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CHROMITE DEPOSITS OF THE NORTH ELDER CREEK AREA TEHAMA COUNTY, CALIFORNIA

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CHROMITE DEPOSITS OF THE NORTH ELDER CREEK AREA, TEHAMA COUNTY, CALIFORNIA

By G. A. Rynearson

ABSTRACT

The principal chromite deposits of Tehama County, Calif., are in the western part of the county, within an area of about 1½ square miles in the canyon of North Elder Creek. They occur in a northward-trending tabular mass of peridotite, which has been intruded into rocks of the Franciscan (?) formation of probable Jurassic age, and the Knoxville formation of Jurassic and Cretaceous age, along their contact. The Franciscan (?) formation is made up of schist, phyllite, conglomerate, and chert. The basal rocks here assumed to be the lowermost part of the Knoxville formation consist of argillite and altered volcanic rocks, and the rocks definitely assigned to the Knoxville consist of shale, sandstone, and conglomerate.

The peridotite mass consists of saxonite, dunite, and wehrlite, listed in order of abundance, and of serpentine derived from the alteration of these rocks. Associated with the peridotite, and chiefly localized in its numerous shear zones, are dikes of pyroxenite and diorite and reefs of rodingite. Dunite, or serpentine derived from dunite, is the host rock of all the ores, which consist partly of disseminated chromite and partly of massive chromite in lenses, irregular stringers, and ellipsoidal nodules. Most of the deposits including the largest, consist of low-grade ore in which the chromite is either evenly disseminated or concentrated in streaks and layers. Most of the ore produced, however, has come from deposits consisting of lenses of massive chromite or of a combination of disseminated chromite and irregular stringers of chromite. The low-grade disseminated ores require concentration to make a marketable product, whereas the massive ores may be shipped crude. The ore shipped recently has had a Cr:Fe ratio of more than 3:1 and a Cr_2O_3 content averaging 44 percent. Except in one small lens of ore, the chromite in the deposits is of good quality, containing more than 50 percent of Cr_2O_3 and having a Cr:Fe ratio of 2.9:1 to 3.4:1. It should therefore be possible to produce metallurgical concentrates from the ores.

The Grau mine, which was the principal producer in the area during World War II, may have reserves of almost 40,000 short tons of concentrating ore, containing about 10 percent of Cr_2O_3, and 4,000 short tons of shipping ore, containing about 44 percent of Cr_2O_3. Adjoining the Grau is the West Pit deposit, which may have reserves of about 8,000 short tons of concentrating ore similar to that of the Grau mine. The largest deposit

in the area is in Mill Gulch. It consists entirely of concentrating ore, of which it may have reserves of about 58,000 short tons containing nearly 12 percent of Cr_2O_3. Of the 13 other known deposits in the area, only 2 appear to have appreciable reserves of either concentrating or shipping ore, and both of these would have to be further developed before any close estimate of their reserves could be made.

F. Y. McLaughlin and G. A. Applegarth of San Francisco, Calif., have operated the Grau mine since October 1941, and they also hold leases on all the other deposits in the North Elder Creek and adjoining areas.

INTRODUCTION

The chromite deposits described in this report are in secs. 8, 9, 16, and 17, T. 25 N., R. 7 W., Tehama County, Calif., about 35 miles west of the town of Red Bluff (pl. 65). They occur within an area of about 1½ square miles in the canyon of North Elder Creek, on the eastern edge of the northern Coast Ranges of California. The steep slopes of the canyon rise to a height of more than 1,000 feet above the creek, which contains sufficient water for mining and milling purposes. The climate of the region permits mining throughout the year. The summer months are hot and dry, but occasional rains fall in September and October and heavy rains are frequent from November to March.

Ores contracted for by the Metals Reserve Co. are trucked to Red Bluff over an all-weather road and then shipped to the stock pile at Sacramento via the Southern Pacific Railroad, Small lots of ore are trucked to the Metals Reserve Co. stock pile at Anderson, which is 20 miles north of Red Bluff on U. S. Highway 99 W.

The field work on which the major part of this report is based was begun in August 1941, and continued to the end of October. The field party consisted of G. A. Rynearson, R. T. Littleton, P. W. Richards, and C. T. Bressler, and was under the supervision of F. G. Wells. F. W. Cater, Jr., assisted in the field work for a week. The district has been revisited several times by the writer to obtain additional information. Mapping in the area was done by plane-table methods with triangulation control. Hearty cooperation and many courtesies were given the field party by Messrs. McLaughlin and Applegarth and their associates, and Mr. S. D. Furber supplied valuable information. Many helpful suggestions were offered by F. C. Calkins, J. W. Peoples, and F. G. Wells during the preparation of this report.

HISTORY AND PRODUCTION

Chromite deposits have been known to exist in Tehama County since 1886,1/ and they have been worked intermittently since 1890. Although chromite has been produced in appreciable quantity from the Kleinsorge mine to the south, the Tomhead and Tedoc mines to the north, and several scattered deposits, the major part of the production credited to the county has come from deposits in the North Elder Creek area.

1/ Preston, E. B., 10th Ann. Rept. of the State Mineralogist, California Min. Bur., p. 692, 1890.

The first shipments of chromite from the area were made in 1893 by the Tehama Consolidated Chrome Co., which operated properties in sec. 16 from 1890 to 1896. J. A. Heslewood continued the operations from 1896 to 1898. Although some ore was shipped in 1911, the deposits were mostly idle from 1898 to 1915. From 1915 until the collapse of the market in 1918, these and other deposits in the county were worked by the Noble Electric Steel Co., the American Refractories Co., and several other operators. A mill designed to treat low-grade ores was erected in 1918, but did not get into production. It is reported that some ore was shipped in 1924, but this ore may have been mined during previous operations. An attempt to reopen the deposit of low-grade ore in the NE¼ sec. 16 was made in the years 1928 to 1930 by Savage, Savage & Furber, and they produced approximately 80 tons of concentrates in the old mill. The present operations were started in 1941, when F. Y. McLaughlin and G. A. Applegarth obtained leases on secs. 16 and 17 and began producing ore from the Grau mine. Since that time, these operators have obtained leases on all the principal deposits in the district, but their operations have been confined largely to the Grau mine.

Chromite production from Tehama County is shown in the following table:

Table 15.—Production of chromite from Tehama County, California

Year	Kind of ore	Ore shipped (long tons)	Grade (percent Cr_2O_3)
1890 1/	Crude ore	2,207	...
1891 1/	Do.	1,069	...
1894 1/	Do.	1,680	...
1895 1/	Do.	950	...
1896 1/	Do.	56	...
1897-1910	......	None	...
1911 1/	Crude ore	13	...
1912-14	......	None	...
1915 2/	Crude ore	42	...
1916 2/	Do.	2,600	...
1917 2/	Do.	2,053	...
1918 2/	Do.	3,261	...
1919-23	......	None	...
1924 1/	Crude ore	188	...
1925-28	......	None	...
1929 3/	Concentrates	80	49
1930-41	......	None	...
1942 3/	Crude ore	961	45
1943 3/	Do.	1,419	43
Total.........		16,579	

1/ Compiled from published and unpublished data of the U. S. Geological Survey and the U. S. Bureau of Mines.

2/ Compiled from published and unpublished data of the California Division of Mines.

3/ Compiled from records of S. D. Furber, McLaughlin & Applegarth, C. Geany, and L. Ehorn.

The deposits are mentioned by Fairbanks 2/ and are briefly

2/ Fairbanks, H. W., Notes on the geology and mineralogy of Tehama, Colusa, Lake, and Napa Counties: 11th Ann. Rept. of the State Mineralogist, California Min. Bur., pp. 55-56, 1891-92.

described by Logan 3/ and by Allen.4/

GEOLOGY

The chromite deposits in the North Elder Creek area occur in bodies of dunite which are part of a heterogeneous, sill-like mass of ultramafic rocks, which are rich in olivine (peridotite) and may collectively be called peridotite. Here as elsewhere, these rocks are more or less altered to the mineral serpentine, and the rocks themselves are popularly known as serpentine. The peridotite is cut by small dikes of pyroxenite and diorite and by reefs of rodingite, which is essentially an altered diorite. This mass of peridotite and associated rocks has a northerly trend and is one of many such masses that occur at intervals along the eastern edge of the northern Coast Ranges. It is mainly bounded on the west by phyllites and schists tentatively assigned to the Franciscan formation, and on the east by sedimentary rocks of the Knoxville formation (pl. 66). Small bodies of argillite and altered volcanic rocks of uncertain age, here assigned tentatively to the Knoxville formation, occur along the eastern and western borders of the peridotite mass. In the area mapped, the peridotite is highly sheared and altered to serpentine along its borders, and its eastern part is shattered and partly altered to magnesite.

Franciscan formation

The oldest rocks in the area lie to the west of the peridotite mass. They are metamorphosed sedimentary and volcanic rocks, tentatively assigned to the Franciscan formation on the basis of their resemblance to rocks known to belong to this formation exposed in other areas. The Franciscan formation is thought to be of Jurassic age. Although no attempt was made to distinguish the types of rock in this unit on the map, mica and chlorite phyllites and schists and occasional layers of quartzite, conglomerate, and chert were noted in the field. Veins and small lenticular masses of quartz are abundant in these rocks.

Most of the rocks in the Franciscan formation are green or grayish-green and weather brown, but some of the chert is reddish. The foliation is believed to be parallel to the bedding, or nearly so, and its strike is roughly parallel to the contact with the peridotite. Part of the mica schist is highly crumpled and coarsely crystalline.

Some of the phyllites and schists are doubtless of sedimentary origin as they contain a few thin layers of quartzite or are interbedded with thicker layers of quartzite, conglomerate, and chert. Although many of the chloritic rocks may have been derived from tuffaceous sediments, some, which are more massive and less foliated than the typical phyllites and schists, are believed to have been derived from flows or sills of basalt or andesite, or both. Conclusive evidence of a volcanic origin is apparently lacking in this area, but similar rocks that exhibit unmistakable volcanic structures have been found in the Franciscan elsewhere.

3/ Logan, C. A., in Bradley, W. W., and others, Manganese and chromium in California: California Min. Bur. Bull. 76, pp. 206-209, 1918.

4/ Allen, J. E., Geological investigations of the chromite deposits of California: California Jour. Mines and Geology, vol. 37, pp. 132-133, 1941.

Knoxville formation

Argillite and metavolcanic rocks.—Several irregular masses of slightly metamorphosed sedimentary and volcanic rocks occur along the eastern and western borders of the peridotite. As these rocks bear a closer resemblance to Knoxville than to Franciscan rocks, they are assumed to represent the lowermost part of the Knoxville formation, and therefore are probably of Upper Jurassic age. Dark-gray and black argillite, usually thin bedded, is the predominant sedimentary rock in these areas, but there are beds of gray arenite and brown grit, composed of grains or fragments of quartz, feldspar, and volcanic material embedded in an argillaceous matrix. Recrystallization is not evident, but fracture cleavage and some pencil structure have been developed. The volcanic rocks include grayish-green andesitic lava and agglomerate, which both weather brown. They are now partially altered to greenstone containing considerable epidote or clinozoisite and some pyrite. Their flow structures have long since been destroyed, but some vesicular structures are still evident. Being more resistant to erosion than other rocks in the area, the volcanic rocks form prominent topographic features.

Shale and sandstone.—In a large area of sedimentary rocks east of the peridotite, several poorly preserved invertebrate fossils have been found that indicate that these rocks are probably part of the Knoxville formation, of Upper Jurassic and Lower Cretaceous age.5/ The relation of these rocks to the argillite and volcanic rocks is obscure, as the original contacts of the two units have been disturbed by faulting and by the intrusion of the peridotite.

In the area mapped, most of these rocks are black, thin-bedded shales and siltstones that weather gray. A few beds of fine-grained sandstone are present, and beds of conglomerate occur some distance east of the peridotite. Some of the shales are limy, and numerous veinlets of calcite and gypsum cut the beds.

The strata strike N. 20°-30° W. and have moderate to steep eastward dips. Near their contact with the peridotite they are highly contorted and faulted, and in some places they are overturned. As the peridotite contact is approached, the shales become harder and blacker, suggesting a slight thermal metamorphism by the peridotite.

Peridotite and serpentine

The mass of ultramafic rocks is nearly 1½ miles wide in the canyon of North Elder Creek, while 3 miles to the north it is only about three-quarters of a mile wide, and 3 miles to the south it is 2 miles wide. It is apparently tabular, with a strike of N. 15° W., roughly parallel to that of the rocks into which it has been intruded, but it dips westward. Three varieties of peridotite have been distinguished in the area. Listed in order of their abundance they are: saxonite, dunite, and wehrlite. Locally, especially near contacts with other rocks, all these peridotites are largely altered to serpentine, and where this alteration has gone so far that the original variety could not be determined, the peridotite is referred to as serpentine.

5/ Fossils identified by Ralph W. Imlay.

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Saxonite.—As used in this report, the name saxonite is applied to olivine-rich rocks that contain more than 10 percent of the rhombic pyroxene, enstatite. The typical saxonite of this area contains 20 to 30 percent of enstatite, and most of it contains chromite as an accessory constituent.

When fresh, the rock is dark green or gray. When weathered, it is brown or reddish brown, and the enstatite crystals, being more resistant than olivine, commonly stand out in relief on the weathered surfaces. Much of the saxonite is almost completely altered to serpentine, and even the freshest rock is 30 to 40 percent altered.

Dunite.—Dunite is a variety of peridotite in which olivine strongly predominates; it may, however, contain a few scattered crystals of pyroxene, especially near contacts with saxonite or wehrlite. Appreciable concentrations of chromite occur only in the dunite, and all of the dunite contains more than one-half of 1 percent of chromite.

The fresh rock is dark green and weathers first to a light-green and then to a buff color, sometimes with a reddish cast. The more highly serpentinized dunite is dark green to black and very dense. The buff color and uniform grain of the weathered surface, and the absence or extreme scarcity of pyroxene, are common characteristics that serve to distinguish dunite from other varieties of peridotite in the field.

Wehrlite.—Wehrlite is relatively scarce in the area, having been observed in only two or three places. It differs mineralogically from saxonite in that it contains a monoclinic pyroxene, which in this case is augite with a fine lamellar parting, commonly known as diallage. The rock usually contains about equal amounts of diallage and olivine, but the proportion varies considerably in some places. A trace of chromite is occasionally present.

The olivine is almost completely altered to serpentine, whereas the diallage is only slightly altered. Because of this difference in degree of alteration, the diallage crystals separate rather easily from the altered olivine and thus impart a characteristic hackly texture to the wehrlite. Another distinguishing characteristic is the mottled appearance of fresh surfaces, due to the color contrast between the dark-green altered olivine and the light-green diallage. As nearly all the wehrlite observed was highly brecciated, its relations to the other varieties of peridotite could not be determined.

Serpentine.—All of the serpentine in the area has been derived from peridotite. Although much of the rock mapped as peridotite would be called serpentine by many writers, the names of the original varieties have been retained here whenever their origin could be ascertained. For example, it is sometimes possible to recognize remnants of enstatite crystals in serpentine derived from saxonite by their cleavage and by their difference in color from the serpentine derived from olivine: on weathered surfaces they appear darker than their matrix, while in unweathered rock they show a silvery color and their matrix appears relatively dark.

Most of the thoroughly serpentinized peridotite is thoroughly sheared. In this highly altered rock, the serpentine fragments are characterized by slick, curved surfaces having a waxy luster. Their surfaces are light to dark bluish-gray and weather almost white, but when they are broken between shear planes, their inner parts are seen to be dark green or black.

Dike rocks

A few thin dikes of pyroxenite cut the saxonite and dunite. They consist largely of coarse-grained enstatite with a small amount of olivine, and contain no chromite. At no place were the dikes observed to be more than 4 inches thick, and most have a thickness of only about 1 inch. They are doubtless closely related to the peridotite.

The peridotite is also cut by numerous fine- to medium-grained dikes, which have a dioritic composition but a diabasic texture. They originally contained approximately equal amounts of andesine ($Ab_{68}An_{32}$) and pigeonite, together with 5 to 10 percent of titaniferous magnetite or ilmenite or both. Now, however these minerals are more or less altered to saussurite, uralite, and leucoxene. Some of the dikes may have contained a small amount of hornblende as an original constituent, but no evidence of olivine could be found.

The diorite dikes appear to be localized along zones of shearing in the peridotite and serpentine. Commonly they are tabular, but they may have irregular shapes (see pls. 69 and 70). They range in thickness from less than a foot to more than 100 feet, and their lengths are commonly not more than two or three times their widths. Some of the dikes appear to pinch out at depth to become isolated masses or "knockers" in the sheared serpentine.

There are also numerous reeflike masses of dense, fine-grained, light-colored rock in the peridotite, which are related to the diorite and are also localized in shear zones. Similar rocks associated with peridotites and gabbros in New Zealand have been called rodingite,6/ and this name is therefore employed here.

Although the rodingite was observed to grade into the diorite in several places, many of the reeflike masses are not closely associated with it. The rodingite consists of grossularite, fine-grained pyroxene (probably diopside), zoisite, chlorite, antigorite, and fine-grained aggregates of other minerals that could not be identified. The reefs are unusually rich in calcium, and it is believed that they represent the end-stage of the diorite intrusion, and that the abnormal composition is due to the addition of constituents derived from the peridotite by the hydrothermal action of solutions accompanying the diorite.

Alteration

All the rocks in the area, except some of the Knoxville sedimentary rocks, have been visibly altered in one way or another. The Franciscan (?) rocks have been partially transformed into phyllites and schists by local metamorphic processes. The argillaceous sediments assumed to be lowermost Knoxville have been changed into argillites, and the volcanic rocks associated with them have been partially propylitized. The shales of the Knoxville formation adjacent to the eastern border of the peridotite seem to have undergone some thermal alteration not intense enough to change them into hornfels. But the most notable alterations have been undergone by the ultramafic rocks and the dikes associated with them.

The ultramafic rocks have all been affected in some degree by hydrothermal alterations, by far the most widespread of which

6/ Grange, L. I., On the "Rodingite" of Nelson: New Zealand Inst. Trans., vol. 58, pp. 160-166, 1927.

is serpentinization; all of them contain a little serpentine, and some have been completely serpentinized. A general serpentinization probably occurred at an early state, and a more intense and localized alteration took place after faulting, fracturing, and shearing of the mass had opened numerous channels for the easy access of hydrothermal solutions. In the process of serpentinization, olivine was altered to antigorite and enstatite was altered to bastite. A small amount of magnetite also was formed; dustlike particles of it are enclosed in the serpentine minerals, and in highly serpentinized areas enough magnetite seems to have been formed to deflect the compass needle several degrees. A little talc was produced in places, and veinlets of chrysotile are common almost everywhere. Thin sections of ores from the principal deposits contain no unaltered olivine except in minute blebs entirely enclosed by solid chromite. Hydrothermal kämmererite and uvarovite are associated in small amount with some of the higher-grade ores.

Peridotite that has been thoroughly shattered, especially some of that in the eastern part of the mass, is commonly altered in part to magnesite. Such alteration is best exemplified in Mill Gulch, where some of the highly sheared serpentine is more than half altered to magnesite. Some of the magnesite forms pisolitic nodules a small fraction of an inch to about 1 inch in diameter. Magnesite also occurs in open fractures as prismatic crystals as much as 2 inches in length and as drusy groups of minute acicular crystals. It is believed that the alteration to magnesite took place late in the history of the mass, presumably by the action of circulating carbonate ground waters upon the magnesian silicates, forming magnesite and liberating silica, which was carried away in solution. Seemingly irrefutable evidence that the deposition of the magnesite was effected by meteoric waters has been found in this area and elsewhere. Perhaps of most significance is the fact that the prismatic and acicular magnesite crystals found in open fractures are usually unbroken, indicating that they must have been formed recently or they would have been crushed during the intense deformation that the serpentine has undergone. Furthermore, the deposition of magnesite on the walls of some of the old mine workings, and cementation of some of the talus and stream gravels, shows that magnesium is being taken into solution at the present time. Although only a few veinlets of opaline silica have been found in this area, numerous veinlets of of similar material have been found elsewhere in all stages of consolidation, from a soft silica gel to hard opal or chalcedony. These veinlets are assumed to represent the silica that was carried away and redeposited by the solutions responsible for the deposition of the magnesite.

The diorite dikes have been altered in various degrees, but most of them are only moderately altered. Feldspar has been partly altered to saussurite, pyroxene to uralite, and titaniferous magnetite or ilmenite to leucoxene. The rodingite reefs represent an alteration of the diorite and adjacent peridotite with notable addition of calcium. The serpentine bordering the dikes and reefs is characteristically dark in color and very dense, indicating that the peridotite and serpentine were altered by the dikes.

Structure

Although, because of the limited amount of time available for field work, no attempt has been made to map the complicated structural details of the rocks in the area, a few general statements regarding the structure can be made. The major structural feature is the tabular mass of ultramafic rocks about 1½ miles wide that has been intruded into eastward-dipping Franciscan and Knoxville rocks along their contact. The attitude of the ultramafic mass is not readily apparent, but the traces of its contacts with the enclosing rocks indicate that it is inclined steeply westward. The mass thus appears to cut across the bedding of the older rocks, and it may possibly have been intruded along a preexisting fault. Isolated masses of supposedly lowermost Knoxville rocks found in the ultramafic mass near each of its borders apparently were carried upward by the intruding mass, rather than faulted into their present positions.

As its contacts are highly sheared, the physical nature of the peridotite at the time of intrusion is somewhat obscure. The intense shearing along its borders and the discordance of the primary structures within the mass to these borders suggest that it may have been relatively rigid or even completely solidified at the time of its intrusion, but a slight thermal alteration of the Knoxville sedimentary rocks near the eastern contact indicates that the temperature of the mass was still rather high.

Primary internal structures of the peridotite are best reflected by the elongate bodies of dunite, which have a rough alinement and generally trend about N. 35° W., with a moderate northeasterly dip. In some of the dunite bodies there is poorly developed sheeting and a layering of chromite crystals, both approximately parallel to the major axes of these bodies. The attitudes of the major structural elements of most of the ore bodies are also concordant with those of the enclosing dunite bodies. It is believed that the sheeting resulted from flowage or fracture or both prior to complete consolidation, and that the layering of the chromite represents primary flowage.

Faults, fractures, shear zones, and breccia zones are common throughout the peridotite, but they are most prevalent in the eastern part of the mass and near contacts with other rocks. It is notable that the eastern part of the mass is generally shattered, possibly because of attrition on the under surface of the mass as it was intruded. Many of the faults and fractures apparently fall into no definite system, but most of the shear zones are approximately parallel to the primary structures and to adjacent contacts. Throughout some areas several hundred feet wide the rocks are so completely sheared that their original character is almost obliterated, and zones of brecciation tens of feet wide are numerous.

Because they are mainly localized within the shear zones in the peridotite, many of the diorite dikes and rodingite reefs have attitudes similar to those of the shear zones. A few, however, have attitudes that have no apparent relation to either the primary or secondary structures of the peridotite mass.

ORE BODIES

Mineralogy

The only ore mineral found in any of the deposits is chromite, whose formula is generally given as $(Fe,Mg)O \cdot (Cr,Fe,Al)_2O_3$. Recent studies,7/ however, have indicated that chromite is an isomorphous mixture of ferro-chromite ($FeO \cdot Cr_2O_3$), magnesio-

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7/ Stevens, R. E., Composition of some chromites of the Western Hemisphere: Am. Mineralogist, vol. 29, pp. 1-34, 1944.

chromite ($MgO \cdot Cr_2O_3$), Spinel ($MgO \cdot Al_2O_3$), hercynite ($FeO \cdot Al_2O_3$), magnetite ($FeO \cdot Fe_2O_3$), and magnesio-ferrite ($MgO \cdot Fe_2O_3$). Chromites from different localities contain these compounds in widely differing proportions. In table 16 are shown some partial and complete analyses of some of the chromites from the North Elder Creek area.

As these analyses show, most of the chromite from the area has a high chromium content and a high Cr:Fe ratio. Sample GAR-140-42 is unusually low in chromic oxide, but is from a small lens and is not thought to represent a type that occurs in significant quantity in this district.

Uvarovite, the green chromium garnet, and kämmererite, the purple chromium chlorite, are occasionally present in the richest concentrations of chromite. Olivine ($(Mg,Fe)_2 \cdot SiO_4$) is rarely present in the ores, but serpentine ($H_4Mg_3Si_2O_3$), its alteration product, is the principal gangue mineral. Magnesite ($MgCO_3$) and talc ($H_3Mg_3(SiO_3)_4$) also occur in small quantity.

Character of ore

Four distinct types of ore have been found in the area. In order of abundance, these types are characterized respectively by disseminated chromite, by lenticular masses of chromite, by irregular stringers of massive chromite, and by nodules of chromite. Some ore bodies consist of only one type of ore; others consist of a combination of two or more types.

Most of the ore bodies consist of chromite grains disseminated in a matrix of serpentine. In some of them the chromite is evenly disseminated; in others it is concentrated in streaks and layers. The diameters of the grains range from 0.25 to 5 millimeters (60 mesh to 3 mesh) and average about 1 millimeter (15 mesh). Where the grains are evenly disseminated they are nearly uniform in size and those in the higher-grade concentrations within the ore are larger than those in lean ore. In tenor the disseminated ores range from a few percent to about 80 percent chromite.

A few of the deposits consist of lenses of massive ore containing 90 to almost 100 percent chromite; there may or may not be lean disseminated ore on the margins of these lenses. The massive ores are usually coarse-grained.

One of the larger ore bodies consists of irregular stringers and small masses of chromite distributed at random in disseminated ore, the massive ore constituting about 15 percent of the total volume.

Several small bodies of ore contain ellipsoidal nodules of chromite whose longer axes range from 1 to 3 centimeters in length. Rarely do these nodules constitute more than 50 percent of the rock, and at no place is this type of material abundant enough to be mined even as milling ore. A lens-shaped group of 10 or 12 closely spaced nodules has been found in saxonite, and enstatite crystals were present in the matrix of the group.

Table 16.—Analyses of chromite from the North Elder Creek area
[M. K. Carron, analyst]

	GAR-143-42	GAR-141-42	GAR-144-42	GAR-142-42	GAR-140-42
Concentrate:					
Cr_2O_3	56.95	55.86	55.01	54.86	35.58
Al_2O_3	....	12.04	....	12.70	....
Fe_2O_3	....	5.22*	....	4.57*	....
FeO	....	9.62*	....	11.59*	....
MgO	....	16.26	....	15.07	....
MnO	....	.16	....	.16	....
CaO	....	.10	....	.04	....
TiO_2	....	.29	....	.31	....
SiO_2	....	.76	....	.80	....
H_2O+	....	.16	....	.12	....
H_2O-	....	None	....	.04	....
P_2O_5	....	.02	....	.01	....
S	....	.01	....	None	....
Total	....	100.50	....	100.27	....
Cr	38.97	38.23	37.65	37.57	24.33
Fe	11.50	11.13	12.86	12.20	10.11
Cr:Fe	3.39	3.44	2.93	3.08	2.41
Ore:					
Cr_2O_3	47.51	49.00	52.22	34.58	34.37
Cr	32.51	33.53	35.73	23.67	22.82
Fe	10.48	10.15	12.96	9.48	10.83
Cr:Fe	3.10	3.30	2.76	2.50	2.11
Chromite	83.4	87.6	95.3	63.0	96.6
Impurity	....	Serpentine	....	Serpentine	....

* Calculated from total iron to give 1:1 ratio $RO:R_2O_3$. All the above concentrates were nonmagnetic.

GAR-143-42. Fine-grained high-grade disseminated ore from the West Pit of the Grau Mine.
GAR-141-42. Crude ore from the Grau mine.
GAR-144-42. Crude ore from lens in gulch at lower workings of the Noble Electric Steel Co.
GAR-142-42. Disseminated ore from the Mill Gulch area.
GAR-140-42. Crude ore from lens west of the Mill Gulch area.

Localization

Although chromite occurs as an accessory throughout the peridotite, concentrations of appreciable size are found only in the dunite. There is no apparent relationship between the size of the dunite mass and the proportion of chromite it contains: a relatively small mass of dunite may enclose one or more minable ore bodies, whereas a much larger mass may have no chromite concentrations.

In most cases, the longer axes of the ore bodies and the individual layers of chromite are roughly parallel to the longer axes of the enclosing dunite mass. Locally, however, these relations have been disturbed by flowage prior to consolidation and by intense shearing.

Origin

The chromite deposits in the North Elder Creek area are similar in many respects to those that occur in the same belt of ultramafic rocks farther south in Glen County.8/ Like those deposits, they exhibit textural and structural features that are believed to indicate that the chromite is an original constituent of the enclosing rock, and that it crystallized before the pyroxenes and the major part of the olivine. Hydrothermal chromite is scarce if not altogether absent.

Size and grade of ore bodies

A large proportion of the ore in the area is low-grade milling ore of the disseminated type. Ore bodies containing this type of ore generally average about 10 percent Cr_2O_3, but the tenor varies greatly within short distances, and some of the ore is rich enough to be mined and shipped crude. The largest body of disseminated ore is 200 to 225 feet long, 5 to 32 feet thick, and perhaps as much as 100 feet wide. This ore body may have been much larger originally, as it occurs in a zone of intense shearring along which fragments of this or other ore bodies are scattered for 850 feet. Some of the smaller bodies of disseminated ore in the district are no more than 10 feet long and 1 or 2 feet thick; most of these are too small to be mined.

The lenses of massive chromite, which have hitherto been the chief source of production, also have a wide range in size. As the largest of these has already been partly mined, its dimensions can only be approximated. One report states that it was 3 to 10 feet thick, and the extent of the workings indicates that it could have been about 50 feet long. Two of the small lenses now exposed are 10 to 15 feet long and 1 to 5 feet thick. One ore body containing both massive and disseminated ore has a length of 120 feet and a maximum thickness of 50 feet, and its total width may be about 100 feet.

The ore shipped recently has had a Cr:Fe ratio of more than 3:1 and a Cr_2O_3 content averaging 44 percent. Except in one small lens of ore, the chromite in the deposits is of good quality.

8/ Rynearson, G. A., and Wells, F. G., Geology of the Grey Eagle and some nearby chromite deposits in Glenn County, Calif.: U. S. Geol. Survey Bull. 945-A, pp. 8-12, 1944.

containing more than 50 percent Cr_2O_3 and having a Cr:Fe ratio of 2.9:1 to 3.4:1. It should therefore be possible to produce metallurgical concentrates from the ores.

Reserves

Reserves of the deposits have been subdivided into three classes according to the reliability of the data used in the calculations. In this report, only ore that has been mined and is on the dumps, and whose grade has been established, is called measured ore. Ore whose volume has been computed from dimensions that are partly known and partly indicated by geologic evidence is called indicated ore. Ore whose volume has been computed wholly on the basis of geologic inference is called inferred ore. In all of the calculations it has been assumed that 10 cubic feet of unbroken ore weighs 1 short ton. As there has been little exploration beyond exposed faces of ore, most of the reserves fall into the indicated and inferred classes. Reserves of concentrating and of shipping ore in each class are tabulated on page 204 for each of the notable deposits in the area.

ORE DEPOSITS

Grau mine

The Grau mine, in the NE¼ sec. 17 (pl. 66) is the only mine in the area from which ore was being produced in 1943. When it was first mapped, in October 1941, its development consisted of a deep trench, an open cut, and 110 feet of underground workings in four adits (see pl. 67). By April 1943, most of the old workings had been obliterated by the enlargement of the open cut, and two new adits had been started in the face of the cut (fig. 21). The operators plan to develop the mine further from another adit, about 75 feet lower than the lowest bench level of the cut.

The ore occurs in an irregular mass of dunite, which is surrounded by saxonite. Many faults and shears have broken the dunite and have helped to give it an irregular shape. Most of the ore occurs in comminuted dunite. A diorite dike and a reef of rodingite follow shear zones in the saxonite.

The ore body consists partly of irregular stringers and small pods of nearly massive chromite, partly of chromite disseminated in the dunite. No definite arrangement of the pods or layering of the disseminated ore has been recognized, but the ore body as a whole trends about N. 80° W., and dips about 40° N. It has been exposed in the open cut for 120 feet along the strike, but the eastern end is covered with talus. The average thickness of the ore is about 30 feet. Magnesite and sheared serpentine occur along the fractures, and some kämmererite and a little uvarovite occur with the massive chromite. Much of the low-grade disseminated ore is embedded in dense serpentine, which is almost black in color when broken and which is difficult to distinguish from the high-grade ore.

The average Cr_2O_3 content of 44 samples from the deposit, taken before mining was started in 1941, was 16.5 percent. A high-grade ore is hand-sorted for shipment and the reject is placed on the dump for possible concentration in the future. Production from October 1941 to January 1, 1944, amounted to 2,419 long tons of shipping ore, which averaged 44 percent Cr_2O_3, and had a Cr:Fe ratio of 3.1:1, and 30,950 long tons of concentrating ore, averaging approximately 10 percent Cr_2O_3. The ratio of concentrating ore to shipping ore (44 percent Cr_2O_3) in the ore body before it is

Table 17.—Reserves of chromite deposits in the North Elder Creek area, Tehama County, California, April 1943

Mine or area	Concentrating ore (short tons)					Shipping ore (short tons)				
	Measured	Indicated	Inferred	Total	Percent Cr_2O_3	Measured	Indicated	Inferred	Total	Percent Cr_2O_3
Grau mine............	16,000	7,700	15,400	39,100	10	--	1,300	2,600	3,900	44
West Pit of Grau mine	--	4,000	4,000	8,000	8.8	20	--	--	20	40
Noble Electric Steel Co. workings:										
Upper............	--	1,000	--	1,000	10	--	--	--	--	--
Lower............	--	2,900	--	2,900	10	20	50	20	90	47
Mill Gulch area......	--	27,000	31,000	58,000	11.6	--	--	--	--	--
Low-grade prospect...	--	--	--	--		25	--	25	50	32
Totals............	16,000	42,600	50,400	109,000	--	65	1,350	2,645	4,060	--

mined is about 6:1, but in actual mining practice the ratio is increased to about 7:1 because of unavoidable addition of high-grade fines to the concentrating ore.

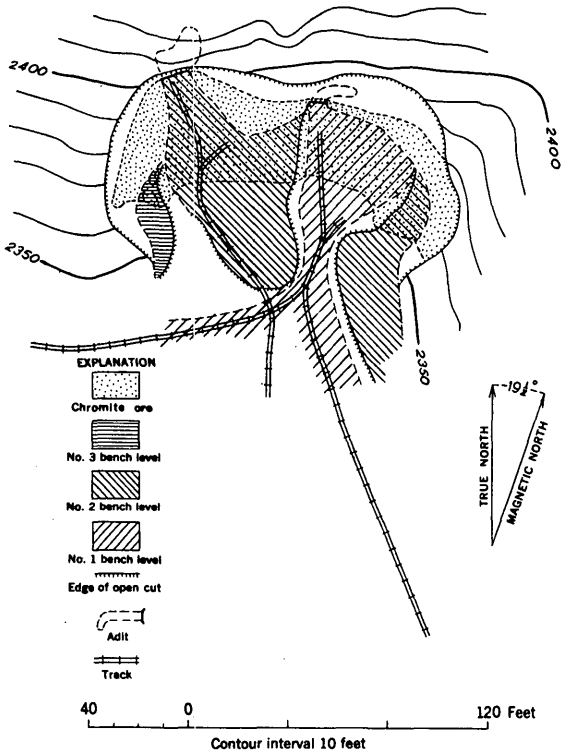

Figure 21. Geologic sketch map of the new workings of the Grau mine.

Certain geologic assumptions used in computing reserves in 1941 have been closely borne out by the mining operations. There is still no indication that the amount of ore is diminishing with depth, and the grade has remained relatively constant. Probably, therefore, the ore body extends at least 25 feet below the depth to which it had been mined in April 1943. Assuming a length of 120 feet, an average thickness of 30 feet, and a depth of 25 feet, it is estimated that the ore body contains 9,000 short tons of indicated ore made up of approximately 7,700 short tons of concentrating ore, containing 8 to 10 percent Cr_2O_3, and 1,300 short tons of shipping ore, containing 44 percent Cr_2O_3. If the ore body extends another 50 feet in depth, reaching the level of the proposed tunnel, the total reserves are three times as large as this. It should be noted that the estimates of reserves given above are based on information available in April 1943. The proposed tunnel should give a more definite basis for estimating reserves.

West Pit of Grau mine

The West Pit deposit, in the NW$\frac{1}{4}$ sec. 17, is developed by three small pits, two short prospect trenches, and a shallow bulldozer cut. The geology of the deposit is partly obscure, as the rocks are exposed only in the workings and road cuts; elsewhere they are covered with 3 to 6 feet of talus (pl. 68). The ore is in a small tabular mass of serpentinized dunite, which is enclosed by saxonite. The dunite strikes about N. 35° W. and dips at a moderate angle to the northeast. Its west contact with saxonite is a shear zone, but the northeast and southwest contacts are probably undisturbed.

Chromite grains of nearly uniform size, averaging about 1 millimeter in diameter, are irregularly disseminated in the serpentinized dunite. In general the ore is of low grade, but it includes small bodies of high-grade disseminated ore and of massive chromite. A weighted average of the Cr_2O_3 content in 25 samples analysed for Wright, Dolbear & Co. is 8.8 percent. Although most of the ore is of milling grade, there is about 20 tons of hand-sorted, high-grade ore on the dump, averaging 40 percent of Cr_2O_3, so that some ore of shipping grade probably could be obtained from the deposit.

If the ore body is 100 feet long, 20 feet in average thickness, and 20 feet in depth down the dip, its reserves of indicated ore are about 4,000 short tons; but if, as is possible, the depth down the dip is 40 feet, the combined reserves of indicated and inferred ore are 8,000 short tons.

The operators plan to strip the talus from the ore body, and then to drive a tunnel to intersect the projection of the ore 25 to 50 feet down the dip. It is hoped that sufficient high-grade ore can be found in this manner to make the venture profitable. The low-grade ore is to be stock-piled for future milling.

Noble Electric Steel Co. workings

Two chromite deposits in the NW¼SE¼ sec. 16 (pl. 66) were worked by the Tehama Consolidated Chrome Co. and J. A. Heslewood in the years 1890 to 1898 and by the Noble Electric Steel Co. in the years 1915 to 1918. Both deposits are in a steep gulch, and are developed, respectively, by what are generally known as the upper workings and the lower workings.

Upper workings.—The geology at the upper workings is obscured by a landslide over the face of the old open cut. A report by the California State Mining Bureau 9/ indicates that the upper ore body was an irregular, flat-lying lens of massive chromite 3 to 10 feet thick. According to S. D. Furber, mining was carried on from three tunnels, one of which was at least 150 feet long when operations were suspended in 1918. The entrances to these tunnels are now covered by a landslide; a small amount of work done with a bulldozer in 1942 failed to uncover them.

The dump is believed to contain at least 1,000 short tons of concentrating ore, which probably has an average Cr_2O_3 content of less than 10 percent. It will be necessary to reopen the underground workings before the amount of ore remaining in the deposit can be estimated, and the operators are tentatively planning to do the necessary exploration.

Lower workings.—Development work at the lower workings consists of a large open cut, three small open cuts, an inclined shaft now filled with debris, and a short opening on the east side of the gulch (pl. 69). Mr. Furber states that the shaft is 30 to 40 feet deep, and that a drift was being driven eastward,

9/ Bradley, W. W., and others, Op. cit., pp. 206-208.

in ore, from the bottom of the shaft at the time the mine was abandoned.

The ore occurs in a tabular mass of dunite, which dips steeply to the northeast and is bounded above and below by saxonite. Both rocks are cut by at least four diorite dikes. The eastern contact of the dunite with saxonite is believed to be a shear zone, the dip of which is not apparent; the western contact is obscured by talus. A thin tabular mass of dunite containing a small outcrop of ore is exposed near the top of the ridge east of the gulch.

The main ore body strikes approximately N. 85° E. and dips 60° to 70° N. It is cut by a diorite dike that trends N. 15° E. and dips about 75° SE. Ore has been mined from both sides of the dike, and remnants of ore frozen to the dike indicate that at least part of the ore mined was massive chromite and high-grade disseminated ore. The ore now exposed at the collar of the shaft contains about 30 percent of chromite disseminated in the dunite. The western end of the ore body is bounded by a fault, but disseminated ore exposed near the diorite dikes to the northwest may represent a western extension of the ore body, offset on this fault. The eastern end of the ore body is highly sheared, and the position of a possible eastward extension would depend on the dip and direction of movement in the shear zone, neither of which could be determined.

A small lens of massive chromite is exposed in the bottom of the gulch, 165 feet east of and 60 feet higher than the collar of the shaft. About 20 short tons of high-grade ore has been mined from this lens and corded on the dump. As neither end of the lens has been delimited, and as the ore still in place has an average thickness of about 2 feet, the lens might possibly yield another 20 tons of ore. Layers of disseminated chromite adjacent to the lens have the same attitude as those in the main ore body.

Thin layers of chromite are exposed on the steep cliff above the mine workings, but there the chromite does not appear sufficiently concentrated to constitute minable ore.

If, as can be assumed, the main ore body is 70 feet long and 10 feet thick and extends 25 feet below the outcrop, it may contain 1,700 short tons of ore. Some of this perhaps could be sorted out as shipping ore, but most if not all would probably have to be concentrated. An estimate of inferred ore is not justified because of the limited knowledge of the deposit. There are probably about 1,200 short tons of low-grade concentrating ore in the dump, and the stream wash in the gulch between the upper workings and North Elder Creek may contain 50 to 100 tons of high-grade lump ore. The total reserves indicated in the areas of the upper and lower workings are thus estimated to be almost 4,000 short tons of concentrating ore and 90 to 140 tons of shipping ore.

Both past production and present indications justify further exploration and development of the lower workings deposit. The shaft and drift should be cleaned out to aid in determining to what depth the main ore body extends, and a possible western extension of the ore body should be looked for by trenching the slope west of the shaft. The operators will probably do this work.

Mill Gulch area

The Mill Gulch area, in the western part of the NE¼ sec. 16, is developed by four short adits, now partly filled and caved, and by several trenches and small open cuts (pl. 70). An old mill, erected in 1918 for the purpose of concentrating low-grade ores from this area, has been dismantled and razed.

The elongate mass of serpentinized dunite in which the ore occurs trends about N. 35° W., and has a moderate dip to the northeast. It is bounded above and below by saxonite, and several dikes of diorite and reefs of rodingite cut both saxonite and dunite. In some places the original contact between the dunite and saxonite is undisturbed; elsewhere both rocks are highly sheared along their contacts. Small masses of saxonite have been isolated in the dunite by the intense shearing, particularly at the northwest end of the area mapped. All the ultramafic rocks are highly serpentinized, especially those which have been sheared, and some of the serpentinized dunite has been further altered to magnesite.

All the dunite contains a little chromite, but only the dunite containing more than 10 percent of chromite is regarded as ore. The concentration of chromite grains in the ore ranges from less than 1 percent to nearly 100 percent, and the grains are more or less concentrated in parallel layers, which attain a maximum thickness of several feet. The diameters of the chromite grains range from 0.25 to 5 millimeters, and average about 1 millimeter. The richer layers of ore commonly contain the coarser grains.

The ore zone, of which only the richer part was mapped, crops out over a vertical range of 850 feet and extends for a distance of about 1,750 feet northwestward from the mouth of Mill Gulch. Along the greater part of the zone the ore bodies are only a few inches thick and a few feet long, but the two largest bodies known may contain appreciable reserves. As most of the smaller ore bodies are in a highly sheared matrix, they may not extend more than a few feet below their outcrops, but other similar bodies probably extend to greater depths. These ore bodies are believed to be remnants of one or more ore zones that may have been continuous before the shearing took place.

The main ore body is exposed on the east side of Mill Gulch, about 500 feet from North Elder Creek. It crops out for 200 feet along the strike, with a maximum thickness of 32 feet and a vertical range of 75 feet. This ore body is relatively undisturbed by shearing except at its southeast end, where it is offset by many small faults and is highly sheared. As the northwest end of the outcrop is obscured by talus and a fault, the ore body may continue in this direction and be more than 200 feet long. On the assumption, however, that its total length is only 200 feet, its average thickness 25 feet, and its extent down the dip 50 feet, the ore body is estimated to contain 25,000 short tons of ore. The ore body may possibly extend as much as 100 feet down the dip, in which case the amount of ore would be about 50,000 short tons; and if it be further assumed that the ore body extends along the strike for 25 feet beyond the fault and under the talus at its northwest end, the estimated total reserves would be 56,000 tons.

Analyses of 17 samples from the main ore body, made for Wright, Dolbear & Co., show a Cr_2O_3 content ranging from 3.48 to 28.16 percent and averaging 11.6 percent. The chromite in a specimen of ore containing 34.58 percent of Cr_2O_3, when analysed by the Geological Survey, was found to contain 54.86 percent of Cr_2O_3 and to have a Cr:Fe ratio of 3.08:1. This ratio is unusually high, and the results of milling operations during the period 1928-30 prove that the ore could yield concentrates containing more than 45 percent of Cr_2O_3, which would be of metallurgical grade.

Float and croppings of ore have been found along the strike of the zone for about 800 feet northwestward from the limits of the area mapped. Although no prospecting has been done in this part of the area, it is believed to contain one ore body averaging 5 feet in thickness, continuous for at least 100 feet along the strike and probably extending 20 feet or more down the dip. On the basis of these figures, the ore body is estimated to contain about 1,000 short tons of ore similar in grade to that of the main ore body.

Another 1,000 tons of ore probably could be mined from other outcrops scattered about the area, and a few tens of tons of milling ore might be recovered from the alluvial material in the gulch. The total reserves of indicated ore in the area are thus believed to be at least 27,000 short tons, and the reserves of indicated and inferred ore combined may be as much as 58,000 short tons. All of the reserves consist of ore that would have to be concentrated. It might be found that a commercial magnesite concentrate also could be recovered from some of the ore that contains an appreciable amount of magnesite.

Estimates of reserves could be made with more assurance, and would probably be increased if additional exploration were carried out. Core drilling would be difficult, if not impossible, because of the highly sheared condition of most of the rocks, but surface trenching of the scattered outcrops of ore would be very easy. Reopening and extending the lower adit also would yield much information regarding the depth to which the main ore body extends. The northwest end of this ore body should be delimited, which could probably be done by removing the talus and sinking one or more shallow test pits. The possibility of discovering additional ore bodies or proving the continuity of the ore indicated by outcrops in the northwestern part of the ore zone should be investigated. Removal of the overburden, by a bulldozer or some other means, should indicate whether further exploration would be necessary or desirable.

Minor deposits

Scattered over the area mapped are 11 chromite deposits in addition to those that have been described. All these have been prospected, and some may have yielded as much as 500 tons of ore in the past, but none of them appear to contain appreciable reserves.

One deposit, in the NE¼NW¼ sec. 16 (pl. 66), is developed by a small open cut, and approximately 25 tons of massive ore is corded on the dump. Another 25 tons of ore may possibly remain unmined in a flat-lying layer or lens of ore, about 2 feet thick and 5 feet long, exposed in the cut. Although the ore is nearly pure chromite—one specimen contained 96.6 percent—the Cr_2O_3 content of the best is only about 35 percent, and the average for the whole deposit is about 32 percent.

The Hill mine, in the S½SE¼ sec. 16, is developed by two short adits, an open cut, and several prospect pits. The workings are now partly filled and expose only a little ore. The 545 tons of ore produced by S. W. Hill in 1917 and 1918 probably came in greater part from this deposit, but some of it may have come from a deposit in the SE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 16, developed by two open cuts and by an adit that is now caved. If the underground workings in these two deposits were reopened and cleaned out, a few more tons of shipping-grade ore might be found.

The other minor deposits in the area are too small and unimportant to warrant separate description in this report.