 0.5 mm thick. The average diameter of the quartz and plagioclase grains in the schist is 0.3 mm. The mica flakes are commonly 0.5–0.6 mm by 0.1 mm, although at some places near contacts with the granodiorite they are more than 1 cm long.

The most abundant rock is muscovite-biotite-quartz schist. The quartz, which generally is the most abundant mineral, is commonly strained and probably stretched, and locally contains minute mineral inclusions. Oligoclase is found in most of the schist; orthoclase is scarce or absent. Biotite, a widespread constituent, is in ragged grains with inclusions of accessory minerals. It is strongly pleochroic, with X tan, Y light brown, Z reddish brown. Muscovite is moderately abundant, scarce, or absent. It occurs in ragged flakes that are commonly alined in parallel bands, and some isolated muscovite crystals or radial growths of muscovite lie across the foliation. A garnet (n=1.825), probably almandine, was noted in one specimen of schist.

Accessory minerals include zircon, in crystals up to 0.05 mm long that form pleochroic halos in biotite; rarely sphene, in crystals less than 0.1 mm long; and opaque minerals, probably chiefly magnetite.

Secondary minerals are chlorite, after biotite; clay minerals, after feldspar; and limonite and hematite, after opaque minerals.

Modal analyses of two thin sections of the schist reveal the following compositions:

	Percent
Plagioclase (An_{18})	36
Quartz	10
Biotite	33
Muscovite	20
Sphene, zircon, opaque minerals, and secondary minerals	1

	Percent
Plagioclase (An_{15})	5
Quartz	29
Biotite	20
Muscovite	23
Clay minerals	22
Zircon, opaque minerals, and chlorite	1

IMPURE QUARTZITE

The impure quartzite consists mainly of a granoblastic assemblage of quartz grains 0.2 to 0.7 mm in diameter. Elongation of quartz crystals and subparallel arrangement of mica flakes are evident in some specimens. The impure quartzite contains mainly the same minerals as the schist, but it lacks the well-developed foliation typical of schists.

The other minerals in the quartzite are biotite, oligoclase, and muscovite. Minor accessory minerals, which constitute about 2 or 3 percent of most of this quartzite, are magnetite(?), pyrite, zircon, and monazite(?). Secondary products include clay minerals, chlorite, calcite, epidote(?), and hematite.

A modal analysis of a thin section of impure quartzite showed it to contain the following:

	Percent
Quartz	70
Plagioclase (An_{20})	15
Muscovite	6
Biotite	8
Opaque and secondary minerals	1

MARBLE

The marble contains 80 to 99 percent dolomite and calcite and is chiefly granoblastic in texture. Stain tests indicate that the carbonate is prevailingly dolomite, although calcite is dominant in some specimens. Although some of the impure marble has discrete bands of other minerals 1 to 3 mm thick, the coarser marbles consist almost entirely of nearly equant grains of calcite or dolomite 2 to 4 mm in average diameter. Locally a blastoporphyritic texture is formed by calcite or dolomite crystals 0.6 to 1 mm in maximum dimension in a groundmass of calcite or dolomite that has a grain size of about 0.1 mm.

The crystals mainly form an interlocking mosaic and are slightly elongated parallel to banding and bedding. Minute flecks of graphite are the only recognizable impurity in some of the purer marbles.

The impure marbles contain a few scattered subrounded quartz grains, less than 10 percent each of diopside and forsterite, a little graphite, pyrite, hematite, and, uncommonly, minor aggregates of chalcedony, presumably remnants of chert. Secondary minerals found only in small amounts are limonite, sericite, and, locally along fractures, clay minerals. Some late-stage calcite forms veinlets that cut chalcedony and other minerals. Intergrowths of tremolite, in elongate crystals up to 3 cm long, and calcite occur in the marble adjacent to some faults.

CALC-HORNFELS

The typical calc-hornfels in the area is a crystalline diopside-grossularite rock with grains mostly 3 to 5 mm in diameter. Garnet is the most abundant mineral in many of these rocks. It is near the grossularite end of the grossularite-andradite series in composition, as indicated by its specific gravity, 3.52, and its index of refraction, 1.752 (Winchell and Winchell, 1951, p. 485). Much of the garnet occurs in large- to medium-sized dodecahedrons enclosng small grains of other minerals. Diopside, the second most abundant mineral, is near the diopside end of the diopside-hedenbergite series. Quartz is moderately abundant in anhedral grains about 2 mm in diameter. Sphene, the principal accessory mineral, occurs in well-formed crystals less than 1 mm long which are pleochroic from colorless to light brown. Calcite veinlets cut garnet and quartz. Clay minerals are sparsely distributed.

Some bands of buff to white calc-hornfels consist mainly of felty aggregates of wollastonite in elongate crystals 2 to 3 mm long.

Local small-scale additive metamorphism is evidenced by small zones of tactite. These contain small masses of scheelite and concentrations of iron minerals.

AGE AND CORRELATION

The rocks of Miller's Kernville series are older than the Cretaceous (p. 188) rocks which intrude them, but as no fossils have been found in them their lower age limit is unknown. Miller and Webb (1940, p. 352, 353), on the poor criteria of degree of metamorphism and lithologic similarity with certain rocks of the Calaveras formation, of late Paleozoic age, tentatively regard the Kernville series as Paleozoic and probably Carboniferous.

The only nearby pre-Nevadan rocks that are accurately dated are those east of Mineral King, about 60 miles north of the Kern River uranium area, and the thick Garlock series of Dibblee (1952) in the El Paso Mountains, about 45 miles to the east. The metamorphic rocks of the Mineral King area have been described by Turner (1893, p. 451) and by Knopf and Thelan (1905, p. 242), and fossils from them were dated as Late Triassic by S. W. Muller (quoted in Durrell, 1940, p. 17). Parts of the Garlock series described by Dibblee (1952, p. 15) contain Permian fusulinids. It is quite possible that the Kernville series includes rocks of several geologic systems.

The Kernville series of the Kern River uranium area correlates in general with similar metamorphic rocks in the Kernville quadrangle (Miller and Webb, 1940, p. 352) and in the Breckenridge Mountain quadrangle (Dibblee and Chesterman, 1953, p. 16, 17).

CRETACEOUS INTRUSIVE ROCKS

The oldest intrusive rocks in the Kern River uranium area are diorite and related rocks, which have been largely assimilated by later magmas. Most of the area is occupied by a mass of intrusive rock known as the Isabella granodiorite of Miller (1931). This mass forms one of the many large plutons that make up the Sierra Nevada composite batholith. The part of this mass that lies within the Kern River uranium area consists mainly of granodiorite, but it includes some moderate-sized facies that range in composition from quartz monzonite to quartz diorite, and it contains many small mafic inclusions. Pegmatite and aplite dikes cut the plutonic and metasedimentary rocks.

DIORITE AND RELATED ROCKS

DISTRIBUTION AND RELATIONS

Dioritic rocks crop out in several patches, the largest of them only a few hundred square feet in area. The only two areas of this unit that were mapped are in sec. 4, T. 27 S., R. 32 E., and in sec. 25, T. 27 S., R. 31 E. (pl. 21). These patches are believed to be partly assimilated remnants of gabbro(?) and diorite that were once much more widespread, and they may represent the oldest part of the Sierra Nevada batholith. They are closely associated with the more mafic parts of Miller's Isabella granodiorite and are cut by pegmatite dikes. They probably correlate with widespread but not abundant similar mafic rocks in the southern Sierra Nevada, which, according to Miller (1931, p. 343), range from olivine gabbro to diorite.

PETROGRAPHY

The dioritic and gabbroic(?) remnants are brownish strongly weathered medium- to coarse-grained rocks characterized by abundant mafic minerals. Because of their scarcity, and the difficulty in obtaining fresh samples, they were not studied in detail. They probably range in composition from quartz diorite to gabbro, as dioritic and gabbroic rocks are abundant in nearby areas (Miller and Webb, 1940, p. 353, 354; Dibblee and Chesterman, 1953, p. 28–31).

The single specimen studied as a typical example is dark hornblende-biotite quartz diorite from an outcrop in sec. 4, T. 27 S., R. 32 E. This rock has a hypautomorphic granular texture and consists of near-equant crystals 4 or 5 mm in average diameter. The dark minerals, which form about half the rock, are chiefly biotite with some hornblende. The light minerals are plagioclase (andesine) and quartz, and the accessory minerals are allanite, apatite, zircon, and opaque minerals. The following elements were detected with an X-ray spectrometer:[2] Fe (strong), Mn (moderate), Ca (moderate), Th (trace), Zr (trace), Ru (trace). Owing to its thorium content, this rock is about three times as radioactive as normal gabbro.

ISABELLA GRANODIORITE OF MILLER (1931)

NAME AND DISTRIBUTION

The name Isabella granodiorite was given by Miller (1931, p. 344) to a composite intrusive body which occupies a large part of the Kernville quadrangle. This mass, according to Miller and Webb (1940, p. 358), was formed by several waves of intrusion that occurred within a relatively short space of time, and it includes rocks that range in composition from granite to diorite. It was named the Isabella granodiorite because the specimens first collected by Miller near the type locality at Isabella consisted of rock that he classed as granodiorite (though they were richer in potassium feldspar than most granodiorite), and this term has become intrenched as a geologic name despite the fact that the most abundant rock in the mass was later found to be quartz monzonite (Miller and Webb, 1940, p. 343). In the Kern River uranium area, Miller's Isabella granodiorite is represented mainly by granodiorite, although it contains subordinate amounts of quartz monzonite and quartz diorite.

The Isabella granodiorite underlies all but about 1 square mile of the Kern River uranium area. It intrudes rocks of the Kernville series, and its contacts are generally sharp and mostly parallel to the bedding (pl. 19A). It also cuts and partly assimilates diorite and related rocks, and it is cut in turn by pegmatite dikes.

Outcrops of the Isabella granodiorite range from poor to bold. Its degree of weathering depends largely on distance from fractures, from which the weathering commonly progresses outward. Blocks of fresh granodiorite, either partly or entirely surrounded by weathered granodiorite, are common, but where erosion has penetrated deeply, as in the lower parts of the Kern River canyon, the granodiorite is fresh.

[2] The terms "strong," "moderate," "weak," and "trace" only roughly indicate relative abundance. Elements with atomic numbers of less than 20, which is the atomic number of calcium, are undetected by the X-ray spectrometer techniques used in this investigation and consequently are not reported.

PETROGRAPHY

The rock that constitutes most of Miller's Isabella granodiorite mass is medium or coarse grained and commonly light gray. Hornblende-biotite granodiorite is the prevailing variety; only slightly less common are biotite granodiorite and hornblende-biotite-quartz diorite. Hornblende-biotite-quartz monzonite, biotite-quartz monzonite, and biotite-quartz diorite are sparsely represented. The granodiorite is typically equigranular, although biotite and hornblende are commonly elongated and alined along flow planes and locally along lines of flow. Porphyritic facies occur in secs. 5 and 6, T. 27 S., R. 32 E., and in secs. 31 and 32, T. 26 S., R. 32 E. Granodiorite with a gneissic texture near contacts with rocks of the Kernville series crops out in secs. 22 and 27, T. 27 S., R. 32 E. The porphyritic rocks consist chiefly of coarse-grained feldspar minerals and quartz whose intercrystal spaces are occupied by small amounts of fine-grained mafic minerals. They weather deeply and are of diverse composition (fig. 23, nos. A-76, A-77, A-97, and A-98.)

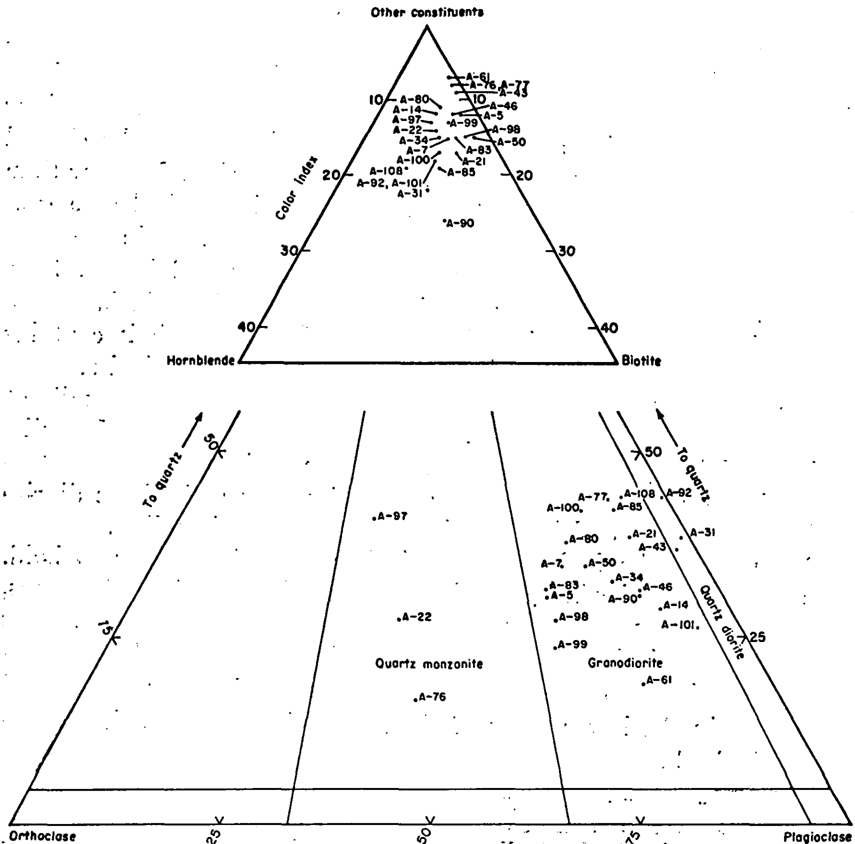


FIGURE 23.—Composition of the Isabella granodiorite of Miller in the Kern River uranium area, exclusive of Miracle and Kergon mine areas. (See pl. 21 for location of specimens.)

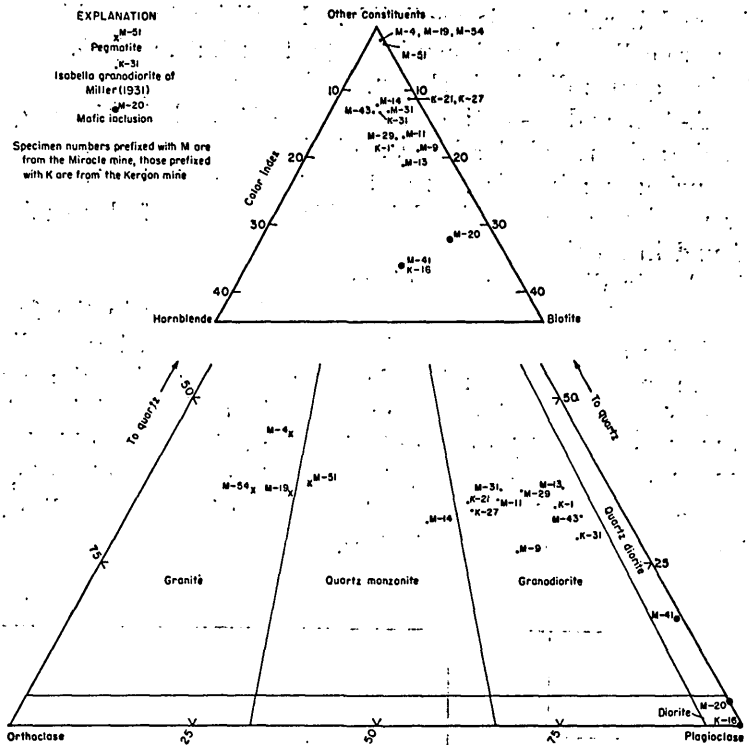


FIGURE 24.—Composition of rocks near the Miracle and Kergon mines.

The texture of the Isabella granodiorite is mostly medium grained, hypautomorphic, and granular; coarse-grained rocks, and those with gneissic and porphyritic textures, are merely local variations.

The composition of the Isabella granodiorite is represented graphically in figures 23 and 24. These are ternary diagrams, based largely on the method of Johannsen (1939, p. 152, 153), and use modes determined by the point-count technique of Chayes (1949, p. 1–11). Locations on the diagram that are marked by specimen numbers denote Johannsen's point F, representing the quartz-orthoclase-plagioclase ratio. Johannsen's method was supplemented by one devised by C. D. Rinehart and D. C. Ross of the U.S. Geological Survey. This scheme uses a small triangle consisting of the upper part of the larger triangle. Points at the lower corners of the small triangle represent 45 percent hornblende and 45 percent biotite, and the apex represents 100 percent combined other minerals, so that a point representing a given specimen shows the percentage of biotite, of hornblende, and of the other minerals collectively, in that specimen. The percentage of other minerals gives a close approximation of the color index since the amount of mafic minerals other than biotite and hornblende is negligible. Localities from which specimens were collected are shown in plates 21, 23, 24, and 25.

Typical quartz diorite is shown on figure 23 by nos. A–31, A–43, A–92, A–101, and A–108; nos. A–22, A–76, and A–97 are quartz monzonite; the remainder is granodiorite.

The primary minerals in the Isabella granodiorite in the Kern River uranium area are listed in table 2. Most of these minerals are found in all the rock species that constitute the Isabella granodiorite, but in different proportions.

Many secondary minerals occur in small amounts in the freshest granodiorite and are abundant in strongly weathered granodiorite. The commonest are clay minerals after feldspar minerals; a pale-green variety of chlorite that probably is (—) penninite, chiefly after biotite; clinozoisite after plagioclase; epidote after biotite and hornblende; and, uncommonly, limonite after opaque minerals, sericite after feldspar, leucoxene probably after ilmenite, uralite after augite, and calcite after plagioclase.

TABLE 2.—*Primary minerals in the Isabella granodiorite of Miller*

Mineral	Abundance (percent)	Remarks
Plagioclase	20–61	Commonly in normally zoned subhedral crystals; between An_{40} and An_{30}.
Potassium feldspar	1–40	Occurs chiefly in medium- or coarse-grained anhedral or subhedral masses. Abundant microperthite.
Quartz	15–40	Interstitial anhedral grains.
Biotite	6–15	Commonly in subhedral flakes. Pleochroism: *X* tan or light yellowish brown, *Y* light to medium brown, *Z* reddish brown to dark brown.
Hornblende	<1–12	Prismatic crystals commonly 4–5 mm long. Pleochroism: *X* light brown or greenish brown, *Y* pale green, yellowish green, or greenish brown, *Z* dark brown, green, or greenish brown. More susceptible to weathering than the biotite.
Augite	<1	Identified in only one thin section.
Sphene	<1–1	Widespread minor accessory mineral. Noted in every thin section.
Apatite	<1	Moderately abundant accessory mineral in small euhedral crystals.
Opaque minerals	<1	Probably chiefly magnetite, subordinate ilmenite.
Zircon	<1	Moderately abundant accessory mineral; small euhedral crystals.
Xenotime	<1	Locally moderately abundant accessory mineral; small euhedral crystals.
Tourmaline	<1	Identified in only three thin sections. Probably a late-stage mineral. Pleochroism; *O*, bluish green, *E* colorless.
Monazite	<1	Very uncommon.
Allanite(?)	<1	Do.

Semiquantitative spectrographic analyses of granodiorite and four related rocks from the Isabella mass are shown in table 3.

MAFIC INCLUSIONS

Sharply defined mafic inclusions, most less than a foot long, are abundant in the Isabella granodiorite in the southern half of the Kern River uranium area. The inclusions are discoidal or flatly ellipsoidal and probably are oriented parallel to the flow planes of the enclosing rock. Their major and intermediate axes are generally 3 to 5 times as long as the minor axis, but they range in shape from nearly spherical masses to long, narrow streaks. Most of them are 6 to 12 inches in maximum and intermediate dimensions, and 2 to 4 inches in smallest dimension. Where present, the inclusions are generally nearly evenly distributed, but locally they occur in bunches or bands (pl. 19*B*). Their distribution is related in a general way to the composition of the host rock: they are most abundant in quartz diorite, less abundant in granodiorite, and scarce in quartz monzonite.

The inclusions consist of diorite or quartz diorite. They are much more resistant to weathering than the coarser grained diorite and gabbro, and in some outcrops they stand out in low relief. Where weathered they are dark brown to black.

TABLE 3.—*Semiquantitative spectrographic analyses, in percent, of some rocks from the Kern River uranium area* [1]

[Analyses by Mona Frank and R. E. Valentine, U.S. Geological Survey]

Sample	Rock type	Al	B	Ba	Be	Ca	Co	Cr
A-1	Isabella Granodiorite of Miller [2]	5-10	0.005-0.01	0.01-0.05	0.00005-0.0001	1-5		0.0005-0.001
A-10	Granodiorite	5-10	.005-.01	.05-.1	.00005-.0001	1-5		.0005-.001
A-15	Granodiorite	5-10	.01-.05	.05-.1	.00005-.0001	1-5		.0005-.001
A-32	Quartz diorite	5-10	.005-.01	.05-.1	.00005-.0001	1-5		.0005-.001
A-53	Granodiorite	5-10	.005-.01	.05-.1	.00005-.0001	1-5		.001-.005
A-76	Quartz monzonite	5-10	.005-.01	.1-.5	.00005-.0001	1-5		.0005-.001
A-89	Granodiorite	5-10	.005-.01	.05-.1	.00005-.0001	1-5		.001-.005
K-2	Pegmatite	5-10	.005-.01	.01-.05		1-5		.001-.005
K-17	Granodiorite	>10	.005-.01	.05-.1		1.5	0.0001-0.0005	.001-.005
M-28	Granodiorite	>10	.01-.05	.05-.1		1.5	.0001-.0005	.001-.005
M-30	Mafic inclusion	5-10	.01-.05	.01-.05	.00005-.0001	1-5		.005-.01
M-35	Granodiorite	>10	.01-.05	.05-.1		1-5	.0001-.0005	.005-.01
M-41	Mafic inclusion	>10	.01-.05	.05-.1		1-5	.0001-.0005	.001-.005
M-56	Granodiorite	>10	.01-.05	.05-.1		1-5	.0001-.0005	.005-.01

Sample	Cu	Fe	Ga	K	La	Li	Mg	Mn
A-1	0.01-0.05	1-5	0.001-0.005	1-5		0.01-0.05	0.5-1	0.01-0.05
A-10	.01-.05	1-5	.001-.005	1-5		.01-.05	.5-1	
A-15	.01-.05	1-5	.001-.005	1-5		.01-.05	.5-1	.01-.05
A-32	.005-.01	1-5	.001-.005	1-5		.01-.05	1-5	.01-.05
A-53	.005-.01	1-5	.001-.005	1-5		.01-.05	1-5	.01-.05
A-76	.01-.05	1-5	.001-.005	1-5		.01-.05	.1-0.5	.005-.01
A-89	.005-.01	1-5	.001-.005	1-5		.01-.05	1-5	.01-.05
K-2	.001-.005	0.5-1	.005-.01	1-5			.1-.5	.005-.01
K-17	.001-.005	1-5	.005-.01	1-5			.5-1	
M-28	.001-.005	1-5	.005-.01	1-5	0.001-0.005		.5-1	.01-.05
M-30	.005-.01	1-5	.001-.005	0.5-1		.01-.05	1-5	.01-.05
M-35	.001-.005	1-5	.005-.01	1-5	.001-.005		.5-1	.01-.05
M-41	.001-.005	1-5	.005-.01	1-5	.001-.005		.5-1	.01-.05
M-56	.001-.005	1-5	.005-.01	1-5	.001-.005		.5-1	.01-.05

Sample	Mo	Na	Ni	Pb	Sc	Si	Sn
A-1	----------	1-5	----------	0.001-0.005	0.001-0.005	>10	0.001-0.005
A-10	----------	1-5	----------	.001- .005	.001- .005	>10	.001- .005
A-15	----------	1-5	----------	.001- .005	.001- .005	>10	.001- .005
A-32	----------	1-5	----------	.001- .005	.001- .005	>10	.001- .005
A-53	----------	1-5	----------	.001- .005	.001- .005	>10	.001- .005
A-76	----------	1-5	----------	.001- .005	.001- .005	>10	.001- .005
A-89	----------	1-5	0.001-0.005	.001- .005	.001- .005	>10	.001- .005
K-2	----------	1-5	----------	.001- .005	----------	>10	----------
K-17	0.0005-0.001	1-5	----------	.001- .005	.001- .005	>10	----------
M-28	.0005- .001	1-5	----------	.001- .005	.001- .005	>10	----------
M-30	----------	1-5	.001- .005	.001- .005	.001- .005	>10	.001- .005
M-35	.0005- .001	1-5	----------	.001- .005	.001- .005	>10	----------
M-41	.0005- .001	1-5	----------	.001- .005	.001- .005	>10	----------
M-56	.0005- .001	1-5	----------	.001- .005	.001- .005	>10	----------

Sample	Sr	Ti	V	Y	Yb	Zr
A-1	0.05 -0.1	0.1 -0.5	0.001-0.005	----------	----------	0.001-0.005
A-10	.05 - .1	.1 - .5	.001- .005	0.001-0.005	0.0001-0.0005	.001- .005
A-15	.05 - .1	.1 - .5	.001- .005	----------	----------	.001- .005
A-32	.05 - .1	.11 - .5	.001- .005	.001- .005	.0001- .0005	.001- .005
A-53	.05 - .1	.1 - .5	.001- .005	.001- .005	.0001- .0005	.001- .005
A-76	.05 - .1	.1 - .5	.001- .005	.001- .005	----------	.001- .005
A-89	.05 - .1	.1 - .5	.001- .005	.001- .005	.0001- .0005	.001- .005
K-2	.005- .01	.001- .005	.001- .005	.001- .005	.0001- .0005	.001- .005
K-17	.01 - .05	.1 - .5	.005- .01	.001- .005	.0001- .0005	.005- .01
M-28	.05 - .1	.1 - .5	.005- .01	.001- .005	.0001- .0005	.001- .005
M-30	.05 - .1	.1 - .5	.001- .005	.001- .005	.0001- .0005	.001- .005
M-35	.05 - .1	.1 - .5	.005- .01	.001- .005	.0001- .0005	.005- .01
M-41	.05 - .1	.1 - .5	.005- .01	.001- .005	.0001- .0005	.001- .005
M-56	.05 - .1	.1 - .5	.005- .01	.001- .005	.0001- .0005	.005- .01

[1] Equivalent and chemical uranium analyses of these and other samples are shown in table 9. Locations of samples are shown on plates 21, 23, 24, 25.
[2] Sample from near type locality at Isabella.

The inclusions are composed mainly of anhedral crystals 0.5 to 2 mm in average diameter. Some of the inclusions are porphyritic, consisting of normally zoned plagioclase phenocrysts 5 to 7 mm long in a medium- or fine-grained groundmass. In some of them the mineral grains are nearly parallel. The composition of three inclusions is represented diagrammatically in figure 24, and further data on the primary minerals in the mafic inclusions are shown in table 4.

TABLE 4.—*Primary minerals of mafic inclusions in the Isabella granodiorite of Miller*

Mineral	Abundance (percent)	Remarks
Plagioclase	47–54	Normally zoned in andesine-oligoclase range.
Quartz	<1–10	
Biotite	22–27	Strongly pleochroic: *X* tan, *Y* light brown, *Z* dark reddish brown. Contains minute inclusions that form with pleochroic halos.
Hornblende	12–17	Generally poikilitic. Pleochroism: *X* light greenish brown to tan, *Y* light brown, *Z* greenish brown.
Augite	<1–9	
Sphene	<1–1	
Opaque minerals	<1–1	Probably chiefly magnetite and ilmenite.
Apatite	<1	
Xenotime	<1	

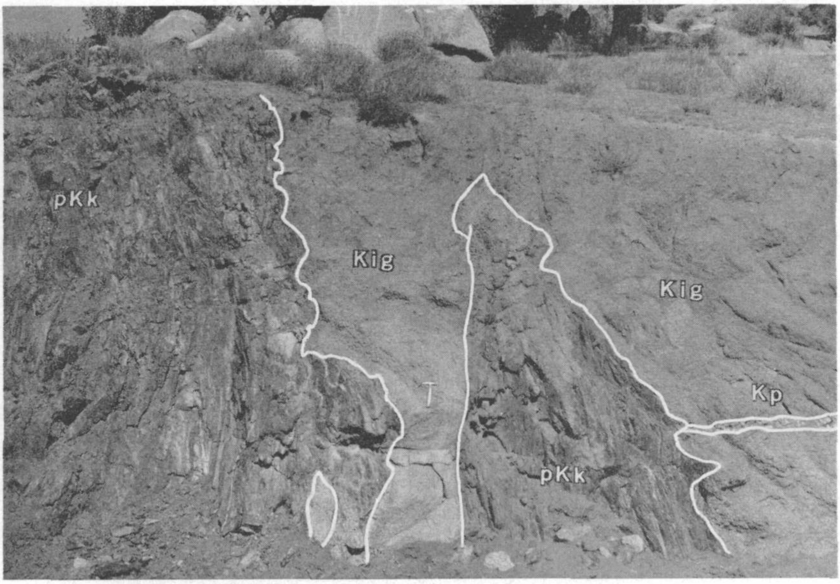
Secondary minerals are pale-green chlorite and epidote after mafic minerals, clay minerals after plagioclase, colorless to light-brown uralite after augite, limonite after mafic and opaque minerals, leucoxene(?) after ilmenite, and hematite, locally with secondary quartz, after opaque minerals.

An X-ray spectrometer examination of a mafic inclusion from the Miracle mine area revealed the following elements (see footnote, p. 181): Fe (strong), Mn (weak), Sr (trace), Ga (trace), Ti (trace), Ca (weak). The results of a semiquantitative spectrographic analysis of a mafic inclusion are shown in table 3 (M–30).

Most of these inclusions probably represent fragments of once widespread mafic plutonic rocks, but some may be reconstituted metamorphic rocks.

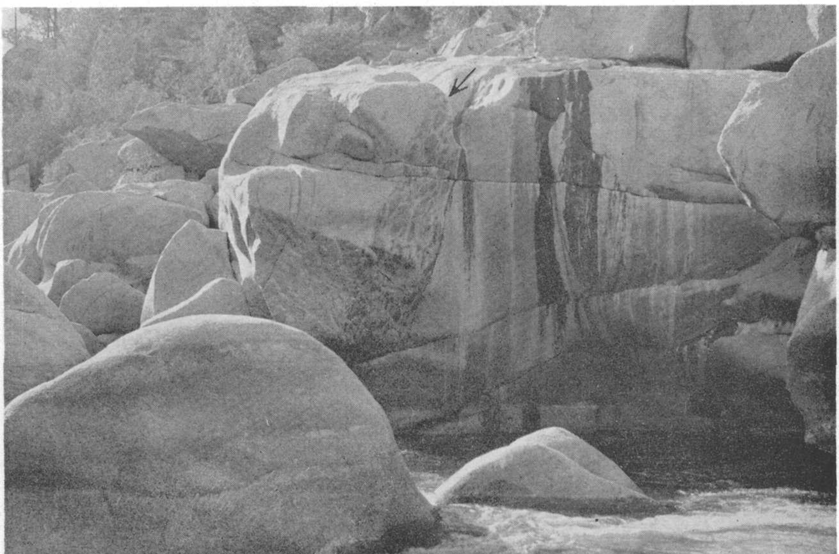
AGE AND CORRELATION

Lead-alpha age determinations (Larsen method) made by H. W. Jaffe on zircon concentrated from a 75-pound sample of Miller's Isabella granodiorite collected near the Miracle Mine range from 85 to 96 million years. These age determinations represent three fractions of different-sized grains of zircon from the same concentrate. The average age is 90 million years, nearly equivalent to the beginning of the Late Cretaceous epoch.



A. KERNVILLE SERIES AND ISABELLA GRANODIORITE OF MILLER

Contact between Kernville series of Miller (pKk) and Isabella granodiorite of Miller (Kig) in road cut, sec. 15, T. 27 S., R. 32 E. Kp is pegmatite.

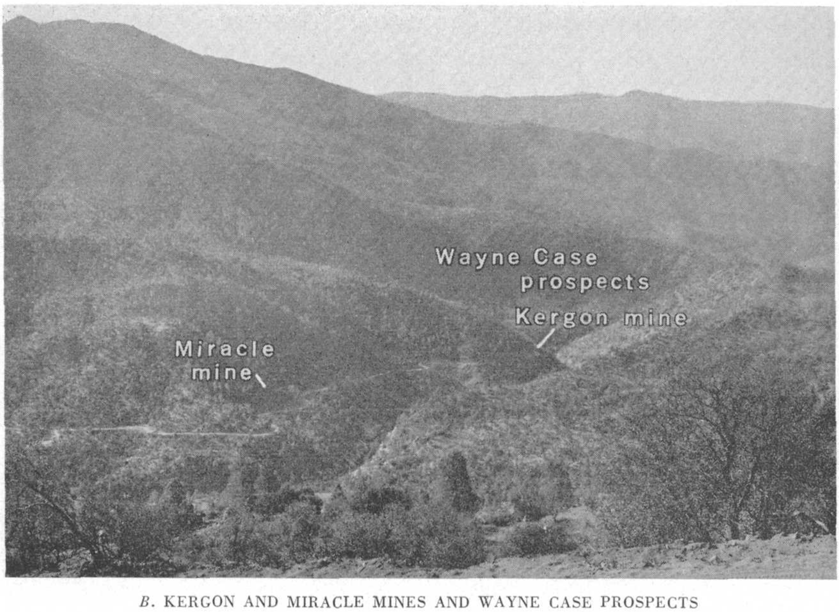


B. INCLUSION-RICH BAND IN THE ISABELLA GRANODIORITE OF MILLER

The band is about 3 feet thick in sec. 17, T. 27 S., R. 32 E., Miracle mine area.

A. PLANAR STRUCTURE IN ISABELLA GRANODIORITE OF MILLER

The planar structure is exemplified by stretched mafic inclusions and leucocratic schlieren, Miracle mine area.



B. KERGON AND MIRACLE MINES AND WAYNE CASE PROSPECTS

Kern River canyon showing the location of the mines and prospects. Camera facing southwest.

The Isabella granodiorite in the area here described is believed to represent a part of a vast batholithic mass, grading outward from a deep-seated central zone typified by the prevailing quartz monzonite of the Kernville quadrangle (Miller and Webb, 1940, p. 357) into contaminated border zones of more mafic rocks. Miller (1931, p. 346) notes that the quartz monzonite and the typical Isabella granodiorite in the vicinity of Isabella (old townsite) and Kernville (old townsite) grades westward into quartz diorite. The part of the Isabella mass within the Kern River uranium area appears to be a single intrusive body.

Most of that part of the Isabella granodiorite which lies in the Kern River uranium area may represent contaminated marginal parts of the batholith. The various kinds of rock grade into one another, and their difference apparently are due to their position in the batholith and to their degree of contamination. Most of the rocks that exhibit considerable textural variations are at high altitudes, and probably they represent border facies formed near the roof of the batholith.

The Isabella granodiorite of the Kern River area correlates with similar rocks in the Kernville quadrangle. Biotite-quartz diorite and hornblende-biotite-quartz diorite in the Breckenridge Mountain quadrangle, described by Dibblee and Chesterman (1953, p. 22–26), are probably contaminated border facies of the same intrusive body.

PEGMATITE

DISTRIBUTION AND THICKNESS

Pegmatite dikes are abundant throughout the Kern River uranium area where they cut all the other crystalline rocks. Surface traces of most of the dikes are delineated on plate 21. The dikes generally form bold outcrops and are particularly well exposed on the north walls of the Kern River canyon in secs. 17, 18, and 19, T. 27 S., R. 32 E.

Few of the pegmatite dikes are exposed for more than 100 or 200 feet, but a few of them are traceable for as much as 2 miles. Most of the dikes are between 1 and 4 feet thick, but they range in thickness from a few inches to about 200 feet. Their attitudes are diverse, but most of them strike northeast and dip gently northwest. In some places reversals in dip produce minor rolls and flexures. Branching dikes are uncommon. The large dike exposed low in the Kern River canyon near the Kergon mine and northeast of it has a roughly elliptical outcrop extending along the Kern River (pls. 21, 22). The pegmatite dikes commonly cut across flow lines and flow planes in the Isabella granodiorite, but in the metamorphic rocks they generally strike parallel to the bedding and schistosity. Inclusions of metamorphic rocks of the Kernville series, as much as 30 feet long and 7 feet thick, occur in a few of the pegmatite dikes, notably the Miracle pegmatite dike and the thick dike in the northern part of the large roof pendant. Host rocks adjacent to the dikes show no metamorphic effects and their contacts are sharp.

PETROGRAPHY

The pegmatite dikes range from extremely quartz-rich types through typical potash feldspar-rich granite and quartz monzonite pegmatites to potash feldspar-rich types with little quartz. Most of them are unzoned and consist largely of medium-grained quartz and microcline with a little plagioclase and mica. A few of the thicker dikes are zoned and contain one or more thin stringers or pods of very coarse grained potash feldspar or quartz, or both, between layers of typical medium-grained pegmatitic material. Generally the very coarse grained minerals occupy the cores, but some of the thicker dikes contain several very coarse grained zones about 1 foot thick. A few dikes 4 to 6 feet thick are symmetrically zoned, with quartz cores 6 to 12 inches thick, intermediate zones of graphic granite commonly about 4 to 6 inches thick, and border zones of medium-grained potash feldspar mixed with a little quartz and plagioclase 1 to 2 feet thick. Fine-grained, saccharoidal aplite makes up a small part of some of the pegmatites. Quartz-lined vugs are an uncommon feature. Small parts of a few pegmatite dikes are slightly radioactive.

The pegmatites are mainly medium- and coarse-grained rocks, but in some places they have very coarse pegmatitic textures, associated with graphic and vermicular intergrowths, and elsewhere they have fine-grained aplitic textures.

They are rich in potassium feldspar, mainly microcline, and in quartz. Most of the potassium feldspar crystals are between 1 and 5 mm in diameter, but microcline crystals as much as 10 cm in maximum diameter were noted in some of the very coarse grained zones. Aplitic parts of the dikes contain potash feldspar in the 0.5 to 2 mm size range.

The quartz content ranges from 10 to 90 percent. Most of the pegmatite dikes contain anhedral grains of quartz 2 to 5 mm in mean diameter, but some of the quartz grains in the cores of the zoned masses are as much as 10 cm across. In some dikes, quartz forms graphic intergrowths with potassium feldspar or black tourmaline, and in places it is microscopically intergrown with potassium feldspar and plagioclase. Fine-grained quartz is the dominant constituent of the aplitic parts of the dikes.

Medium-grained intermediate oligoclase, An_{23-20}, makes up between 10 and 20 percent of most of the pegmatites, but plagioclase is apparently absent in the cores and graphic-textured intermediate zones of the zoned dikes.

Biotite in flakes a few millimeters long to plates and books about 5 cm long generally makes up 1 to 4 percent of the medium-grained parts of the pegmatites. Its pleochroism is stronger than that of the biotite in the Isabella granodiorite: *X* light brown, *Y* brown, *Z* very dark brown. Some of the biotite is slightly radioactive, probably owing to minute inclusions of radioactive minerals.

Muscovite in fine- and medium-grained frayed subhedral crystals generally constitutes less than 1 percent of the pegmatites. A little black tourmaline occurs in spherical clots a few centimeters in diameter, in graphic intergrowths with quartz, or in irregular veinlets. Its pleochroism is *O* bluish black, *E* colorless.

Other minor constituents are magnetite, garnet, sphene, apatite, euxenite, allanite, goethite(?), and xenotime(?). The magnetite forms nearly perfect crystals as much as 1 cm long but commonly 1 or 2 mm. Garnet forms reddish-brown dodecahedrons as much as 5 mm in diameter. The specific gravity of three garnet specimens, determined on a Berman balance, was 3.985, 3.990, and 4.000, and the index of refraction as determined by oil-immersion methods ranged between 1.81 and 1.82. The garnets are in the pyrope-almandine (+ andradite) series of Winchell and Winchell (1951, p. 485, fig. 378). Sphene occurs in very small weakly pleochroic crystals, some of them included in biotite. Apatite forms sparsely distributed euhedral crystals less than 0.4 mm long, commonly enclosed in potash feldspar. Euxenite occurs in a few pegmatite dikes in dark-gray to black crystals about 1 cm in diameter. It was identified by X-ray diffraction methods. Allanite and goethite(?) are widely scattered.

Secondary minerals in the pegmatites are clay minerals, after feldspar minerals; sericite, after feldspar minerals; chlorite in minor amounts, after biotite; epidote, rare, after biotite; and limonite, after opaque minerals and also intermixed with very fine grained chlorite(?) on the peripheries of garnet crystals. In a few pegmatites, fracture walls are coated with colorless botryoidal opal that fluoresces bright yellow green.

A semiquantitative spectographic analysis of a pegmatite sample from the Kergon mine area is shown in table 3 (K–2). The following elements were found by X-ray spectrometer examination of a pegmatite sample from the Miracle mine area: Fe (strong), Ca (moderate), Zr (trace), Y (trace), Sr (trace), Rb (trace).

AGE AND CORRELATION

The pegmatite dikes were emplaced at a late stage in the magmatic activity of the Sierra Nevada batholith. They are probably of Cretaceous age, as is Miller's Isabella granodiorite (p. 188).

Pegmatites similar to those in the Kern River uranium area are widespread and abundant throughout the southern Sierra Nevada. Miller and Webb (1940, p. 351) briefly described the pegmatites in the Kernville quadrangle. Dibblee and Chesterman (1953, p. 32) described pegmatites in the Breckenridge Mountain quadrangle that are like those in the Kern River uranium area. Minor radioactivity anomalies have been found in many pegmatites in the southern Sierra Nevada (W. A. Bowes, oral communication, 1955).

QUATERNARY SEDIMENTARY ROCKS

RIVER TERRACE DEPOSITS

Unmapped mantles of unconsolidated river terrace deposits, 2 or 3 acres in maximum area, locally overlie the intrusive rocks in the Kern River canyon near the eastern boundary of the mapped area (sec. 10, T. 27 S., R. 32 E.). The deposits consist of well-rounded pebbles, cobbles, and boulders of granitic and metamorphic rocks. They are 10 to 15 feet in maximum thickness, and their base is about 15 feet higher than the river's present average water level. The river terrace deposits are probably Recent in age.

STRUCTURE

The structural features of the area reflect two orogenic periods. The oldest, the Nevadan, is manifested by the northward trend of the metamorphic pendant near Clear Creek and a similar trend of planar structures in granitic rocks near the pendant. These features are probably attributable to compression from the east and west. The youngest orogenic activity probably began during the Cenozoic, and, according to the belief of Hill (1954, p. 8), it is characterized by compression from the north and south. Most of the fractures in the area are believed to be related to this period of activity. These steep fractures are mainly joints and minor faults; slips ranging from a few inches to about 12 feet are locally evident. The features shown as fissures on plate 21 are believed to be steeply dipping fractures. They are conspicuous on aerial photographs but commonly are not exposed or are poorly discernible in the field. North-south compressional forces have probably caused small-scale movement on many fractures. The fractures are roughly divisible into four sets, all of which dip steeply. The stronger sets trend N. 15°–40° W.

and N. 60° E. to east, and the weaker sets trend N. 15°–35° E. and N. 50°–80° W. This diversity in attitude probably resulted from rotation in the direction of regional compression, and the weaker fracture sets may be of the second order (McKinstry, 1953, p. 401–414). An alternative but closely similar interpretation is that the 4 sets represent 2 conjugate fracture systems, 1 set having formed later than the other, after the reorientation of compressive forces.

In places it is difficult to distinguish between joints and faults. Many fractures have iron-stained and slickensided walls, yet few exhibit offsets of more than a few inches. It is likely that major adjustments in response to regional forces were made on nearby faults outside the Kern River uranium area such as those of the Kern Canyon fault zone, and that only local minor movements occurred within that area.

FAULTS

No major faults were found in the Kern River uranium area. Minor movements on local segments of the four fracture sets produced a few definite faults, and the fissures shown on plate 21 probably include numerous minor faults.

The principal faults are right lateral, strike N. 20°–40° W., and dip steeply. They are exemplified by the Miracle shear zone (pl. 24). Minor steep faults strike N. 60° E. to east and N. 15°–30° E. Where observed, the faults of the former group are left lateral, probably conjugate with the northwest-striking faults. The direction of movement on the faults of the latter group was not ascertained, but slickensides and grooves indicate a strong strike-slip component.

MIRACLE SHEAR ZONE

The Miracle shear zone, along which the workings of the Miracle uranium mine extend, is traceable for about 1,300 feet in the granodiorite and pegmatite (pl. 24). The shear zone is mainly composed of many nearly parallel fractures. It passes into a joint to the north, and to the south it splits into numerous weak fractures. The shear zone generally strikes N. 33° W., and its constituent fractures commonly dip from 80° NE.–80° SW. The thickness of the shear zone reaches a maximum of about 6 feet, but in most places it ranges from a few inches to about 2 feet (pl. 25). Displacement along this fault, as determined by offset pegmatite dikes in the Miracle mine, is as great as 12 feet and right lateral. The slickensides on its walls are nearly horizontal or plunge gently northwest. Many of the fractures contain gouge and coatings of secondary iron oxides and, locally, autunite. The strongest fractures are mostly along the southwest margin of the shear zone.

KERGON SHEAR ZONE

The Kergon shear zone is exposed for a strike length of about 230 feet (pl. 22) and attains a thickness of 15 feet (pl. 32). It commonly strikes N. 26° E. and dips 50°–65° SE. Many shear surfaces of diverse trend are present in the highly altered rock and gouge between the major fractures of the shear zone. Other sets of fractures apparently branch off from, or are cut by, the Kergon shear zone (pl. 22). Many slickensides are superposed on gouge; some of these are nearly horizontal and others plunge as much as 30° NE. Bleached argillic alteration products and iron and molybdenum stains locally pervade the shear zone.

OTHER FAULTS

Faults representing each of the four sets of fractures are discernible. The dominant faults are nearly vertical and strike N. 20°–40° W. They are exemplified by the fault at the lower cut C–11 in the Miracle mine area (pls. 24 and 25), whose probable extension is traceable for at least 2,500 feet on the north side of the Kern River, and by the fault in cuts C–9 and C–10 of the same area (pls. 24 and 25). The major fissures trend N. 20°–40° W., and many are in part faults.

Steeply dipping faults that strike N. 60° E. to east and fissures with similar attitudes are moderately abundant. Steep faults dipping southeastward and striking N. 15°–30° E., probably related to the Kergon shear zone, and fissures indicative of similar fractures, are widespread. Steep faults trending N. 50°–80° W. are less common.

JOINTS

The most numerous fractures are secondary joints that cut all the crystalline rocks (pls. 21, 23, and 24). Most of them are steep and belong to two sets that form a conjugate system. One major set strikes N. 15°–40° W. and the other N. 60° to east. The other steep joints are generally parallel to one of the lesser sets of fractures. The flatter joints, which are probably due to sheeting, range in dip from nearly horizontal to about 25°; they are best exposed along the steep sides of Kern River canyon. The joints are generally spaced at intervals of 20 to 40 feet, but in places they are more closely spaced. Most of the joints are tight, clean fractures. Some joint surfaces, however, are coated with limonite and other secondary minerals.

Primary joints that were formed late in the Nevada orogeny concurrent with the solidification of the granitic rocks or shortly thereafter are locally discernible. These joints are recognized by their relations to the flow planes and flow lines in the Isabella granodiorite. Most of the numerous gently dipping pegmatite dikes in the central part of the area (pl. 21) are believed to occupy primary flat cross joints, and a few were emplaced in primary diagonal joints and primary longitudinal joints (Balk, 1937, p. 34).

PLANAR AND LINEAR STRUCTURES IN THE ISABELLA GRANODIORITE OF MILLER (1931)

Most of the Isabella granodiorite exhibits well-developed planar structure by the alinement of mafic inclusions along flow planes. Planar structures are also represented by schlieren and schlierenlike bands which consist mostly of mafic minerals but in places consist of light-colored minerals (pl. 20*A*).

The planar structures commonly strike between N. 70° E. and east, or between N. 70° W. and west. Steep southerly to vertical dips prevail. The planar structures trend north and dip steeply adjacent to the roof pendant of Kernville series rocks and in the southwestern part of the area. In these places, flow lines became adjusted to preexisting structures in older rocks, for attitudes of the planar structures are nearly parallel to foliation in the metamorphic rocks and to the intrusive contacts.

Lineations due to the orientation of elongate minerals, chiefly hornblende, occur locally but were not studied in detail. Where observed, they are alined in flow planes and plunge steeply east or west.

STRUCTURES IN THE KERNVILLE SERIES OF MILLER (1931)

Structures other than the faults and fissures shown on plate 21 are common in the Kernville series but were not studied in detail. The bedding strikes nearly north and dips 45° W. to vertical. Bedding and foliation, where observed, are parallel. The foliation is chiefly schistosity due to parallelism of mica flakes in schist.

The dominant fractures in the metamorphic rocks strike nearly east and are nearly vertical. Other fractures, closely spaced and diverse in attitude, are associated with minor folds; these are probably fracture or slip cleavage. Minor drag folds and plications are abundant in the metamorphic rocks, generally trending northward and plunging steeply. Marble beds involved in the folding generally thicken and thin.

GEOLOGIC HISTORY

The earliest event recorded in the Kern River uranium area was the deposition of the sediments of Miller's Kernville series, probably during late Paleozoic and early Mesozoic time. The thick, largely pelitic, sedimentary sequence was probably deposited in a miogeosyncline trending northwestward.

The next major geologic event was probably in Cretaceous time and entailed uplift of the thick sedimentary sequence, general east-west compression, and local faulting. Metamorphism commenced with deep infolding of the sediments and continued in various degrees throughout the period of batholithic intrusion probably into Late Cretaceous time. Minor dioritic bodies crystallized near the margins of the batholith; these were followed by, and locally engulfed in, the prevailing granodiorite-quartz monzonite magma, possibly in successive surges. Pegmatite dikes were emplaced in the waning stages of igneous activity but prior to the deposition of gold-quartz veins. By the close of the Nevadan orogeny, the area had presumably been elevated to great heights.

Post-Cretaceous geologic history is poorly recorded in the area. Dibblee and Chesterman (1953, p. 52, 53), as a result of their studies in the Breckenridge Mountain quadrangle, believe that erosion prevailed during Eocene time, that diastrophism reelevated the southern Sierra Nevada into rugged mountains during the Oligocene, that the Miocene was largely a time of erosion, that deposition and minor diastrophism took place in the Pliocene, and that the Cascadian orogeny dominated Pleistocene geologic activity and culminated in the uplift of the Sierra Nevada, tilting, and the development of many faults in late Pleistocene time.

The age of the secondary fractures and the uranium deposits in them in the Kern River uranium area is conjectural. Probably most of the secondary fractures formed early in the Cascadian orogeny (early Pleistocene), the time when Dibblee and Chesterman (1953, p. 53) believe most of the major faults of the southern Sierra Nevada originated. Although a few of the fractures in the area are quartz bearing and contain minor gold deposits supposedly associated with the Nevadan orogeny, the few fractures involved are possibly remnants of an older set. Most, if not all, of the uranium deposition probably took place in the Quaternary period.

Erosion prevailed during the Recent epoch and carved the steep-walled Kern River canyon. Minor Recent deposition is indicated by the deposits of stream gravels in the eastern part of the area.

URANIUM DEPOSITS

Uranium deposits are widespread in the area but are most abundant in the central part. Except for minor deposits in pegmatite, the uranium deposits are epigenetic and were formed where uranium minerals, principally autunite, coat fracture surfaces, locally form small pods and veinlets, or are spottily disseminated in the granodiorite wallrock. The richest deposits found so far are associated with braids of faults that constitute shear zones. Limonite and clay minerals, indicative of weak to locally intense argillic alteration, generally accompany the uranium minerals, but common gangue minerals are notably scarce in many of the uranium occurrences in this area. Fractures in each of the four sets found in the area locally contain some autunite, but most of the known uranium deposits are in steep fractures trending N. 20°–40° W., as shown by the plots of uranium prospects and radioactivity anomalies in plates 21, 23, and 24. Uranium minerals are intermittently distributed along the favorable fractures, but only in small areas are they sufficiently concentrated to form ore; local accumulations of uranium minerals along the fractures are generally separated by wide gaps of barren or lean material.

Local minor anomalous radioactivity in some pegmatites probably indicates small quantities of sparsely disseminated syngenetic complex uranium-thorium minerals. Euxenite, allanite, and questionably xenotime have been found in a few of the pegmatite dikes, and it is probable that other uranium-bearing minerals are present but were not detected.

Many uranium claims have been staked in the area, but on most of them no work other than that required for location has been done. The only underground workings are at the Kergon and Miracle mines, and the only uranium shipments from the area were from these mines. Most of the prospects are shown in plates 21, 23, and 24, but some, particularly those consisting of shallow bulldozed cuts at sites lacking anomalous radioactivity, are not plotted on the maps. Most of the workings are shallow pits, trenches, and opencuts along weakly radioactive fractures cutting the Isabella granodiorite. A smaller number of minor surface workings are in pegmatites, and some are in nonradioactive, apparently barren host rock. Mining development has been hampered by overlapping claims and the ensuing legal entanglements, but more particularly by the lack of ore. Early in 1956 there was little mining activity in the area. Most of the uranium discoveries, including the first ones at the Miracle mine, were made by amateur prospectors, and from time to time the area has been invaded by hordes of weekend prospectors.

KERGON MINE

LOCATION

The Kergon mine is in sec. 20, T. 27 S., R. 32 E., Mount Diablo base line and meridian, on the steep south wall of the Kern River canyon (pls. 20*B*, 21, and fig. 21). The mine area is at altitudes between 2,200 and 2,700 feet and is readily accessible from State Highway 178, which cuts across it.

HISTORY AND PRODUCTION

The Kergon claims were located by J. Kerns and W. Waggoner of Taft, Calif., in May 1954, and shortly thereafter they were sold to the Great Lakes Oil and Chemical Co. According to Walker, Lovering, and Stephens (1956, p. 30), during the summer of 1954 the company enlarged the original discovery cut (Charley's cut) to a depth of 10 feet, excavated cut A, and drove the main adit under cut A (pl. 22). Subsequent work, consisting chiefly of extending the main underground workings, was carried on intermittently until January 1956, when the property was shut down.

Production[3] consisted of two shipments made to the Vitro Uranium Co. at Salt Lake City during the summer and fall of 1955. The first shipment consisted of 50.7 tons that contained 0.14 percent uranium. The second shipment, chiefly black ore from level C, contained about 50 tons that averaged 0.18 percent uranium.

WORKINGS

The underground workings, which are accessible through the main adit (pl. 23), comprise three levels, an interconnecting winze, a subsidiary winze, and minor stopes (pl. 22). Level A, the adit level, at an altitude of 2,435 feet, consists of a crosscut adit 40 feet long and about 70 feet of drifts. The level B workings, at an altitude of 2,407 feet, consist of short drifts totaling about 30 feet, north and south of the main winze. Level C, at an altitude of 2,355 feet, consists of about 195 feet of drifts, 25 feet of crosscuts, and local small stopes. The main winze, which connects all three levels, is 88 feet in slope length and has an average inclination of about 67°. A subsidiary winze extends 32 feet northeastward from near the head of the main winze on level A, at an inclination of 28°.

The principal surface workings are cut A and Charley's cut (pls. 22 and 23). Cut A is a trench, about 25 feet long, 5 to 6 feet deep, and commonly 10 to 12 feet wide that extends southward into a trench 20 feet long and 4 feet wide.

Charley's cut actually consists of a cut, a shallow pit, and a trench. The cut (pl. 22), which extends northeastward, is about 90 feet long and 2 to 12 feet deep. The pit, whose long side parallels the cut, is about 12 feet long, 6 feet wide, and 2 to 3 feet deep. The trench, which extends northwestward, is about 20 feet long, 4 to 8 feet wide, and 4 to 6 feet deep.

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[3] Permission to publish production figures granted by mine owners, the Great Lakes Oil and Chemical Co.

Many other cuts and trenches on the property are in only slightly radioactive material and are not described. Many narrow trenches 1 or 2 feet deep and as much as 150 feet long were dug by hand to test for radioactivity; these are shown in plates 22 and 23.

GEOLOGY OF THE KERGON MINE AREA

The rocks in the Kergon mine area are the Isabella granodiorite, with its mafic inclusions, and pegmatite dikes (pl. 23). All of the Isabella granodiorite specimens from the Kergon mine area that were studied in thin sections have the composition of granodiorite (fig. 24). The one sample of fresh granodiorite from the Kergon mine area that was analyzed (K–17, table 9) contained the abnormal amount of 30 ppm uranium. The mafic inclusions and pegmatite dikes are typical of the inclusions and dikes throughout the entire area.

The principal faulting in the mine area has taken place on the Kergon shear zone, which strikes N. 20° E and dips 50°–65° SE. (pl. 23). Some other steep faults in the area strike N. 55°–80° E. and N. 30°–60° W., but these cannot generally be traced for more than 200 feet. The faults are mainly single iron-stained slickensided breaks, probably formed by local movement on the regional fracture sets.

Closely spaced multiple fractures and shears are evident in the shear zone exposed in Charley's cut. This shear zone is 5 feet wide, strikes N. 35°–45° W., and dips 65°–80° NE. It apparently curves into and is truncated by the Kergon shear zone (pl. 22). Elements of the northwest-striking shear zone are represented by small cross fractures within the Kergon shear zone. Still weaker fractures generally strike within 20° of east and dip about 45° N. Few displacements of pegmatite dikes have been seen. At a few localities, faults that strike N. 55°–80° E. offset the dikes, producing left-lateral displacements of 1 or 2 feet.

The dominant joints are nearly vertical and strike N. 20°–40° W. and N. 60°–80° E. Planar structures, rendered conspicuous by mafic inclusions alined in the Isabella granodiorite, strike within the 40° sector bisected by due east and dip 60° S. to vertical. The few lineations observed in the Isabella granodiorite are nearly vertical.

URANIUM DEPOSITS

Uranium minerals are indicated in the mine area by many weak radioactivity anomalies (pls. 22 and 23), but the only places where they appear to be concentrated are in the Kergon shear zone and the northeast-dipping shear zone exposed in Charley's cut. Most of these anomalies are probably due to secondary uranium minerals dispersed along fractures.

DEPOSITS IN THE KERGON SHEAR ZONE

The uranium deposits in the Kergon shear zone are of two types—black ore and autunite-rich ore. The black ore, which contains sooty pitchblende and secondary molybdenum minerals, forms pods and minor disseminations. Some of the autunite-rich ore forms irregular halos around pods of the black ore, and some of it forms fracture coatings and minor veinlets or is disseminated in altered granodiorite and the gouge of the shear zone. In places it encloses flecks of a dark uranium mineral. The autunite-rich ore is dominant near the surface and was probably derived for the most part from the black ore.

The uranium deposits are irregularly distributed along the Kergon shear zone and are separated by considerable barren or submarginal material. The shear zone is intermittently uranium bearing for at least 200 feet along its strike at the surface. Radioactivity anomalies in test trenches south of Charley's cut indicate that a weak southward extension of the Kergon shear zone contains sparsely distributed uranium minerals for at least another 150 feet (pl. 22).

CHARLEY'S CUT DEPOSIT

Surface exposures of autunite-rich deposits along the Kergon shear zone can be seen in Charley's cut and cut A (pl. 22). In Charley's cut the shear zone is 1 to 5 feet wide and contains concentrations of autunite for about 20 feet along the strike near its junction with a northwest-striking shear zone. The autunite-rich body is about 1 foot thick, and most of the autunite is localized along iron-stained fractures that form part of the Kergon shear zone, but some was deposited in minor iron-stained northwest-striking fractures where they cross the Kergon shear zone. A little autunite is disseminated, also, in gouge and argillized granodiorite wallrock. Radioactivity in the deposit ranges from 0.08 to 0.60 mr per hr (milliroentgens per hour) against a background rate of between 0.02 and 0.03 mr per hr (pl. 22). Grab samples collected from the deposit by U.S. Atomic Energy Commission geologists contained as much as 0.18 percent U_3O_8 (Walker, Lovering, and Stephens, 1956, p. 30).

The deposit associated with the northwest-trending shear in Charley's cut is described under "Other deposits."

CUT "A" DEPOSIT

An autunite-rich zone 1 to 3 feet thick is exposed in cut A for a strike length of about 20 feet (pl. 22). Most of the autunite is confined to the Kergon shear zone and is chiefly associated with the predominant northeast-trending shears and minor cross fractures. In places a little autunite is disseminated in altered granodiorite wallrock. Radioactivity in the deposit ranges from 0.09 to 1.5 mr per hr against a background of 0.02 to 0.0 3 mr per hr. According to U.S. Atomic Energy Commission data, chip samples and dump material from cut A assayed about 0.17 percent uranium.

DEPOSITS EXPOSED IN UNDERGROUND WORKINGS

Discontinuous uranium deposits, generally less than 1 foot thick, extend along the Kergon shear zone on level A over a length of about 47 feet (pl. 22). Very thin coatings of uranium minerals line some of the other fractures cut by level A. Most of these uraniferous fractures probably belong to the Kergon shear zone, but some of those on level A are outside the main shear zone. Elements of other fracture sets do not generally contain uranium here. Autunite-bearing deposits prevail and are mainly confined to intensely sheared parts of the Kergon shear zone. The radioactivity ranges from 0.20 to 1.0 mr per hr, and the background radioactivity is about 0.04 mr per hr. U.S. Atomic Energy Commission assays of samples 1 to 6 feet long from the Kergon shear zone show 0.13 to 0.26 percent uranium. A sample 1 foot long from a high-grade uraniferous concentration near the face of the southwest-trending drift assayed 0.43 percent uranium.[4] Six tons of ore sorted from the drift north of the main winze assayed 0.20 percent uranium, and about 50 tons sorted from the crosscut probably contained about 0.08 percent uranium.

An autunite-bearing deposit on level B, north of the main winze that is about 2 feet thick and 12 feet long (pl. 22), contains small pockets of black ore. The deposit appears to be a lens that pinches out a few feet above and below the level. It may have been formed between concavities in the walls that were brought opposite each other by faulting, or at places where the zone of brecciation was widened at the intersection of the Kergon shear zone with strong fissures trending N. 60° E. The autunite occurs mainly in surface coatings and veinlets, principally where minor shears abound in the shear zone. Radioactivity in the deposit ranges from 0.2 to 2.2 mr per hr; the background radioactivity underground is about 0.04 mr per hr. Channel samples representing lengths between 1 and 7 feet assayed 0.05 to 0.35 percent uranium. There are lean deposits of uranium minerals in the southern part of the level.

On level C black ore preponderates as more or less discrete deposits along the Kergon shear zone (pl. 22). North of the winze small deposits of this type are spottily distributed along fissures in

[4] Assay data are from U.S. Atomic Energy Commission sources unless otherwise noted.

the shear zone. Black ore, irregularly fringed with autunite-rich ore and stained with secondary iron and molybdenum minerals, occurs intermittently along the drift for about 25 feet south of the foot of the main winze in masses 2 to 5 feet thick. The uranium minerals are found chiefly along diversely trending subsidiary shears between the major shears. Nearly horizontal slickensides are common on surfaces of the major shears. The radioactivity of the deposit is between 0.50 and 1.5 mr per hr; the lowest background count in the drift is 0.05 mr per hr. Samples 2 to 5 feet long from this deposit contained between 0.05 and 0.24 percent uranium.

The ore body exposed near the south end of level C is about 30 feet long and a maximum of 3 feet thick but pinches out in small stopes a few feet above and below the level. The deposit lies between two major fractures of the Kergon shear zone, in gouge-rich material cut by numerous variously trending subsidiary shears. There are nearly horizontal slickensides on the walls of the main shear zone. Black ore constitutes the bulk of the deposit. It grades laterally into a thin autunite-rich aureole which merges into a region of intense argillic alteration. Much of the black ore appears to be a pod deposited in an open space within the shear zone. Most of the autunite forms films in subordinate flat-lying fractures. Radioactivity ranges from 0.30 to 4.0 mr per hr, and background near the southern face of the drift is 0.05 mr per hr. Company and U.S. Atomic Energy Commission assays as well as the second shipment indicate that this ore body averages about 0.17 percent uranium. Intersections, exposed at the south end of the drift, between the northwest-striking shear zone (exposed in Charley's cut) and the northeast-striking Kergon shear zone are apparently barren of uranium minerals.

The main winze goes through scattered uranium deposits along the Kergon shear zone (pl. 22). Chief among these are a deposit extending a few feet below level A, the level B ore body, and a deposit near the foot of the winze on level C. In general, autunite-rich ore is dominant above level B and black ore below.

OTHER DEPOSITS

The only known significant uranium deposit in the mine area that is not controlled by the northeast-trending Kergon shear zone is localized in the northwest-trending shear zone exposed in Charley's cut (pl. 22), which contains the first uranium deposit to be discovered at the Kergon mine. This deposit, which is rich in autunite, is erratically distributed along a strike length of about 15 feet and a thickness of 5 feet and is accompanied by white clay minerals. Its maximum radioactivity is 0.45 mr per hr, against a background of 0.03 mr per hr. A chemical analysis of a sample 0.6 feet long revealed 0.16 percent uranium.

MINERALOGY AND COMPOSITION

BLACK ORES

The friable black ores are very fine grained intimate mixtures of various minerals, pervaded by the blue and black stains of secondary molybdenum minerals.

The mineral constituents of the black ores, most of them originally identified by U.S. Atomic Energy Commission personnel and also subsequently during the present investigation, are sooty pitchblende, the secondary molybdenum minerals ilsemannite and jordisite, fluorite, clay minerals, gypsum, and limonite(?). The black ore grades outward into the autunite-rich type. Most of the uranium is contained in dark-gray powdery masses of sooty pitchblende. Some of the masses have a blue-black color imparted by ilsemannite and jordisite, the latter probably subordinate to the former. Fluorite occurs in small crystals 1 to 2 mm across. The prevailing clay mineral is montmorillonite. The ilsemannite-rich black ore is locally coated with gypsum, which forms small colorless acicular crystals, partly in divergent aggregates and partly in fine shreds.

A sample of black ore from a pocket in the main winze near level B contained 1.08 percent U_3O_8, 1.1 percent CaF_2, and 1.84 percent molybdenum (Walker, Lovering, and Stephens, 1956, p. 30). The composition of two black ore samples from level C as determined by X-ray spectrometer examinations is shown in table 5 (C-1, C-2).

TABLE 5.—*X-ray spectrometer analyses of some uranium-bearing samples from the Kergon mine* [1]

[S, strong; M, moderate; W, weak]

Sample	Location	Type of ore	As	Cu	Fe	Mn	Mo	Sr	U	V	Y
K-11	Cut A	Autunite-rich	W	Trace	S	Trace	----	Trace	M	Trace	--------
K-30	Level B	Autunite-rich	W	Trace	S	--------	----	W	S	--------	--------
C-1	Level C	Black	M	Trace?	S	W	S	--------	M	--------	--------
C-2	do	do	M	--------	S	--------	S	--------	M	--------	Trace
C-4	do	Autunite-rich	W	--------	S	--------	----	W	S	--------	--------

[1] See footnote 2, p. 181.

The minerals that contain the arsenic, strontium, manganese, yttrium, and copper disclosed in the X-ray spectrometer analyses have not been identified.

AUTUNITE-RICH ORE

The autunite-rich ore consists chiefly of autunite, limonite, and clay minerals associated with minerals of the granodiorite host rock and their alteration products. It locally contains minute quantities of a yellow nonfluorescent uranium mineral, probably carnotite or uranophane. Stilbite forms veinlets 2 mm thick in parts of the level B deposit. It is in colorless prisms as much as 2 mm long that are oriented perpendicular to the walls of the veinlet; in some places the stilbite is coated with autunite.

The autunite is generally in minute crystals, but autunite crystals as much as 1.5 mm across were found in a veinlet in the level B deposit. The crystals are thin, fragile, and tabular parallel to (001). The autunite is bright yellow and fluoresces brilliant yellow in short-wave ultraviolet light. X-ray diffraction patterns indicate that it is in the meta-autunite I phase, a lower hydrated phase due to partial desiccation of natural autunite.

The light-yellow-brown color of the autunite-rich deposits is largely due to abundant limonite. Associated clay minerals consist generally of white very fine felty masses of montmorillonite and lesser amounts of illite. Opal in minute pearly botryoidal surface coatings occurs near some autunite-rich deposits. The opal is pale green and fluoresces yellow green under short-wave ultraviolet light.

Uranium analyses and semiquantitative spectrographic analyses of two selected autunite-rich samples are shown in table 6.

TABLE 6.—*Chemical and equivalent uranium analyses, in percent, and semiquantitative spectrographic analyses, of selected ore specimens from the Kergon mine*

[Spectrographic analyses by K. E. Valentine; chemical analyses by Carmen Johnson; and radioactivity analyses by B. A. McCall, U.S. Geological Survey]

Sample	Location	Chemical U	Equivalent U	Al	B	Ba	Be	Ca
K-7	Charley's cut	0.47 .51	0.25 .27	>10	0.005-0.01	0.05-0.1	0.00005-0.0001	1-5
K-30	Level B Ore body	10.0 10.3	6.3 7.8	>10	.005-.01	.05-.1	.00005-.0001	1-5

Sample	Cd	Cr	Cu	Eu	Fe	Ga	Gd
K-7	----------	0.005-0.01	0.005-0.01	----------	1-5	0.001-0.005	----------
K-30	0.01-0.05	.0005-.001	.001-.005	0.001-0.005	1-5	.001-.005	0.005-0.01

Sample	Ho	K	La	Li	Mg	Mn	Mo
K-7	----------	1-5	----------	0.01-0.05	1-5	0.01-0.05	----------
K-30	0.001-0.005	0.5-1	0.001-0.005	.01-.05	0.5-1	.005-.01	0.0005-0.001

Sample	Na	Nd	Ni	P	Pb	Sc	Si	Sr
K-7	1-5	----------	----------	----------	0.001-0.005	0.001-0.005	>10	0.05-0.1
K-30	0.5-1	0.005-0.01	0.005-0.01	0.1-0.5	.001-.005	.0005-.001	>10	.05-.1

Sample	Ti	Tm	U	V	Y	Yb	Zr
K-7	0.5-1	----------	0.1-0.5	0.10-0.05	----------	----------	0.001-0.005
K-30	.1-0.5	0.001-0.005	5-10	.01-.05	0.01-0.05	0.001-0.005	.0005-.001

Aside from the obvious increase in uranium, the autunite-rich ore is not very different in composition from representative Isabella granodiorite (table 3). Specimen K-7 contains slightly abnormal amounts of titanium and vanadium. Specimen K-30 contains abnormal amounts of phosphorous and vanadium but is deficient in potassium and sodium. X-ray spectrometer analyses of three autunite-rich samples are shown in table 5. The arsenic and copper content suggests the presence of small amounts of metazeunerite.

WALLROCK ALTERATION

Argillic wallrock alteration, characterized by bleached montmorillonite-rich zones, is general alongside the uranium deposits and is best exposed adjacent to both shear zones in Charley's cut (pl. 22). The altered zones are a few inches to about 3 feet thick. Argillic alteration accompanies most uranium deposits of the Kergon shear zone. It is most intense near fractures in the shear zone and fades out away from the shear zone. In the level C ore body, clay minerals form a crude halo, about 2 feet thick, around black ore and autunite-rich ore.

MIRACLE MINE

LOCATION AND ACCESSIBILITY

The Miracle mine is in secs. 17 and 20, T. 27 S., R. 32 E., on the steep south slope of the Kern River canyon. It is in the south-central part of the area about a mile west of Miracle Hot Springs (pls. 20*B*, 21, and fig. 21). The mine area is about 2,200 to 3,100 feet above sea level (pl. 24); it is crossed by State Highway 178 and is readily accessible.

HISTORY AND PRODUCTION

Uranium was first discovered in the Kern River uranium area at the site of the Miracle mine, in January 1954, by Henry Brooks Mann and associates of Taft, Calif. These prospectors, using a car-borne scintillation counter, detected the abnormal radioactivity of the Miracle shear zone while traversing State Highway 178. Mann and his associates thereupon commenced mining, and on July 31, 1954, they shipped a 46-ton carload of ore that averaged 0.62 percent U_3O_8 to the Vitro Uranium Co. at Salt Lake City. This ore was mined from the northernmost 100 feet of the main adit. The adit was driven a total length of 255 feet before the property was sold to the Wyoming Gulf Sulfur Corp. in September 1954 (Walker, Lovering, and Stephens, 1956, p. 30). The new owners extended the adit, drove minor crosscuts, and excavated most of the numerous surface cuts and trenches.

On June 21, 1955, a 42½-ton ore shipment containing 0.16 percent uranium and 0.06 percent vanadium was made to the Vitro Uranium Co.[5] This shipment contained material mined between 50 and 75 feet from the portal of the main adit and also from cut C–2.

WORKINGS

The main adit and associated workings are the only important underground excavations; several other adits have been started but the longest extends only 16 feet. The main adit extends 380 feet S. 33° E. along the Miracle shear zone (pl. 25). Associated workings are a winze 8 feet deep near the portal of the adit, a minor overhand stope 85 to 100 feet from the portal, and 3 short crosscuts that aggregate 34 feet in length. The surface workings include many bulldozer cuts, shallow pits, and trenches (see pls. 24 and 25). Only workings at sites of significant radioactivity are included in the following descriptions and shown on plate 25.

Cuts C–1, C–2, C–3, C–4, and C–5 (pl. 25) are mainly on the Miracle shear zone or subsidiary fractures generally in granodiorite. Recent work has extended cut C–2 about 10 feet farther to the southeast than is shown in plate 25.

Cuts C–9 and C–10 are on the same structure, a steeply dipping shear zone striking N. 40° W., in weathered granodiorite (pl. 5). The two cuts C–11 (pl. 25) are mainly on separate northwest-trending faults that cut granodiorite.

GEOLOGY OF THE MIRACLE MINE AREA

The Miracle mine area is underlain by rocks of the Isabella granodiorite mass and many pegmatite dikes. Xenotime was identified either questionably or definitely in all thin sections of specimens of granodiorite from the Miracle mine area, and each of the 4 analyzed samples of these rocks (table 9) contained 20 ppm uranium, or about 5 times as much as average granitic rock. Mafic inclusions in the Isabella granodiorite are abundant in the mine area.

The numerous pegmatite dikes, which are allied in composition chiefly to granite but partly to quartz monzonite, contain the minerals typical of other pegmatites in the general area. A few fracture surfaces in the pegmatites are thinly coated with pale-green botryoidal opal. The dikes range in thickness from 2 or 3 inches to about 180 feet and attain outcrop lengths of up to several thousand feet. The Miracle pegmatite dike, the largest dike in the mine area, is exposed for a length of about 2 miles and is nearly 180 feet in maximum thickness. It contains widely scattered inclusions

[5] Production data published with permission of the mine owners, the Miracle Springs Mining Corp., a subsidiary of the Wyoming Gulf Sulfur Corp.

of schist up to 30 feet long that are derived from the Kernville series.

The dominant fracture sets, represented by joints, faults, and shear zones, are steep and strike either N. 20°–40° W. or N. 60°–80° E. The Miracle shear zone, the principal structural feature of the mine area, splits toward the south into numerous, generally weaker fractures. Where this shear zone crosses the competent Miracle pegmatite, many sharp, clean fractures that vary irregularly in attitude have been developed (pl. 25). Shear zones similar in attitude to the Miracle shear zone cut the Isabella granodiorite in cuts C–9, C–10, and C–11 (pl. 25). Near cuts C–9 and C–10 (pl. 24), a shear zone generally 4 or 5 feet thick and containing 3 to 5 individual fractures is traceable for about 180 feet on the surface. It strikes N. 40° W. and is made up of fractures that dip 75° NE.–80° SW. Slickensides on one of the prominent fault surfaces in cut C–10 plunge 55° NW.

Two shear zones crop out in cuts C–11 (pls. 24 and 25). They generally trend N. 20°–40° W., are nearly vertical, and are traceable to the southeast for about 250 feet. Northward extensions are difficult to follow, but they may be represented by a shear zone of similar trend exposed for several hundred feet north of the Kern River.

Faults of the northeast-striking sets are less well developed and commonly not recognizable for more than 100 feet along the strike. They are represented by faults in cuts C–2, C–4, and C–5 and elsewhere, notably along the south side of Highway 178 in the western part of the mine area.

Numerous planar structures, best indicated by the alinement of inclusions, generally strike N. 65° E. to east and dip steeply south. Lineations, marked by hornblende and biotite alined in flow planes, commonly plunge steeply southwest where observed.

URANIUM DEPOSITS

The uranium deposits of the Miracle mine are chiefly in the Miracle shear zone and associated divergent fractures near its south end. Northwest-striking shear zones similar to the Miracle shear zone localized uranium deposits at the sites of cuts C–9, C–10, and C–11. Small bodies of uranium-bearing material occur in some of the northeast-striking, steeply dipping faults, principally near intersections with components of the Miracle shear zone. The uranium deposits are irregularly distributed along the controlling structures and are separated by wide barren gaps or by zones of sparsely dispersed uranium minerals. The deposits are highly oxidized and are commonly associated with limonite. Secondary uranium minerals, dominantly autunite, occur in small pods, in coatings on gouge and wallrock, in erratic disseminations in gouge, in weathered and altered wallrock, and rarely in minute veinlets.

DEPOSITS IN THE MIRACLE SHEAR ZONE AND ASSOCIATED FRACTURES

Most of the uranium deposits are localized in the strongly fractured medial parts of the Miracle shear zone where it crosses weathered granodiorite. Many small deposits are found along divergent fissures that make up the southern part of the shear zone.

DEPOSITS EXPOSED IN THE MAIN ADIT

The larger deposits in the Miracle mine are exposed intermittently along the northernmost 130 feet of the main adit (pl. 25). They are individually from a few inches to about 5 feet thick, and the longest is about 27 feet long. The richest deposit was in the back of the adit, 45 to 72 feet from the portal. Most of the ore bodies are localized along a strong nearly vertical fault that coincides with part of the west wall of the adit (pl. 25). Local slickensides on this fault plunge about 20° N. In some places the intersections of lesser divergent fractures with the main throughgoing fractures apparently formed loci for the deposition of ore. Most of the deposits are in weathered and locally slightly altered granodiorite. Uranium minerals are uncommon in the southernmost 250 feet of the adit where the fractures of the shear zone are less intense and diverge.

Radiation intensities, as recorded by W. A. Bowes, in counts per second for the northernmost 256 feet of the Miracle adit are shown by Walker, Lovering, and Stephens (1956, p. 29, fig. 23) and in plate 25 of this report. The highest values were about 6,000 counts per second against a background of 160 counts per second. Radioactivity in the southernmost 124 feet of the adit is insignificant. The grade of the deposits is indicated by the two shipments, mainly from the northernmost 100 feet of the main adit. The first shipment contained 0.62 percent U_3O_8, and the second shipment contained 0.16 percent uranium and 0.06 percent vanadium. Further indications of grade are given by U.S. Atomic Energy Commission assays. Grab samples collected near the adit portal contained as much as 0.48 percent U_3O_8 (Walker, Lovering, and Stephens, 1956, p. 30). Samples from ore bodies 1 to 2½ feet long in the northernmost 50 feet of the adit contained 0.8 and 0.30 percent uranium. A sample from a cut across the 1½-foot-long high-grade ore body between 55 and 75 feet from the portal contained 1.39 percent uranium, and 2 samples each representing about nine-tenths of a foot from the same ore body assayed 7.6 percent and 4.7 percent uranium. Other samples taken in nearby parts of the ore body assayed 0.12 and 0.19 percent uranium, indicating abrupt fluctuations in tenor in short distances. In the interval between 75 and 130 feet from the portal, assay values range between 0.09 and 0.96 percent uranium and average near 0.20 percent. Most samples from the southernmost 250 feet of the adit yielded less than 0.05 percent uranium.

DEPOSITS EXPOSED IN SURFACE WORKINGS

Deposits in cuts C–1, C–2, and C–3 are on iron-stained multiple faults of the Miracle shear zone and chiefly in coatings on gouge and weathered granodiorite. Radioactivity from these deposits, in counts per second, is shown in plate 25. The highest count, 3,500 counts per second against a background of 125 counts per second, was recorded from cut C–2. Atomic Energy Commission assays show that a sample 3 feet long from cut C–1 contained 0.014 percent uranium, a sample 2 feet long from cut C–2 contained 0.23 percent uranium, and a sample 1 foot long from cut C–3 yielded 0.013 percent uranium. Part of the second ore shipment was from cut C–2.

Anomalous radioactivity was detected in cuts C–4 (pl. 25), mainly on tight fractures that branch from the Miracle shear zone and cut pegmatite. Radioactivity as great as 1.3 mr per hr, against a background of 0.02 to 0.03 mr per hr, was detected in the east cut C–4. The greatest radioactivity in the west cut C–4 is only 3 or 4 times the background count.

In cut C–5, autunite is irregularly distributed along faults of the Miracle shear zone for a strike length of about 40 feet (pl. 25). Most of the deposits there are accompanied by iron staining and are in weathered granodiorite. Anomalous radioactive emanations from the deposits range from 0.05 to 1.2 mr per hr against a backround rate of between 0.02 and 0.03 mr per hr. Uranium minerals in a fracture of the Miracle shear zone in the trench about 100 feet southeast of cut C–5 (pl. 24) emit radiations 3 or 4 times the background rate.

In the cut about 100 feet northwest of the highway, autunite in the Miracle shear zone is spottily distributed along two major fractures. A select sample assayed 1.00 percent uranium. Chip samples taken for a length of about 4 feet across the shear zone at the cut contained 0.042 and 0.076 percent uranium (table 8, samples 6–1, 6–2).

DEPOSITS ASSOCIATED WITH OTHER FAULTS

In cuts C–9 and C–10, uranium minerals are distributed along fissures of a shear zone for about 130 feet (pls. 24 and 25). The country rock is weathered granodiorite. In cut C–9 and its adit, uranium-bearing deposits 1 to 3 inches thick and up to 20 feet long were found on each of the 3 northwest-trending faults cut by the workings. The maximum radioactivity associated with these deposits was 0.5 mr per hr, with a background of 0.03 mr per hr. Uranium deposits are scattered along the northwest-trending faults of cut C–10. The principal deposit is the pits southwest of the cut, where the radioactivity is as great as 50 times that of the background. The deposit is approximately 15 feet long and 2 feet thick.

In cuts C–11 (pl. 25), secondary uranium minerals are associated with northwest-trending faults. Although anomalous radioactivity is detectable for a strike length of 40 feet along one of the faults, the deposits are sporadic and generally only 1 or 2 inches thick. Maximum radioactivity in both the upper and lower cuts C–11 is 1.0 mr per hr, with a background radioactivity of 0.03 mr per hr. Analyses of chip samples from cuts C–11 are shown in table 8. The samples are between 2 and 4 feet long and include wallrock granodiorite that is intermixed with uraniferous material. The highest assay values—0.20 and 0.16 percent uranium—were from samples collected near the southeast end of the lower cut C–11, where multiple iron-stained gouge-coated fractures served as loci for erratic uranium deposition.

Minor abnormally radioactive deposits occur along many of the northeast-trending fractures in the area, notably at cuts C–4 and cut C–5, the upper cut C–11, and the trench about 100 feet southeast of cut C–5. Up to 1956 little exploration had been done on these deposits, and they had been opened only near intersections with northwest-trending faults. Most of these uranium occurrences are on steeply dipping faults that strike N. 50°–80° E., although a few of the host faults trend more nearly north. The shear in cut C–5 that strikes N. 68° E. and dips 75° SE. (pl. 25) contains irregular deposits of autunite over a thickness of 3 feet—probably the best uranium deposit in a northeast-trending structure on the property. Its radioactivity is about 25 times as great as the background.

MINERALOGY AND COMPOSITION

The uranium deposits in the Miracle mine area are very fine grained assemblages of secondary uranium minerals that occur as thin surface coatings, as minor disseminations and impregnations in gouge and wallrock, and, in small part, as very thin veinlets. They are almost everywhere stained with iron oxides and are generally associated with clay minerals probably formed in parts by hydrothermal alteration and in part by near-surface weathering of the granodiorite. Wallrock alteration, however, is notably slight, and the common gangue minerals are unusally scarce.

Autunite is the prevalent uranium mineral and is found in all the deposits. It forms minute pale-yellow-green crystals that fluoresce bright yellow green in short-wave ultraviolet light. Intermixed with the autunite is a yellow nonfluorescent crystalline material that is probably carnotite; this occurs in the cut C-2 deposit and, less commonly, in other deposits (tables 7, 8) where analyses generally indicate an abnormal vanadium content. Scattered small dark-gray to black pods of sooty pitchblende and gummite were reportedly mined from the ore body between 50 and 60 feet from the adit portal (W. A. Bowes, 1955, oral communication). Unfortunately, however, none of this material was available during the present study. According to geologists of the U.S. Atomic Energy Commission, small amounts of fluorite were found in some of the deposits in the main adit (Walker, Lovering, and Stephens, 1956, p. 30).

The chemical composition of the deposits is indicated in tables 7 and 8. The samples shown in table 7 are selected uranium-bearing specimens with a minimum of barren wallrock. They indicate a general increase in vanadium content with an increase in uranium—a fact that has been noted by R. P. Fischer (1955, written communication)—and they commonly record the presence of strontium, arsenic, gallium, and antimony which are mineralogically unaccounted for.

Table 8 represents chip samples 1 to 4 feet long that include the thin uraniferous zones and the adjacent generally weathered or altered wallrock. The samples are generally similar in composition

TABLE 7.—*X-ray spectrometer analyses of some uranium-bearing samples from the Miracle mine area*[1]

[S, strong; M, moderate; W, weak]

Sample	Location	Ag(?)	As	Cd	Cu(?)	Fe	Ga
M-3	Cut C-2	Trace	W	----------	----------	S	W
M-37	Cut C-10	Trace	Trace	----------	----------	S	W
M-39	Cut C-10	----------	W	----------	----------	S	W
M-40	Cut C-11	----------	Trace	Trace	Trace	S	Trace
M-46	Main adit, 47 feet from portal.	----------	Trace	----------	----------	S	Trace

Sample	Mn	Rb	Sb	Sr	Ti	U	V	Zr
M-3	Trace	----------	Trace	W	----------	S	M	----------
M-37	Trace	Trace	W	Trace	----------	W	Trace	----------
M-39	Trace	----------	Trace	M	Trace	W	----------	----------
M-40	Trace	Trace	----------	W	----------	M	----------	Trace
M-46	----------	----------	----------	Trace	----------	S	W	----------

[1] See footnote 2, p. 181.

TABLE 8.—*Chemical and equivalent uranium analyses and semiquantitative spectrograhic analyses, in percent, of uraniferous chip samples from the Miracle mine area.*

[Spectrographic analyses by Mona Frank; chemical analyses by Roosevelt Moore; and radioactivity analyses by B. A. McCall, U.S. Geological Survey]

Sample	Location	Chemical U	Equivalent U	Al	B	Ba	Be	Ca
1-0	Cut, about 100 feet southeast of cut C-5.	0.018	0.020	>10	0.01–0.05	0.1–0.5	0.00005–0.0001	1–5
2-0	Cut C-5	.038	.036	>10	.01– .05	.1– .5	.00005– .0001	1–5
4-1	Lower cut C-11	.20	.17	>10	.01– .05	.1– .5	.00005– .0001	1–5
4-2	Lower cut C-11	.16	.15	>10	.01– .05	.1– .5	.00005– .0001	1–5
5-1	Upper cut C-11	.056	.056	>10	.01– .05	.1– .5	.90005– .0001	1–5
5-2	Upper cut C-11	.038	.037	>10	.01– .05	.1– .5	.00005– .0001	1–5
6-1	Cut on Miracle shear zone below highway.	.042	.040	>10	.01– .05	.1– .5	----------	1–5
6-2	Cut on Miracle shear zone below highway.	.076	.078	>10	.01– .05	.1– .5	----------	1–5

Sample	Co	Cr	Cu	Fe	Ga	K	La
1-0	0.001–0.005	0.001–0.005	0.001–0.005	1–5	0.005–0.01	1–5	0.001–0.005
2-0	.001– .005	.001– .005	.001– .005	1–5	.005– .01	1–5	----------
4-1	.001– .005	.001– .005	.001– .005	1–5	.005– .01	1–5	.001– .005
4-2	.001– .001	.001– .005	.001– .005	1–5	.005– .01	1–5	.001– .005
5-1	.001– .005	.001– .005	.001– .005	1.5	.005– .01	1–5	----------
5-2	.001– .005	.001– .005	.001– .005	1–5	.005– .01	1–5	----------
6-1	.001– .005	.001– .005	.001– .005	1–5	.005– .01	1–5	.001– .005
6-2	.001– .005	.001– .005	.001– .005	1–5	.005– .01	1–5	----------

Sample	Mg	Mn	Mo	Na	Ni	Pb	Sc	Si
1-0	1–5	0.01–0.05	0.0005–0.001	1–5	0.005–0.01	0.001–0.005	0.001–0.005	>10
2-0	1–5	.01– .05	.0005– .001	1–5	.005– .01	.001– .005	.001– .005	>10
4-1	1–5	.01– .05	.001 – .005	1–5	.005– .01	.001– .005	.001– .005	>10
4-2	0.5–1	.01– .05	.01 – .05	1–5	.005– .01	.001– .005	.001– .005	>10
5-1	1–5	.01– .05	.01 – .05	1–5	.005– .01	.001– .005	.001– .005	>10
5-2	1–5	.01– .05	.0005– .001	1–5	.005– .01	.001– .005	.001– .005	>10
6-1	.5–1	.01– .05	.0005– .001	1–5	.005– .01	.001– .005	.001– .005	>10
6-2	.5–1	.01– .05	.0005– .001	1–5	.005– .01	.001– .005	.001– .005	>10

Sample	Sr	Ti	U	V	Y	Yb	Zr
1-0	0.05–0.1	0.1–0.5	----------	0.005–0.01	0.005–0.01	0.0005–0.001	0.001–0.005
2-0	.05– .1	.1– .5	----------	.005– .01	.001– .005	.0001– .0005	.001– .005
4-1	.05– .1	.1– .5	0.1–0.5	.005– .01	.001– .005	.0005– .001	.001– .005
4-2	.05– .1	.1– .5	.1– .5	.005– .01	.001– .005	.0001– .0005	.001– .005
5-1	.05– .1	.1– .5	----------	.005– .01	.001– .005	.0001– .0005	.001– .005
5-2	.05– .1	.1– .5	----------	.005– .01	.001– .005	.0001– .0005	.005– .01
6-1	.05– .1	.1– .5	----------	.01 – .05	.001– .005	.0001– .0005	.005– .01
6-2	.05– .1	.1– .5	----------	.01 – .05	.001– .005	.0001– .0005	.001– .005

to fresh and weathered Isabella granodiorite (table 3), except that they all contain more uranium, and most of them contain molybdenum, vanadium, gallium, and nickel.

WAYNE CASE PROSPECTS

The Wayne Case prospects are on the Eureka group of claims in secs. 19 and 20, T. 27 S., R. 32 E., bordering the Kergon mine on the southwest (pls. 20*B* and 28). The claims were located during the summer of 1954 by Wayne Case of Taft, Calif. The best deposits appear to be on the Eureka claim 13 in an opencut about half a mile S. 40° W. of the Kergon adit portal (pl. 21). This cut, which trends S. 35° E., is 20 feet long, 15 feet deep at its southeast face, and about 4 feet wide. Scattered autunite deposits are localized in a steep iron-stained shear zone that strikes N. 35° W. The shear zone cuts granodiorite, in which there is local weak argillic alteration. The uranium deposits are thin and irregular. Selected samples assayed by the U.S. Atomic Energy Commission contained as much as 0.47 percent equivalent U_3O_8 and 0.61 percent U_3O_8 (Walker, Lovering, and Stephens, 1956, p. 30), but more representative samples contained considerably less uranium.

LAST CHANCE PROSPECT

The Last Chance prospect, owned by Robert Martin of Miracle Hot Springs, is in the pendant of Kernville series metamorphic rocks about a quarter of a mile east of Miracle Hot Springs, in sec. 15, T. 27 S., R. 32 E. (pl. 21). It is primarily a tungsten prospect. Its workings consist of 2 irregular, shallow surface pits about 20 feet in maximum diameter. The country rock, which is iron-stained calc-hornfels and tactite, locally emits anomalous radioactivity. Radioactivity measurements by the U.S. Atomic Energy Commission were as much as 10 times the background rate, but selected samples yielded less than 0.055 percent U_3O_8 (Walker, Lovering, and Stephens, 1956, p. 30). No uranium minerals have been identified in this deposit.

MONTE CRISTO PROSPECT

The Monte Cristo prospect, owned by Lenwood Barnes of Taft, Calif., lies in sec. 19, T. 27 S., R. 32 E., at altitudes near 2,700 feet (pl. 21). A small pit exposes two parallel veins in granodiorite that strike N. 60° W. and dip 80° SW. The veins are about one-half foot in maximum thickness and are traceable for about 20 feet. They consist predominantly of coarse calcite that contains carnotite-rich bands less than 0.5 mm thick. Minor amounts of autunite are associated with the carnotite. Vugs in the veins are lined with calcite crystals, some of which are coated with carnotite.

LITTLE SPARKLER PROSPECT

The Little Sparkler prospect is in sec. 17, T. 27 S., R. 32 E., 2,400 to 2,850 feet above sea level (pl. 21). The property was located during 1954 by A. B. Scouler and associates, but little work was done on it until 1956, after the field investigations leading to this report had been made. W. A. Bowes (oral communication,

1956) reports that during the summer of 1956 small deposits of uranium minerals were exposed in small test pits on the prospect, along a steep northwest-trending fracture that cuts granodiorite and pegmatite. The fracture may represent an extension of the shear zone exposed in the Miracle cuts C-9 and C-10. Metazeunerite, which was identified by H. G. Stephens (oral communication, 1956), is probably the chief uranium mineral at the Little Sparkler prospect.

OTHER PROSPECTS

Many small workings have been excavated at sites of weak anomalous radioactivity, and most of these are shown on plate 21. These prospects commonly expose fractures in the Isabella granodiorite that contain a little uraniferous material here and there, or are in pegmatite that contains widely scattered radioactive minerals. Some of the anomalous emanations from the pegmatites are due to radioactive inclusions in biotite. Most of the lesser prospects were located during the wave of prospecting that came in 1954, and by mid-1956 many were abandoned or otherwise inactive.

The Scouler prospect (pl. 23), which is between the Miracle and Kergon mines, consists of a large bulldozer cut and two short opencuts. Anomalous radioactivity is weak in the prospect area.

ORIGIN OF THE URANIUM DEPOSITS

Most of the uranium deposits in the Kern River uranium area, except those in pegmatites, were probably formed by low-temperature hydrothermal solutions in near-surface environments. They are believed to fit into Lindgren's (1933, p. 212) epithermal class. A hydrothermal origin is advocated because many of the constituent minerals are commonly associated with hydrothermal deposits, because wallrock alteration accompanies some of the deposits, and because most of the deposits are localized in fractures. The solutions were probably weak, however, as indicated by the weakness of the wallrock alteration, the sporadic distribution of the deposits, the scarcity of common gangue minerals in most of them, and the general lack of persistent veins. The mineralogy of the deposits indicates deposition from low-temperature slightly alkaline solutions. These conditions are most clearly indicated by calcite, which occurs in the Monte Cristo prospect, by montmorillonite, by stilbite, and by other compatible minerals.

Most of the secondary uranium minerals in the area were probably formed by oxidation of pitchblende, as exemplified by the autunite-rich aureole surrounding the black ore on level C in the Kergon mine. Many of the deposits are far from known primary uranium minerals, and some of the deposits probably resulted from mobilization of uranium contained in primary minerals, transportation in aqueous solutions, and subsequent deposition in the form of oxidized uranium minerals.

Some of these uranium deposits may be genetically related to the thermal springs of the area, although D. E. White (oral communication, 1956) believes that hot-spring water generally contains less uranium than many other types of water. Most of the springs here emit hydrogen sulfide and are not radioactive. A water temperature of 122°F was recorded for the Miracle Hot Springs, the warmest in the area. Minor amounts of hydrogen sulfide issue from a trickle in a northwest-trending fracture on the south side of the Kern River that is almost in line with the Miracle shear zone. Radon is believed to occur in spring water about 1½ miles north of the Miracle mine (George Sawyer, 1955, oral communication), and radium is reported from calcareous spring deposits about 5 miles east of the Kern River uranium area (Walker, Lovering, and Stephens, 1956, p. 31). It is conceivable that soluble uranyl ions, $(UO_2)^{+2}$, could be reduced and pitchblende UO_2 precipitated by the hydrogen sulfide of the springs. Uranium could have been an original constituent of the spring water, or uraniferous solutions may possibly have intermingled with the spring water.

An example of Recent uranium deposition from an aqueous medium can be observed at the Pettit Ranch, about two-thirds of a mile northwest of the northwest corner of the Kern River uranium area (fig. 21). At this place uranium was and is being fixed in carbonaceous matter of a mountain meadow. Analyses by the U.S. Atomic Energy Commission of water from the cold springs discharging into the meadow show an abnormal uranium content of 0.04 to 0.3 parts per million, and also abnormal quantities of vanadium, molybdenum, and copper, elements which occur in some of the Kern River uranium deposits. The Pettit Ranch deposits are out of equilibrium (the chemical uranium content is greater than the equivalent uranium), which is typical of young deposits.

Possibly the uranium of some deposits was derived from the Isabella granodiorite. Analyses indicate that the Isabella granodiorite in the area contains slightly abnormal amounts of uranium (table 9). Locations of samples listed in table 9 are shown in plates 21, 23, 24, and 25. Sample numbers with a prefix letter A are from the general area (pl. 21), with a letter K from the Kergon mine area (pl. 23), and with a letter M from the Miracle mine area (pls. 24 and 25).

The uranium content of the average granitic rock as determined by testing samples from many areas is about 3 or 4 ppm, and the

TABLE 9.—*Chemical and equivalent uranium analyses, in percent, of some igneous rocks from the Kern River uranium area* [1]

[Chemical analyses by Roosevelt Moore and Carmen Johnson; radioactivity determinations by B. J. McCall, all of the U.S. Geological Survey]

Sample	Rock type	Chemical U	Equivalent U
A-1	Isabella granodiorite of Miller [2]	0. 002	0. 003
A-10	Granodiorite	. 001	. 002
A-15	do	. 001	. 002
A-32	Quartz diorite	. 001	. 002
A-53	Granodiorite	. 001	. 002
A-76	Quartz monzonite	. 003	. 002
A-89	Granodiorite	. 001	. 002
K-2	Pegmatite	. 001	. 003
K-17	Granodiorite	. 003	. 004
M-28	do	. 002	. 002
M-30	Mafic inclusion	. 001	. 001
M-35	Granodiorite	. 002	. 002
M-41	Mafic inclusion	. 002	. 003
M-56	Granodiorite	. 002	. 003

[1] Semiquantitative spectrographic analyses of these samples are shown in table 3.
[2] Sample from near the type locality at Isabella.

uranium content of the average intermediate igneous rock is slightly less (various sources cited by Larsen and Phair, 1954, p. 77); in samples of the Isabella granodiorite from the Kern River uranium area, however, it ranges from 10 to 30 ppm (0.001 to 0.003 percent).

Xenotime is probably the chief uranium carrier in the Isabella granodiorite, although some uranium may be localized on crystal surfaces and on boundaries between grains. Studies by Neuerburg (1956, p. 59) and at the California Institute of Technology (1955; Brown and others 1953, p. 1400) indicate that about 25 percent of the primary uranium in granite is leachable, that uranium is one of the earliest dissolved elements, and that generally about 1 percent of the total granite is leachable.

The leached uranium may have been incorporated in the ground-water system and subsequently deposited in fractures, particularly in permeable shear zones whose multitude of fractures facilitated weathering to considerable depths and also provided open spaces in which uranium compounds could be deposited. Possibly uranium minerals were precipitated where uranium-bearing ground water locally intermingled with spring water containing hydrogen sulfide.

The Kern River uranium deposits contain elements such as iron, molybdenum, arsenic, fluorine, and vanadium that are common in many other uranium deposits, especially in some of those in the Colorado Plateau region.

Granodiorite in the Miracle and Kergon mine areas has a higher molybdenum content than other rocks in the Kern River uranium area and may be the source of some of the molybdenum in the Kergon deposits. The granodiorite contains as much as 10 ppm molybdenum (table 3, samples with prefix M and K), whereas the molybdenum content of the average silicic rock is 2.5 ppm (Sandell and Goldich, 1943, p. 168).

The Kern River uranium deposits are believed to be of Quaternary age, although conclusive evidence is lacking. Indications of Quaternary deposition are recent deposition of uranium from the nearby Pettit Ranch springs; the possibility that some of the uranium deposits are related to hot springs, many of which are active at the present time; and the disequilibrium of the deposits—a requisite but not conclusive condition for Quaternary age.

TUNGSTEN DEPOSITS

Tungsten deposits are confined to the southeastern part of the area, either within or near the metamorphic rocks of the Kernville series. Scheelite, the only ore mineral in the deposits, occurs both in tactite and in hypothermal quartz veins that resemble silexite. The scheelite is irregularly distributed in both types of deposits.

There are many small scheelite mines and prospects close to the southeastern boundary of the Kern River uranium area, but only the Prosperity mine and some minor prospects are actually within its boundary. The Prosperity mine (pl. 21), located in 1936, consists of a 35-foot crosscut adit, a few hundred feet of drifts, an opencut about 200 feet long and 40 feet in maximum depth, and lesser surface excavations. The workings are mainly in metamorphic rocks near their contact with the Isabella granodiorite.

Intermittent minor production has come from a scheelite-bearing quartz vein about 4 feet thick that strikes N. 10° E. and dips 72° NW. Scheelite is irregularly disseminated in the vein as crystals ranging from less than 1 mm to about 5 mm in diameter. Tucker and Sampson (1940, p. 333) report that some ore from this property contained about 1 percent WO_3. The vein also contains a little pyrite, limonite, and chlorite(?).

GOLD DEPOSITS

A member of Fremont's party made the first gold discovery in Kern County in 1851 in the Kern River uranium area at Greenhorn Creek near the Kern River (Brown, 1915, p. 481). Historically, gold has been the chief attraction for prospecting in the area. Gold prospects and inactive mines are widespread, particularly north of the Kern River, but in 1956 there was little interest in gold mining in the area. Both placer and lode deposits are represented. Placer gold was localized in channels in the Kern River and in river terrace gravel, and in at least one locality, the Greenhorn Caves placer deposit, it occurs in gravel in a crevice cutting granodiorite. The Greenhorn Caves placer deposit includes large tracts mainly next to the west-central border of the area in secs. 12, 13, and 24, T. 27 S., R. 31 E. Tucker, Sampson, and Oakeshott (1949, p. 233) say that this deposit is supposed to have yielded $60,000 worth of gold.

The lode deposits consist of quartz stringers and pods localized along faults. Some of the deposits contain limonite and small amounts of pyrite or arsenopyrite or both. Most of the mines and prospects are inaccessible, but California State Division of Mines reports and the volume of dump material indicate that the underground workings of individual properties are generally no more than 300 or 400 feet in extent.

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