ECONOMIC DEPOSITS OF THE KLAMATH MOUNTAINS *

By John P. Albers
U.S. Geological Survey, Menlo Park, California

INTRODUCTION

The metallic substances that have been produced from the Klamath Mountains of California (fig. 1) include gold, copper, zinc, pyrites, lead, silver, chromite, quicksilver, iron, platinum, and manganese. Limestone (for cement), sand, gravel, building stone, crushed rock, brick, rubble, and riprap are the important nonmetallic products. In 1965 these nonmetallic materials and quicksilver were the principal mineral products of the province. Table 1 summarizes the approximate total production of the major mineral commodities from 1880 through 1963; figures 2 and 3 show graphically the annual production trend of these commodities.

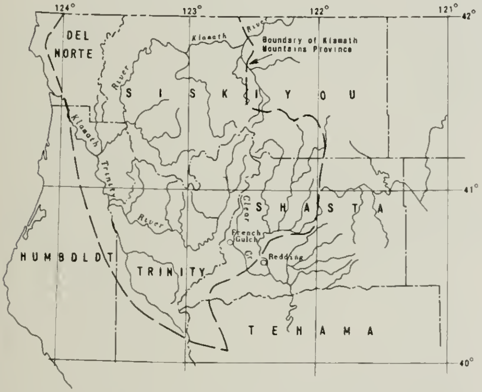


Figure 1. Index map showing location of physical features referred to in text.

For purposes of discussion, the economic deposits are subdivided as follows: (1) deposits found in ultramafic igneous rocks (chromite, asbestos, and nickel); (2) deposits found chiefly in metamorphosed sedimentary and volcanic rocks, and inferred to be genetically related to the intrusion of granitic rocks, (gold, silver, copper, lead, zinc, pyrites, iron); (3) deposits inferred to be associated elsewhere with late volcanic activity (quicksilver); and (4) deposits concentrated by sedimentary processes (managanese, placer gold and platinum, and the building materials). The building materials will not be discussed in this paper and only brief mention will be made of placer deposits and manganese. Occurrences of antimony, arsenic, clay, graphite, molybdenite, ocher, talc, tin, and tungsten are also known in the Klamath Mountains, but production is negligible, and thus the occurrences of these materials will not be described.

DEPOSITS FOUND IN ULTRAMAFIC IGNEOUS ROCKS

Chromite.—Chromite has been produced from the Klamath Mountains only during World Wars I and II, when access to foreign sources was more difficult, and during the 1950's, when the U.S. Government purchased chromite at incentive prices for the national strategic mineral stockpile. At other times domestic chromite has been unable to compete with foreign sources.

Figure 2. Production of gold, copper, lead, zinc, and pyrites between 1880 and 1963, in millions of dollars.

---

* Publication authorized by the Director, U.S. Geological Survey.

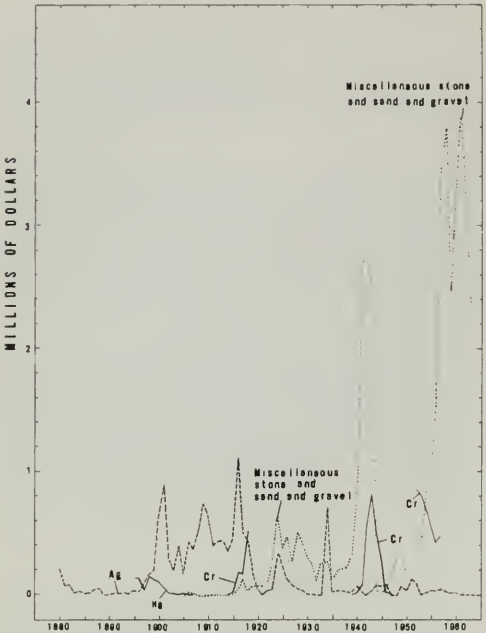


Figure 3. Production of chromite, silver, stone, sand and gravel, and quicksilver between 1880 and 1963, in millions of dollars.

Because of the interest in chromite during World War II, the more important deposits in the Klamath Mountains were intensively studied during that period by the U.S. Geological Survey. The following description is summarized largely from reports by Allen (1941); Wells, Cater, and Rynearson (1946); Wells, Smith, Rynearson, and Livermore (1949); and Wells and Cater (1950).

Chromite is found exclusively in ultramafic igneous rocks and in serpentine derived from them. The distribution of ultramafic rocks and the location of the principal chromite deposits is shown on figure 4. The ultramafic rock generally forms sill-like tabular bodies that lie parallel to bedding or foliation in the intruded rocks. Individual ultramafic masses are commonly composed of more or less discrete bodies of several different rock types—saxonite, dunite, lherzolite, pyroxenite, and hornblendite. The chromite occurs in tabular or lenticular bodies of dunite that may be any size or shape and may occur anywhere within an ultramafic mass. The dunite is composed of at least 95 percent olivine and less than 5 percent pyroxene.

Wells and others (1949, p. 26) describe dunite in weathered outcrops of the eastern Klamaths as characterized by a yellowish-red color, a smooth fine-grained surface, protruding scattered grains of chromite or magnetite, and an irregular jointing. Unaltered dunite has a ragged uneven fracture, a glassy to oily luster, and is light yellowish green to grayish green on the fresh surface. Highly serpentinized dunite, however, has a conchoidal fracture, a waxy or corneous luster, and is bluish green to greenish black. Under the microscope, dunite shows interlocking angular grains of olivine from 0.5 to 1.0 mm in diameter, and enstatite, augite, and hornblende in minor amounts. Serpentine is common along cracks and cleavages and as rinds around olivine grains in dunite. Serpentine may also surround chromite grains, forming an association that is of great importance in crushing the ore.

Chromite occurs in various degrees of concentration within dunite—from tabular or podlike aggregates of almost solid chromite to deposits containing only a few percent of chromite as disseminated grains. Thus two general types of chromite deposits are recognized: (1) pod, and (2) disseminated. The pod deposits consist of clean ore that can be mined, sorted, and shipped as lump ore. Almost all the deposits of Del Norte County in the western Klamaths are this type. Ore has been shipped from about 50 pod deposits which yielded from 5 to 20,000 tons each. Pod deposits commonly occur in shear zones, which may be as much as several hundred feet wide and several miles long. Allen (1941, p. 103) points out that elongate masses of chromite may be horizontal and parallel to the trend of a shear zone or may be inclined at any angle up to 90°. Deposits of the disseminated type are composed of chromite grains scattered through dunite or serpentine derived from dunite. The chromite may range in concentration from accessory amounts to as much as 80 percent of the rock. Deposits of disseminated ore range in size from a few tons to more than 200,000 tons. The largest disseminated deposit is the Seiad Creek or Mountain View deposit in the eastern Klamaths which according to Wells and others (1946, p. 33) measures 1,300 feet long by 250 feet wide and 250 feet down dip. Most of the chromite in the Klamaths, in both pod and disseminated deposits, is of metallurgical grade, with a Cr/Fe ratio of 2.50 or higher and a Cr_2O_3 content in excess of 45 percent. The richer pod deposits have yielded most of the ore to date, but ore reserves are mostly in disseminated deposits.

Geologists who have studied the chromite deposits of the Klamaths generally agree that the chromite was formed syngenetically with the enclosing ultramafic rock. Allen (1941, p. 103), in discussing chromite in California, states that most of the chromite bodies were emplaced late in the magmatic cycle, in some cases while differentiation was still going on. Wells and others (1949, p. 34), on the basis of detailed studies of structures in the ore and studies of internal structures of the enclosing ultramafic rock masses in the Seiad Valley-McGuffy Creek area, conclude that the chromite was as truly a component of the original ultramafic magma as the olivine and pyroxene. In their view the chromite crystallized early and accumulated

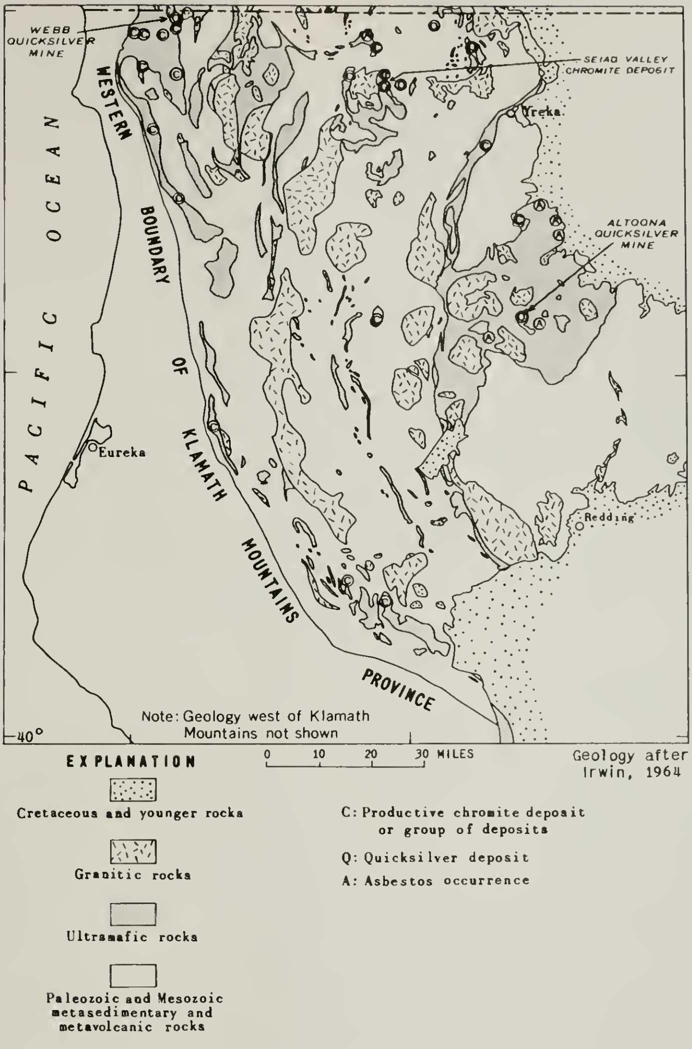


Figure 4. Distribution of chromite, asbestos, and quicksilver deposits in the Klamath Mountains of California.

Table 1. Approximate value of principal mineral commodities produced in the Klamath Mountains from 1880 through 1963

Commodity	Value
Gold	$140,127,320
Copper, lead, and zinc	139,503,044
Miscellaneous stone[1]	42,030,009
Pyrites[2]	21,178,850
Silver	13,046,907
Chromite	8,975,260
Mercury[3]	1,310,796
Platinum	185,830
Total	$366,358,016

(Data from U.S. Bureau of Mines Mineral Yearbooks and California Division of Mines and Geology publications.)

[1] Includes sand and gravel; excludes brick and cement.

[2] Data in part from Mountain Copper Company of California.

[3] Trinity County only.

in certain zones within the melt to form chromite-rich layers and bodies. They also think that crystallization of most of the chromite, much of the olivine, and some of the pyroxene was completed when the crystal-bearing mush moved from its crystallization chamber into its present position.

Because chromite is syngenetic with ultramafic rock, which was emplaced before the granitic rocks with which most of the epigenetic mineral deposits are believed to be related, it is inferred that the chromite ore bodies represent the oldest mineral deposits in the Klamath Mountains.

Asbestos.—Occurrences of asbestos are fairly numerous in the Klamath Mountains but the quantity mined to date is insignificant. Nearly all occurrences are in serpentine derived from peridotite (fig. 4). Two types of asbestos are found: (1) chrysotile or cross-fiber asbestos; and (2) amphibole (tremolite) or slip-fiber asbestos. Chrysotile has the higher tensile strength and therefore has a higher value. The chrysotile deposits commonly consist of a small zone of closely spaced veins that range in thickness from a fraction of an inch to about an inch. The fibers are oriented at right angles to the vein walls. The amphibole asbestos veins, on the other hand, are commonly along shear zones a few inches wide and have fibers oriented more or less parallel to vein walls. In a few places the amphibole veins contain lenticular pockets of fiber several feet wide. Rice (1957) describes a vein at the Sylvester mine, in Shasta County, which had a maximum width of 30 inches and was mined over a length of at least 110 feet. Owing to a limited market and the expense of handling, few amphibole veins are worked to depths greater than 25 feet. It appears that a successful amphibole asbestos industry in the Klamaths would depend on the discovery of deposits having a minimum strike length of several hundred feet.

Although the spatial relationship of both chrysotile and amphibole asbestos deposits to serpentine is clear, the genetic relationship is uncertain. The occurrence of asbestos in veins and shear zones indicates an epigenetic origin, possibly related to the process of serpentinization or to the intrusion of granitic rocks.

Nickel.—Ferruginous nickeliferous lateritic soils—formed by weathering of ultramafic rocks in place—are rather widespread in the Klamath Mountains but no production has yet been realized. Hotz (1964) believed that the soils were formed by chemical weathering in a climate characterized by alternate wet and dry seasons—similar to that prevailing today. The most likely time of their formation is post-Miocene to Pleistocene. Because the deposits are small, are low grade, and have a scattered distribution in a rugged and relatively isolated terrain, they are unlikely to be exploited in the foreseeable future.

DEPOSITS CHIEFLY IN METAMORPHOSED SEDIMENTARY AND VOLCANIC ROCKS AND INFERRED TO BE GENETICALLY RELATED TO GRANITIC ROCKS

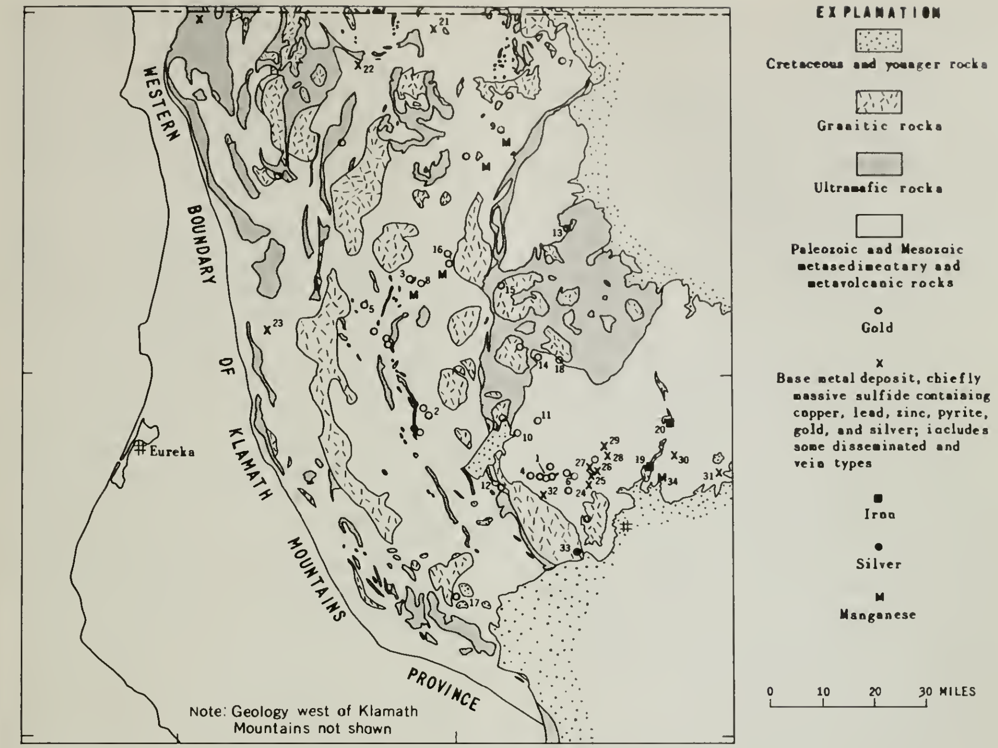
Gold.—Gold ranks as the principal mineral product of the Klamath Mountains. Approximately $140 million worth of gold has been produced since 1880 (table 1); in addition at least several million dollars worth was mined between 1848 and 1880.

As shown by figure 1, gold production reached an early peak of about $3 million in 1894 and then declined irregularly to less than $1 million annually during the 1920's. Then, in the 1930's, stimulated by the Great Depression which drove many people into prospecting, and by a substantial rise in price from $20.67 to $35.00 a fine ounce in 1934, production rose sharply and reached a peak of about $5.5 million in 1941. World War II resulted in a very sharp decline; since 1943 production has averaged well under $1 million a year.

The gold has come from three main sources: (1) placer deposits; (2) lode deposits; and (3) as a by-product of massive sulfide deposits mined chiefly for their copper content, and from gossan derived from massive sulfide. About $12 million of the $140 million total has come from massive sulfides. Of the remaining $128 million, about 70 percent has come from placer deposits, and the remainder from lode deposits (Irwin, 1960, p. 64).

During the first few years after its discovery in 1848 gold was produced mainly from placer deposits. The first lode mining began at the Washington mine (fig. 5) in 1852, but for many years the output of lodes was far below that of the rich gulches and bench gravels (Ferguson, 1914, p. 33). Lode mining increased in relative importance in the 1880's and probably yielded at least as much gold as placer mining until World War I. During the 1930's the great bulk of the gold produced was from dredging operations. Fineness of gold in the Klamaths has averaged about 850.

Placer deposits are located mainly along the Trinity and Klamath Rivers and their tributaries and along Clear Creek. Pleistocene gravels and gravels of the Tertiary Weaverville Formation have also yielded sig-



Note: Geology west of Klamath Mountains not shown

LIST OF MINES AND DEPOSITS REFERRED TO IN THE TEXT

GOLD MINES

1. Washington
2. Alaska
3. Black Bear
4. Brown Bear
5. Gilta
6. Gladstone
7. Hazel
8. Klamath
9. Golden Eagle (Sheba)
10. Fairview
11. Five Pines
12. Venecia
13. Dewey
14. Headlight
15. Cummings (Oro Grande)
16. Highland I
17. Midas (Harrison Gulch)
18. Trinity Bonanza King

IRON DEPOSITS

19. Shasta
20. Hirz Mountain

BASE METAL DEPOSITS

21. Blue Ledge
22. Gray Eagle
23. Copper Bluff
24. Iron Mountain
25. Keystone and Balaklala
26. Shasta King
27. Early Bird
28. Mammoth
29. Sutro
30. Bully Hill-Rising Star
31. Afterthought
32. Greenhorn

SILVER MINE

33. Silver Falls-Consolidated

MANGANESE MINE

34. Shasta Copper mine

Figure 5. Distribution of gold lodes, iron, base metal, silver, and manganese deposits in the Klamath Mountains of California.

nificant amounts of gold. The gold in all these placer deposits was derived from eroded segments of the lode deposits described below.

No overall study of the lode deposits of the Klamath Mountains has been made. However, geologists of the U.S. Geological Survey (MacDonald, 1913; Ferguson, 1914; and Albers, 1961, 1964) have studied individual districts and groups of districts, and geologists and engineers of the California Division of Mines and Geology have reported on the geology of individual mines, mainly on a county basis (Brown, 1916; Averill, 1931, 1933, 1935, 1941). The summary description of the principal kinds of deposits given below is based partly on these writings and partly on the writer's knowledge of the region.

Figure 5 shows that most of the principal lode deposits lie in an arcuate belt that parallels the gross structural grain in the central part of the Klamaths. They are predominantly in weakly metamorphosed sedimentary and volcanic rocks of Paleozoic age, and the great majority are closely associated with dike-like or sill-like bodies of a porphyry known by local miners as "birdseye" porphyry. This porphyry differs somewhat in composition from place to place and includes two principal rock types—diorite porphyry and dacite porphyry. Overall, the "birdseye" porphyry bears a strong affinity to the quartz diorite and granodiorite plutonic rocks of the Klamath Mountains and appears to be genetically related to the plutons. In addition to the "birdseye" porphyry, dikes of quartz porphyry are commonly associated with gold lodes in the southeastern part of the region.

The principal lode deposits are veins that occur in the following geologic environments: (1) steeply dipping veins in black carbonaceous shale or slate (Alaska, Black Bear, Brown Bear, Gilta, Gladstone, Hazel, and Klamath deposits are examples); (2) steeply dipping veins in greenstone that underlies shale or slate in much of the region (Golden Eagle, formerly Sheba, deposit); (3) gently dipping veinlike deposits along faulted contacts between shale and greenstone (Fairview, Five Pines, Venecia, and Washington deposits); (4) steeply or gently dipping veins in "birdseye" porphyry dikes or quartz porphyry dikes (Dewey and Headlight deposits); and (5) steeply dipping dikes in schists and miscellaneous rock types (Cummings, formerly Oro Grande, Highland I, Midas, and Trinity Bonanza King deposits).

Several of the five types of deposits may be found within an individual district. Such a district is the French Gulch-Deadwood district, which has yielded at least 800,000 ounces of gold. It contains some of the largest producing mines representing at least three of the five types of deposits. The district lies about 20 miles northwest of Redding in the southern part of the region and is in an eastward-trending highly fractured belt about 9 miles long and a mile wide. It includes the Brown Bear mine at its western end and the Gladstone mine at its eastern end (fig. 5). The rocks are chiefly shaly rocks of the Mississippian Bragdon Formation and the underlying Devonian(?) Copley Greenstone, which delineates an eastward-trending archlike structure just north of the fractured belt (Albers, 1961, p. C1). The contact between the Bragdon and Copley Formations is structurally discordant and is interpreted as a low-angle thrust fault that has been disrupted by later high-angle faulting (Albers, 1964, p. J62).

The Shasta Bally batholith of silicic quartz diorite and granodiorite intrudes the Bragdon and Copley Formations about a mile west of the French Gulch-Deadwood district. In the western part of the district numerous "birdseye" porphyry dikes intrude the Bragdon Formation and locally form sill-like bodies along the contact between the Bragdon and Copley. One group of these dikes is similar in composition to the Shasta Bally batholith, and at least one dike is also similar in texture. Because of the similarity the dikes are regarded as offshoots from the batholith, and a salient of the batholith is inferred to extend in an easterly direction beneath the fractured, intruded, and mineralized belt (Albers, 1961, p. C2). Most fractures trend parallel to the belt and are thought to be at least in part tension fractures formed by the upward push of the magma of the salient. Subsequently, many of the fractures controlled the emplacement of "birdseye" porphyry dikes and quartz veins.

The types of lodes in the French Gulch-Deadwood district include: (1) steeply dipping quartz and quartz-calcite veins in shaly rocks of the Bragdon Formation; (2) gently to moderately dipping quartz and quartz-calcite veins along the thrust contact between the Bragdon and Copley Formations; and (3) veins in the "birdseye" porphyry dikes and sills. In addition, a fourth type of deposit—steeply dipping quartz veins in greenstone—occurs in at least one mine in the district (Washington) but has accounted for very little production.

Most gold has come from the steeply dipping veins in the Bragdon Formation. Workings of the two largest mines—Brown Bear and Gladstone—as well as several other mines, are on such veins, and although some workings are more than 1,000 feet deep they have not penetrated the Copley Greenstone contact. On the other hand, most gold from the intervening Washington mine (fig. 5) has come from lodes along the contact between the Bragdon and Copley Formations. The "birdseye" porphyry dikes and sills that are abundant in the Brown Bear and other mines of the western part of the district are in many places cut by gold-bearing quartz veins. Quartz porphyry dikes and sills —the soda granite porphyry of Ferguson (1914)—are also common in the western part of the district. No "birdseye" porphyry is known in the mines of the eastern part of the district but some quartz porphyry has been reported in the Gladstone mine.

The ore shoots in the steeply dipping veins at the Brown Bear and other mines in the district are commonly at the intersection of veins which have opposing dips or at the intersection of veins with contacts between shale and porphyry. The two principal veins at the Brown Bear mine are essentially parallel in strike but intersect in places because of variable and opposing dips. Subsidiary veins also intersect the main veins. Nearly horizontal ore shoots are thus formed along the line of intersection at two main levels in the mine. In contrast to the highly productive, steeply dipping veins in the Bragdon Formation, similar steep veins in the Copley Greenstone, as in the deeper levels of the Washington mine, are commonly narrow and of poor grade; only at the contact with the shale of the Bragdon are they productive.

Much of the richest gold ore within the Bragdon was reportedly along contacts between the quartz veins and black slickensided graphitic shale, or associated with inclusions of graphitic shale in the vein, suggesting the importance of graphitic material as a precipitating agent for gold. This importance of carbon or graphite as a precipitating agent has been noted by Hershey (1910) and Ferguson (1914, p. 40–43). Ferguson thought that the pocket gold deposits of the Klamath Mountains, found mainly at the contact between the Copley and Bragdon Formations, were of surficial origin, formed as a result of precipitation of gold from surficial waters where these waters first came in contact with graphitic material of the Bragdon. According to this interpretation the gold was taken into solution by surface waters from pyritized zones in greenstone in the presence of manganese oxide. Although this may be a valid hypothesis for the origin of some pockets, it seems to the writer that to be effective the depositional process would require ascending surficial solutions, inasmuch as the shaly rocks overlie the greenstone. A preferred interpretation is that the gold was deposited by rising hydrothermal solutions at and above the contact between greenstone and overlying shaly rocks. By this interpretation the gold in steeply dipping veins within the Bragdon, or in veins cutting "birdseye" porphyry dikes in the Bragdon, represents a residue in solutions that must have come past the more favorable contact between Copley and Bragdon. Therefore the possibility that additional ore will be found at depth in mines such as the Brown Bear and Gladstone that have not penetrated as deep as the Copley Greenstone appears promising.

The mineral composition of veins shows little variation. Quartz is the chief gangue mineral, calcite and mica are present in minor amounts, and locally manganese oxide occurs near the surface. Pyrite, galena, sphalerite, arsenopyrite, and less common chalcopyrite are the sulfides. Gold occurs mainly as free gold but also occurs in the sulfide minerals.

If the inference that the porphyry dike rocks in the western part of the French Gulch-Deadwood district are offshoots from an underlying salient of the Shasta Bally batholith is correct, it appears highly probable that the gold-bearing quartz veins originated from the same magmatic source. The veins are apparently controlled by the same eastward-trending fracture system that controls the dikes, and are at least slightly younger than the dikes. The veins are interpreted as residual fluids rising from the cooling batholith salient along reopened fractures of the same system that had previously given access to the dikes. As the veins traversed the Copley Greenstone little gold was deposited except in small pockets, but where the solutions encountered graphitic material at and above the Copley-Bragdon contact, gold was precipitated, particularly at the intersections of fractures where graphitic material was abundant.

Elsewhere in the Klamath Mountains many of the best gold mines are in a geologic environment grossly similar to that of the French Gulch district. However, a few gold lodes are in schistose rocks, as the Midas (Harrison Gulch) deposit in the extreme southern part of the region, and the Bonanza King deposit in the east-central part (fig. 5). As in the French Gulch-Deadwood district, the principal ore is free gold in quartz or quartz-calcite veins. Tellurides are reported in a few localities.

"Birdseye" porphyry dikes are associated with many but not all the deposits throughout the Klamath Mountains. The importance of the "birdseye" porphyry dikes was recognized by MacDonald (1913, p. 19), who, in discussing the Carrville district of the central Klamath Mountains, advised prospectors to search all contacts of "birdseye" porphyry dikes. The close association between gold lodes and porphyry dikes in so many localities strongly suggests a genetic relationship. It seems equally clear that the "birdseye" porphyry dikes are offshoots from large plutonic bodies as previously described in the French Gulch-Deadwood district. Probably the gold-bearing quartz and quartz-calcite veins came from the same magmatic source and followed very nearly the same fracture systems as the dikes.

The outcrop pattern (fig. 5) suggests that silicic plutonic rocks may lie at relatively shallow depth beneath much of the eastern part of the Klamaths where most of the gold lodes occur. Therefore those lodes that have no associated "birdseye" porphyry dikes may have been derived from plutonic rocks at depth. The only condition necessary for their formation was a fracture system allowing access of mineralizing fluids from the plutonic bodies to the host rocks.

Iron.—Only two iron ore deposits of economic significance are known in the Klamath Mountains province. These are the Shasta and Hirz Mountain deposits along the McCloud River arm of Shasta Lake a few miles north of Redding (fig. 5). Iron ore was produced on a small scale from the Shasta deposit inter-

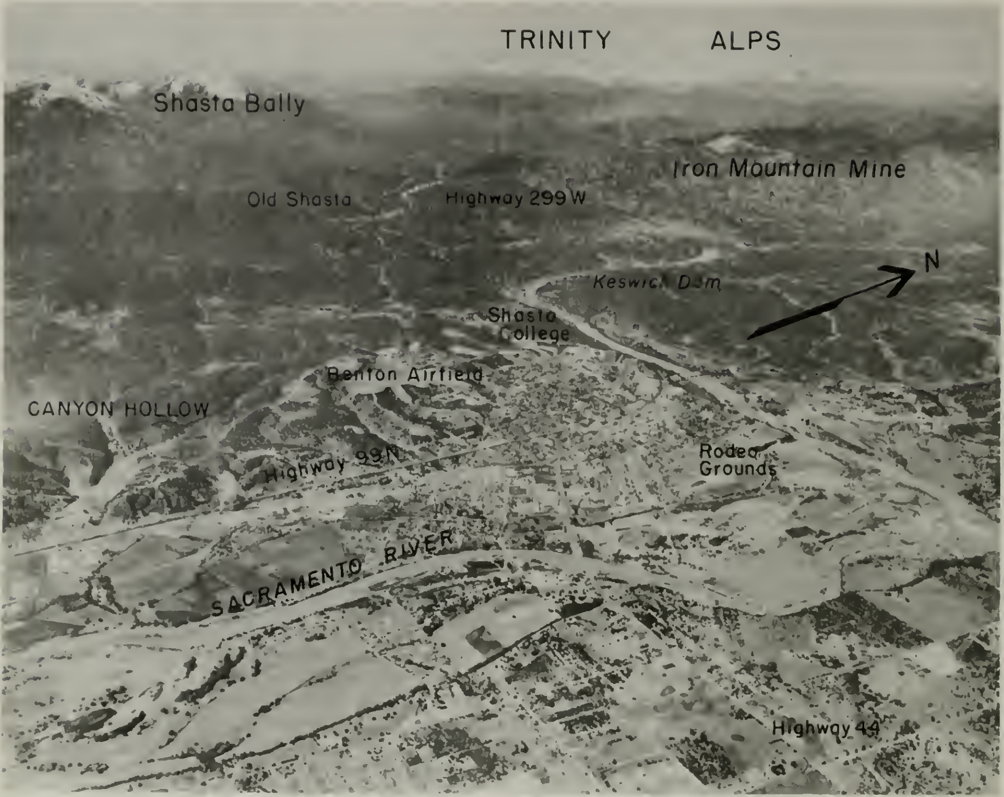


Photo 1. Aerial photo of Redding and the Trinity Alps.

mittently between 1907 and 1926, and several hundred thousand tons were mined during the period 1942–1944 for use as ballast by the U.S. Navy. No production has been realized from the Hirz Mountain deposit. Both deposits are contact metasomatic replacement deposits localized along contacts between the Permian McCloud and Nosoni Formations and an irregular large dikelike body of quartz diorite. The ore occurs as a replacement of the McCloud and Nosoni Formations and also as a replacement of the quartz diorite. It consists chiefly of magnetite accompanied by garnet and epidote. For a more complete description of these deposits the reader may refer to Lamey (1948a, 1948b).

Massive sulfides and replacement veins.—The base metals, particularly copper, and to a much lesser extent zinc and lead, rank with gold as the chief mineral products of the Klamath Mountains (table 1), and well over 90 percent of these base metals have come from massive sulfide deposits of the West Shasta and East Shasta copper-zinc districts in the eastern part of the region. The remaining base-metal production is mainly from the Blue Ledge and Gray Eagle replacement vein deposits near the Oregon border, and the Copper Bluff deposit in the western part of the province.

The first massive sulfide deposits were discovered in the 1860's, and during the early years their oxidized outcrops were worked for precious metal content. Beginning in 1896 and for more than 20 years thereafter, the unoxidized sulfide ore was exploited, and a large mining industry grew up in the area north of Redding. The massive sulfides were direct smelted during most of this period, and copper along with some gold and silver were the only metals recovered. Zinc was successfully recovered from some ores in 1918, and thereafter was an important product of the district. Lead production has been relatively insignificant.

As shown in figure 2, the production of base metals reached a high of $11 million (nearly all from copper) in 1917 and declined sharply to virtually nothing in 1920. During the 1930's about 2.6 million tons of gossan derived from oxidation of massive sulfide at the Iron Mountain deposit (fig. 5) was treated for its gold content, and from 1948 until 1962 the same deposit yielded pyrite from which sulfur was extracted for use in making sulfuric acid. In all, the Iron Mountain mine in the West Shasta district was a continuous producer of mineral products for a period of more than 65 years, and it (as well as the other massive sulfide mines) was of prime importance in the economic development of northern California.

Important deposits in addition to Iron Mountain are the Mammoth, Balaklala, Keystone, Early Bird, Shasta King, and Sutro (fig. 5); these make up the West Shasta copper-zinc district which has yielded the bulk of the production. The Bully Hill-Rising Star and Afterthought mines make up the East Shasta copper-zinc district (fig. 5). Both districts have been studied in detail in recent years by the U.S. Geological Survey (Kinkel, Hall, and Albers, 1956; Albers and Robertson, 1961). The Greenhorn mine is another fairly large massive sulfide deposit that lies a few miles west of the West Shasta district.

The massive sulfide deposits of the West Shasta copper-zinc district lie in a belt about 9 miles long, 1 mile wide and trending N. 25° E. All the deposits are in an altered silicic volcanic rock unit of Devonian age called the Balaklala Rhyolite. The deposits lie at a more or less consistent stratigraphic position within the formation, beneath a layer of pyroclastic rocks in some places, and in other places beneath a coarsely porphyritic facies of rhyolite that is the stratigraphic equivalent of the pyroclastic beds. The massive sulfide bodies are mainly lenses, pods, or cigar-shaped masses. They are in sharp contact with wallrocks which are everywhere altered and more or less pyritized. The length and width of massive sulfide bodies are commonly 2 to 10 times the thickness, and except at the extreme north end of the district the long axes of the sulfide bodies are essentially horizontal. The bodies range in size from a few thousand tons to more than 5 million tons. However, the several discrete bodies mined at Iron Mountain were, before faulting and erosion, a continuous mass about 4,500 feet long and containing perhaps 25 million tons of massive sulfide.

Although the sulfide bodies are everywhere in sharp contact with the wallrocks, the contacts are not frozen. Typically, a thin seam of gouge separates massive sulfide from wallrock. In many localities the evidence is clear that the sulfide has replaced the enclosing host rocks. A fault set striking about N. 70° E. across the N. 25° E. grain of the district is older than the mineralization and probably provided the main feeder channels for the sulfide ore. All the ore bodies are near these faults but not all are adjacent to them. Some ore bodies in the West Shasta district are on or near the axes of folds in the host rock, but there seems to be no preference for anticlines or synclines; in any case not all sulfide bodies show a preference for folds.

The massive sulfide ore is typically 90 to 95 percent sulfide minerals—dominantly pyrite, with lesser amounts of chalcopyrite, sphalerite, quartz, and calcite. The ore has a brassy appearance and is generally structureless. The average grain size is about half a millimeter, but locally it is much coarser. Much of the massive sulfide is essentially pyrite that contains very little chalcopyrite or sphalerite. This low-grade copper ore has been mined at Iron Mountain for its sulfur, but elsewhere in the district it has been treated as waste during mining operations. The low-grade massive pyrite occurs as separate bodies and also as parts of ore bodies that contain copper and zinc values high enough to be mined as base-metal ore. The copper content of ore mined for copper ranged from 2 to 7.5 percent. Zinc content ranged as high as 21.1 percent in parts of the Mammoth mine, but the content of this metal is extremely variable and would probably average well under 5 percent in the base-metal ore mined throughout the district. No lead is present in the West Shasta sulfide ores, but most of the ore contained 0.02 to 0.06 ounce of gold and 1 to 8 ounces of silver per ton.

Kinkel, Hall, and Albers (1956, p. 93), as well as other geologists who have worked in the West Shasta district, believe that the massive sulfide deposits formed by replacement of the Balaklala Rhyolite. Perhaps the most convincing evidence for this is the presence in a few places of relict quartz phenocrysts of the replaced host rock in the massive sulfide ore. Other evidence in the sulfide is local banding, which is probably inherited from foliation in the enveloping host rock. Also, the abundant disseminated pyrite that occurs throughout the district is clearly replacement in origin. The ore controls in summary are: (1) favorable stratigraphic position in the Balaklala Rhyolite; (2) the N. 70° E. trending premineralization feeder faults; and (3) in local areas, secondary foliation in the host rock. The deposits are probably late Jurassic or possibly very early Cretaceous in age.

The source of the solutions that deposited the massive sulfides is unknown. However, the district lies at the north end of a large stock of altered quartz diorite (fig. 5) and only a few miles from the Shasta Bally batholith. Either of these bodies may continue at depth beneath the West Shasta district and either could have supplied the mineralizing fluids. The metallic constituents could have come from the plutonic masses themselves or could have been derived in large part from the Copley Greenstone that lies at depth beneath the mineralized belt. Computations based on spectrographic analyses indicate that the Copley Greenstone and rocks of similar character in the stratigraphic section contain roughly 1 million tons of metallic copper and over 2 million tons of metallic zinc per cubic mile. These rocks are strongly and pervasively altered, and large amounts of material have been added and removed by metasomatic processes. Probably at least 5 to 10 cubic miles of greenstone lie directly beneath the West Shasta district; only a small percentage of their copper and zinc need to have migrated from the greenstone and been concentrated in the sulfide deposits to account for the 340,000 tons of copper and 30,000 tons of zinc that the ore bodies have yielded.

The speculations in the preceding paragraph apply if—as the available evidence seems to indicate—the deposits are strictly epigenetic. However, the evidence for epigenetic origin is not conclusive, and the idea that massive sulfide deposits of this type may be syngenetic is gaining favor among some geologists. It is possible that the sulfides were precipitated in a submarine environment in stagnant waters heavily laden with metallic exhalations from a nearby volcanic source. Such a syngenetic origin, however, would seem to require some redistribution of the sulfides during a subsequent orogeny to account for the epigenetic relationships observed.

The massive sulfide deposits in the East Shasta copper-zinc district are much smaller than those in the West Shasta district and have yielded only about 15 percent as much base metal—about 30,000 tons of copper and 25,000 tons of zinc. The assay of mined ore averages about 15 to 20 percent zinc, 3 percent copper, 0 to 2 percent lead, 5 ounces silver, and 0.03 ounce gold per ton. The deposits occur as lenses that replace two rock units of Triassic age—an altered silicic volcanic rock unit called the Bully Hill Rhyolite, and the Pit Formation consisting of shale and tuff. Most of the sulfide lenses are tabular and steeply inclined. A few are cigar shaped. They range in size from a few inches to as much as 400 feet in greatest dimension. The largest lenses have a maximum thickness of 35 to 40 feet. Most lenses are clearly controlled by shear zones, and they lie generally parallel to schistosity or bedding in the host rocks. Their walls are either frozen to the country rock or are separated from it by a layer of clayey gouge. The walls of most sulfide lenses are sharp and smooth, but the edges, in contrast, are commonly irregular. Some lenses taper to a knife edge. Others pinch out in many thin layers or sheets extending a few inches to a few feet into the host rock. Much of the sulfide ore is banded, and in places near the edges of lenses the banding parallels bedding or schistosity in the host rock. Both the banding and the presence of structurally oriented horsts of country rock enclosed in sulfide lenses are convincing evidence of a replacement origin for the sulfide.

Much of the sulfide ore is fine grained; it consists of intimate mixtures of pyrite, sphalerite, chalcopyrite, galena, and tetrahedrite-tennantite. Quartz, barite, calcite, anhydrite, and gypsum are the principal gangue minerals. In general the proportion of gangue minerals to sulfides is appreciably higher than in the West Shasta deposits, and the proportion of pyrite to other sulfide is much lower. The problem of the origin of mineralizing solutions and the source of the base metals is essentially the same as in the West Shasta district. The closest plutonic rock outcrops are two small stocks of altered quartz diorite about 5 miles away on either side of the deposits, but possibly these stocks are merely eminences rising from a subjacent mass concealed at a depth of a few thousand feet beneath the deposits.

The occurrence of massive sulfide deposits in formations of vastly different age (Devonian and Triassic) within the restricted area of the West and East Shasta copper-zinc districts is additional strong evidence favoring an epigenetic origin for both the West and East Shasta deposits. It is highly improbable that identical conditions conducive to the formation of syngenetic massive sulfides had been repeated in an area with such an active tectonic and depositional history.

The Blue Ledge mine, near the California-Oregon border (fig. 5), has yielded about 11,151 tons of ore containing 12.12 percent copper, 0.092 ounce of gold, and 5.24 ounces of silver per ton (Hundhausen, 1947, p. 5). Most of the production was during World War I. The deposit is a replacement vein that dips about 60° W. in quartz-muscovite schist. Although the deposit consists of fairly massive sulfide (pyrite, pyrrhotite, chalcopyrite, and sphalerite), it is not strictly the massive sulfide type of deposit because of its veinlike form. The vein is 1,300 feet long, 5 feet thick, and has been followed to a depth of 350 feet.

A second deposit with production of some significance in the northern part of the area is the Gray Eagle mine (fig. 5). According to Brown (1916, p. 818), this deposit is a vein 10 to 80 feet thick that strikes northwest and dips 45° northeast. An ore shoot over 300 feet long consists of chalcopyrite and pyrite. The ore carries from 2.5 to 18 percent copper and $1.50 per ton in gold. The surface outcrop is marked by a gossan.

The Copper Bluff deposit in the western Klamaths (fig. 5) is a bedded replacement deposit in chlorite schist beneath a black carbonaceous phyllite (H. K. Stager, written communication, 1959). The ore has an average thickness of 5 feet. During the 1950's about 10,000 tons of ore milled had an average gross value of $6.50 per ton. Silicic plutonic rocks crop out no closer than 4 or 5 miles from any of the three deposits mentioned above. Hence there may or may not be a genetic relation between these deposits and the emplacement of plutonic rocks.

Silver.—About $13 million worth of silver has been recovered from ore mined in the Klamath Mountains. Most of this ore was produced from the massive sulfide deposits in the West and East Shasta copper-zinc districts.

The only silver mine of any consequence is the Silver Falls-Consolidated mine about 12 miles southwest of Redding (fig. 5). This mine was discovered about 1866, and most of its production was achieved prior to 1900. Veins striking N. 45° E. to N. 60° E. are from 10 inches to 2 feet wide and dip steeply. The veins are in quartz diorite of the Shasta Bally batholith. According to Tucker (1923, p. 313) the silver-bearing mineral is tetrahedrite, associated with galena, pyrite, sphalerite, chalcopyrite, and gold. A few other silver-bearing veins near the Silver Falls-Consolidated deposit are also known.

All are along fractures in the Shasta Bally batholith and are inferred to be genetically related to the batholith.

DEPOSITS INFERRED TO BE ASSOCIATED WITH LATE VOLCANIC ACTIVITY

Quicksilver.—Occurrences of quicksilver are found at several widely scattered localities in the Klamath Mountains, but the only deposit having significant production is the Altoona mine in the east-central part of the area (fig. 4). This deposit, discovered in 1871, has a recorded production of about 34,000 flasks, mostly recovered prior to 1900, and significant reserves of good grade ore reportedly still remain. The geology of the deposit has been reported on by Swinney (1950). More recently the deposit was explored under a Defense Minerals Exploration Administration contract, and much of the material below is taken from H. K. Stager (written communication, 1958), who studied the geology in connection with the exploration work.

The ore bodies are along steeply dipping shear zones up to 30 feet wide that cut altered porphyritic diorite and serpentinized peridotite. The ore bodies are found only in diorite. They are tabular lenses that average 5 feet thick and are as much as 270 feet long and extend down dip as much as 300 feet. The diorite host is intensely altered and replaced by quartz and carbonates. The resulting rock resembles the silica-carbonate rock of Coast Range quicksilver deposits. Ore minerals are cinnabar and native mercury. The cinnabar is in small crystals disseminated in the sheared and altered diorite and as veinlets and fracture coatings. Native mercury is common in vugs and cinnabar-lined cavities in the rock, and some vugs have yielded as much as several pounds of native mercury. Gangue minerals are ankerite, pyrite, barite, quartz, and clay minerals. The two main types of ore are an altered diorite type and a carbonate type. Although both types may be found in the same shear zone, most of the production has come from the diorite type.

Of the several other localities in the Klamath Mountains where quicksilver is known to occur (see Irwin, 1960, p. 72) one of the most promising is the Webb deposit in the extreme northwestern part of the area. According to Cater and Wells (1953) this deposit is on a shear zone in serpentinized saxonite intruded by small irregular bodies of diorite and by felsite dikes. Production has been very small.

The age and genesis of quicksilver deposits in the Klamath Mountains cannot be directly determined from the observed relations. The quicksilver deposits in the California Coast Ranges to the west and south are generally regarded as post-Miocene in age and are genetically related to late Tertiary or Quaternary volcanism. However, there are no known volcanic centers near the Klamath Mountains deposits.

DEPOSITS CONCENTRATED BY SEDIMENTARY PROCESSES

The mineral commodities genetically associated with sedimentary processes include placer gold and platinum, building materials, and manganese. Placer gold, important historically, has been discussed earlier; platinum was produced from placer deposits intermittently. Stone and sand and gravel are important economic commodities, as shown by figure 3, but the occurrence of mineable deposits will not be discussed here as it depends more on economic factors than on geologic relations.

Manganese.—Although numerous occurrences of manganese are known in the area, production has been negligible. A small production has come mostly from the Shasta Copper mine (fig. 5) where about 1,000 tons of ore containing 27 percent manganese was produced. Most of the deposits are associated with bedded chert in greenstone or schist. The primary manganese mineral is the silicate rhodonite, which cannot under present technologic conditions be utilized as ore, and which oxidizes slowly, yielding only small shallow pockets of manganese oxide. The individual manganese deposits are described by Trask and others (1950).

REFERENCES

Albers, J. P., 1961, Gold deposits in the French Gulch-Deadwood district, Shasta and Trinity Counties, California: U.S. Geol. Survey Prof. Paper 424-C, art. 147, p. C1–C4.

—— 1964, Geology of the French Gulch quadrangle, Shasta and Trinity Counties, California: U.S. Geol. Survey Bull. 1141-J, p. J1–J70.

—— 196__, Economic geology of the French Gulch quadrangle: California Div. Mines and Geology Spec. Rept. (In press)

Albers, J. P., and Robertson, J. F., 1961, Geology and ore deposits of east Shasta copper-zinc district, Shasta County, California: U.S. Geol. Survey Prof. Paper 338, 107 p.

Allen, J. E., 1941, Geologic investigation of the chromite deposits of California: California Jour. Mines and Geology, v. 37, no. 1, p. 101–167.

Averill, C. V., 1931, Preliminary report on economic geology of the Shasta quadrangle: California Div. Mines, 27th Rept. State Mineralogist, no. 1, p. 2–65.

—— 1933, Gold deposits of the Redding and Weaverville quadrangles [California]: California Jour. Mines and Geology, v. 29, nos. 1, 2, p. 2–73.

—— 1935, Mines and mineral resources of Siskiyou County [California]: California Jour. Mines and Geology, v. 31, no. 3, p. 255–338.

—— 1941, Mineral resources of Trinity County: California Jour. Mines and Geology, v. 37, no. 1, p. 8–90.

Brown, G. C., 1916, The counties of Shasta, Siskiyou, Trinity: California Mining Bur., 14th Rept. State Mineralogist (1913–1914), pt. 6, p. 745–925.

Cater, F. W., Jr., and Wells, F. G., 1953, Geology and mineral resources of the Gasquet quadrangle, California-Oregon: U.S. Geol. Survey Bull. 995-C, p. 79–133.

Ferguson, H. G., 1914, Gold lodes of the Weaverville quadrangle, California: U.S. Geol. Survey Bull. 540-A, p. 22–79.

Hershey, O. H., 1910, Origin of gold "pockets" in northern California: Mining and Sci. Press, v. 101, p. 741–742.

Hotz, P. E., 1964, Nickeliferous laterites in southwestern Oregon and northwestern California: Econ. Geology, v. 59, no. 3, p. 355–396.

Hundhausen, R. J., 1947, Blue Ledge copper-zinc mine, Siskiyou County, California: U.S. Bur. Mines Rept. Inv. 4124, 16 p.

Irwin, W. P., 1960, Geologic reconnaissance of the northern Coast Ranges and Klamath Mountains, California, with a summary of the mineral resources: California Div. Mines Bull. 179, 80 p.

—— 1964, Late Mesozoic orogenies in the ultramafic belts of northwestern California and southwestern Oregon: U.S. Geol. Survey Prof. Paper 501-C, p. C1–C9.

Kinkel, A. R., Jr., Hall, W. E., and Albers, J. P., 1956, Geology and base-metal deposits of the West Shasta copper-zinc district, Shasta County, California: U.S. Geol. Survey Prof. Paper 285, 156 p.

Lamey, C. A., 1948a, Hirz Mountain iron-ore deposits, Shasta County, California: California Div. Mines Bull. 129, p. 129–136.

—— 1948b, Shasta and California iron-ore deposits, Shasta County, California: California Div. Mines Bull. 129, p. 137–164.

MacDonald, D. F., 1913, Notes on the gold lodes of the Carrville district, Trinity County, California: U.S. Geol. Survey Bull. 530, p. 9–41.

Rice, S. J., 1957, Asbestos, in Wright, L. A., ed., Mineral commodities of California: California Div. Mines Bull. 176, p. 49–58.

Swinney, C. M., 1950, The Altoona quicksilver mine, Trinity County, California: California Jour. Mines and Geology, v. 46, no. 3, p. 395–404.

Trask, P. D., and others, 1950, Geologic description of the manganese deposits of California: California Div. Mines Bull. 152, 378 p.

Tucker, W. B., 1923, Silver lodes of the South Fork mining district, Shasta County: California Mining Bur., 18th Rept. State Mineralogist, pt. 7, p. 313–321.

Wells, F. G., and Cater, F. W., Jr., 1950, Chromite deposits of Siskiyou County, California: California Div. Mines Bull. 134, pt. 1, chap. 2, p. 77–127.

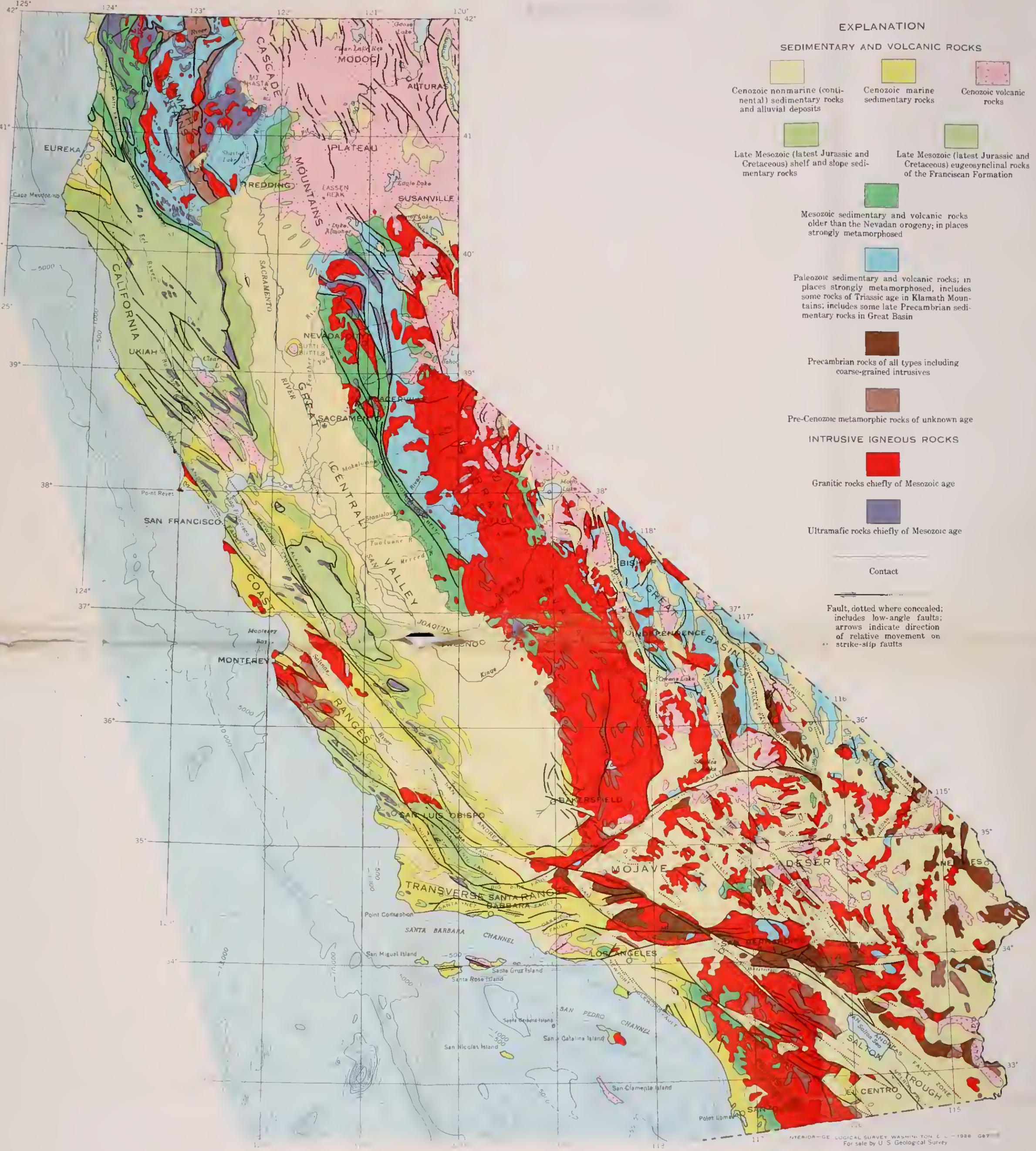
Wells, F. G., Cater, F. W., Jr., and Rynearson, G. A., 1946, Chromite deposits of Del Norte County, California: California Div. Mines Bull. 134, pt. 1, chap. 1, p. 1–76.

Wells, F. G., Smith, C T., Rynearson, G. A., and Livermore, J. S., 1949, Chromite deposits near Seiad and McGuffy Creeks, Siskiyou County, California: U.S. Geol. Survey Bull. 948-B, p. 19–62.

Photo 2. Castle Crags, Shasta County.

DEPARTMENT OF INTERIOR
UNITED STATES GEOLOGICAL SURVEY

MISCELLANEOUS GEOLOGICAL INVESTIGATIONS
MAP I-512



EXPLANATION

SEDIMENTARY AND VOLCANIC ROCKS

- 🟨 Cenozoic nonmarine (continental) sedimentary rocks and alluvial deposits
- 🟨 Cenozoic marine sedimentary rocks
- ▨ Cenozoic volcanic rocks
- 🟩 Late Mesozoic (latest Jurassic and Cretaceous) shelf and slope sedimentary rocks
- 🟩 Late Mesozoic (latest Jurassic and Cretaceous) eugeosynclinal rocks of the Franciscan Formation
- 🟩 Mesozoic sedimentary and volcanic rocks older than the Nevadan orogeny; in places strongly metamorphosed
- 🟦 Paleozoic sedimentary and volcanic rocks; in places strongly metamorphosed, includes some rocks of Triassic age in Klamath Mountains; includes some late Precambrian sedimentary rocks in Great Basin
- 🟫 Precambrian rocks of all types including coarse-grained intrusives
- 🟫 Pre-Cenozoic metamorphic rocks of unknown age

INTRUSIVE IGNEOUS ROCKS

- 🟥 Granitic rocks chiefly of Mesozoic age
- 🟪 Ultramafic rocks chiefly of Mesozoic age

Contact

Fault, dotted where concealed; includes low-angle faults; arrows indicate direction of relative movement on strike-slip faults

INTERIOR—GEOLOGICAL SURVEY WASHINGTON D C —1966 G67
For sale by U S Geological Survey

GEOLOGIC MAP OF CALIFORNIA

COMPILED BY U.S. GEOLOGICAL SURVEY
AND CALIFORNIA DIVISION OF MINES AND GEOLOGY

SCALE 1 2 500 000
0 50 100 MILES
SUBMARINE CONTOUR INTERVALS 500 AND 1000 FEET DATUM IS SEA LEVEL

1966