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CHROMITE DEPOSITS OF THE PILLIKEN AREA ELDORADO COUNTY, CALIFORNIA

BY

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CHROMITE DEPOSITS OF THE PILLIKEN AREA,

ELDORADO COUNTY, CALIFORNIA

By F. G. Wells, L. R. Page, and H. L. James

ABSTRACT

The Pilliken chromite area, which is in Eldorado County, Calif., near the western edge of the foothills of the Sierra Nevada, has yielded more than 10,000 tons of lump ore and concentrates. The chromite deposits are in an elongate sill-like body of ultrabasic rocks, 0.7 mile wide and 4 miles long, which trends a few degrees west of north and dips steeply east. This ultrabasic mass has been intruded into amphibolite schists and is cut off by a granodiorite stock on the northwest.

The sill-like mass is irregularly layered. The western, or lower, part consists mainly of dunite--olivine rock--alternating with pyroxenite; the eastern part consists mainly of lherzolite--an olivine-pyroxene rock--but includes small areas of dunite. These rocks have been cut by two kinds of dioritic dikes and by faults. The dunite and lherzolite have in places been altered to serpentine, talc, magnesite, or jasperoid. The chromite ore is all in dunite. In places the grains of chromite are disseminated, elsewhere they are clustered or are concentrated in layers. Some layers of nearly pure chromite are as much as 2 or 3 feet thick. Although mining in the past has been confined mainly to these layers of high-grade ore, the future of the area depends on blocking out large tonnages of milling ore. The chromite-bearing dunite, except that which has been altered to jasperoid, is easily crushed.

The chromite contains from 30 to 50 percent of chromic oxide, so that the richest obtainable concentrates can hardly contain more than 45 percent of Cr_2O_3. Some rough estimates of reserves, in terms of chromite content, which is from two to three times the chromic-oxide content, are as follows: Reserves of milling ore, containing over 20 percent of chromite, are estimated to be at least 550,000 tons. This includes possibly 10,000 tons containing over 50 percent of chromite, and 540,000 tons of 20 to 50 percent. In addition there may be 4,120,000 tons of 10 to 20 percent. A very large tonnage of rock containing less than 10 percent chromite is also available, but is not likely to be successfully mined and milled by methods now in use.

INTRODUCTION

The Pilliken property of the United States Chrome Mines, Inc., is in the Salmon Falls mining district, in secs. 21 and 22, T. 11 N., R. 8 E., western Eldorado County, Calif. Auburn, 12 miles to the north, is on the main line of the Southern Pacific Co. and on U. S. Highway 40; Folsom, 9½ miles to the south, is on the Sacramento & Placerville Railroad and U. S. Highway 50. The Auburn-Folsom road, which is oiled but narrow and circuitous, passes through the property.

The property lies between the North and South Forks of the American River, in the low western foothills of the Sierra Nevada. The rough hilly topography has a maximum relief of about 900 feet, and the highest hilltops are about 1,450 feet above sea level. Thickets of manzanita, scrub oak, and chamisal, which in places are very dense, cover the hills. The climate is mild and semiarid.

Geologic study of an area that includes the Pilliken property was begun in late October and continued until late in November 1939. The field party consisted of F. G. Wells, in charge, L. R. Page, H. L. James, Robert Yates, W. M. Furnish, and Martin Koenig; Page and James prepared a preliminary description of the area, which has been utilized in preparing this report.

The area was mapped mainly by plane-table methods. A triangulation net was first prepared for the map forming plate 66, and some plane-table traverses were run. Details of topography and geology on this map and the other maps were plotted by stadia methods.

This occasion is taken to thank the personnel of the U. S. Chrome Mines, Inc., and the Rustless Mining Corporation for their unfailing cooperation and courtesy. Mr. George Beers, engineer in charge of U. S. Chrome Mines, Inc., and Mr. H. L.

Byrom, who took charge of the property in November 1939, were especially helpful. Mr. F. C. Calkins, of the Geological Survey, contributed friendly and helpful criticism during the preparation of this report.

HISTORY AND PRODUCTION

Attention was first called to the chromite deposits between the North and Middle Forks of the American River in 1853.[1/] Lindgren reported [2/] in 1892 that a few pockets of chromite had been worked in Flagstaff Hill, but not until the first World War were prices high enough for profitable mining of this chromite. The Pilliken property, owned by George Pilliken, was then leased to the Noble Electric Steel Co. and was operated by them from 1915 to 1918. The collapse of the market in 1918 brought mining to an end, and the property remained inactive until 1936, when it was acquired by the U. S. Chrome Mines, Inc. This company, which had acquired title to 3,000 acres, has built a 200-ton concentrating plant and has been mining since 1937. The production from the property is tabulated below.

Production of Pilliken mine

Year	Type of ore	Ore shipped (tons)	Grade (percent of Cr_2O_3)
1917	Shippers ore..........................	3,398	43
1918	....do................................	3,624	--
(1/)			
1937	Concentrates..........................	464	50
1938	....do................................	759	49
1939	....do................................	3,036	45-48

1/ No production 1919-36.

1/ Ann. Rept. State Mineralogist No. 4, California Min. Bur., p. 136, 1883-1884.

2/ Lindgren, Waldemar, and Turner, H. W., U. S. Geol. Survey Geol. Atlas, Placerville, Sacramento, and Jackson folio reprints (nos. 3, 5, and 11), p. 4, 1894, reprinted 1914.

GEOLOGY

The main features of the geology of this region have been described in the Sacramento folio.[3/]

The Pilliken deposits occur in a tabular, steeply dipping body of ultrabasic rock, commonly called serpentine, shown in the Sacramento folio as lying west of Salmon Falls. The mass is three-quarters of a mile wide and 4 miles long, trends north-northwestward, and dips steeply to the east. The serpentine is surrounded by hornblende and chlorite schists, described in the Sacramento folio as amphibolite schist, except at the northwest end, where it is cut off by a large mass of granodiorite. The serpentine mass is cut by two groups of diorite dikes.

The rocks collectively called serpentine consist of several varieties of ultrabasic rocks and their alteration products. The types recognized and mapped in the Pilliken area are dunite, lherzolite, pyroxenite, and metadiorite. Their most abundant and pervasive alteration product is the mineral serpentine, but especially intense alteration has changed them locally to mappable masses consisting mainly of silica, talc, or magnesite.

Metamorphic rocks

The map (pl. 66) shows two separate areas of metamorphic rocks along the western contact of the ultrabasic intrusives, but further mapping probably would show that these were parts of a single area. The schists on the eastern contact of the mass were observed at only two places but are apparently continuous for some distance to the north and south.

The most abundant of the metamorphic rocks consist mainly of hornblende and feldspar and are medium- to coarse-grained, with either a schistose or a gneissic structure. The horn-

3/ Lindgren, Waldemar, and Turner, H. W., op. cit., pp. 3-5.

blende and feldspar form spindle-shape aggregates arranged in distinct lines that pitch directly down the dip of the foliation. These hornblende rocks appear to have been originally andesitic or dioritic in character; they may be intrusive but are more probably effusive in origin.

Interlayered with these coarse-grained schists and gneisses are finer-grained chlorite schists with metacrysts of amphibole or, more rarely, of pyroxene. Black, fine-grained hornblende schist, with lenticular epidote patches, is present in subordinate amounts.

This assemblage of regionally metamorphosed rocks has also undergone contact metamorphism at its contacts with both granodiorite and the ultrabasic rocks. The contacts of the metamorphic rocks with dunite, pyroxenite, and lherzolite are intricate in detail. In places there is a zone of variable width in which innumerable thin sheets of the ultrabasic rocks have been injected along the foliation planes of schist and gneiss. In immediate contact with dunite and pyroxenite a zone from 5 to 25 feet wide of chlorite-epidote schists and gneisses, locally containing metacrysts of pyroxene, has been formed by alteration of the hornblende-feldspar schists and gneisses. At the dunite contact west of the northernmost group of chromite workings is a garnet-chlorite rock containing over 80 percent of red-brown garnet.

Igneous rocks

Dunite

The largest bodies of dunite are in the western part of the peridotite mass, but many thin layers and small irregular bodies of dunite are found elsewhere. The contacts of dunite with other rocks, including siliceous masses probably derived in part from dunite, are very intricate. Gradations between dunite and pyroxenite add to the difficulty of mapping the contacts, and although the lherzolite shades toward dunite in many places, only a few areas of rock are rich enough in olivine to be mapped as dunite.

The dunite has been so generally altered that little if any of it is entirely fresh. Its alterations include (1) serpentinization, (2) silicification, (3) alteration to talc schist, (4) alteration to siliceous platy schist, and (5) replacement by magnesite.

Fresh dunite consists almost entirely of olivine, a mineral of characteristic olivine-green color; but the freshest observed in this district is slightly serpentinized, and is dark yellowish green, with a glassy to greasy luster on fresh fracture and a buff to brown color where weathered. It is granular and fine- to medium-grained. Almost everywhere at least a few subhedral to euhedral grains of chromite are scattered through it. With increasing serpentinization the rock becomes lighter-colored, and in some places it is yellow or even white. Narrow veinlets of greenish- or brownish-yellow serpentine have pervaded the entire ultrabasic mass, cutting across both the dunite and the associated chromite.

Chromite is an original accessory constituent of the dunite and is visible in almost every outcrop of the rock. Nearly all of the dunite is estimated to contain 1 percent or more of chromite, about half of it contains 2 to 5 percent, and perhaps a quarter of it 5 to 10 percent. These are mere visual estimates, not checked by assays, and such estimates, for low-grade ore especially, may be very erroneous.

The dunite grades, by increase of pyroxene content, into lherzolite and pyroxenite. Rock containing less than about 5 percent of pyroxene is classed as dunite, but very little of the rock mapped as dunite contains any pyroxene or any recognizable alteration products of pyroxene.

Lherzolite

The eastern two-thirds of the area mapped is underlain by more or less altered rocks that are provisionally called lherzolite; small patches of the same rocks occur in the southern part of the area.

Lherzolite, by definition, is a granular rock composed chiefly of olivine and containing both orthorhombic and monoclinic pyroxene as essential constituents. Before it was altered, the rock in the Pilliken area that is here called lherzolite consisted mainly of olivine, with which a smaller proportion of pyroxene was associated. The nature of the pyroxene is in most places uncertain, because most of it has been completely replaced; but both the orthopyroxene, enstatite, and the clinopyroxene, diallage, have been found here and there, either separately or together. Some of the olivine-pyroxene rock, therefore, is almost certainly lherzolite, and this name seems to be the most suitable, if only one name is to be used, to apply to all of this rock. It is possible, however, and even probable, that some saxonite--olivine-enstatite rock--is present in the areas mapped as lherzolite. In hand specimen the freshest lherzolite resembles fresh dunite, and the color of the rock is not much altered by weathering. It is distinguished in weathered ledges by the presence of rectangular crystals of pyroxene, which have been altered to a white or pale-green silky mineral. The olivine in the lherzolite, like that in the dunite, is more or less altered to serpentine.

Most of the alteration of the lherzolite has produced talc as well as serpentine. The talc-bearing rocks are of two fairly distinct types, though these are not distinguished on the map. One is a schistose, silicified, talcose serpentine, weathering into platy pinnacles, which occurs in the southeastern part of the lherzolite area. In this rock the pyroxene crystals characteristic of lherzolite are still recognizable, although they have been completely altered and much distorted. The second type includes talc schist and massive talc rocks.

Some of the lherzolite has been so thoroughly silicified as to form jasperoid masses that are large enough to be shown on the maps. In some of this rock the texture is completely destroyed, although some distorted and altered pyroxene crystals are recognizable as whitish patches, elongated parallel to shear zones, in a brown, fine-grained groundmass.

Very little high-grade chromite was noted in the lherzolite itself, but some is found in narrow dunite bands in the gradational zones. The northeastern part of the open pit east of the shaft in East Basin is in a rock that appears, strictly speaking, to be lherzolite, and it was mapped as such on the large map, although it is very close to dunite in composition. The rock in general contains about 5 percent of pyroxene; but it contains a streak of rather high grade disseminated chromite (apparently over 20 percent), which probably extends for some distance to the north and south.

Pyroxenite

Most of the pyroxenite occurs in the southwestern part of the area mapped, as small irregular masses associated with dunite and silicified rocks. The largest single body crops out around the common corner of sections 20, 21, 28, and 29, in a roughly oval area, which lies between two bands of metamorphic rocks but is separated from them on the west by a thin band of dunite. A small patch of dunite was noted, also, on the southeast side.

Two small patches of pyroxenite occur in the northern part of the mapped area, both of them near areas rich in chromite. Southeast of the large mass and north of the northeast-southwest fault are several patches of pyroxenite, which appear to have been parts of north-trending bands until they were separated by the formation of jasperoid and silicified zones. South of the fault a rather large area of pyroxenite appears to trend northeast-southwest, parallel to the pyroxenite bands in the nearby gradational zone. The boundaries of this mass are so irregular and angular as to suggest that its present shape and position resulted from shearing and faulting. This mass is unique in its rather broad border of lherzolite in which bands of pyroxenite as much as a foot or more in width are common.

The pyroxenite is a coarse-grained dark-gray to greenish-black rock consisting almost entirely of diallage. It is locally altered by shearing to a green talcose chlorite schist. Where zones of silicification cross the pyroxenite, it is altered to a dark-brown jasperoid, which contains very little or no chromite.

In texture and other features the pyroxenite is rather uniform. The average grain size is about half an inch, although there are some isolated patches of pyroxene crystals as much as an inch in diameter. In two places near the north end of the area mapped are pegmatitic rocks that are more than half pyroxene; they contain 2-inch pyroxene crystals in an apparently feldspathic groundmass.

In weathering, the pyroxenite loses its greenish color and becomes gray to black; it is slightly iron-stained in places. Being more resistant to weathering than most of the other rocks in the area, it is commonly well exposed and forms several hills. The soil derived from the pyroxenite supports a characteristic thick growth of chamisal.

Dike rocks

Two kinds of dikes have been noted in the area. The most prominent and numerous are narrow masses of dark-green talc-chlorite schist, trending a few degrees east of north, which cut the dunite but are mostly in the lherzolite and pyroxenite. In the interior of some of these dikes the schist grades into a nonschistose greenish, massive metadiorite. At the contacts of some of them with ultrabasic rocks are zones of cross-fibered asbestos, outside of which are usually narrow silicified zones. The schistose structure of the dikes is probably due to shearing along the walls, the movement being localized where resistance was least. The dikes of the second type, in striking contrast to those of the first, are almost unaltered. They have in general a more westerly trend than the schistose dikes and apparently cut them, though no direct evidence of this relation was found. These dikes, like the others, are dioritic, but some of them appear to be of quartz diorite, a variety not noted in the other group. They are fine- to medium-grained and dark gray to black. Their feldspar phenocrysts, which are as much as half an inch in diameter, are sparingly distributed in a groundmass of hornblende and felsic minerals.

Granodiorite

On the northwest edge of the area the metamorphic and ultrabasic rocks are invaded by a gray medium-grained granodiorite. Near the contact the granodiorite has an obscure gneissic structure. The hornblende content of the rock ranges from 5 to 40 percent in places. Quartz can readily be distinguished in hand specimen. A typical specimen contains about 45 percent of andesine (near An_{35}), 20 percent of quartz, 10 percent of orthoclase, 10 percent each of green hornblende and brown biotite, and accessory titanite, magnetite, apatite, and zircon.

The average grain size is about 1 or 2 millimeters, although some plagioclase crystals are as much as 4 millimeters long.

This granodiorite is probably an outlier of the main Sierra Nevada batholith. Its boundary cuts across the regional trend of the schistosity, which is N. 35° W. It is clearly of later age than the schists and the ultrabasic rocks.

Hydrothermal alteration

Chief products.--The peridotites--both dunite and lherzolite--have everywhere been altered slightly, and in large areas completely replaced, by hydrothermal agencies. The pyroxenites, on the contrary, are little altered. Four types of alteration, listed in order of their extent, have been recognized: (1) serpentinization, (2) silicification, (3) the formation of talc, and (4) the formation of magnesite. Alteration, especially to talc, has been most intense along shear zones. Serpentinization probably took place during the late magmatic stage of the early igneous cycle. Talc and magnesite probably were formed a little later, and their formation was controlled by structural features. Magnesite apparently was formed only in dunite. Silicification was probably caused by hydrothermal solutions released from the granodiorite magma as it cooled.

Serpentinization.--Serpentinization is so general in the peridotites that practically none of the dunite or lherzolite is wholly free from serpentine. Olivine is the mineral chiefly affected; pyroxene is not attacked until the olivine has been largely replaced. The original character of the rock may often be apparent even after serpentinization has been complete; for olivine alters to aggregates of flakes and fibers in random orientation, which are dark green and lusterless, whereas the pyroxenes alter to pseudomorphs consisting largely of parallel fibers, the luster of which readily catches the eye. Where movement along fractures has occurred, and in schists, the serpentine fibers throughout the rock tend to lie parallel to the fractures or the foliation; but the serpentine fibers in veinlets that fill tension cracks lie at right angles to the walls.

Silicification.--Silicified zones are highly characteristic of the area and are of economic interest because the silicified rock is difficult to crush. Nearly all of the silicified zones are in ultrabasic rock, only one or two poorly developed narrow ones having been observed in the metamorphic rocks. One interesting detail that may help to explain their distribution is this: The fissure of the northeast-southwest fault in section 28 contains a four-foot vein of milky quartz where its footwall is of schist, but it is followed only by a zone of silicified dunite and talc schist where both its walls are of ultrabasic rocks. It seems probable, therefore, that the incompetent ultrabasic rocks were unable to hold large spaces open, so that the silica deposited in them took the form of fine-grained cherty masses rather than vein quartz.

The silicified zones in ultrabasic rocks have several definite trends. The more pronounced trend about N. 10° W. and N. 60° E.; others less well developed are N. 45° E. and N. 10° E. Maximum silicification took place at the intersections of shear zones. Several zones intersect in most of the silicified areas, and it is probably for this reason that the areas are somewhat irregular. It was impossible to show on the map all the shear zones and faults that controlled silicification. The ragged outline of some silicified areas indicate the main directions of shearing but not the minor trends.

The silicified rocks grade from slightly silicified dunite, lherzolite, or pyroxenite to jasper. The jasper is a dense, fine-grained, usually brownish rock that breaks with a smooth conchoidal fracture. It is strongly resistant to weathering and commonly forms jagged outcrops. Less silicified rock weathers to a rough cellular mass. Because the boundaries of the silicified masses are indefinite they are represented on the map by dotted lines.

Some of the differences in the silicified rocks are due to differences in the original rocks. The jasper that is especially rich in iron seems to have been derived from pyroxenite. In dunite that has been moderately silicified, the chromite retains its original distribution, whether disseminated or banded, although the bands are much faulted and strung out along shear planes. Such rock has been thoroughly prospected because it crops out prominently, but little of it could be profitably mined, in view of the high cost of extracting the chromite from such refractory material. It might be profitable, however, to mine some high-grade zones in jasper by underground methods.

Talc schist.--Some of the talc schist probably was derived from dunite, some from lherzolite, and some from pyroxenite. The rock is especially abundant in and around the main mass of lherzolite, but that derived from lherzolite and that derived from dunite are almost indistinguishable. Except where silicified, the talc schist is white to gray and very soft. Pits and other workings have been dug in chromite-rich portions of the talcose zones, and their distribution suggests that the chromite-bearing talc schist was derived from dunite. Some of it, in fact, contains recognizable remnants of dunite.

The cleavage in the talc zones is apparently a shear cleavage developed over a large area. Talc schist has been formed along the great fault in section 28 where both walls are of ultrabasic rocks.

Magnesite.--Creamy-white fine-grained compact magnesite forms veins, and irregular masses of it have replaced dunite, especially that which is highly fractured and rich in chromite.

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It is associated with veins of chalcedony and opal. The magnesite veins are best exposed in the open-pit workings of West Basin. Two of the veins here are about 3 feet thick and are laminated. In the shaft area magnesite replaces dunite but not the serpentine veinlets and chromite within it.

Sequence of alterations.--Serpentinization was probably the earliest of the alteration processes. The replacement of dunite by magnesite may be a result of the leaching of silica from the rock by waters that may either have been given off by the cooling ultrabasic magma or have had a more recent hydrothermal origin. Some of it must be later than the magnesite, for magnesite is cut by veinlets of talc.

Evidence as to when the talc was formed is conflicting. The talc along the fault in section 28 must be of the same age as the fault, which cuts some of the jasperoid masses and silicified zones; some talc therefore was deposited after the period of most intense silicification. On the other hand, much of the talc schist in the eastern part of the peridotite mass is silicified, so that some of the silica was formed after some of the talc. The schistosity, however, in the largest area trends northward, toward a jasperoid zone which it apparently does not affect, so that the schistosity, and the talc also, may here be pre-jasperoid in age, instead of post-jasperoid as in section 28. It is evident, at least, that either talc or silica or both must have been formed during more than one period. Thin veinlets of pure talc cut the talcose schist as well as the magnesite and the serpentine.

Structure

Structural features older than faults

The original bedding of the metamorphic rocks, in the few places where it was recognized, strikes a little east of north and dips 65°-80° E. The foliation of these rocks, in general, strikes N. 35° W. to N. 35° E. and dips 65° E. to vertical. Variations from the general trend occur near the peridotite, where foliation tends to be parallel to contacts.

The ultrabasic igneous rocks were intruded as a sill-like mass parallel to the foliation of the schists. The contacts on both sides, where they are crossed by the Auburn-Folsom highway, dip about 70° E. Within the mass is a rude alinement of the areas of dunite, pyroxenite, and lherzolite in zones roughly parallel to the long axis of the intrusion, though the zoning is somewhat obscured on the map by areas of jasperoid and talcose rocks. In a few places thin pyroxenite layers in dunite are similarly oriented.

As the chromite layers in dunite are essentially igneous, they would naturally be expected to have about the same strikes and dips as the elongate bodies of dunite. This expectation is not fully borne out, because later shearing has considerably disturbed the chromite bands. The alinement of prospect pits, however, shows that the general trend of the chromite zones is parallel to the long dimension of the intrusive body.

Faults

Faults, both large and small, are numerous in the area, though the character of the rocks involved and the incompleteness of the exposures make it impossible to map them very satisfactorily. The major faults are readily found where they cross contacts between schist and ultrabasic rocks but are indistinct within the ultrabasic mass. The largest fault mapped is well-defined in section 28 and is probably continuous with a shear zone that crosses the southeast corner of section 21. It strikes about N. 25° E. and dips about 60° SE. It displaces the schist-peridotite contact more than 2,000 feet in the same direction that it would if it were a normal fault without horizontal shift; but some horizontal displacement may have occurred. The fault probably is later than the shear zones along which silicification occurred, for it apparently cuts masses of jasperoid and no silicification along it was observed.

Another fault, just north of the center of section 28, strikes about N. 60° E. and, though poorly defined, may be continuous with a fault of more easterly trend near the center of the NE¼ of the same section. Both these faults dip steeply southward, and their hanging walls have probably moved down and to the west. They may form a branch of the great fault already described, but there is some evidence that the eastern portion continues beyond that fault.

Three faults offset the peridotite contact in the NW¼ sec. 21. One, nearly west of the center of the section, strikes east and causes a horizontal displacement of the schist boundary of 450 feet to the west on the south side. The configuration of silicified areas and lherzolite outcrops suggest that this fault continues east-northeastward for some distance. Nearly north of the center of the section are the other two faults, which are parallel to each other and show combined horizontal displacement of 800 feet north-northwestward on the east side. Evidences of faulting farther southeast may mean that this fault extends at least to the chromite deposits in the East Basin.

Many other faults were seen to displace the ore bands, but their throws, though nowhere measurable with exactness, are probably a few feet or a few tens of feet. They strike a few degrees east or west of north, and most of them dip to the east.

The silicified shear zones give little evidence as to the character of faulting involved. Where shear cleavage is present it may give an indication of direction and dip, but this evidence cannot be considered definite. Of the shear zones that strike northwest, some apparently dip northeast and some southeast, the dip being about 45° in both cases; those striking northeastward dip 50°-90° S.

ORE BODIES

Mine workings

Chromite prospects and workings are scattered throughout the area mapped, which is about 2 miles from north to south and 1¼ miles from east to west; but the more important workings are all within an area 2 miles long and half a mile wide. The maximum vertical range of the prospects is 800 feet. Most of the openings are clustered into small areas, which are indicated on the map by numbers from 1 to 11.

Four of these areas, numbered 1, 2, 3, and 6, are being actively prospected, and chromite has recently been mined from each of them. Area 5 has perhaps the largest number of workings, but they are old and inaccessible. The other areas indicated by index numbers have been prospected by means of small trenches, adits, and pits.

The Rustless Mining Corporation's mill, southwest of the West Basin, concentrates 20-percent ore to a product containing over 45 percent of Cr_2O_3. The mill's capacity is being enlarged to 300 tons a day.

Minerals of ore deposits

The only ore mineral of chromium is chromite. Pure chromite ($FeCr_2O_4$) contains 68 percent of chromic oxide and 32 percent of ferrous oxide, but the natural mineral is a mixture in varying proportions of the oxides of chromium, iron, aluminum, and magnesium. The chromite from the Pilliken area varies in composition from place to place, containing from 45 to 50 percent of chromic oxide and from 16 to 20 percent of metallic iron. The purple chromium chlorites uvarovite and kaemmererite and, it is said, green chromium garnets are present in very minor amount.

Serpentine, talc, and magnesite veinlets cut the ore bands. The gangue minerals are olivine ($(Mg,Fe)SiO_2$), serpentine ($H_4Mg_3Si_2O_9$), magnesite ($MgCO_3$), and talc ($H_2Mg_3(SiO_3)_4$), with chert or other siliceous material in the silicified zones. Most of these are alteration products or were introduced, so the character of the ore differs greatly in different areas and even in different parts of the same pit. Weathering produces a "soft" ore which, if wet, clogs the crusher. "Hard" unweathered ore, with a gangue consisting largely of olivine or silica, sustains high losses because of sliming.

Texture of ores

Disseminated chromite grains are distributed throughout the dunite of the mapped area in concentrations of less than 0.5 percent to more than 30 percent. Disseminated chromite in lherzolite rarely exceeds 1 percent of the rock, although it may be more highly concentrated in enclosed thin lenses of dunite. Most of the disseminated grains have more or less definite crystal form, but some are rounded at the corners as if corroded. Some grains are rounded at one end but not at the other, and many are completely rounded. Some clusters of irregular grains appear to have filled up spaces between crystals of other minerals; some have the shapes of coalescing globules. Some grains have curved cracks, which may indicate that they grew from a rounded nucleus. Chromite grains of all shapes enclose gangue minerals and are enclosed by them. Some grains in sheared rocks have eyelike outlines and tail out into thin streaks of dust along the foliation.

The disseminated grains are far from uniform in size, and in general they are largest where they are most abundant. In rock that contains less than 1 percent of chromite the grains are usually less than 1 millimeter in diameter.

The average tenor of the disseminated ores where they are exposed in trenches and shovel pits is rarely over 10 percent, but in many places the disseminated ore encloses thin lenses of much higher tenor. The lenses are of three types: (1) those consisting almost entirely of chromite and sharply bounded on both sides, (2) those sharply bounded on the lower, or west, side and having gradational boundaries on the upper, or east, side, and (3) those having gradational boundaries on both sides. In any one area the three types may be about equally common or one type may predominate. Individual rich layers range from a fraction of an inch to 4 feet in thickness. They may pinch out either gradually or abruptly, or frazzle out into streaks of disseminated grains. Pinching and swelling along the strike is characteristic and may result in a series of small sharply-bounded lenses or pods. As a rule the rich layers have sharper boundaries where disseminated grains are sparse than where they are more abundant.

The chromite streaks, except where disturbed by later deformation, are parallel to the walls of the dunite masses. Individual lenses are erratically distributed and discontinuous, but some zones made up of many lenses, such as those in the shaft and shovel-pit areas of East Basin, persist for a considerable distance.

Texturally, bands that are moderately rich but contain much silicate are similar to those in which the grains are more sparsely disseminated. Euhedral grains are less common and rounded grains more common in the rich bands than in disseminated ore, and where chromite makes up the entire band the individual grains are intergrown. The forms outlined by serpentine that has been introduced along grain boundaries and cracks without replacement are angular in part, but a surprisingly large proportion of them are bounded by cracks.

Nodular ore, locally known as "leopard" or "grape" ore, is found north of Chrome Gulch, and its occurrence in the workings of the Chrome Placer Co., in the NW¼ sec. 21, has been described by Diller.[4/] In the SE¼ sec. 21 chromite nodules are associated with disseminated grains and irregular bands of chromite. The spheroidal or ellipsoidal masses of chromite in the nodular ore are sharply bounded. In some places they are separate but elsewhere they are grown together, leaving small interstices filled with olivine or serpentine or both. Grains of these silicates are also enclosed in the nodules. No thin sections of the nodular ore from the Pilliken area have been examined, but one of Diller's sections of material from Briggs Creek, Oregon, shows the boundary of a nodule to be sharp, though roughened by projecting grains of chromite partly bounded by crystal faces. The chromite grains, outlined by introduced serpentine, within the orbicules are anhedral, owing to mutual interference during growth.

Localization

The most outstanding fact regarding the localization of the chromite ore is that it is all in dunite. Some prospect pits in areas mapped as lherzolite show concentrations of chromite, but probably all of these prospects are in lenses of dunite which, being at most a few feet thick, cannot be mapped. No large ore bodies are likely to be found in such environments.

4/ Diller, J. S., Chromite in the Klamath Mountains, California and Oregon: U. S. Geol. Survey Bull. 725, p. 12, 1921.

A few streaks in the dunite masses may contain enough disseminated chromite to be minable. These streaks are, in general, parallel and near to contacts between dunite and pyroxenite. Chromite has not been formed at the contacts of dunite with the schists. Massive chromite ore containing from 40 to 50 percent of chromic oxide, which may be mined and sold directly, can be obtained only from fairly thick layers of nearly solid chromite. Most of the milling ore comes from zones in which groups of discontinuous bands of massive chromite are associated with disseminated chromite. It is mined both from open pits and from underground workings. These zones lie parallel to the trend of the enclosing dunite masses, and they are fairly persistent, though they are so much broken by small faults that individual bands cannot easily be followed. The minable width of these zones is determined by the grade of ore desired.

More than one ore zone may occur in any single mass of dunite just as more than one band of dunite may occur in any one peridotite area.

Field relations indicate that these are reasonable guides to prospecting, but they must be used in conjunction with the knowledge that the original ore bodies have been highly fractured, faulted, sheared, and silicified. Only in undisturbed areas do the chromite bands trend parallel in strike and dip to the nearest dunite boundary.

Origin

It is generally believed that chromite is a pyrogenetic mineral, that is, a mineral that crystallized directly from a silicate melt, the same as the enclosing olivine or pyroxene, and that the chromite crystals were concentrated by settling or by convection currents. The geologic facts at Pilliken are consistent with such an origin for the ore. If this is true, the average chromite content of the ultrabasic rocks is likely to be about the same at any depth to which it is practicable to mine.

Size and grade of ore bodies

Chromite ore bodies of a particular grade are very hard to delimit, for high-grade lenses are irregularly distributed and of variable thickness and extent, and the tenor of the disseminated ore varies greatly within short distances. However, zones composed of both types of ore are continuous over considerable distances and, in general, maintain their grade reasonably well.

The larger high-grade lenses, as much as 4 feet wide, containing from 40 to 50 percent of chromic oxide, may be continuous for 100 feet or more horizontally, but faulting usually makes it difficult to follow them so far. They also pinch and swell abruptly, and individual lenses along the same trend may be widely separated. Their extension in depth is also very problematical. The very nature of these ore bodies, in short, makes it almost impossible to estimate their size accurately; but perhaps 10,000 tons of ore containing 40 to 50 percent of Cr_2O_3 could be mined from these larger high-grade lenses.

The larger bodies of milling ore, containing about 20 percent of chromite or 10 percent of Cr_2O_3, include most of the smaller high-grade lenses together with adjacent disseminated ore. Deposits of milling ore as much as 600 feet long and 200 feet wide have been mined, but the usual minable width of such ore is from 20 to 30 feet. It seems probable that ore zones of this grade 1,200 feet or more long can be proved by additional exploration, but very careful prospecting and assaying will be necessary to delimit them accurately. It is estimated that the areas 1, 2, and 3, in East Basin and West Basin, might yield more than 500,000 tons of this grade but that less than 50,000 tons in all could be produced from the other areas.

The ore bodies containing from 10 to 20 percent of chromite are very much larger. Open-pit mining of this grade of ore, before removal of higher-grade ore, would yield more than 4,000,000 tons. Most of this tonnage, again, is in West and East Basins. The deposits in West Basin are three times as large as those in East Basin and are better situated for large-scale open-pit mining; and it seems probable that they might be profitably mined at present prices.

In this marginal group of deposits a gradual lowering of the grade of ore required for mill heads would continue for some time to increase available tonnages, because decrease in the tenor of the ores away from higher-grade zones is gradual. It is estimated that at least 25,000,000 tons of rock containing from 5 to 10 percent of chromite may be available. The five areas that contain from 1,000,000 to 15,000,000 tons apiece are, with one exception, well situated for open-pit mining. Two of these areas contain little or no higher-grade ore, but most of the higher-grade ore that is present in any of the areas is enclosed in dunite that contains 5 percent or more of disseminated chromite, which could be mined by extending operations on the richer ore.

Enormous tonnages of dunite containing from 3 to 5 percent of chromite are available, but, as ores so lean as this could hardly pay for mining under any conditions, only one area (area 5), believed to contain associated higher-grade ores, is described.

Reserves

The leanest ore that can be profitably mined at present must contain 20 percent of chromite, equivalent to about 10 percent of chromic oxide. About 60,000 tons of such ore is thought to be virtually proved by underground and surface workings in East and West Basins. This estimate is based on the assumption that the exposed ore extends down dip about 100 feet below present workings, and depends on field observations, for assays are not available.

The other estimates of ore reserves, shown in the table opposite, are speculative but are intended to indicate the order of magnitude of expectable ore of the various grades. All estimates are stated as percent of chromite to avoid inaccuracies resulting from erroneous assumptions regarding chromic-oxide content, but much of the chromite is known to contain more than 45 percent of Cr_2O_3. The estimates of tonnage and chromite content on this basis are as follows: 10,000 tons of ore containing more than 50 percent of chromite; 540,000 tons of 20 percent or more; 4,120,000 tons of 10 to 20 percent; and 24,000,000 to 37,500,000 tons of 5 to 10 percent. Dunite with 3 to 5 percent of chromite is present in very large quantities.

The estimates are based on the assumption that ore is continuous between prospect pits and exposures, but at no place is a continuation of more than 100 feet below present workings assumed. In the larger low-grade ore bodies only that portion above the lowest exposure was estimated. Percentage of chromite is based on visual estimates of exposed ore. Although it is believed that the estimates are conservative, it is impossible to evaluate or to delimit the deposits accurately on the basis of field studies unsupported by assays. One difficulty is that the variable chromic-oxide content of the chromite cannot be estimated visually. The estimation of percentages of chromite within any ore zone is beset with further difficulties; high-grade lenses may pinch out abruptly along strike or dip; disseminated ore between the lenses varies widely in tenor; and the passage from relatively rich disseminated to leaner ore is gradual in most places but abrupt in others.

Estimated 1/ reserves of chromite ore, in short tons, at Pilliken, Calif.

Area	Estimated percentage of chromite 2/				
	50-100	20-50	10-20	5-10	3-5
1	1,000	180,000	500,000	5,000,000- 8,000,000	
2	1,500	140,000	500,000	1,000,000	
3	1,500	195,000	3,000,000	5,000,000-10,000,000	
4				10,000,000-15,000,000	
5					25,000,000
6	500				
7	4,000	25,000	100,000	3,000,000	
8		(3/)	20,000	500,000	
	8,500	540,000	4,120,000	24,000,000-37,500,000	25,000,000

1/ Estimates only approximate, being based on field data, not assays and ore shipments.

2/ Chromite of the Pilliken area ranges between 30 and 50 percent of chromic oxide.

3/ Further exploration may develop commercial tonnages.

Ore-bearing areas

The wide distribution of the prospects in the district and uncertainties regarding the continuity of individual high-grade lenses make it inexpedient to describe each prospect separately. The composition and structure of the ore indeed are such that mining by open pits, each one large enough to include several prospects, is likely to prove most profitable. Areas, therefore, rather than prospects or mine openings, are discussed on the following pages. Eleven areas contain chromite that is now being mined, or is minable, or that shows promise enough to warrant further prospecting. These areas are referred to by index numbers, which appear on the map (pl. 66).

Area 1, Shaft area in East Basin

Deposits and workings.--The shaft in the SW¼NE¼ sec. 28, T. 11 N., R. 8 E., penetrates a zone of chromite-bearing dunite (see pls. 66 and 67), about 2,000 feet long from north to south with a maximum width of 1,000 feet. It lies between two pyroxenite masses, is bounded on the northwest and northeast by silicified zones trending approximately N. 15° E. and N. 35° W., and is cut off at the south by a fault striking N. 25° E. None of these features appears on plate 67, but all may be seen on plate 66.

The ore zone probably extends along the entire length of the dunite body and may even continue into the silicified zones, but its limits are difficult to locate because of poor exposures and the presence of some small faults. Its trend is about N. 10° W. and its width about 400 feet. A fault of considerable displacement offsets the ore body just south of the present workings. The entire ore zone is estimated to contain 5 to 10 percent of chromite.

The workings in this area (see fig. 65) include a 70-foot shaft from which a crosscut extends 90 feet east. Drifts 80 feet north and 150 feet south connect with stopes to the surface. Three large open pits and two smaller ones have been worked with power shovels and draglines. The areas to the southwest and northeast have been prospected by means of bulldozer trenches.

The shaft area is now producing from a high-grade streak, which is from 30 to 35 feet in average width, trends about N. 10° W., and has an average dip of 60° E. Individual bands strike from N. 10° W. to N. 50° E. and dip from 40° to 80° E. These differences are due chiefly to small faults but partly to original irregularities. Chromite is disseminated and occurs also in high-grade lenses. The disseminated ore contains about 10 percent of chromite on the average, but some of it contains more than 30 percent. The bands in general are sharply defined and contain from 90 to nearly 100 percent of chromite. Underground workings are confined to the highest-grade portion of the ore zone, which averages 10 feet in thickness and includes from 8 to 10 high-grade bands that are from 3 to 12 inches thick. Individual bands are not continuous, but this 10-foot width maintains an average of more than 50 percent of chromite throughout its exposed length of 200 feet.

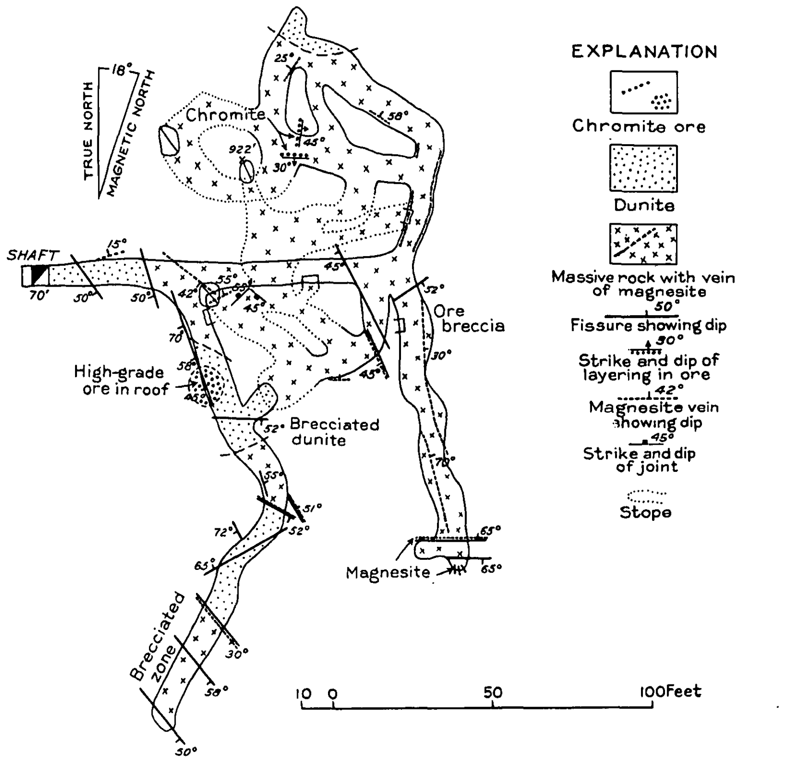


Figure 65.--Geologic map of the Shaft mine.

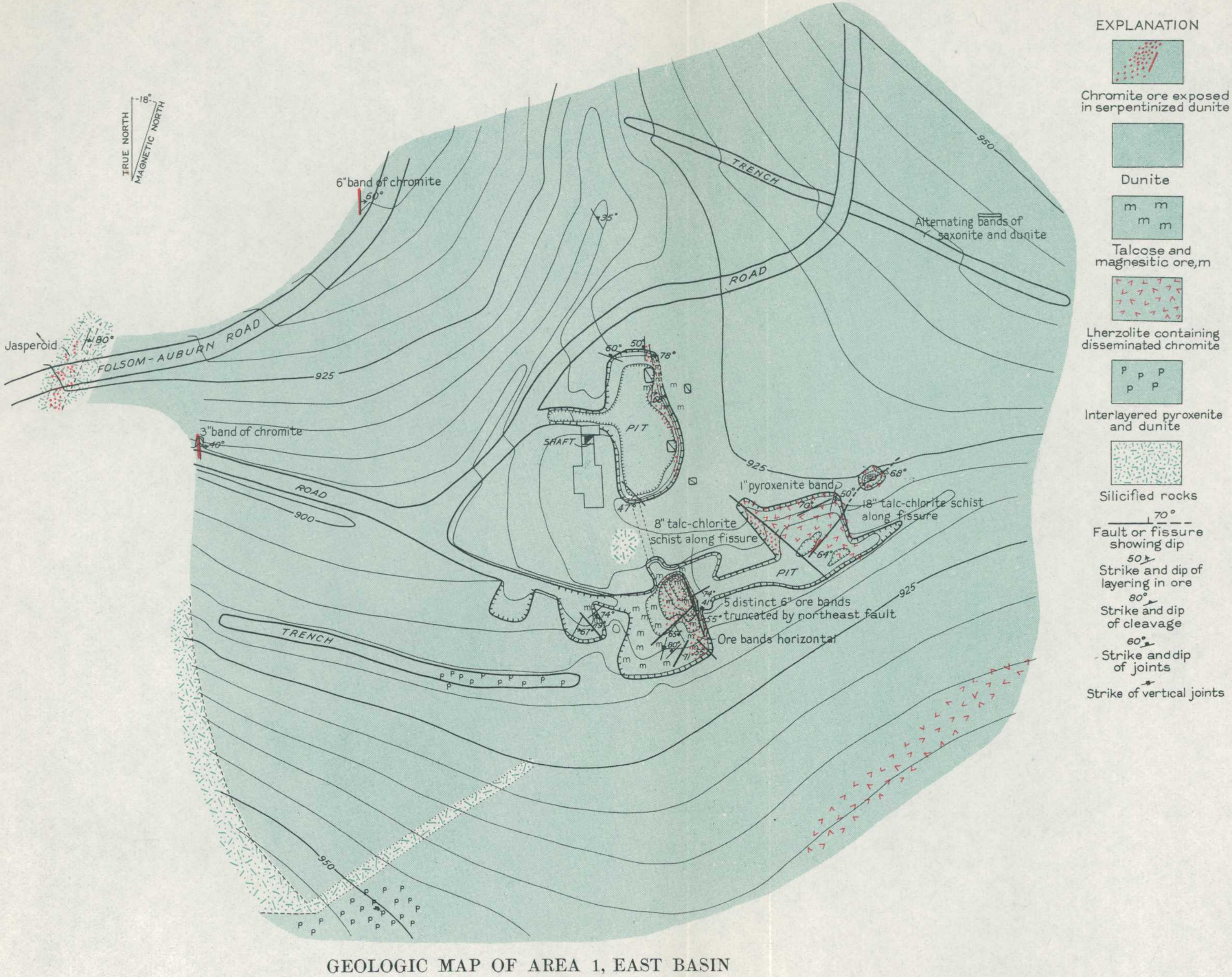
The gangue minerals are primarily serpentine, talc, magnesite, and other carbonates, intimately intergrown in a white to gray soft mass. Olivine is present in the least altered dunite, and some enstatite and diallage have been found in the eastern workings. About 60,000 tons of milling-grade ore is proved by present workings, and it is estimated that 120,000 tons more may reasonably be expected. The total tonnage of lower-grade ore that could be mined, providing the high-grade ore is left in to keep up its tenor, is very large--roughly 500,000 tons containing from 10 to 20 percent of chromite and from 5,000,000 to 8,000,000 tons containing 5 to 10 percent are indicated. Careful prospecting in other parts of the dunite area, particularly south of the shaft, might reveal other deposits of 20-percent chromite ore.

Desirable exploration.--As can be seen from the mine map and the detailed surface map, further surface prospecting should be carried out in order to determine the extent of the zone that trends N. 10° W., which apparently has not been exposed on the surface in bulldozer pits. Diamond drilling should be done in order to determine whether it extends to a depth of as much as 150 or 200 feet. If surface workings prove that the ore extends continuously from the silicified zone to the fault, a series of vertical holes should be spaced along a line trending N. 10° W. and passing through a point 655 feet east of the center of section 28. Two of these holes should be in the south half of the section.

Area 2, Old Pilliken workings, East Basin

Deposits and workings.--The old Pilliken workings in East Basin, which have been described in a report of the California Mining Bureau [5/] (see pls. 66 and 68), consist of two adits, which connect with a large glory hole, and many smaller pits, shafts, and adits. Recent production has come from an open pit in chromiferous dunite 1,000 feet S. 65° E. of the quarter corner between secs. 21 and 28, T. 11 N., R. 8 E. The dunite is surrounded and cut by silicified zones except on the east, where a narrow band of pyroxenite separates it from the talcose ores of area 7. The area of chromiferous dunite, which in-

5/ Bradley, W. W., and others, Manganese and chromium in California: California Min. Bur. Bull. 76, pp. 141-143, 1918.

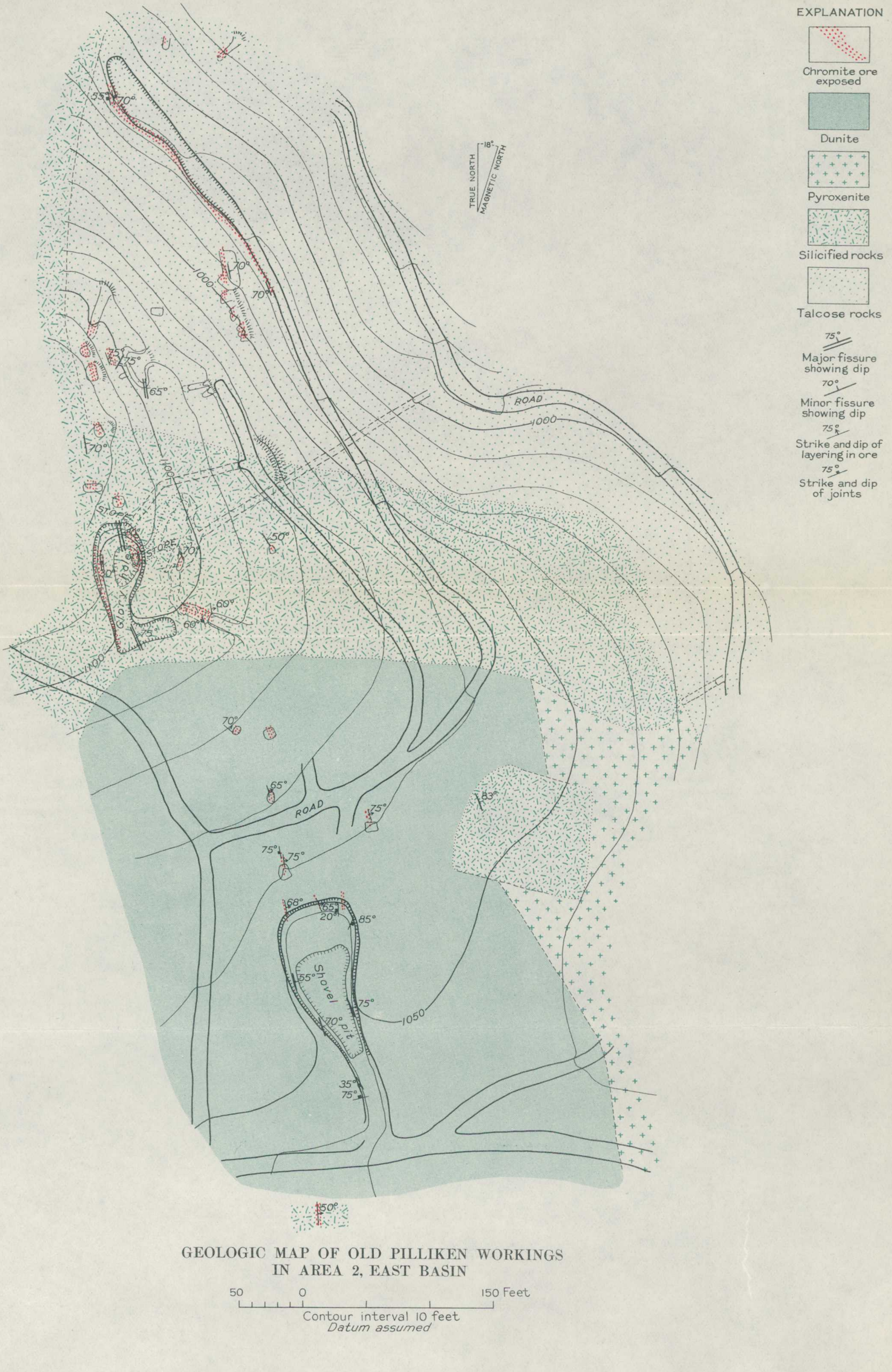


GEOLOGIC MAP OF AREA 1, EAST BASIN

50 0 150 Feet

Contour interval 5 feet

Datum assumed



GEOLOGIC MAP OF OLD PILLIKEN WORKINGS IN AREA 2, EAST BASIN

GEOLOGIC MAP OF OLD PILLIKEN WORKINGS IN AREA 3, WEST BASIN

50 0 150 Feet

Contour interval 10 feet

Datum assumed

cludes several discontinuous ore zones, is 2,000 feet long and 500 feet wide. The entire area probably averages 5 to 10 percent of chromite.

The main high-grade zone has been worked from the two adits (see fig. 66), the glory hole, and a large shovel pit. Both glory hole and shovel pit are probably on the same ore zone, which apparently is offset by movements along the silicified zone in which the glory hole is located. The workings indicate an ore zone from 15 to 30 feet wide by about 600 feet long and trending N. 20° W. Streaks of nearly pure chromite as much as 4 feet thick, containing from 40 to 50 percent of Cr_2O_3, occur in the disseminated ore. Individual high-grade lenses strike N. 5°-10° W. and dip 60°-75° NE. The zone as a whole probably averages close to 20 percent of chromite. The ore in the glory hole and main adits is brecciated, silicified, and associated with kaemmererite and uvarovite. The gangue minerals include serpentine and olivine as well as cherty silica. In the open pit the ores are soft and have serpentine, talc, carbonate, and some olivine as gangue. The northern part of the dunite area appears to merge into the extension of area 7, and old workings in high-grade bands and "leopard" ore show that it contains a fairly large quantity of milling ore.

About 600 feet southwest of the large open pit brecciated high-grade lenses in jasperoid and silicified serpentine are exposed in many old shafts, pits, and trenches. These old workings are in one or two zones, which may extend southeastward into the dunite in area 1, but this connection would be hard to prove for the rocks are deformed in such a way that the ore bands strike in all directions. There may be a good deal of milling ore in this area, but because of the siliceous gangue the cost of crushing would be high and much chromite would be lost in the slimes.

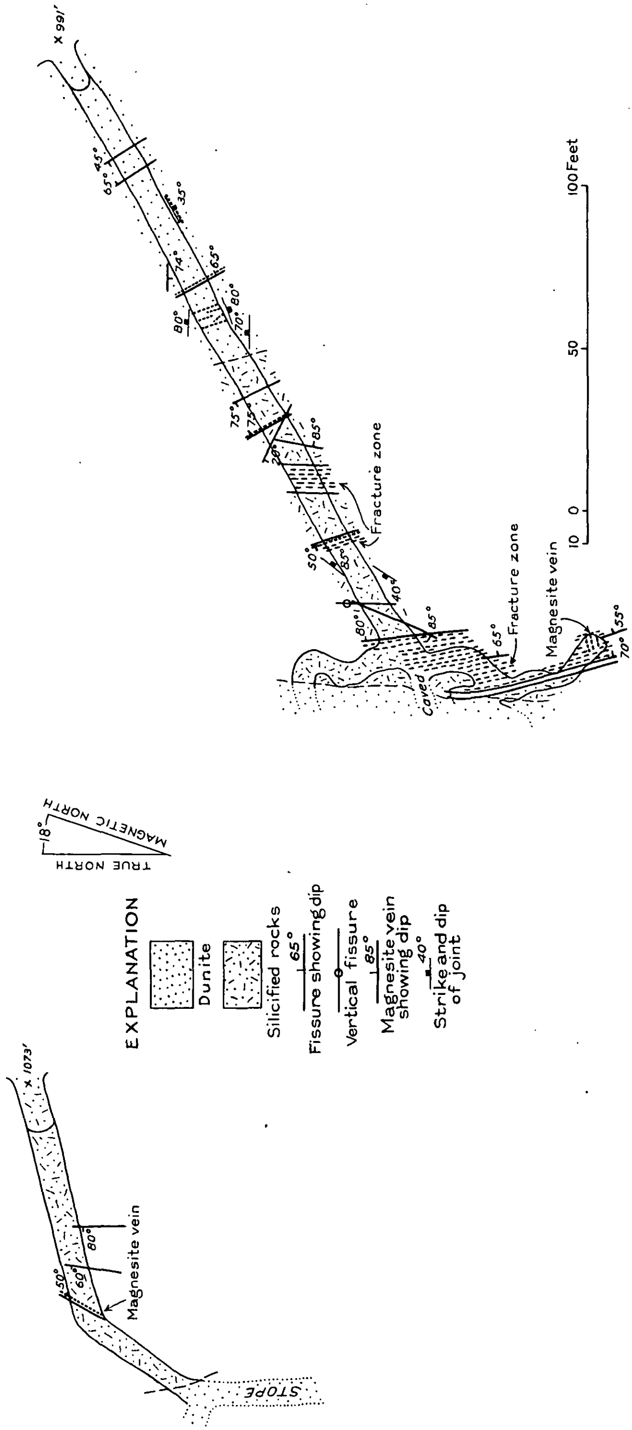


Figure 66.--Geologic map of adits of old Pilliken workings in area 2, East Basin.

The reserves of milling ore, containing about 20 percent of chromite, in this area are estimated at 140,000 tons. Some 1,500 tons of high-grade ore, containing from 40 to 50 percent of chromic oxide probably could be produced. Reserves of low-grade ore containing from 5 to 10 percent of chromite amount to about 1,000,000 tons.

Desirable exploration.--This area is well prospected, but further sampling is needed for blocking out milling-grade ore and for identifying individual ore zones in order that offsets may be proved. Diamond-drill holes should be put down 100 or 200 feet in order to test the downward persistence of the ore. Two or three holes drilled westward from the lower road level about 30° down from the horizontal across the entire zone of more than 400 feet might prove the presence of a large ore body and give useful facts regarding the distribution of high-grade streaks. Two holes 200 feet from either side of the section line should be drilled first.

Area 3, Old Pilliken workings, West Basin

Deposits and workings.--The old no. 1 Pilliken workings, described in detail by Bradley,[6/] and the recently opened underground workings and open cut are in a dunite area, about 1,200 feet square, in the northeast corner of the NW¼ sec. 28 and in the SW¼ sec. 21, T. 11 N., R. 8 E. (see pl. 66).

The dunite lies between schists on the west and silicified zones on the north, east, and south. Small pyroxenite masses project into the area or are enclosed within it. Details of the relation of the silicified zones to the dunite and pyroxenite, as well as the distribution of the workings, are shown on the detailed map of West Basin (pl. 69). The dunite of this

6/ Bradley, W. W., and others, op. cit., pp. 137, 138.

area contains, on the average, from 5 to 10 percent of disseminated chromite, besides the chromite in many high-grade lenses. It includes at least three major ore zones, the general trend of which is N. 30°-35° W., parallel to the schist-dunite contact.

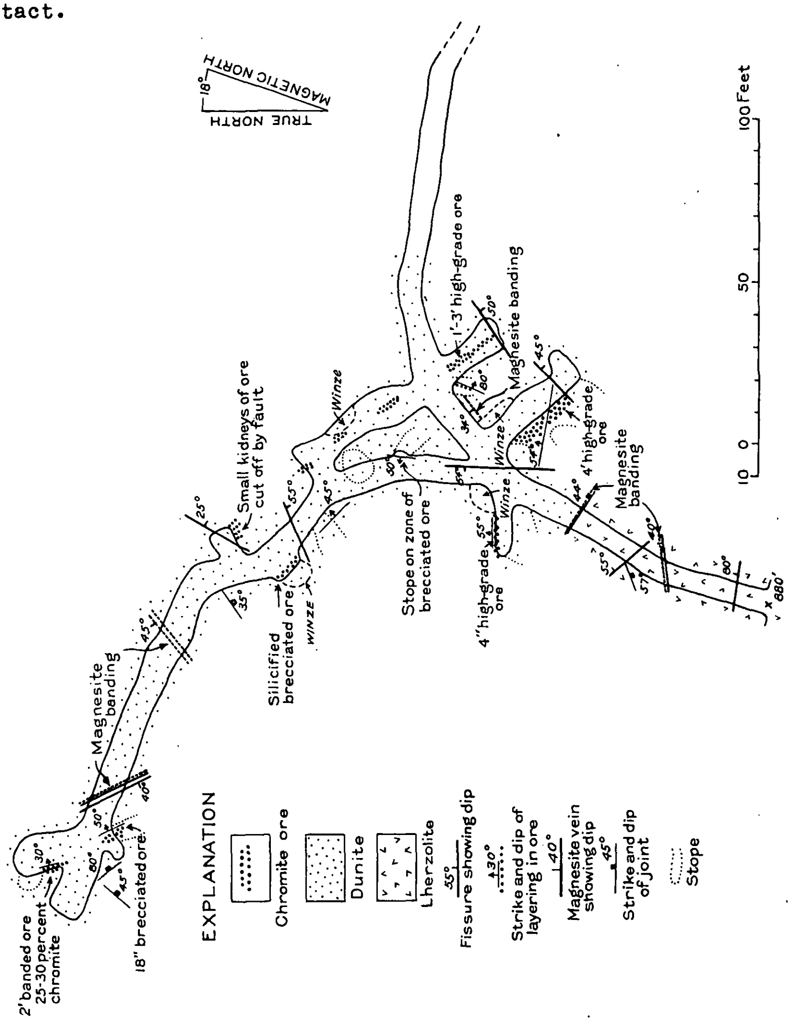


Figure 67.--Geologic map of old underground workings in West Basin.

The purpose of the older workings (see fig. 67) was primarily to mine the high-grade banded ore that could be sold without milling. Disseminated ore that contains over 20 percent of chromite and is associated with lenses that contain over 90 percent of chromite and are as much as 5 feet thick is common in the major ore zones. The limits of the zones are indefinite because of strong shearing, faulting, and brecciation, as a result of which the chromite lenses in adjacent prospects or even in different parts of the same workings may differ widely in strike and dip. Segments of the shattered lenses vary widely in strike and dip from 10° to 80° E., no westerly dips having been observed.

The northernmost zone has been opened up by the largest open pit in the West Basin; this pit is 200 feet long and 50 feet wide and has exposed ore to a depth of 50 feet. The chromite is disseminated, and forms high-grade streaks, in green to yellow serpentinized dunite. The ore bands are folded and are cut by many small faults and shear zones. The largest fault, which extends along the south rim of the pit, strikes N. 75° E. and dips 65° SE. Along this fault the ore bands are highly fractured, drag-folded, and pulled out parallel to the fault plane. No measurement of the amount of movement is possible.

Most of the minor fractures are filled with veins of laminated magnesite and yellow serpentine. The magnesite veins are divisible into three groups; those of the first strike N. 20° W. and dip 50° SW., those of the second strike N. 20° E. and dip 86° SE., and those of the third strike 55°-60° E., dip 45°-50° NW. Most of the magnesite veins are only a few inches thick, but two of those with a strike of N. 55°-60° E. are 2 to 4 feet thick.

This zone extends southeastward from the large pit, as shown by exposures in smaller open pits, adits, and prospects; it may even be continuous with the ore zone in area 1. A northerly extension, also, may be represented by a silicified area that contains 20 percent of disseminated chromite. It is estimated that this zone includes an area about 200 feet wide and 700 feet long containing very nearly 20 percent of chromite.

The second ore zone, which crosses the middle of the West Basin, has been worked by drifts, glory holes, stopes, and open pits. The chromite of this zone is partly in high-grade lenses, which are separated by rock that contains 5 to 10 percent of disseminated chromite. The largest high-grade lens observed is 4 or 5 feet thick, and several are a foot or two thick. The ores are concentrated in a body from 100 to 150 feet wide, which is exposed for about 1,200 feet horizontally and 100 feet vertically. Although the high-grade ore above the adit level has been removed, much material averaging between 10 and 15 percent of chromite remains. This zone may extend 1,000 feet southeastward to a group of old prospects on top of the ridge.

A third ore zone lies just above the schist-dunite contact, near the southwestern rim of the basin. This zone has been prospected by shallow shafts, pits, and trenches. The ore is mostly of the disseminated type, containing from 10 to 15 percent of chromite. It includes a few high-grade streaks, but none of these are present in the lower or southwestern 10 to 15 feet. This zone has been prospected for 600 feet horizontally, 100 feet across the strike, and 150 feet vertically. It may extend southeastward to the great fault near the center of section 28. This zone might produce about 1,500 tons of minable high-grade ore containing 40 to 50 percent of chromic oxide, though the high-grade bands are so shattered by faulting that an estimate of their content is very difficult. Available 20-percent ore is estimated as 195,000 tons, 10- to 20-percent ore as 3,000,000 tons, and 5- to 10-percent ore as 5,000,000 to 10,000,000 tons.

Desirable exploration.--Area 3, particularly the eastern and middle zones, is very favorable for large-scale open-pit or glory-hole mining, and it seems possible that large-tonnage operations might be successful under present milling practice and at present prices.

Because of the complex faulting, it would be difficult to identify individual layers in diamond-drill cores. Drilling therefore should be planned to prove the tenor of fairly large blocks of ore rather than of individual ore bodies. As a preliminary to the systematic drilling, some holes might be drilled from the present workings. Assays should represent considerable lengths rather than short segments of core.

Area 4, Chrome Gulch

Deposits and workings.--About 15 or 20 shallow, widely scattered pits and short adits have been opened in the SW¼ sec. 21, T. 11 N., R. 8 E., just north of a large pyroxenite mass (see pl. 66). The prospects are all within an area 1,200 feet long and 800 feet wide, elongated parallel to the contacts between peridotite and schist.

The country rock here is relatively fresh unsheared dunite, which is in part continuous with that in West Basin. The dunite is unusually rich in disseminated chromite, and it contains thin lenses of nearly solid chromite, though none over 3 inches thick were seen. The rock as a whole is estimated to average between 5 and 10 percent of chromite. The ore has a pronounced banding, which usually trends N. 20°-40° W.; but the trend at places in the eastern part of the area, perhaps because of shearing, is N. 50°-70° E.

No large bodies of 20-percent chromite are indicated by present exposures, although ore of this grade might still be proved by careful assaying and further exploration. If 5- to 10-percent chromite can be profitably milled the entire area may be considered ore. The vertical range of prospects is 300 feet and, considering a possible connection with the ore bodies of the West Basin, a conservative estimate indicates 10,000,000 to 15,000,000 tons of this grade.

Desirable exploration.--Systematic sampling and diamond drilling of the area by vertical holes is recommended for this area as well as for area 3.

Area 5, Placer Chrome Co. workings

The old workings of the Placer Chrome Co. are on the crest and sides of a northward trending ridge in the western part of the NE¼ sec. 21, T. 11 N., R. 8 E. (see pl. 66). The chromiferous dunite area is roughly 1,000 feet square and has a relief of 330 feet.

Prior to 1920 there was much activity in this area, and judging from the size of the glory holes, shafts, and pits, there must have been considerable production. According to Bradley,[7/] most of the ore shipped contained 38 percent or less of Cr_2O_3. At the present time most of these workings are inaccessible, but they have been described in detail by Bradley.

The chromite, which is here disseminated through the dunite with unusual evenness, constitutes between 3 and 5 percent of the rock. Richer streaks of disseminated ore and thin lenses of nearly solid chromite occur, but in few places is the tenor above 10 percent. Ore piles near old workings indicate that higher-grade bands were present in a north-south zone, from 50 to 100 feet wide, trending along the crest of the ridge, and smaller high-grade zones are indicated by scattered prospect pits.

The chromiferous dunite interfingers with chlorite, epidote, and hornblende schists and amphibole contact rocks to the northwest. Thin bands of these schists, as well as schistose and massive dioritic dikes, usually less than 5 feet thick, are common in the dunite but occupy less than 1 percent of the en-

7/ Bradley, W. W., and others, Manganese and chromium in California: California Min. Bur. Bull. 76, pp. 141-143, 1918.

tire area. The dunite is in fault contact with hornblende and chlorite schists on the west. Eastward it grades through lherzolite into a small pyroxenite mass. Shearing is prominent only near the edges of the area, where silicified shear zones truncate the chromiferous dunite on the north and south.

The present exposures do not show ores of grade that is now workable, but if tonnages of very low grade material--4 to 5 percent of chromite--could be used, the entire area could be mined. About 25,000,000 tons of such grade is exposed above the lowest point in the dunite area.

Careful prospecting in the higher-grade zone worked by the Placer Chrome Co. might yield a considerable tonnage of milling ore.

Area 6

Deposits and workings.--Milling ore has been produced on a small scale from a lenticular mass of dunite in the north-central part of the SE¼ sec. 28, T. 11 N., R. 8 E. This mass is 800 by 500 feet in maximum surface dimensions, and the prospected area, 100 by 200 feet, extends along its axis. (See pl. 66.)

The chromiferous dunite is bordered by lherzolite on the north and by pyroxenite on the east and west. The adjacent lherzolite is massive and unsheared but is cut by numerous dikes. These dikes continue into the dunite and although relatively narrow they lower the tenor of the chromiferous rock. The ore is mainly of the disseminated type but contains high-grade streaks. The disseminated variety is rather uneven in tenor, but the entire ore zone, 100 by 800 feet, probably averages 10 percent of chromite. The ore lenses strike N. 10° W. and dip 70° E. and are but little sheared. Ore is exposed to a depth of 100 feet, and it seems to be richer at this depth than nearer the surface.

This area may contain reserves of about 20,000 tons containing 20 percent of chromite and 500,000 tons containing 10 percent of chromite. Possibly larger reserves could be found by prospecting the area south of the present pits.

Desirable exploration.--The best method for exploring this area seems to be to dig bulldozer trenches at right angles to the trend of the dunite in order to find out whether the high-grade zone of area 1 continues southward into area 6. This zone, if present, will probably be found on the west side of the gulch, where only two small pits have thus far been dug. The showings in the bulldozer trenches may indicate that additional stripping is advisable.

Area 7

Area 7 is in the NE¼ sec. 28 and the SE¼ sec. 21, T. 11 N., R. 8 E., trends N. 10° E. to N. 35° W., and connects with the northern extension of area 2 (see pl. 66).

The present workings in the area consist of a few small pits and trenches. They expose banded and disseminated ore in a talcose dunite band, 200 feet wide and 1,500 feet long, which probably connects with the northern extension of area 2. The ore zone is separated from pyroxenite by 20 feet of talc rock that contains only a little disseminated chromite. In a gully about 400 feet northeast of the large open pit in area 2, talcose ore containing from 30 to 40 percent of Cr_2O_3 is exposed for a width of at least 20 feet and a length of 60 feet, trending N. 35° W. parallel to the pyroxenite-dunite contact.

It is difficult to estimate the reserves in this area, but apparently the zone as a whole would average between 5 and 10 percent of chromite, or about 3,000,000 tons. Reserves of milling ore containing over 20 percent of chromite are estimated as 25,000 tons. Additional tonnage may be found by further prospecting.

Area 8

Area 8 lies in the SE¼NW¼ sec. 21, T. 11 N., R. 8 E., near the schist-dunite contact and about halfway between Chrome Gulch and the Placer Chrome Co. workings (see pl. 66). It extends parallel to the schist-dunite contact for about 700 feet and is 300 feet wide.

Six pits and short adits, now caved, have opened up high-grade layers (40 percent of Cr_2O_3), as much as 24 inches thick, which have a general trend of N. 25° E. The enclosing dunite contains from 2 to 4 percent of disseminated chromite. This area is probably of a larger zone that is more or less continuous along the trend of the main dunite body.

Included stringers of metamorphic rocks, intrusive diorite dikes as much as 50 feet thick, and silicified rocks make up a considerable portion of the area, and it is improbable therefore that mining could be carried on in the area without hand picking. By this method 500 tons or so of ore containing 40 percent of Cr_2O_3 might be produced under favorable conditions.

Area 9

An area of chromiferous dunite about 50 by 300 feet in extent lies in the SE¼ sec. 21, T. 11 N., R. 8 E. Several shafts and adits in high-grade streaks probably indicate some commercial production. The chrome-bearing rock is dunite, which is almost completely altered to talc and serpentine though it lies between relatively fresh lherzolite and silicified lherzolite. Rich ore occurs in streaks as much as 18 inches thick and is accompanied by some disseminated chromite. The many diorite dikes that cut across the ore bands would interfere with mining, and the area, even though it may contain a good deal of high-grade ore, is unlikely to become very productive.

Area 10

Area 10 is in the southeast corner of the NW¼ sec. 28. It is about 1,000 feet long, and it has an average width of 250 feet but tapers out to the south. At a contact of dunite with schist four small pits show disseminated chromite and high-grade streaks that strike N. 25° W. and dip 75° E., parallel to the contact. Bands of ore-bearing dunite as much as 400 feet wide, lying between pyroxenite and silicified zones, extend 1,200 feet southward to the major fault.

Although the present workings reveal some fairly good ore, none of it may be rich enough to be profitably mined. However, bulldozer cuts at right angles to the trend should be made before this area is eliminated as a possible producer.

Area 11

Area 11, which is 500 feet long north and south and 300 feet wide, is probably in the same ore zone as areas 1 and 2. It is described separately because it is characterized by silicification and strong shearing. The area contains several shallow inclined shafts, caved adits, and pits opened for working high-grade lenses; in parts of the workings nearly pure chromite 3 feet thick was mined. The strike of the lenses ranges from N. 60° W. to N. 60° E. It was impossible to follow any one of them far. Because of the discontinuity of the ore streaks and of the difficulty of milling ore with a siliceous gangue, no large production from this area seems probable.

Other localities

Small prospects at widely scattered places in the area mapped show chromite but not in large amount. Thin dunite bands, containing disseminated and banded chromite, at the eastern contact are scientifically interesting but probably not commercially important. They should be investigated more carefully, however, before eliminating them as possible producers.

Suggestions for prospecting

1. The chromite is definitely related to dunite in origin; consequently dunite areas are the best places to prospect.

2. All the dunite contains chromite as disseminated particles in varying amounts. Careful sampling may indicate large areas of disseminated ore that would pay milling charges.

3. Concentrations of chromite are most probable parallel to the western contacts but may occur at any place in the dunite bands. Bulldozer prospect cuts extending east and west should therefore be made completely across the dunite areas.

4. Shearing and offsetting of ore bands is very evident in most places, so that cross-trenching, where it reveals likely areas, should be followed by longitudinal trenching. Samples should represent fairly large areas, or blocks, because of the difficulty of following individual high-grade bands when they are much faulted.

5. High-grade lenses may pinch out abruptly along strike and dip; so where profit depends on the extent of such lenses they should be sampled with especial care.

6. Where silicified dunite occurs, the nearby unsilicified dunite, which may be poorly exposed, is likely to contain chromite and should be prospected by trenching. In judging whether a given body of the silicified rock itself is worth mining, the high cost of milling and the large losses due to sliming should be taken into account. It must also be remembered that the silicified zones are shear zones, so that the ore bands in them are likely to be very discontinuous, as well as irregular in trend. Some of the siliceous ores, however, may be rich enough to pay despite these handicaps.

7. Areas mapped as lherzolite should not be entirely neglected, for they contain some narrow bands of dunite. But as these bands are too small to map, so the ore bodies within them may be too small to mine.

8. Pyroxenite, again, though itself barren of chromite, may enclose thin layers of chromite-bearing dunite. Pyroxenite also has an indirect significance in that the richest ore bodies are close to pyroxenite masses. Dunite areas between pyroxenite areas are therefore good places to prospect.

9. Talcose areas, especially those west of the lherzolite, contain considerable dunite, and trenching at right angles to their trend might develop considerable ore.

10. Dike rocks and other barren material occupy as much as 25 percent of certain areas, and in large-scale mining they must be reckoned as waste.

11. Ore along fault planes, even though of high grade, may be unprofitable because of its irregular distribution. This caution also applies to most ore in bands that are not parallel to the trend of the dunite masses.

12. Some of the dikes of dunite that cut the metamorphic rocks on both the eastern and the western margins of the area are very rich in chromite, but because they are short and of variable width it seems unlikely that they can be profitably mined on a large scale.

13. A chromite zone that is not faulted or sheared may be expected to continue in depth with an east dip of 50° to 80°.

14. Samples that are to guide large-scale mining should represent fairly large areas or blocks rather than any one streak or lens. Assays of rocks of various textures might help to determine where the chromite in chromic oxide is likely to be poor and where it is likely to be rich.

Summary of potential ore reserves

Estimation of ore reserves without benefit of systematic assays is hazardous at best; consequently, it should be remembered that the following figures are based upon field estimates and poor exposures and, although believed conservative, are rough approximations that need to be checked by assays. These estimates assume that ore bodies exposed at the surface extend to a depth of 100 feet without decrease in size or grade.

Under existing conditions, when ore with 20 percent of chromite is required for profitable milling, exploration of the areas described should be made in the following order: (1) Area 1; (2) area 3; (3) area 2; (4) area 6; (5) area 7; (6) area 4; (7) area 9; (8) area 5; (9) area 10; (10) area 8, and (11) area 11. It is estimated that the first three areas can be counted on to supply about 500,000 tons of ore that contains 20 percent of chromic oxide. Further exploratory work might reveal showings that would justify an estimate two to four times as large.

The tonnage of lower-grade ore is much larger. If 10-percent chromite could be profitably mined, the reserves would probably amount to 5,000,000 tons. The reserves of areas 1, 2, and 3 would be extended by at least 50 percent, areas 4 and 7 would undoubtedly be in part minable, and smaller parts of other areas would also become productive.

The probable tonnage of ore containing 5 percent or more of chromite is in the neighborhood of 25,000,000 to 50,000,000 tons. Twice that tonnage of ore containing from 3 to 5 percent of chromite could readily be found. Assuming that ores containing 5 percent or more of chromite might become desirable, area 4 would be the best place to prospect with the hope of developing a large tonnage for open-pit mining. The relief of 200 feet on either side of Chrome Gulch indicates a minimum depth of ore on the edges of an area approximately 1,000 feet square, which would yield at least 10,000,000 tons of ore containing at least 5 percent of chromite. Drilling might indicate twice as large a tonnage.

If ore containing less than 5 percent of chromite were usable, area 5 would be a very good prospect, for this area is 800 feet by 1,000 feet and has 440 feet of relief; at least 15,000,000 tons of ore would be available.

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