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NICKEL DEPOSIT NEAR RIDDLE DOUGLAS COUNTY, OREGON

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DOUGLAS COUNTY, OREGON

By William T. Pecora and S. Warren Hobbs

ABSTRACT

The Riddle nickel deposit, on the slopes of Nickel Mountain about 5 miles northwest of Riddle, Douglas County, Oreg., was discovered in 1864. Since then much prospecting and preliminary development work has been done, but no ore has been shipped except small lots used for metallurgical tests.

The deposit is a layered blanket, containing the nickel silicate garnierite, which rests upon unserpentinized peridotite. This blanket ranges in thickness from a few feet to a maximum of 60 or 70, but with an average of about 20 feet. It is best developed on terraces, flats, and gentle mountain slopes above an elevation of 2,000 feet. It consists of three layers, a top brick-red soil layer, an intermediate thick yellow limonitic layer with some quartz-garnierite boxwork, and a root layer composed of quartz-garnierite boxwork in nearly fresh bedrock that is a transitional phase between weathered material and fresh peridotite. The disposition of the boxwork veins was controlled by original blocky jointing in the peridotite. Nickel occurs in all three layers of the blanket but is most abundant in the boxwork veins carrying garnierite. The darker green varieties of the garnierite contain the highest percentage of nickel.

The nickel is believed to have been derived from olivine in the peridotite by decomposition during lateritic weathering, which probably took place during late Tertiary time, before the present regional surface at an elevation of 2,000 feet was dissected. This process formed limonite and nickel-poor garnierite. Under present climatic conditions the original laterite has undergone a change resulting chiefly in a boxwork of quartz and nickel-rich garnierite.

About 162 acres of ground are underlain by a blanket containing over 6,000,000 tons of material, 1 to 2 percent of which is probably nickel. Eighty thousand tons have been proved to contain 2 to 3 percent of nickel, and 75,000 tons have been proved to contain 1 to 2 percent of nickel. A new method of treating low-grade silicate material would have to be devised before this large deposit could be utilized.

INTRODUCTION

The Riddle nickel deposit is on Nickel Mountain, also called Piney Mountain, about 5 miles northwest of Riddle, Douglas

County, Oreg. (fig. 20). The deposit is an unevenly distributed surficial blanket, containing the nickel silicate garnierite, which rests upon peridotitic rocks on the western, southern, and southeastern slopes of the mountain above an elevation of 2,000 feet.

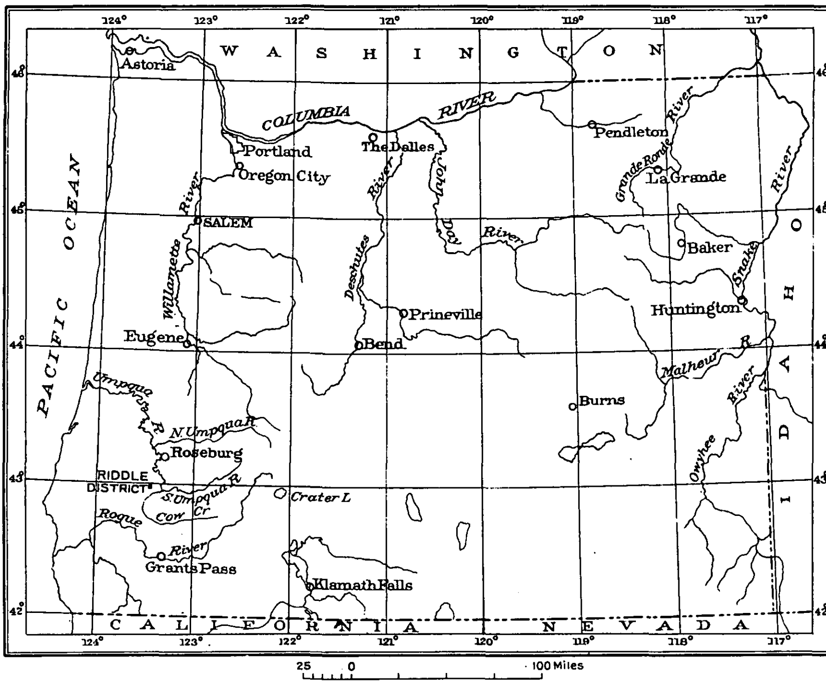

Figure 20.--Index map showing location of the Riddle nickel deposit.

Riddle, which has a population of about 200, is at an elevation of about 700 feet on the north side of Cow Creek a mile west of its junction with the South Umpqua River. It is on the Southern Pacific Railroad, and it is about 230 miles by highway south of Portland. A poorly conditioned dirt road about 5 miles long connects the town with the nickel deposit.

History and development

Since the discovery of the deposit by sheepherders in 1864, much prospecting and exploration has been done on Nickel Mountain, but up to the present no nickel ore has been shipped except small lots used for experimental metallurgical tests. From 1880 to 1900, Mr. W. Q. Brown of Riddle owned a large portion of the deposit, and under his direction it was actively explored. Mr. Brown also experimented with concentration and treatment of the ore. The property that contains most of the deposit is now owned by Mr. Edson F. Adams of Oakland, Calif.

The accessible workings include 75 small pits and trenches, 6 adits, 3 shafts, and about 5 large open cuts. The longest adit is 300 feet long and the deepest shaft is 83 feet deep. The dump piles contain about 4,000 tons of material--practically all that has been excavated from the workings--in which the nickel content ranges from 1/2 to 3 percent. If garnierite ore of this low grade could be successfully concentrated or treated, there would be a huge potential reserve of nickel in the deposit. Mining of the deposit would involve no unusual problems; the principal obstacle to operation is the difficulty of profitably treating such low-grade ore.

Field work and previous investigations

During September and October 1940, the writers made a detailed study of the mode of occurrence of the nickel and prepared a map of the deposit. The geology of the Riddle quadrangle, in which the deposit is situated, has been described by Diller and Kay,[1/] and the nickel deposit has been described by Clarke,[2/] Von Foullon,[3/] Austin,[4/] Ledoux,[5/] and Kay.[6/]

1/ Diller, J. S., and Kay, G. F., U. S. Geol. Survey Geol. Atlas, Riddle folio (No. 218), 1924.

2/ Clarke, F. W., Some nickel ores from Oregon: Am. Jour. Sci., 3d ser., vol. 35, pp. 483-488, 1888; U. S. Geol. Survey Bull. 60, pp. 21-26, 1890.

3/ Von Foullon, H. B., On Riddle, Oregon: K. K. Geologische Reichsanstalt, Jahrb., vol. 42, pp. 224-234, Vienna, 1892.

4/ Austin, W. L., The nickel deposits near Riddle's, Oregon: Colorado Sci. Soc. Proc., vol. 5, pp. 173-196, 1896.

5/ Ledoux, A. R., Notes on Oregon nickel prospects: Canadian Min. Inst. Jour., vol. 4, pp. 184-189, 1901.

6/ Kay, G. F., Nickel deposits of Nickel Mountain, Oregon: U. S. Geol. Survey Bull. 315, pp. 120-128, 1906.

The authors are indebted to F. C. Calkins and H. G. Ferguson, of the Geological Survey, for many helpful suggestions during the preparation of this report. The chemical analyses were made by Victor North, also of the Geological Survey.

Topography

The topography of the Riddle quadrangle is typical of a large part of the Pacific Coast Ranges. The relief is about 3,000 feet. The summit of Nickel Mountain has an altitude of 3,533 feet and rises a few hundred feet above the neighboring ridges. The ridge crests are fairly uniform in altitude and were believed by Diller [7] to represent the widespread Klamath peneplain of late Tertiary age. Dissected erosion surfaces, the chief of which has an elevation of about 2,000 feet, are also recognizable at lower altitudes. In a detailed analysis of the topography of Nickel Mountain, given in a later section, the distribution of the ore is correlated with the topography. The physiographic history of the region has been an important factor in the formation and localization of the nickel deposit.

GEOLOGY

The areal distribution of the rocks in the vicinity of Nickel Mountain is shown on plate 37.[8] A large irregular body of peridotite and serpentine, which extends northeast and southwest from Nickel Mountain, is of principal interest, because the nickel deposits are related to the peridotite. The peridotite and serpentine body is intrusive into Jurassic sandstone and late Jurassic greenstone and related rocks, and is probably late Jurassic. The structure of these older rocks has a predominant northeasterly trend. They are unconformably overlain by the Knoxville formation and younger sedimentary rocks.

7/ Diller, J. S., Mineral resources of southwestern Oregon: U. S. Geol. Survey Bull. 546, pp. 12-14, 1914.

8/ The geology shown on plate 37 is modified from Diller and Kay, op. cit.

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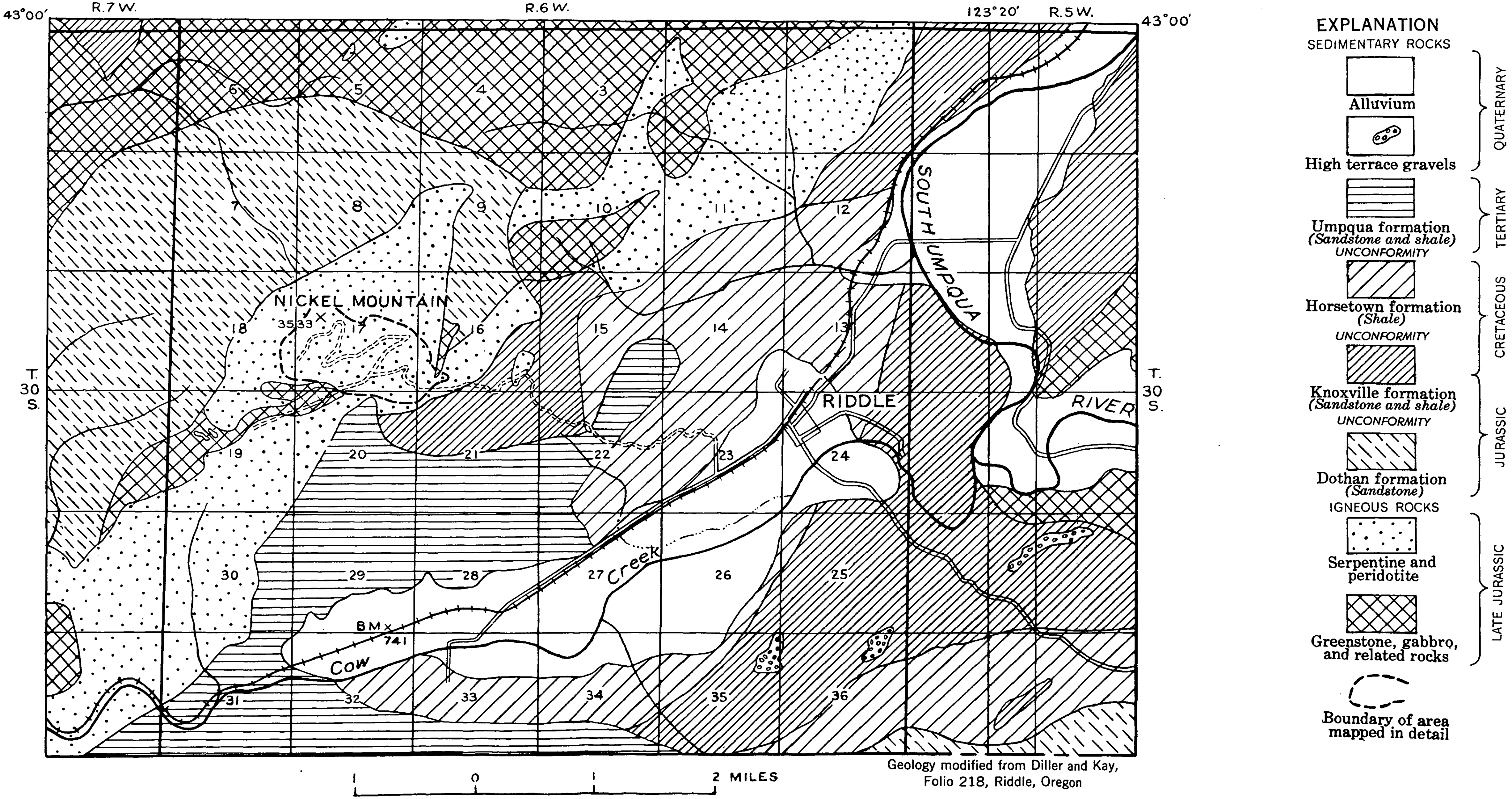
BULLETIN 931 PLATE 37



GEOLOGIC MAP OF THE VICINITY OF NICKEL MOUNTAIN, DOUGLAS COUNTY, OREGON

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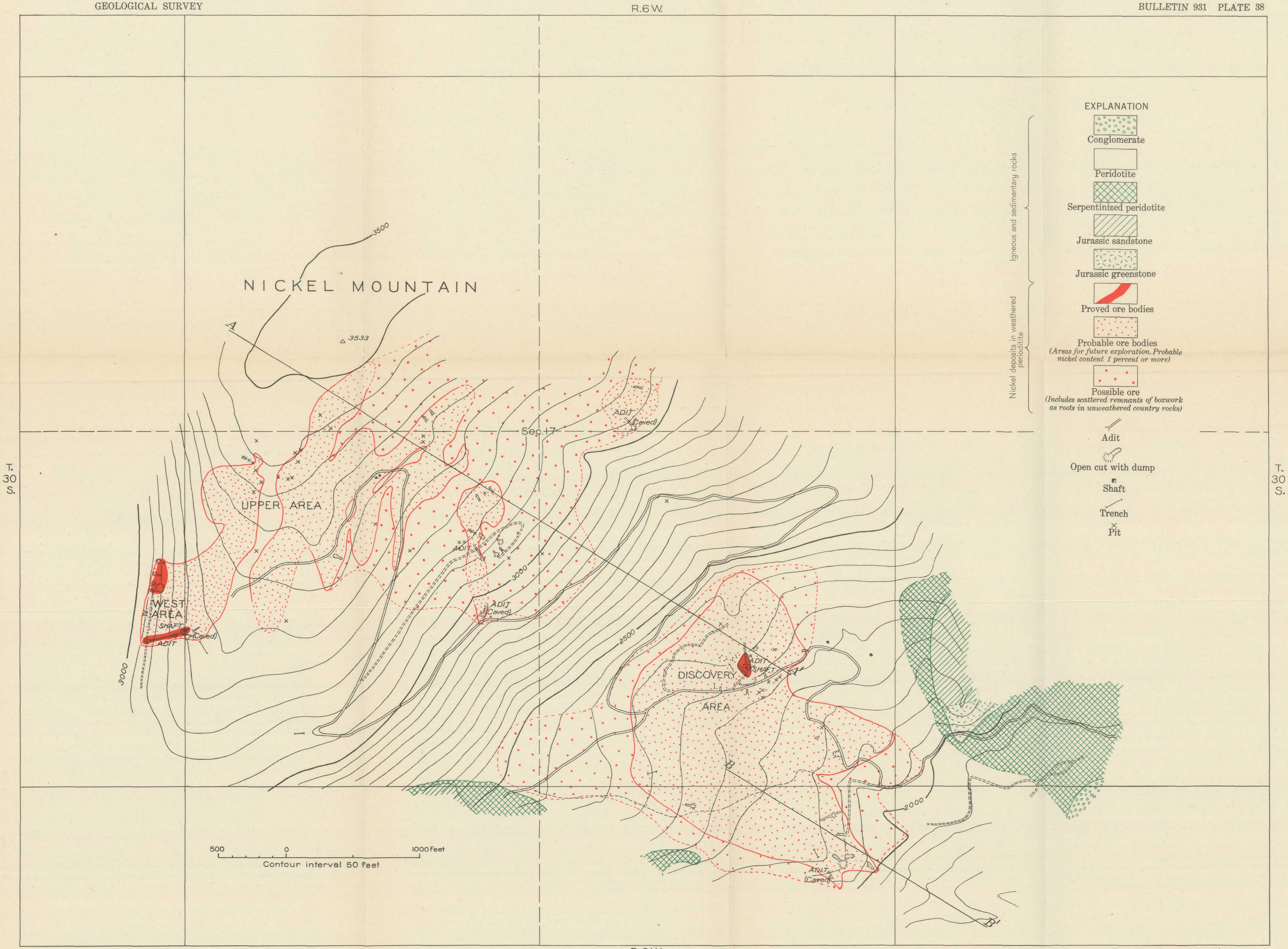
(Faces p. 208)



TOPOGRAPHIC AND GEOLOGIC MAP OF THE NICKEL DEPOSIT NEAR RIDDLE, DOUGLAS COUNTY, OREGON

Topography and geology by S.W. Hobbs and W.T. Pecora

Peridotite

In the ultrabasic intrusive mass of Nickel Mountain, peridotite is far more abundant than its derivative, serpentine. This is true of the entire intrusive body as well as the small part shown on plate 38, with which the nickel deposits are associated. In previous geologic reports on this region, "serpentine" is commonly used as a collective term for all the ultrabasic intrusive rocks, but as the nickel ore is associated only with the unserpentinized peridotite, it is essential to discriminate in this report between true serpentine and the peridotite from which the serpentine is derived. The name serpentine is therefore applied only to the serpentinized ultrabasic rocks, and the unaltered rock is called peridotite.

The peridotite is partly dunite and partly saxonite. Dunite contains more than 90 percent of olivine, ($(Mg,Fe)_2SiO_4$), and saxonite contains, with its dominant olivine, as much as 40 percent of the orthorhombic pyroxene enstatite, ($(Mg,Fe)SiO_3$). Dunite and saxonite are not shown separately on the geologic map (pl. 38). Field study revealed no system in the distribution or structural orientation of masses of the two rocks. Although no fine-grained or chilled varieties were seen, large irregular masses of saxonite appear in places to be intrusive into dunite. Probably both rocks were formed in the same intrusive episode, but the saxonite crystallized later than the dunite.

The saxonite and dunite are coarse-grained and hard, and both contain a little scattered chromite, ($FeCr_2O_4$), but the few segregations of chromite are always associated with the dunite. Both rocks are dark yellow green on unweathered surfaces. In weathered outcrops the dunite is brownish green and exhibits a fine-textured lattice-work of joints. The weathered saxonite is dark reddish brown and has a coarse blocky jointing that makes it more resistant to weathering than the dunite, and it is further distinguished by a pitted surface, because the pyroxene in

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it is more resistant to weathering than the olivine. This feature is especially noticeable where decay of the rock is far advanced, the olivine being completely changed to yellow limonite whereas the pyroxene remains in recognizable crystals.

As the nickel content of olivine is greater than that of enstatite (see table on p. 211), unweathered dunite has a higher nickel content than unweathered saxonite. Under certain conditions of weathering the nickel originally contained in the olivine became concentrated in the nickel-magnesium silicate garnierite, which, together with quartz, forms veinlets in both rocks. These veinlets are more abundant in the dunite than in the saxonite, as the dunite is the more closely jointed. The ratio of garnierite to quartz is also higher in the veins cutting dunite, as the larger olivine content affords a larger supply of nickel.

A brick-red soil which is developed on the surface of the nickel deposits is described in the section that deals with the deposits.

Serpentine

A band of partly or completely serpentinized peridotite, from 10 to several hundred feet in width, separates the unaltered parts of the intrusive body from the older rocks wherever the contact was observed. This border facies of the ultrabasic intrusive rock consists mainly of a black, fine-grained serpentine. In many specimens the pyroxene is unaltered although the olivine is completely serpentinized, but commonly the pyroxene also is serpentinized, being altered to lustrous bronze-colored pseudomorphs of bastite. Some of the partly altered peridotite contains veins of serpentine.

In places within the border zone of the intrusive there are masses of green slickensided serpentine. This material encloses rounded blocks of the black, fine-grained serpentine, from which it evidently was derived. A similar association was observed by Palache 9/ in the serpentine of the California Coast Ranges.

Analyses of two samples of serpentine show that it contains more nickel than the olivine samples that have been analyzed (see table below). However, no nickel deposit has been found in serpentine. Both varieties of serpentine weather to a gray-brown soil that is conspicuously different from the soil over peridotite.

Analyses of rocks and minerals from Nickel Mountain

	1	2	3	4	5	6
SiO_2	41.43	42.81	....	....	....	....
Al_2O_3	.04	Not det.	....	....	....	....
Fe_2O_3	2.52	2.61	....	....	....	....
FeO	6.25	7.20	....	....	....	....
CaO	.55	None	....	....	....	....
MgO	43.74	45.12	....	....	....	....
NiO	.10	.26	0.32	0.05	0.45	0.33
Cr_2O_3	.76	.79	....	....	....	....
Loss on ignition	4.41	.57	....	....	....	....
	99.80	99.36	....	....	....	....
Ni	.08	.20	.25	.04	.35	.26

1. Peridotite (saxonite) with more than two-thirds olivine. Clarke, F. W., op. cit. (1888), p. 485.
2. Olivine, not entirely free from enstatite and chromite. Clarke, F. W., op. cit. (1888), p. 485.
3. Olivine. Von Foullon, H. B., op. cit., p. 226.
4. Orthorhombic pyroxene ("bronzite"). Von Foullon, H. B., op. cit., p. 226.
5. Serpentine from locality near border east of stock. Von Foullon, H. G., op. cit., p. 233.
6. Serpentine from locality northeast of Nickel Mountain. Kay, G. F., op. cit., p. 126. George Steiger, analyst.

THE NICKEL DEPOSIT

The typical ore 10/ of the nickel deposit is a blanket of deeply weathered peridotite, now almost entirely altered to limonite, which is host to an intricate lattice boxwork of quartz-garnierite veins. The deposit was formed during the weathering

9/ Palache, Charles, Lherzolite and associated rocks of the Potrero, San Francisco: California Univ., Dept. Geology, Bull. 1, pp. 161-180, 1894.

10/ The term "ore" is not used here in the strict sense, being applied for convenience to material not rich enough to be worked profitably, in place of such cumbersome phrases as "potential ore", "nickel-bearing material".

of the unserpentinized peridotite upon which it rests, by a two-fold supergene process which involved the release of nickel from the primary minerals and its combination in nickel-poor secondary minerals under a humid tropical climate, and its subsequent concentration in nickel-rich garnierite under a humid temperate climate. The deposits are the remains of a once more extensive blanket, which probably at one time covered most or all of the peridotite in the area. Landsliding, rill wash, and slope wash have stripped parts of the deposit from the unweathered peridotite. The weathered blanket is constantly undergoing further chemical change, so that in small areas further enrichment in nickel is being effected, apparently by the breaking down of early formed garnierite that contains relatively little nickel and the formation of nickel-rich garnierite and quartz. Garnierite does not seem to be forming directly from the peridotite under present climatic conditions.

Mineralogy

The principal minerals of the nickel deposit are garnierite (hydrous nickel-magnesium silicate), quartz, chalcedony, and chert (three varieties of silica), and limonite (hydrated iron oxide). A small quantity of chromite ($FeCr_2O_4$) and manganese oxide are also present.

Garnierite.--The garnierite ranges in color, even in the same vein or hand specimen, from yellowish green through apple green to blue green. The darkest variety, which presumably has the highest nickel content, occurs in some places as veinlets in the yellowish-green variety. When the mineral is wet it is darker-colored than when it is dry. Some of it then crumbles under slight pressure, and some spreads like paste. The dry garnierite is soft but brittle, and will adhere to the tongue. Analyses of garnierite from Nickel Mountain are shown in the table on page 213.

Analyses of garnierite from Nickel Mountain

	1	2	3	4
SiO_2	44.73	48.21	40.55	48.82
$Al_2O_3 + Fe_2O_3$	1.18	1.38	1.33	.06
MgO	10.56	19.90	21.70	18.49
NiO	27.57	23.88	29.66	19.04
H_2O+	6.99	6.63	7.00	12.29
H_2O-	8.87			
	99.90	100.00	100.24	98.70
Ni	21.67	18.77	23.31	14.97

1. Clarke, F. W., op. cit. (1888), p. 484.
2 and 3. Blake, W. P., Nickel: Mineral Resources U. S., 1882, p. 404.
4. Von Foullon, H. B., op. cit., p. 272. (Apple-green garnierite.)

Enriched garnierite.--Much of the garnierite of the main ore zone shows evidence of recent enrichment in nickel through the breakdown of an earlier-formed, nickel-poor variety. Near the base of the decomposed mantle rock a greenish-yellow to colorless variety of garnierite has been found in partly weathered dunite. This material is always below the ore and is well-exposed along the road bed and road cuts in the southeastern part of the deposit, in some places on the steep slopes in fresh peridotite, and on the bed-rock areas of the summit of Nickel Mountain. Quartz and green garnierite are both absent or rare at these localities, but if one is present, the other is also. Both enriched garnierite and quartz may occur as veins in the pale garnierite, but the quantity of the enriched material increases toward the surface and develops a network of cross-cutting quartz-garnierite veins. This is well shown at the Discovery and West Workings. The order of formation in all places is from pale garnierite to deeper-colored garnierite, and a rude zoning indicates a progression from pale varieties at depth to deeper-colored varieties toward the surface. This indicates a process of supergene nickel enrichment in garnierite, and the pale, unenriched garnierite, which is accompanied by limonite, is believed to be the source of both the nickel and the silica concentrated by the recent enrichment process.

Quartz.--The quartz which is persistently associated with the garnierite in the boxwork veins is commonly white and fine-grained. The quartz of the thin, flaky veinlets in the garnierite is porcellaneous, while that of the thicker veins is coarser and partly brownish. Brown chalcedony or cherty silica is common near the surface of the deposit. Quartz is generally more abundant than garnierite in the boxwork, but its relative abundance decreases downward from the surface.

Limonite.--Most of the limonite is soft and easily removed from the boxwork, but at a few places near the surface part of the limonite is silicified to a brown, chert-like mass. One sample of limonite from between the quartz-garnierite veins of the boxwork contained about 1 percent of nickel.

Layers of the deposit

The nickel deposit is layered, as is well shown in the vertical section exposed at the Discovery workings and represented in figure 21. A top layer of brick-red soil, 2 to 3 feet thick, covers the main layer, 40 feet thick, of quartz-garnierite boxwork in limonite. Locally the boxwork layer contains "boulders" of peridotite, which are incompletely altered residuals. The base of the boxwork layer is very irregular, but is approximately parallel to the hill slope. Below the boxwork layer is the basal or root layer. In it prongs of the peridotite project upward, and, conversely, roots of the boxwork project downward into fresh peridotite. The maximum depth of boxwork roots in peridotite is not known but is estimated to be about 150 feet.

Brick-red soil layer

The top layer of the deposit averages 2 to 3 feet in thickness and ranges from a thin veneer up to 9 feet. It consists of brick-red soil, soft and incoherent, containing small round pellets of red iron oxide and, at the surface in a few places,

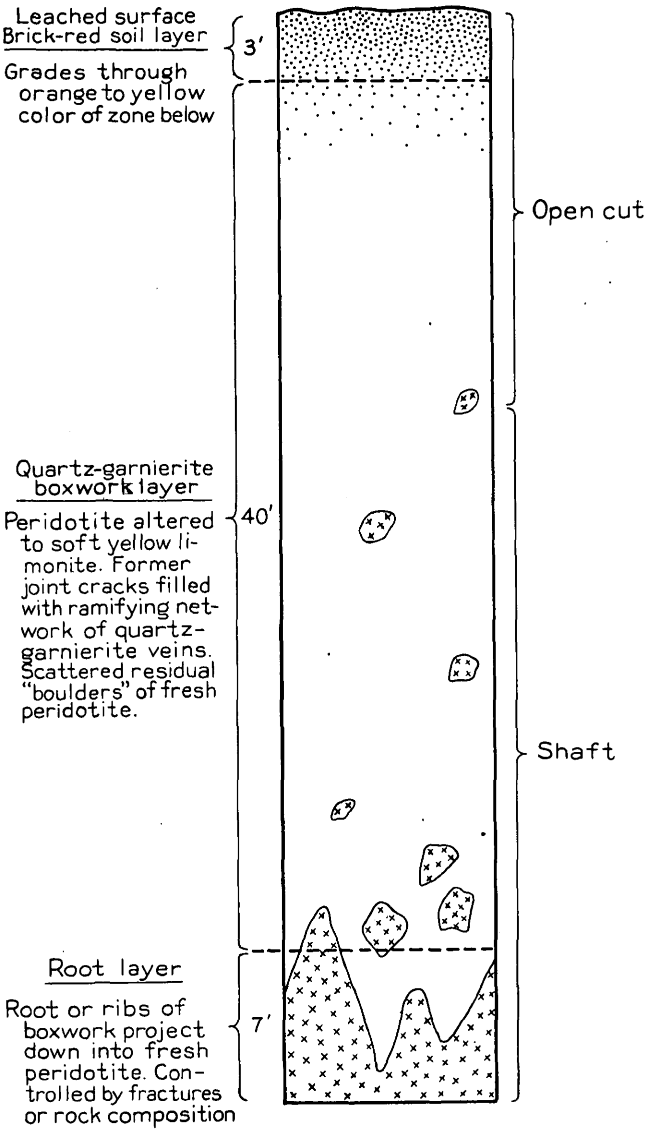

Figure 21.--Diagrammatic sketch of a vertical section of the mineral deposit at the Discovery workings.

small pieces of dull quartz or larger fragments of spongy quartz. The quartz, which is commonly stained with much manganese oxide, is a residue of weathered boxwork, and hence may be an excellent guide to unexposed boxwork ore.

The brick-red soil layer, originally derived from peridotite, supports a moderately heavy growth of vegetation, which contrasts with the scant growth on areas underlain by serpentinized peridotite. Many of the trees that grow on it are tilted and curved, showing that even on gentle slopes the soil tends to creep, and as a consequence of this creep and the action of plant roots all structures of the original peridotite are obliterated in the soil layer.

Analyses of three composite samples of the brick-red soil show that they contain 0.95, 1.10, and 1.02 percent of nickel. (See table below.) The mineral in the soil that contains the nickel is unknown. It is reported that the soil contains between 0.75 and 2 percent of Cr_2O_3, which is probably in the form of chromite. No complete analysis of the red soil is available.

Nickel content of red soil and red-soil wash, Nickel Mountain
[Victor North, analyst]

Sample No.	Description	Location	Ni (percent)
1	Red-soil wash.......	Composite samples from surface southeast of the Discovery area.	0.61
2	Red-soil wash.......	Composite samples from surface southeast of the Discovery area.	.71
3	Brick-red soil......	Composite sample from surface near summit of Nickel Mountain.	.95
4	....do..............	Composite sample from surface of 2 acres around Discovery shaft.	1.10
5	....do..............	Channel sample at Discovery open cut, 4 ft. below surface, 3 ft. above boxwork ore.	1.02

Wash derived from the brick-red soil layer of the upper slopes partly covers terraces and the bottoms of small valleys on the lower slopes of Nickel Mountain. Analyses of two composite samples of this wash material collected southeast of the Discovery area (see pl. 38 and fig. 22) show that they contain 0.61 and 0.71 percent of nickel. The wash also contains very small grains of chromite.

Quartz-garnierite boxwork layer

The boxwork layer attains a thickness of 40 feet at the Discovery workings, but it is between 10 and 20 feet thick in most other places. At several places, boxwork ore can be seen to project downward like roots into the underlying peridotite. This is well shown at the West shaft where a narrow irregular root of boxwork extends downward from the surface for at least 85 and possibly 100 feet. Scattered patches of boxwork ore in areas of fresh peridotite are common in the vicinity of the main ore bodies, and probably represent the lower ends of the root zone of a once more extensive boxwork layer.

Two striking features characterize the boxwork in both the boxwork layer and the roots: (1) The intimate quartz-garnierite veins form a honeycomb in yellowish, hard or soft limonitic material weathered from peridotite, and (2) local fractures and fracture veins with slickensided walls are common.

Boxwork veins.--Individual veins in the boxwork layer consist mainly of intergrown quartz and garnierite, and they range from paper-thin sheets to veins 2 inches or more in thickness. Quartz commonly forms the walls of the veins and encloses the garnierite, but it also forms intricate networks of very thin, white, porcellaneous veins in the nickel mineral. The relative proportions of the two minerals in the veins vary greatly from place to place. The boxwork layer on the north face of the Discovery open pit, which is exceptionally rich in garnierite, is estimated to contain 5 percent of garnierite, 15 percent of quartz, and 80 percent of limonite. Here, the boxwork layer averages between 3 and 4 percent of nickel. Elsewhere, garnierite commonly makes up 5 to 10 percent of the individual boxwork veins, but less in the veins near the surface in which leaching or rain wash have been active. Below the surface the veins are compact, but near and at the surface they contain open spaces whose walls are coated with brown-stained quartz. Brown quartz locally replaces the white quartz.

The garnierite varies in color and composition in the same vein. Green is the predominant color, and the shade of green is darker when the boxwork is wet. Both the percentage of garnierite in the veins and the nickel content of the mineral itself must be estimated before any evaluation of a boxwork exposure can be made by inspection in the field.

In some places the boxwork, naturally exposed on the surface, is almost entirely leached of its garnierite, and there remains a heavy, spongy mass of brown and white quartz. When this leached outcrop material is broken, small angular or rounded fragments of garnierite are frequently found within the protective quartz. Much of the boxwork ore of the dump piles also shows this feature. The exposed garnierite is more easily washed from the boxwork by rain than leached by the chemical activity of the water. Large masses of the sponge-quartz outcrops are exposed on the surface of the gentle slope immediately below the summit. Prospect pits prove conclusively that such leached outcrops can be used as guides for location of unexposed boxwork ore, but it is reported that the boxwork ore exposed beneath such leached outcrops contains less than 2 percent of nickel.

Joints and fractures in the fresh peridotite have been the main factor in controlling the pattern as well as the thickness of the veins. The coarse rectangular joint plan of the saxonite supports a very coarse boxwork. The largest observed joint block of saxonite is about 4 feet in diameter, many are 1 to 2 feet, but most of the blocks are only a few inches across. The thickness of the individual veins of the boxwork varies in proportion to the size of the joint blocks that the veins enclose. The thickest of the veins of the boxwork are about 2 inches; the thinnest are mere films a fraction of an inch across. The individual cells of the boxwork frequently contain a core of unweathered peridotite in a soft limonitic matrix, and this relationship is evidence of the process by which the peridotite was altered to form the ore. The closely spaced joints of the dunite, on the other hand, support a finer-textured boxwork of thinner septa; the joint blocks are rarely more than an inch across, are completely weathered, and are enclosed in a lacework of quartz and garnierite.

The limonite interstitial to the boxwork veins is soft and crumbly in the boxwork layer but is hard and compact at some places in the boxwork roots. A carefully collected sample, weighing about an ounce, of soft limonite from the boxwork deposit at the portal of the Discovery adit contained 1.3 percent of nickel (see table on p. 220).

Fracture veins.--Open fractures are numerous in the boxwork ore and also in the peridotite that contains the boxwork root. Brown and white quartz and light- to dark-green garnierite form veins along these fractures, and both minerals show slickensides. The thickest vein, observed at the West shaft, ranges in thickness from 6 inches to a foot in a distance of 30 feet. Some fragments of the vein on the dump are 14 inches wide and consist predominantly of white and brown quartz, which encloses scattered small pellets of garnierite. The brown quartz is banded and flinty and clearly replaces the white quartz. Some cavities in quartz are lined with mamillary crusts of dark-green garnierite and brown quartz.

Along some parts of the veins apple-green to blue-green garnierite has been deposited. The thickest vein of garnierite was observed on the south wall of the West open cut, where it ranged in thickness from 1 to 3 inches in a distance of 15 feet. The veins are not persistant in depth and commonly extend less than 20 feet along the strike. Boxwork is characteristically present in the wall rock and at the edges of the fracture veins.

The attitude of the veins in the deposit is not systematic. Low dips are commoner than high ones for veins near the surface, but high dips are most characteristic for fracture veins in the roots. Where slickensides are present, movement is indicated in a direction down the present slopes of Nickel Mountain. The fractures that contain the fracture veins are possibly results of slumping, landsliding, or local collapse of the mineral deposit.

Nickel content of samples from boxwork and root zone, Nickel Mountain
[Victor North, analyst]

Sample No.	Description and Location	Ni (percent)
1	Limonite between boxwork, portal of Discovery adit.	1.31
2	Rich pocket of garnierite ore from fracture vein in west wall of Discovery shaft.	8.09
3	Composite of five channel samples of boxwork ore from walls of Discovery open pit, representative of upper 15 ft. of boxwork.	2.07
4	Composite sample from 30 ft. of boxwork ore in Discovery shaft.	2.81
5	From bottom 5 ft. of Discovery shaft; part boxwork ore and part peridotite.	1.84
6	Composite sample from outer 150 ft. of Discovery adit; part boxwork ore and part peridotite.	2.06
7	From breast of Discovery adit, 175 ft. from portal; part boxwork ore and part peridotite.	1.35
8	Composite sample from upper 35 ft. of West shaft; mostly boxwork ore.	1.94
9	From bottom 4 ft. of West shaft (84-88 ft. below surface); mostly peridotite with films of garnierite and glassy quartz along fractures in rock.	.83
10	Composite sample from outer 155 ft. of West adit; mostly boxwork.	1.04
11	Composite sample from inner 145 ft. of West adit (to face at 300 ft. from portal); mostly peridotite.	.34

Root layer

The lowermost part of the blanket of ore is a zone in which root-like extensions of the boxwork material above penetrate the underlying fresh peridotite. The zone is very irregular and marks the transition from ore to bedrock. The boxwork roots project downward into the fresh peridotite to an unknown depth.

In the boxwork deposits of the West area and of the steep slope northwest of the Discovery deposit, which are interpreted as parts of the root zone, the greatest known depth of the roots is about 85 feet. This figure depends on the fact that the breast of the West adit, which lies about 40 feet directly below the bottom of the West shaft, is in partly weathered peridotite with thin flakes of quartz and garnierite.

Only the boxwork roots need be explored in the root zone. Except where enrichment has taken place, the boxwork roots reportedly contain less than 1 percent of nickel.

Origin

Relation to slopes

It is generally recognized that the best deposits of garnierite lie on terraces and gentle slopes at altitudes above 2,000 feet, and such ground therefore has been the most thoroughly prospected. (See fig. 22.) Some terraces cut on fresh peridotite below 2,000 feet, are mantled with wash, consisting partly of boxwork and partly of red soil derived from upper slopes. The West area and the steep slope northwest of the Discovery area contain root deposits of a former gentle surface of higher elevation which, before erosion to the present slope, was probably rich in boxwork ore. Debris from the West area boxwork is abundant on a 2,500-foot terrace west of the mapped area of plate 38.

The dissected terrace at 2,000 feet is part of a widespread erosion surface, and it is evidently much older than the stream terraces, at least 500 feet lower, from which Pleistocene vertebrate remains have reportedly been collected. The deposits are probably not much younger than the 2,000-foot terrace, for no garnierite and limonite layer is known to have formed on any terrace cut on peridotite below the 2,000-foot terrace level. All local terraces in peridotite between 2,000 feet and the

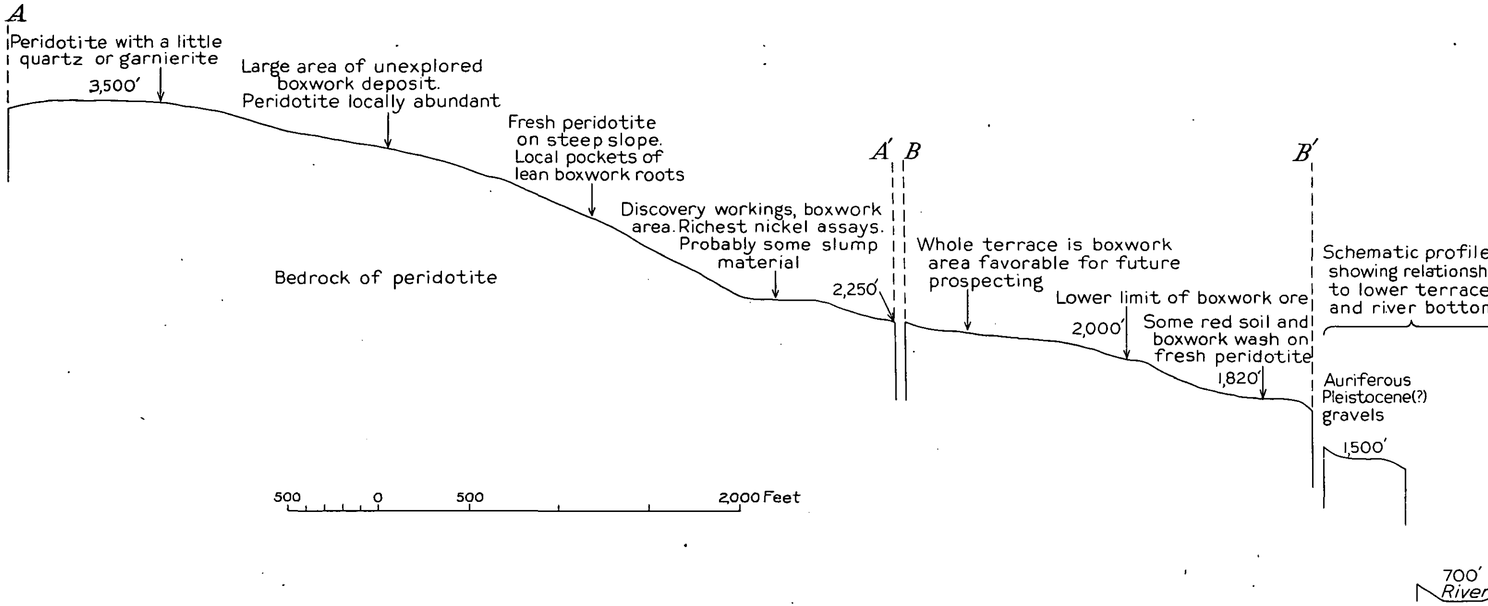

Figure 22.—Composite and schematic profile of the southeast side of Nickel Mountain and the adjacent area, showing relationship of ore to topography.

summit of Nickel Mountain, on the other hand, have deep roots of boxwork ore. The writers therefore believe that the weathering of peridotite to a lateritic soil made up chiefly of limonite and nickel-poor garnierite took place during the time interval, probably late Tertiary, in which the Klamath Upland Surface was uplifted and dissected, to form ultimately a widespread mature erosion surface whose base level in the area near Nickel Mountain is now represented by the 2,000-foot terrace. According to this interpretation, the present nickel deposit is largely a partially reworked remnant of a lateritic soil blanket, which originated in late Tertiary time, and no further weathering of this kind occurred in the peridotite that was later exposed by dissection of the 2,000-foot terrace.

Formation of boxwork

Either of two conditions may have produced a deeply weathered limonitic blanket on the peridotite during the formation of the late Tertiary 2,000-foot erosion level: (1) climatic conditions differing from that of later, presumably Quaternary time, or (2) longer weathering under the same climatic conditions. The writers favor the first alternative, and believe that the late Tertiary weathering was lateritic. A humid and tropical to subtropical climate would produce laterite on a peridotite surface of low relief. While the olivine was decomposing under these conditions, magnesium, nickel, and silica combined with water to form nickel-poor garnierite, and iron oxidized to form limonite. In true laterites, quartz is not precipitated within the deposit.

Under Recent humid-temperate climatic conditions new laterite did not form, but the laterite already formed became further altered. Decomposition of garnierite at the surface released silica, magnesium, and nickel. Much of the silica was precipitated as quartz, some magnesium was leached and lost, and much nickel was redeposited lower down to form green nickel-rich garnierite associated with quartz. In the root zone the nickel-poor garnierite has been partly decomposed and enriched in place.

The quartz-garnierite boxwork is therefore attributed to Recent weathering of the lateritic product of Tertiary weathering. Garnierite and quartz are being deposited at the present time along fractures in peridotite below the boxwork.

Both Von Foullon [11/] and Kay [12/] have argued that garnierite was formed by the weathering of serpentine derived from peridotite; and Austin [13/] believed that the quartz-garnierite veins were of hydrothermal origin. In the writers' opinion, on the contrary, field evidence strongly indicates that the garnierite was derived from peridotite rather than serpentine and deposited, together with quartz, by a secondary supergene rather than hydrothermal action.

Reserves

Grade

Under present conditions, garnierite ore containing less than 5 percent of nickel cannot be worked profitably. Most of the deposit at Nickel Mountain contains only 1 or 2 percent of nickel, and only a relatively small part, reckoned in minable tonnages, contains as much as 2 to 3 percent.

Calculations from samples totaling a few hundred pounds indicate that the boxwork ore at the Discovery workings contains between 2 and 3 percent of nickel, but representative samples of boxwork ore from other parts of the deposit contain less than 2 percent of nickel. Samples weighing a few pounds and containing 3 to 5 percent or more of nickel can indeed be collected--one taken by the writers from the richest pocket of garnierite ob-

11/ Von Foullon, H. B., op. cit.
12/ Kay, G. F., op. cit.
13/ Austin, W. L., op. cit.

served contains 8.09 percent of nickel--but these samples are not representative. The results of the writers' sampling indicate that the nickel content of the deposit is lower than has been reported. Kay,[14/] for example, states that two specimens, collected as representing average boxwork ore, contained 5.35 and 4.94 percent of nickel, and that about 20 tons of ore, shipped by the Oregon Nickel Mines Co. for experimental purposes, was reported by the company to contain between 5 and 8 percent of nickel.

Estimates of tonnage

At the Discovery shaft, adit, open cut, and adjacent trenches there is a proved minimum of 80,000 tons [15/] of boxwork ore in which the nickel content is estimated to be at least 2

Estimated tonnage of nickel ore at Nickel Mountain

Location	Proved ore (tons)	Probable ore (tons)	Estimated Ni content (percent)
Boxwork:[1/]			
Discovery workings........	80,000	200,000	2 to 3
West workings.............	50,000	....	1 to 2
Miscellaneous trenches, pits, short adits, dumps	25,000	....	1 to 2
Discovery area............	......	2,000,000	1 to 2
West area.................	......	500,000	1 to 2
Upper area................	......	3,000,000	1 to 2
Brick-red soil:[2/]			
Discovery area............	......	240,000	½ to 1½
West area.................	......	48,000	½ to 1½
Upper area................	......	300,000	½ to 1½

1/ Boxwork calculations based on 20 cu. ft. per ton.
2/ Red soil calculations based on 25 cu. ft. per ton.

but not more than 3 percent. In the area surrounding the Discovery open cut there is probably at least 200,000 tons of the same grade. The exposures over a wider area about the Discovery workings indicate that there is probably about 2,000,000 tons

14/ Kay, G. F., op. cit., p. 124.

15/ Calculations of boxwork ore are based on an estimate of 20 cubic feet per ton.

more material with a nickel content of 1 to 2 percent. Further prospecting within this promising area might justify a higher estimate.

At the West workings, the shaft, open cuts, and adit develop a proved minimum of 40,000 tons of boxwork ore, and at the open cuts north of the West adit there is at least 10,000 tons of proved ore, having a nickel content between 1 and 2 percent. The probable ore in the area about the West workings amounts to about 500,000 tons, of the same grade.

Scattered pits, trenches, short adits and dump piles partly block out about 25,000 tons of boxwork ore containing between 1 and 2 percent; this also may be regarded as proved ore.

For the large area east of the West workings, the estimate of probable ore is 3,000,000 tons with a grade of 1 to 2 percent. Much of this area is as yet unexplored, so that a larger tonnage is possible. In some places, however, the boxwork ore may contain less than 1 percent and in others more than 2 percent.

In all, the Nickel Mountain deposit contains more than 6,000,000 tons of boxwork ore, composed of limonite, quartz, garnierite, and chromite, with a nickel content of 1 percent or more. There is, in addition, over 600,000 tons of brick-red soil containing 1/2 to $1\frac{1}{2}$ percent of nickel.

The deposit can be mined by power shovels at low cost, but a new method of treating nickel silicate ores or a great increase in the price of nickel would be required to make mining of the deposit profitable.

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