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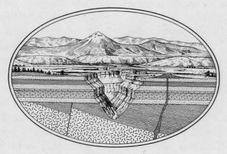
QUADRANGLE MAPS

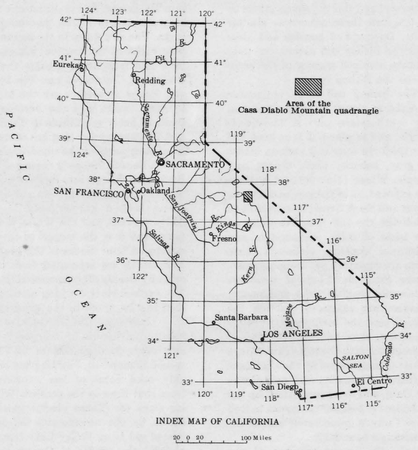
OF THE

UNITED STATES

GEOLOGY
OF THE
CASA DIABLO MOUNTAIN QUADRANGLE
CALIFORNIA

By
C. Dean Rinehart and Donald C. Ross





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GEOLOGY
OF THE
CASA DIABLO MOUNTAIN QUADRANGLE, CALIFORNIA

By
C. Dean Rinehart and Donald C. Ross

INTRODUCTION

The Casa Diablo Mountain quadrangle was mapped in the summers of 1952 and 1953 by the U.S. Geological Survey in cooperation with the California State Division of Mines as part of a study of potential tungsten-bearing areas.

The quadrangle is in southern Mono County, Calif. It includes a small area of the eastern Sierra Nevada and extends northeastward into the Basin and Range country between the Sierra Nevada and the White Mountains, which are about 7 miles east of the quadrangle boundary. The quadrangle has no settlements; the nearest towns are Benton, 3 miles north of the quadrangle limit, Lee Vining, 35 miles northwest of Benton, and Bishop, 20 miles south of the quadrangle boundary. Access to the area is provided by a network of secondary roads from U.S. Highways 6 and 395.

The topography of much of the area is moderate, but Glass Mountain Ridge, in the northwestern corner of the quadrangle, and the Sierra Nevada are characterized by more rugged relief. The maximum relief of the area is 6,742 feet; the altitude ranges from 5,000 feet at the bottom of Owens River Gorge at the south boundary of the quadrangle to 11,742 feet atop Wheeler Crest in the Sierra Nevada.

The only permanent streams are Rock Creek and Hilton Creek, which drain part of the Sierra Nevada. The Owens River has been dammed to form Lake Crowley and is periodically dry below the dam owing to the diversion of water to power plants of the Los Angeles Department of Water and Power. The remaining stream valleys in the area contain water only during the short time in the spring and early summer when snow is melting, or in the summer after thundershowers. With the exception of Rock Creek, Hilton Creek, and the Owens River, springs and wells furnish the only year-around water supply in the quadrangle.

The climate and vegetation, except for that part of the area in the Sierra Nevada, is typical of semiarid regions, with most of the precipitation occurring as light winter snow and the remainder as scattered summer thundershowers. The Sierra Nevada receives considerably more winter snow, but is also relatively dry in summer. Much of the Benton Range and part of the area immediately to the west is sparsely forested with piñon pine and juniper, part of the Volcanic Tableland and the Sierra Nevada supports Jeffrey and lodgepole pine, and most of the rest of the area is covered by sagebrush and other desert vegetation.

ROCK UNITS

The oldest rocks in the quadrangle are metasedimentary rocks of early Paleozoic or older age, which are contained in a moderately large pendant in the Benton Range, in several smaller masses west of the Benton Range, and in the Sierra Nevada. In the pendant the most common rocks are quartz-sericite hornfels and quartz-mica phyllite; graphite-andalusite hornfels, siliceous hornfels, calc-hornfels, tactite, and marble are less common. In the smaller masses the dominant rocks are calc-hornfels and biotite-quartz hornfels. The metasedimentary rocks are intruded by a sequence of plutonic rocks of Cretaceous age, which range in composition from gabbro to alaskite. In the Benton Range a genetically related swarm of steeply dipping, north-trending dikes and sills of porphyritic rhyolite intrude both the metasedimentary and plutonic rocks. Volcanic rocks of Tertiary and Quaternary age, which cover about half of the quadrangle, are principally tuff but include basalt and rhyolite. Sedimentary deposits of Tertiary(?) and Quaternary age, which cover about one-fourth of the quadrangle, are glacial till, lake sediments, and alluvium.

METAMORPHIC ROCKS OF PALEOZOIC OR PRECAMBRIAN AGE

The largest mass of metamorphic rocks is in the northeastern part of the quadrangle in the Benton Range; smaller masses crop out west of the Benton Range, in Rock Creek gorge, and in the Sierra Nevada on Wheeler Crest. Micaceous and siliceous rocks are the dominant types and include quartz-sericite hornfels, quartz-mica phyllite, graphite-andalusite hornfels, siliceous hornfels, and biotite-quartz hornfels, in order of decreasing abundance. Less common are calcareous rocks, which include calc-hornfels, marble, and tactite, in order of decreasing abundance. The rocks are generally massive, but in a few places bedding and crossbedding are preserved. The sedimentary rocks from which the various hornfelses were derived were probably a sequence of shales, siltstones, and argillaceous sandstones that were locally carbonaceous. Interstratified in this sequence were layers of pure limestone as well as limestone with varied amounts of argillaceous and siliceous impurities.

The units shown on the map are lithologic units. No formational names have been applied, inasmuch as it seems unlikely that a positive correlation of these rocks with others will ever be possible. The calcareous rocks were mapped separately, and where possible, graphite-andalusite hornfels and siliceous hornfels were differentiated from the quartz-sericite hornfels. Furthermore, in the northeastern part of the metamorphic terrane it was possible to set up a tentative local sequence of stratigraphic units (fig. 1)[1] using the calcareous layers (units 2 and 4 of fig. 1) as marker beds. No criteria for the determination of the tops of beds were found, but the overall outcrop pattern in the northern part of the area shown on figure 1 suggests a stratigraphic sequence more than 10,000 feet thick in which the strata are progressively younger to the north. The section south of unit 2 (unit 1, b, and c) is dissimilar from the section north of unit 2 and probably represents a considerable thickness in addition to the 10,000 feet estimated.

The age of the metamorphic rocks is not known. Rocks of early Paleozoic and late Precambrian age are present in the White Mountains east of the quadrangle, and rocks of Ordovician and Pennsylvanian age have been identified in the Sierra Nevada immediately west of the quadrangle. This distribution of rocks suggests that the section in the Casa Diablo Mountain quadrangle is probably of Paleozoic age or older.

Micaceous and siliceous rocks.—The quartz-sericite hornfels, in the northeastern corner of the map, is the most abundant metamorphic rock. It is a fine-grained, gray, tan, or reddish-brown, locally phyllitic, spotted rock. The common minerals of the hornfels are sericite, biotite, andalusite, quartz, and plagioclase. Round to subrectangular spots that range from 1 to 5 mm across are both lighter and darker than the matrix and are conspicuous in most of the specimens. Most of the spots are composed of extremely fine grained sericite and biotite, but some contain corroded remnants of andalusite. The remnants, as well as the subrectangular outline of some spots, indicate that the spots originally were andalusite porphyroblasts. In general the rock is homogeneous, although dark, biotite-rich varieties predominate near the center of the mass, but they are poorly defined and were not mapped separately. Farther south, the quartz-mica phyllite that occurs south of Chidago Canyon is probably a coarsened, foliated equivalent of this darker variety. It contains more biotite and less sericite and quartz than the typical quartz-sericite hornfels.

Dark-gray, brown, or black, graphite-andalusite hornfels is locally abundant west and northwest of the Black Rock mine, on the eastern side of the Benton Range. The dark color and the prominent euhedral, gray to green, acicular andalusite porphyroblasts, as much as 2 inches long and commonly partly altered to sericite, are distinctive. This rock grades locally through a transitional, lighter colored variety, which contains abundant sericite as well as euhedral andalusite crystals, into quartz-sericite hornfels. This transitional variety is most common near the north end of the metamorphic terrace, where it is associated with light-colored quartz-sericite hornfels and interlayered with numerous thin layers of calcareous rock.

Lenses of siliceous hornfels are interlayered with light-colored quartz-sericite hornfels and graphite-andalusite hornfels in the northern part of the metamorphic terrane and are restricted to unit 5 of figure 1. The rock is composed of a fine-grained granoblastic aggregate of quartz and plagioclase with minor amounts of sericite, biotite, and chlorite.

The biotite-quartz hornfels forms part of the small septum exposed on Wheeler Crest in the Sierra Nevada and is composed of a fine-grained granoblastic aggregate of quartz and biotite with a moderate preferred orientation of the biotite.

Calcareous rocks.—The calcareous rocks occur as well-defined layers and irregular lenses in the micaceous and siliceous rocks of the Benton Range, as many small inclusions in the diorite-gabbro and alaskite, as small inclusions in the gorge of Rock Creek, and as part of a septum in the Sierra Nevada. Masses of calcareous rocks too small to be shown on the map also crop out in the Benton Range along the ridge east of Banner Springs. Marble and calc-hornfels are by far the most common, and they crop out chiefly in the north half of the metamorphic terrane. Tactite is found in a large enough body to be shown on the geologic map only in the Black Rock mine area. The marble and calc-hornfels are commonly interbedded on too small a scale to be differentiated from each other on the geologic map. Minor amounts of tactite are locally mixed with the marble and calc-hornfels.

[1]Figure 1 is shown on map page.

The marble is gray to white, and commonly thin layered. Most of it is fine grained, but some is medium to coarse grained. Graphite, tremolite, diopside, grossularite, epidote or clinozoisite, biotite, quartz, and plagioclase are present in small amounts. Irregular, siliceous pods aligned parallel to the layering of the marble may be chert nodules.

The calc-hornfels includes a large variety of rocks that formed chiefly by the reconstitution of impure calcareous sediments during metamorphism, although some may have been formed from pure calcareous sediments by the addition of material during metamorphism. The calc-hornfels is commonly gray to pale green, thinly laminated to massive, and fine grained; some local layers are coarse grained. The common minerals are gray to pale-green pyroxene (diopside to salite), epidote, clinozoisite, light-colored amphibole (tremolite?), pale-brown garnet (grossularite), wollastonite, quartz, and calcite.

The name tactite was first used by Hess (1919) to describe the dark-colored rocks of complex mineralogy that form in calcareous rocks along contacts with granitic rocks. Economically, tactite is important because it serves as a host rock for scheelite, one of the chief ore minerals of tungsten. In the Casa Diablo Mountain quadrangle the tactite is composed chiefly of one or more of the following minerals: dark-colored garnet of the grossularite-andradite series, dark-green pyroxene (ferrosalite to hedenbergite), dark-green amphibole, and epidote; it also contains locally lesser amounts of wollastonite, quartz, and calcite. In the Black Rock mine area the tactite locally contains scheelite and pyrite, and south of the Black Rock mine it contains powellite and molybdenite. The tactite is generally dark red brown to dark green or a mixture of these two colors. Most of the tactite is fine to medium grained, but locally it is coarse grained and vuggy. It only locally exhibits irregular layering.

Most of the tactite in the quadrangle is not in contact with plutonic rocks at the surface, but the texture and mineral content are identical with tactite of known contact-metamorphic origin. The presence of plutonic stocks within the metamorphic area, the plutonic rocks in part of the periphery of the metamorphic area, and the hornfelsic, spotted fabric of the associated micaceous metamorphic rocks, commonly considered to be a product of contact metamorphism, suggest that plutonic rock may be present at shallow depth below the tactite masses.

Tactite has been formed by replacement of the following rocks: (1) pure limestone, (2) impure limestone, and (3) black siliceous hornfels. An example of (1) occurs at the Black Rock mine, where large, irregular blocks of pure marble are enclosed in tactite and are interpreted as residuals of parent rock. These blocks might be interpreted as layers or lenses that were unreplaced because they were not of a suitable composition, but the shape of the blocks does not support such interpretation. An example of (2) occurs on the ridge east of Banner Springs, where dikelike fingers of dark-green amphibole-pyroxene tactite have replaced light-colored calc-hornfels. Here as well as at the Black Rock mine small, wispy, discontinuous layers of calc-hornfels are locally enclosed in massive tactite. Evidence of (3) is the pale tactite at the Black Rock mine that has formed from black, dense hornblende-biotite-quartz hornfels. The hornfels is replaced by fine-grained, pale-green epidote-pyroxene hornfels, which encloses irregular, coarse-grained masses of epidote, pyroxene, microcline, and grossularite.

The relative amount of tactite that has formed from the replacement of each of these types is difficult to evaluate. The local abundance of marble blocks in the ore bodies of the Black Rock mine, the only mineralized tactite of importance known in the quadrangle, suggests that marble was the parent rock for most of the scheelite-bearing tactite and that the tactite which formed from calc-hornfels and hornblende-biotite-quartz hornfels is less favorable for scheelite mineralization.

INTRUSIVE ROCKS OF CRETACEOUS AGE

Intrusive rocks are exposed over an area of about 30 square miles in the Benton Range and about 15 square miles in the Sierra Nevada. The following rock types comprise the plutonic suite: granite and alaskite, quartz monzonite, granodiorite, diorite, and gabbro. The nine plutonic units that are delineated on the geologic map have been distinguished from one another on the basis of texture and mineral content. The plutonic rocks exposed in the Benton Range are small, irregular-shaped stocks, but some of the bodies in the Sierra Nevada are continuous with much larger bodies to the south and west. In addition to the stocks, numerous dikes and sills of porphyritic rhyolite and aplite intrude the metamorphic and plutonic rocks, particularly in the Benton Range. These light-colored dikes and sills are cut by diorite and gabbro dikes. The exposed contacts between granitic and metamorphic rocks and between various types of granitic masses are generally sharp and well defined. The contacts of granitic rocks with gabbroic rocks are in general gradational. The petrography of the intrusive rocks is summarized in table 1. Figure 2 shows the composition of individual specimens of the granitic rocks.

That stocks shown on the geologic map are of slightly different ages is indicated by the following field observations: the granite of Casa Diablo Mountain intrudes the diorite of the Benton Range, the granodiorite of Rock Creek intrudes the quartz monzonite of Wheeler Crest, and the alaskite is younger than the diorite-gabbro and the granodiorite of the Benton Range. The most recent data on the age of these intrusives comes from studies based on the method described by Larsen and others (1952). The granitic rocks in the Sierra Nevada immediately south of the Casa Diablo Mountain quadrangle have been determined by this method to be of Cretaceous age (Larsen et al., 1954).

The granitic rocks of the Benton Range commonly show the effects of contamination by the assimilation of gabbroic and metamorphic rocks. Such contamination is indicated by dark-colored, dioritic border zones with irregular, splotchy fabric, characteristic of the quartz monzonite of Deer Spring. This quartz monzonite is intermixed with, and in numerous places shows gradational contact with, gabbro and diorite. Contamination is also suggested by the scattered distribution of five modes of this rock plotted in figure 2. Specimens of an uncontaminated intrusive unit, such as the quartz monzonite of Wheeler Crest, do not commonly show this wide scattering of modes. An example of contamination of granitic rock by metamorphic rocks is the large mass of granodiorite northwest of the Black Rock mine. Adjacent to the metamorphic rocks that bound it, this intrusive is dioritic and contains abundant dark recrystallized xenoliths. The dark border zone, as well as the zone of abundant dark inclusions, is interpreted as evidence of the assimilation of metamorphic material by the intruding magma.

Diorite and gabbro are common in the southern and western parts of the Benton Range and in the dominantly volcanic terrane to the west; in addition, two small masses are exposed in the Sierra Nevada southwest of Toms Place. They are characteristically dark colored with an irregular fabric. Plagioclase (andesine to bytownite) and dark-green amphibole comprise most of the rock with clinopyroxene and epidote less abundant. Olivine and hypersthene occur only in the northernmost of the two gabbro masses in the Sierra Nevada.

The diorite and gabbro masses may have originated as intrusive bodies or as hybrid rocks that formed by the reaction of granitic magma with metamorphic rocks or older gabbroic rocks. The largest gabbroic mass of the Sierra Nevada is chiefly hornblende diorite-gabbro with scattered, sporadically distributed patches of olivine-hypersthene gabbro that are probably residuals of the reaction of quartz monzonite with an inclusion of older olivine-hypersthene gabbro. Some of the other diorite and gabbro masses resemble the contaminated border facies between the granodiorite of the Benton Range and the metamorphic rocks. This resemblance, as well as the extremely varied texture and mineral content of the diorite and gabbro masses, suggests that some of the masses originated by the variable assimilation or hybridization of metamorphic rocks. For the great bulk of the diorite and gabbro, however, data are not sufficient to choose between the two possible modes of origin.

Only one of the granitic formations of the Benton Range can be correlated with a formation of the Sierra Nevada. The texture and mineral content of the quartz monzonite of Wheeler Crest and the granodiorite of the Benton Range are in part identical and have led to the conclusion that both crystallized from the same magma. The quartz monzonite is part of a large body that extends several miles south into the adjacent Mount Tom quadrangle (Bateman, P. C., written communication) and is in marked contrast with the small, scattered stocks of the correlative granodiorite of the Benton Range. The petrography of the quartz monzonite of Wheeler Crest and the granodiorite of the Benton Range is summarized in table 1. Figure 2 shows a comparison of specimens from both ranges. The data in table 1 and figure 2 suggest that the granodiorite masses in the Benton Range are different from the quartz monzonite of Wheeler Crest. Nevertheless, the difference between the two types may be accounted for by contamination which, as shown in preceding paragraphs, was effective in modifying certain intrusive rocks in the Benton Range.

The darker and more variant intrusive masses in the Benton Range have probably assimilated a considerable amount of metamorphic or dioritic rock. As these masses are probably the upper parts of larger bodies the effects of assimilation are better preserved, and the variation expressed by figure 2 would be expected. In the Sierra Nevada the upper parts of the plutonic bodies and the associated roof rock have been removed, exposing deeper and more homogeneous parts. This inference is supported by figure 2, which shows the field of the granodiorite of the Benton Range scattered over a considerably larger area than the field for the correlative quartz monzonite of Wheeler Crest. The small amount of granodiorite of Rock Creek and granite-quartz monzonite exposed in the Sierra Nevada precludes correlations with rocks of the Benton Range at this time.

TABLE 1. SUMMARY OF THE INTRUSIVE ROCKS

ROCK	COLOR	TEXTURE	ESSENTIAL MINERALS						ACCESSORY MINERALS	REMARKS
			Potash feldspar Percent	Plagioclase feldspar Percent	Plagioclase feldspar Kind	Quartz Percent	Biotite Percent	Hornblende Percent		
Porphyritic rhyolite and aplite.	White, gray, bluish gray.	Porphyritic with micropegmatitic, fine-grained hypautomorphic, granulose or aplitic groundmass; less commonly nonporphyritic and aplitic.	Euhedral phenocrysts, as much as 5 mm in diameter, of quartz, potash feldspar, sodic plagioclase, and less commonly, biotite. Groundmass, dense to fine grained, of quartz, potash feldspar, sodic plagioclase, with minor amounts of biotite and black opaque minerals.							Occurs as dikes, sills, and small stocks. Quartz phenocrysts commonly have square, beta-quartz, outline.
Alaskite	White to cream.	Fine- to coarse-grained; generally equigranular.	20-40	10-40	An_{5-20}	25-60	Tr.		Muscovite, pink garnet, magnetite, allanite, sphene, apatite.	Muscovite common in some bodies.
Granite of Casa Diablo Mountain.	White, cream, and pink.	Coarse-grained, equigranular.	40-55	25-30	Albite	20-30	Tr.		Magnetite	Weathers to distinctive massive hummocks.
Granite-quartz monzonite.	Gray	Fine-grained, sugary, locally porphyritic.	40	20	Calcic oligoclase	35	5		Apatite, sphene.	
Quartz monzonite of Deer Spring.	Gray to dark gray.	Medium-grained, variable.	10-35	25-50	Andesine	25-40	2-10	0-3	Apatite, magnetite, allanite.	Locally grades into diorite and gabbro; dark inclusions uncommon.
Granodiorite of Rock Creek.	Dark gray	Medium-grained, equigranular, with well-formed crystals.	15-20	50	Andesine	20	10±	5±	Magnetite, apatite, sphene, zircon.	Dark inclusions common.
Quartz monzonite of Wheeler Crest.	White to gray.	Medium- to coarse-grained seriate, locally porphyritic.	20-45	20-45	An_{15-35}	20-50	1-10	Tr.	Apatite, magnetite, zircon, sphene.	Dark inclusions rare.
Granodiorite of the Benton Range.	Gray to dark gray.	Medium- to coarse-grained, commonly porphyritic.	5-45	30-60	An_{30-45}	10-35	1-10	0-15	Magnetite, allanite, sphene, zircon, apatite.	Dark inclusions common; dioritic border phase around part of body west of Tower mine in the NE corner of the map.
Granodiorite of Red Mountain.	Gray to dark gray.	Medium-grained	5-10	60-70	Intermediate andesine	5-10	10	10	Magnetite, apatite, sphene, allanite.	Biotite and hornblende ragged and sievelike.
Diorite-gabbro	Dark gray to black.	Medium- to coarse-grained.		0-60	Intermediate andesine-bytownite	Tr.-5		20-60 Clinopyroxene 0-30	Hypersthene, olivine, epidote, sphene, magnetite, apatite.	Mineralogy extremely varied.

VOLCANIC ROCKS OF TERTIARY AND QUATERNARY AGE

Volcanic rocks underlie about half the quadrangle and consist of rhyolitic rocks and a lesser amount of basalt. The rhyolite consists of tuff, perlitic glass, obsidian, and pumice. The basalt consists predominantly of dense to vesicular flow rock, but locally agglomeratic and tuffaceous material is present. The oldest rocks are in the north part of the quadrangle and include basalt flows overlain by a variety of rhyolitic rocks; both types are considered by Gilbert (1941) to be of Pliocene age. The age is based on the position of these two units in a volcanic sequence that is correlated with a similar sequence in the Hawthorne quadrangle, Mineral County, Nev., which overlies the Esmeralda formation of late Miocene and early Pliocene age. The youngest volcanic unit is the Bishop tuff of Gilbert, a rhyolite tuff which, according to Gilbert (1938), is the product of *nuées ardentes*. The tuff is middle Pleistocene in age; according to Putnam (1938, 1949, and 1952) it overlies the Sherwin till of Blackwelder (1931) and underlies the Tahoe till of Blackwelder. More detail on the Tertiary history of the area and a comprehensive discussion of the Bishop tuff and its origin can be found in two papers by Gilbert (1938, 1941).

Basalt.—The largest outcrops of basalt along the north side of the quadrangle probably are the remnants of a single series of flows that is broken by faulting and erosion. The smaller isolated outcrops north of Deer Spring, west of Moran Spring, in Chidago Canyon, and in the Owens River Gorge are probably of about the same age but may represent different flows. The small basalt flow east of the Black Rock mine is younger than the large flow along the north edge of the quadrangle and was probably extruded from a vent near a small cinder cone a few hundred yards east of the quadrangle boundary. The small flow overlies older alluvium, which underlies the large flow.

The different masses of basalt, though they may be of somewhat different ages, have essentially the same mineral content. The basalt is gray to black, vesicular and locally porphyritic, with phenocrysts of olivine, augite, and plagioclase. The groundmass is predominantly a fine-grained felty mass of plagioclase microlites with abundant small grains of apatite and magnetite. West of Watterson Meadow the flow is locally andesitic, with no olivine, a minor amount of augite, and more sodic plagioclase.

The basalt is at least 100 feet thick east of Watterson Meadow and appears to be about 25 to 50 feet thick near the east end of the same outcrop, suggesting a western source, probably a basalt cone west of Wildrose Canyon. In the Owens River Gorge a 400-foot section of basaltic material is exposed beneath the Bishop tuff and the locally underlying Sherwin till of Blackwelder; agglomeratic, cindery, and tuffaceous material is common in this section but uncommon in other basalt areas.

Rhyolite.—Glass Mountain Ridge is underlain by a great variety of rhyolite, which includes perlitic glass and obsidian intermixed with pumice. The mantle of pumice and glass in the large area south of Wilfred Canyon as well as in numerous small areas to the east is part of this rhyolitic sequence. The unconsolidated pumiceous members of the Bishop tuff are nearly devoid of the glass fragments that are common in the pumice in the rhyolitic sequence, and this difference serves to distinguish these otherwise similar units. Outcrops of pumice and glass near the Bishop tuff almost certainly contain admixed pumice of the same age as the Bishop tuff.

The Bishop tuff is an ignimbrite underlying about 75 square miles in the southeastern part of the quadrangle, and in places it is at least 800 feet thick. In color it is various shades of gray, salmon, pink, brown, and purple. Where thick vertical sections are exposed, as in the gorges of Owens River and Rock Creek, it is possible to subdivide the tuff into five units on the basis of color, compaction, and columnar jointing, although these units are generally not mappable elsewhere. Small inclusions of metamorphic rocks, granitic rocks, and locally, obsidian are scattered through the tuff. Where the inclusions are fairly abundant, they indicate the kind of bedrock beneath the tuff. This feature is best demonstrated by the abundant inclusions of granitic rock near Crowley Dam, and to a lesser extent by the inclusions of metamorphic rock in Red Rock Canyon immediately east of the quadrangle boundary.

Only the lowest member of the Bishop tuff exposed in the Owens River and Rock Creek gorges is a true welded tuff; it is glassy, dense, and contains collapsed pumice fragments and bent glass shards. Most of the Bishop tuff is light in weight and porous, contains uncollapsed pumice fragments, and does not appear to meet the requirements of welded tuff, if this rock is defined as a tuff in which the dominant process of formation is softening and union of shards and lapilli by heat. The term *sillar* (Spanish, meaning a rough or hewn stone used in masonry) is used by Fenner (1948) for *nuée ardente* deposits in which induration is primarily the result of recrystallization, and the process of softening by heat is not dominant. This term is well suited for most of the Bishop tuff. The sillar is genetically related to the dense welded tuff in the bottom of the Owens River and the Rock Creek gorges, but the sillar is not welded; the pumice fragments are not crushed and drawn out, and the shards are not markedly bent and twisted. A pink tuff layer directly above the welded layer in the bottom of the Owens River Gorge is gradational downward from sillar to typical welded tuff. The compaction, degree of consolidation, and therefore the specific gravity increase with depth as a general rule, but exceptions are found; for example, unconsolidated pumiceous layers south of Lake Crowley and in Chidago Canyon are overlain by consolidated tuff. The change from consolidated to unconsolidated tuff is gradational. A similar reversal in specific gravity is found near the top of Owens Gorge where consolidated salmon-colored tuff is underlain by a less dense, but consolidated, white tuff.

Small, well-formed phenocrysts of quartz, oligoclase, and sanidine are present in most specimens. The groundmass is predominantly glassy in some specimens, but in most specimens part or all of the glass was crystallized, after the emplacement of the tuff, to a fine-grained mixture of potash feldspar (probably sanidine) and tridymite. Because of the conversion of plutonic hornblende to basaltic hornblende in a few accidental granitic fragments and the reddening of biotite in the tuff, Gilbert (1938, p. 1856) thinks that the temperature of the Bishop tuff was probably not greater than 750° C nor less than 500° C.

Subdivisions of the tuff can be observed in the gorges, and it appears that the tuff was extruded in five closely spaced flows. As there is an overall increase in specific gravity from top to bottom in the tuff section, each successive flow was probably extruded before the previous flow had completely consolidated. Minor reversals of specific gravity between units also separable on the basis of color and jointing indicate that they were deposited in individual flows.

SEDIMENTS OF TERTIARY(?) AND QUATERNARY AGE

The sediments comprise gravel, glacial till, lake beds, valley fill, slope wash, alluvial fan material, and talus. The oldest sediment is the older alluvium (QToa) in the northeastern part of the quadrangle. It is a gravel that rests on a dissected, east-sloping pediment and is composed of subangular to subrounded fragments of plutonic rocks, metamorphic rocks, basalt, rhyolitic glass, and pumice. In several places, some of which are east of the quadrangle boundary, the Bishop tuff overlies the gravel; reworked unconsolidated layers of the tuff probably constitute some of the intermixed pumice in the gravel.

Glacial till of three ages is present along Rock Creek and Hilton Creek, in the Sierra Nevada. The younger glaciers generally followed the same paths as the older ones, so that the younger and smaller moraines are typically nested within the older and larger moraines. Sherwin till, the oldest till, mantles a large area east of the mouth of Rock Creek canyon and is also present in the Owens River Gorge, where it overlies basalt but underlies the Bishop tuff. In contrast with the formless Sherwin till, the younger Tahoe and Tioga tills of Blackwelder (1931) form typical moraines. The Tahoe till is distinguished somewhat arbitrarily from the younger Tioga till on the basis of the sharpness of Tioga ridges that are nested within the less distinct Tahoe ridges. Tentative correlations of the Sierra Nevada glacial stages with the continental glacial stages have been made by Blackwelder (1931). He considers the Sherwin till to be equivalent to till of the Kansas stage, but he also states that, "...it is...not unlikely that glacial deposits of Illinoian age are present but are as yet undifferentiated from those of the typical Sherwin stage." The Tahoe and Tioga tills are considered to have been deposited during the Wisconsin stage.

A lake filled most of Long Valley after the extrusion of the Bishop tuff; it was first described by Mayo (1934), who named it Long Valley Lake. Sediments deposited in the lake are exposed along the margins of the artificial reservoir Lake Crowley and consist of finely laminated layers of clay, silt and sand (Ql), gravel (Qg), and some tufa (Qtu). The gravel rests on lake terraces and consists chiefly of subrounded to well-rounded fragments of perlitic glass and obsidian, interbedded with sandy layers composed of volcanic fragments and clear quartz and feldspar grains, presumably weathered phenocrysts from volcanic material. Near Crowley Dam the gravel contains, locally, cobbles of granitic and metamorphic rock that resemble the bedrock exposed in the Sierra Nevada. Near Glass Mountain Ridge the gravel contains a few fragments of locally derived granitic rock.

STRUCTURE

Structures preserved in the quadrangle can be conveniently divided into Basin and Range structures and older structures in the metamorphic rocks. The structures in the metamorphic rocks of the Benton Range are folds and faults that predate the intrusives of Cretaceous age. The Basin and Range structures are the block-forming faults and the associated faults of lesser magnitude of Tertiary and Quaternary age that are common in various parts of the quadrangle.

The Benton Range is typical of the Basin and Range province. It lies in the central part of a wide and complexly faulted graben between the Sierra Nevada and the White Mountains, and it is the largest of several east-tilted fault blocks in this graben. The blocks are separated from each other by steeply dipping normal faults. The earliest block-forming movement that can be dated in the quadrangle took place after the extrusion of the basalt and rhyolite of Pliocene(?) age and before the deposition of the Pleistocene Bishop tuff. Faulting has probably been more or less continuous from that time to the present. Warping since the Tahoe glacial epoch is shown by the considerable deformation of old Long Valley Lake terraces and by the profile of Owens River Gorge, which is anomalously convex upward.

STRUCTURE IN THE METAMORPHIC ROCKS

Large folds in the metamorphic rocks that are of sufficient amplitude to be shown on the map are generally open, with the limbs dipping 50° to 60°. Minor folds, however, are locally tight and isoclinal. Folded structures can be demonstrated most convincingly west and north of the Black Rock mine area, where sparse data indicate generally north-trending, north-plunging folds. Section *A-A'* shows a cross-sectional view of the folded structure and section *B-B'* shows the north plunge. The folding predates the Cretaceous intrusives, a conclusion based on the truncation of the folded rocks by the intrusive rocks.

Some of the faults shown on the map in the metamorphic terrane are also probably older than the intrusive rocks. The northwest-trending fault about a mile west of the Black Rock mine and the north-trending fault about a mile northwest of the Black Rock mine are the best examples of probable pre-Cretaceous faults. They displace metamorphic rocks but do not have the surface expression of the Basin and Range faults. Reactivation of these faults at some time after the consolidation of the intrusives is indicated by faint traces of the faults, with minor displacement, into the adjoining granodiorite. The association of breccia zones and mafic dikes in linear zones in the Black Rock mine area also indicates older faulting, but thermal metamorphic effects have tended to obscure these faults.

BASIN AND RANGE FAULTING

Most of the major segments of the Benton Range and the volcanic area to the west are bounded on the western side by block faults downthrown on the west. The earliest Basin and Range faulting that can be dated in the quadrangle occurred after the extrusion of the rhyolite and basalt of Pliocene(?) age. The best evidence is along the west side of the Benton Range and near the north boundary of the quadrangle, where range-bounding faults cut and displace the basalt as much as 1,000 feet vertically. Farther to the south, along the west side of Casa Diablo Mountain, a range-bounding fault cuts the Bishop tuff but is marked by a scarp of only a few tens of feet. These relationships suggest that faulting may have recurred since its inception and that the small offset of younger formations is an expression of a small interval of time rather than a decrease in intensity of faulting.

Continuous or recurrent faulting is also suggested by the fault in the north-trending segment of Owens River Gorge. Faulting occurred sometime after the extrusion of the basalt and may have been accompanied or followed by considerable erosion before the Bishop tuff was deposited, as suggested by the lack of relief on the upper surface of the basalt at the fault contact. This lack of relief may, however, also be explained by considering the upper surface of the basalt as the slightly eroded top of a flow that buried rather rugged topography, in which case early movement along the fault may have been only minor. Movement along the fault since the extrusion of the Bishop tuff has displaced the tuff about 25 feet vertically.

The faults that are prominent in the Bishop tuff trend north, are predominantly downthrown to the west, and are probably contemporaneous with similar faults that cut the basalt east of Watterson Meadow. The average throw on the faults is less than 100 feet, but several scarps as much as 160 feet high have been noted. These faults are similar in trend and direction of movement to most of the older faults in the Benton Range and may in part represent movement along older faults in the underlying basement rocks. The preservation of small-scale fault scarps is favored both by the brittle and tabular nature of the basalt and the Bishop tuff and by the fact that these bodies form surfaces of low relief. Therefore, the relative abundance of faults mapped in these rocks is probably due to ease of recognition rather than localization of faulting. Though the small-scale faulting is not apparent in most of the bedrock, the granite of Casa Diablo Mountain south and north (out of the quadrangle) of the basalt is cut by north-trending faults that are in part continuous with faults in the basalt. These faults may also represent late movement along an older set of joints in the granite.

The southwest front of Glass Mountain Ridge in the northwest corner of the quadrangle is bounded by a fault, although the throw on the fault could not be determined. No datum plane was found from which the displacement might be measured. Much of the present relief may be partly the result of volcanism and partly the result of faulting.

No faults of large offset were observed along the front of the Sierra Nevada. Many of the faults mapped along the front, however, cut and displace recent talus and alluvium, indicating that faulting is still active in this region. The position of these faults strongly suggests that at least some of them may reflect continued or recurrent movement along older faults, although the small part of the range included in the quadrangle precludes further discussion of the structural history of the Sierra Nevada.

POST-TAHOE WARPING

Warping is shown by a profile constructed along Owens River Gorge from Crowley Dam to the confluence with Rock Creek in the Mount Tom quadrangle, adjacent on the south. The profile is markedly convex upward, indicating that the Bishop tuff has been arched since the overflow of ancient Long Valley Lake (fig. 3). The high point shown on the profile of the rim of the gorge could not have been the point of initial spillover because lake terraces extend less than half a mile east of the dam, whereas the present high point is more than 3 miles east of the terraces. The profile of Rock Creek appears to be normally concave upward and is in marked contrast to the profile of Owens River.

Warping is also indicated by the position of the lake terraces. The east margin of the terraces is assumed to mark the uppermost level attained by Long Valley Lake, and ranges in altitude from 7,000 feet near Crowley Dam to about 7,900 feet near the mouth of Wilfred Canyon—demonstrating at least 900 feet of deformation since the impounding of Long Valley Lake.

EVOLUTION OF THE PRESENT LANDSCAPE

The quadrangle may be divided into five principal geomorphic elements: (1) the Benton Range, including Casa Diablo Mountain, (2) the topographically irregular area between the Benton Range and Long Valley, including Glass Mountain Ridge, (3) the Volcanic Tableland, (4) Long Valley, and (5) the Sierra Nevada.

The Benton Range (1) and the range of hills adjacent on the west (2) can probably best be described together. The land surface prior to the extrusion of the basalt (Tob) was in part one of low relief, judging from the low relief of the surface of the disrupted basalt flow near the north boundary of the quadrangle. After the extrusion of the basalt, the rhyolitic material (Tr), which blankets Glass Mountain Ridge and much of the area to the south, erupted from sources probably in the vicinity of Glass Mountain Ridge. This rhyolite probably was the source of some pyroclastic material found in the older alluvium (QToa) in the northeastern part of the quadrangle. The transport of material from Glass Mountain Ridge across the area where the Benton Range now stands is indicated by well-rounded cobbles of perlitic glass in the unit of older alluvium. The older alluvium mantles an east-sloping pediment that probably antedates Basin and Range faulting in the area and correlates with the surface onto which the basalt was extruded. The pediment is best seen east of the quadrangle, where it slopes 3° to 4° east to the valley floor 5 miles away. Only a relatively small upper part of the pediment lies within the quadrangle. It has been moderately dissected as a result of relative uplift of the Benton Range along Basin and Range faults. The earliest faulting along the west front of the Benton Range that can be dated therefore took place after the extrusion of the rhyolite from Glass Mountain Ridge and vicinity.

The broad south-sloping Volcanic Tableland underlain by the Bishop tuff forms a distinct geomorphic unit. The old topographic surface upon which the tuff was deposited was one of moderate relief, as demonstrated by the "hills" of bedrock exposed in the Owens River Gorge and Round Mountain. The most striking features developed in the tuff are the deep, steep-walled gorges of Owens River, Rock Creek, and Chidago Canyon. The Owens River Gorge was probably cut by spillover from ancient Long Valley Lake. At its deepest point immediately west of the bedrock outcrop the gorge is about 800 feet deep. Rock Creek flows through a deep canyon in the Sierra Nevada and has cut a gorge in the Bishop tuff as much as 600 feet deep. It originally flowed out through Little Round Valley into Long Valley, but now it almost completely reverses direction and flows south along the east front of the Sierra Nevada. Capture of Rock Creek drainage by a stream working headward along the east front of the Sierra may account for the reversal, or the drainage may have been diverted to the east by sudden flooding, connecting the stream with the drainage along the east front of the Sierra Nevada. A detailed account by Putnam (1952) of the origin of Rock Creek and the Owens River Gorge is in preparation. Chidago Canyon is the easternmost gorge cut into the Bishop tuff. Near the head of the canyon and north of the east-trending part of the canyon, large areas underlain by brown and pink pumice suggest that much of the tuff has been stripped away. The canyon carries no water today, and it apparently owes its origin to increased drainage during wetter climates in the past.

Long Valley is probably the north part of a larger valley that connected with Owens Valley to the south prior to the extrusion of the Bishop tuff. The deposition of the tuff blocked the valley south of the area now occupied by Lake Crowley and impounded a lake at least 80 square miles in area. The existence of the lake is demonstrated by the sediments (Ql, Qg, and Qtu) described above by shorelines and terraces cut in the tuff, which are well exposed south, east, and northeast of Lake Crowley. In addition, terraces as well as a considerable thickness of sediments deposited in the lake are prominent in the area northwest of Lake Crowley and west of the quadrangle boundary.

The part of the Sierra Nevada within this quadrangle is too small to permit discussion of the physiographic history of the range.

Faulting has modified the landscape to a minor degree since the extrusion of the Bishop tuff. Fault scarps are abundant in the tuff and have an average throw of less than 100 feet, though several scarps are as high as 160 feet. Along the west front of the Benton Range, range-bounding faults cut the Bishop tuff in the vicinity of Chidago Canyon and Casa Diablo Mountain. The faults are marked by scarps that are only a few tens of feet in height, indicating that the Benton Range attained most of its present height prior to the deposition of the Bishop tuff. Terraces in Chidago Canyon and near Clover Patch, whose distance above present drainage channels is comparable to the throw on the small-scale post-Bishop tuff faults, may be the result of down cutting of the streams in response to minor rejuvenation due to faulting.

MINERAL DEPOSITS

The mineral deposits of the Casa Diablo Mountain quadrangle are contact metamorphic tungsten deposits, minor fissure vein deposits of gold, silver, lead, and copper, and a replacement and contact metamorphic iron deposit in the Benton Range, as well as minor occurrences of pumice, perlite, sand, and gravel. In 1954 the only mining activity was at the Black Rock mine, an important tungsten producer, and at a small pumice pit south of Lake Crowley where building bricks are manufactured. A detailed description of the Black Rock mine with accompanying large-scale maps of the mine area and the workings as well as descriptions of the other mineral deposits by the writers is in press by the California State Division of Mines (Rinehart and Ross, 1956).

TUNGSTEN

Contact metamorphic tungsten deposits have been found at various places in the Benton Range, and one small deposit was mined from an inclusion in the quartz monzonite near the contact with the Bishop tuff along Rock Creek. The Black Rock mine had yielded about 275,000 tons of tungsten ore by October, 1954, and is the most productive tungsten mine in the quadrangle[2]. Only a few thousand tons of ore has been shipped from all the other tungsten properties in the quadrangle. Scheelite, the only tungsten ore mineral present, is disseminated in tactite that was formed by the thermal metamorphism of calcareous rocks.

The Black Rock mine is on the dissected east slope of the Benton Range, in the east-central part of the quadrangle. An asphalt road connects the mine with U. S. Highway 6, about 8 miles to the east.

Scheelite was first discovered in the mine area in 1917, although development was not undertaken until 1928. The property has been worked intermittently since that time, but the major production has been since World War II. The total production has been more than 275,000 tons of ore that averaged about 0.5 percent WO_3[2]. In 1953 the Black Rock mine yielded the second largest quantity of tungsten concentrates in California and was the sixth most productive tungsten mine in the United States. It is developed by means of five open cuts and several adit levels that total a little more than one mile in length. Most of the underground production has come from one level, which consisted of about 3,300 feet of accessible workings in 1952. Development and production have been greatly accelerated since 1952, and by 1954 many hundreds of feet of new workings had been added.

Rocks exposed in the mine area include a layered sequence of calc-hornfels, marble, and tactite totalling at least 400 feet in thickness, overlain conformably by several thousand feet of quartz-sericite hornfels. The basal contact of the calcareous strata is not exposed. The rocks have been folded into an asymmetric, north-plunging anticline with a gently undulating crest; the fold may be broken along the crest line by a steeply dipping pre-mineral fault. Minor post-mineral faults are common in the mine. Dikes of porphyritic rhyolite and fine-grained diorite cut the metamorphic rocks in several places, and granitic rocks crop out within short distances west and south of the mine.

Scheelite is sporadically distributed in tactite at many scattered localities in the mine area. The ore averages 0.5 percent WO_3, but locally the grade is as high as 2.0 percent WO_3. Scheelite in quantities of minable grade is for the most part localized in the crest of the fold and in the gently dipping west limb. Although there is considerable tactite in the east limb of the anticline, only one small ore body has been found east of the crest. The localization of scheelite in the crestal region of a fold is uncommon in contact metamorphic tungsten deposits.

[2]Data furnished by the Wah Chang Mining Corporation. Published with permission.

GOLD, SILVER, LEAD, AND COPPER

All of the known gold, silver, lead, and copper deposits are confined to the Benton Range and are in fissure veins. The most common mineral assemblage is pyrite, limonite, and galena in quartz with some free gold as well as gold and silver contained in sulfides. Copper minerals are localized in the Chidago Canyon area and are chalcopyrite, chrysocolla, azurite, and malachite. Quartz is the gangue in most of the veins, but some ore is found in breccia and gouge zones with no apparent vein quartz. The veins range in thickness from thin stringers to as much as 20 feet but their average thickness is 2 to 3 feet. A predominant set of veins strikes north to northwest and dips west 40° to 80°; a lesser number of veins strikes northeast to east, and a few veins fit neither set.

The first mining in the Benton Range appears to have been in the early 1870's. The district was active intermittently until the late 1930's, but since then activity has consisted mainly of assessment work and prospecting. The total value of gold, silver, lead, and copper that has been produced is probably less than $1,000,000. The Tower, Wildrose, Gold Crown, Casa Diablo, and Sierra Vista mines account for more than one-half of the total production.

OTHER DEPOSITS

Other metallic and nonmetallic mineral deposits in the quadrangle are iron, uranium, pumice, perlite, and sand and gravel.

A deposit of magnetite and hematite that occurs in the northeastern part of the quadrangle is partly a replacement of andalusite hornfels along a fault zone and partly the result of the additive metamorphism of calcareous rocks. A layer 50 feet thick containing an unknown percentage of magnetite and hematite is exposed over a strike length of 70 feet, and a short adit exposes 22 feet of this layer about 60 feet below the outcrop.

At the Banner mine, now mostly caved, anomalous radioactivity was traced to a thin band of limonitic material along the footwall of a gently dipping quartz vein. Assays showed as much as 0.10 percent of uranium oxide for selected samples, but no minable quantity of material was found.

Pumice is quarried and made into building blocks at a pit south of Lake Crowley; the pits in the northeastern part of the quadrangle are inactive.

Perlite deposits of undetermined grade and extent crop out along the ridge northwest of Wilfred Canyon in the northwestern part of the quadrangle.

The Los Angeles Department of Water and Power has excavated large quantities of sand and gravel from pits in the alluvial fan of Rock Creek and south of Lake Crowley; the material was used for road and dam construction.

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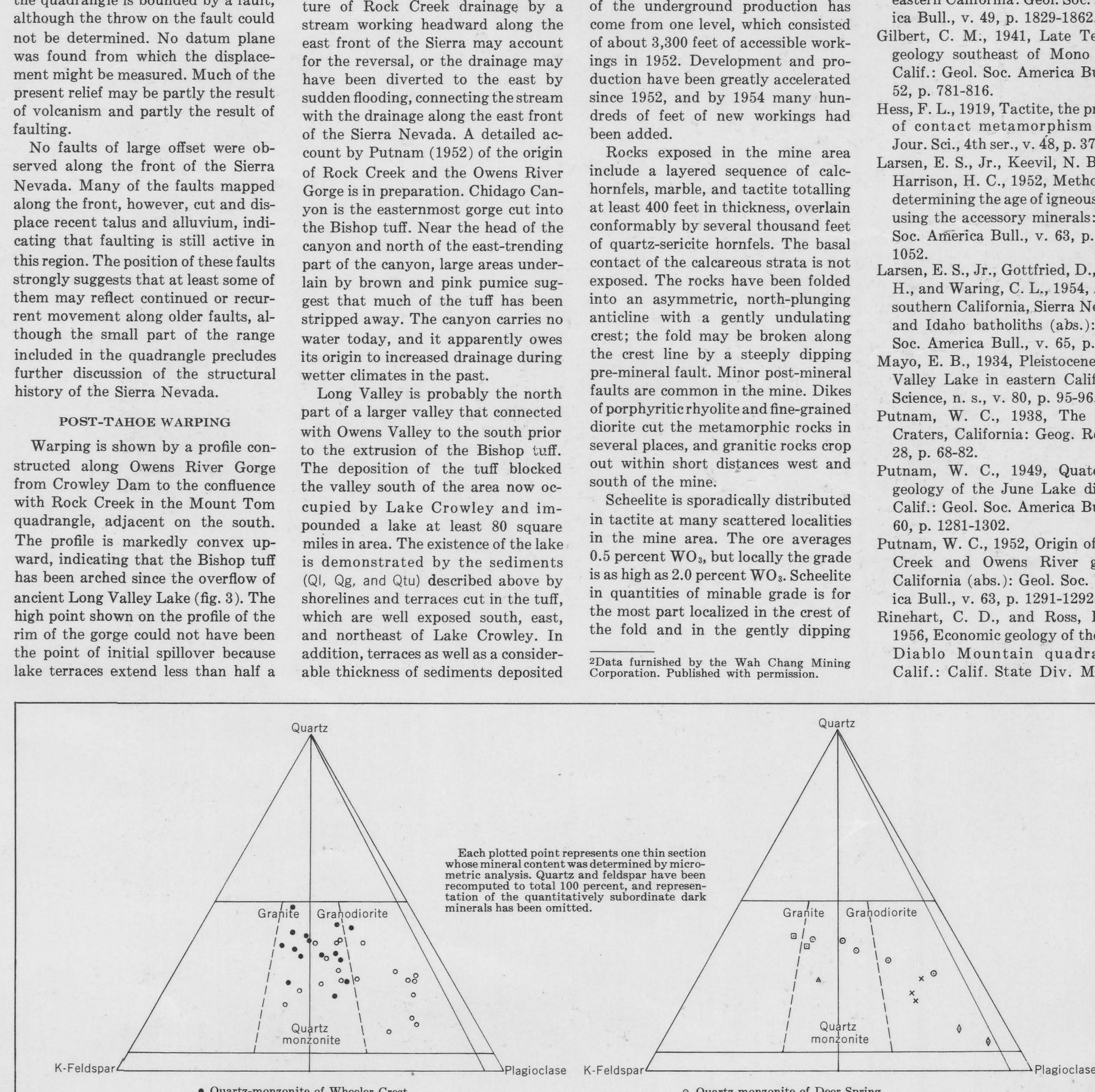

FIG. 2—TRIANGULAR DIAGRAMS SHOWING COMPOSITIONS OF INDIVIDUAL SPECIMENS OF GRANITIC ROCKS

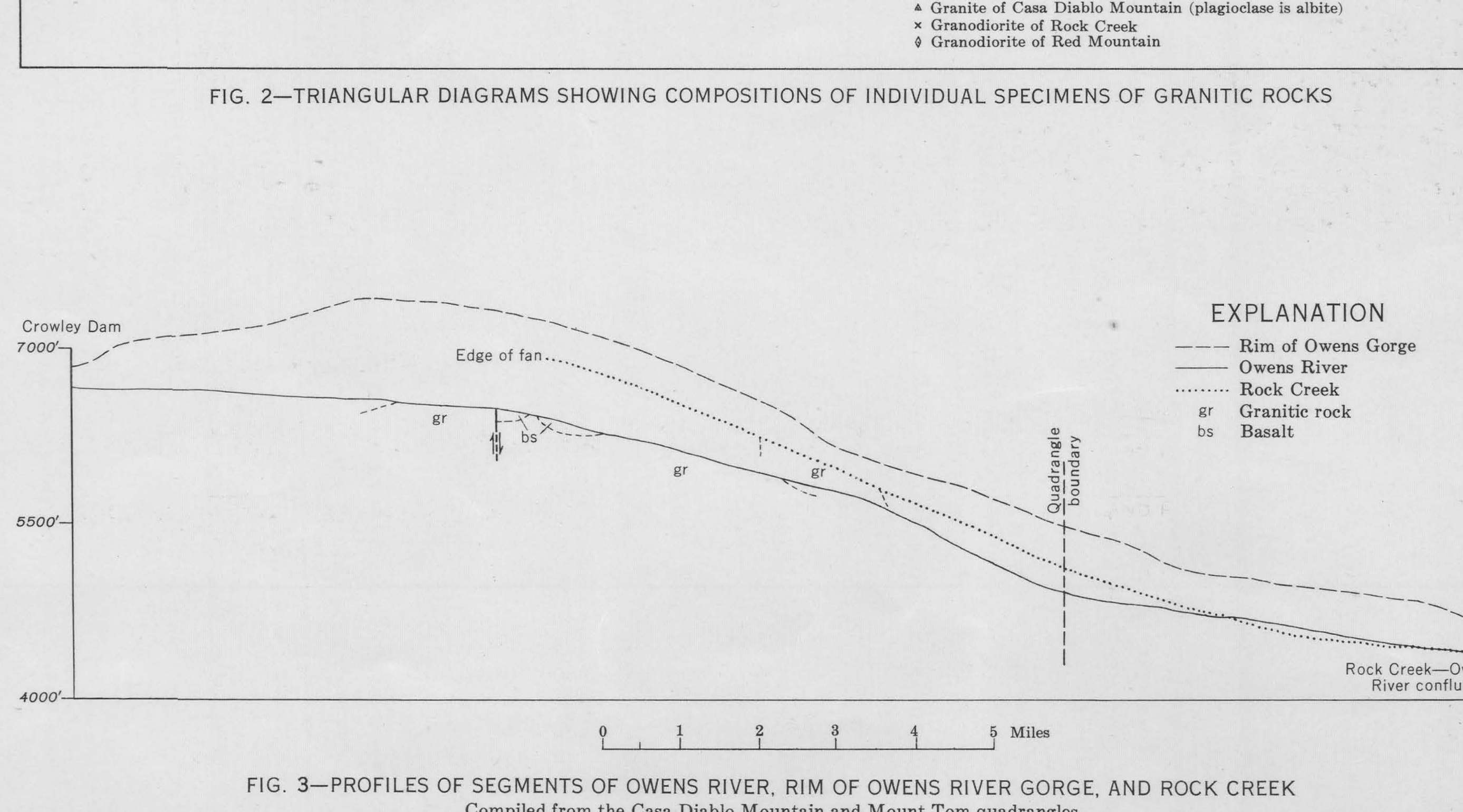

FIG. 3—PROFILES OF SEGMENTS OF OWENS RIVER, RIM OF OWENS RIVER GORGE, AND ROCK CREEK
Compiled from the Casa Diablo Mountain and Mount Tom quadrangles

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