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UNIVERSITY OF NEVADA BULLETIN

VOL. XXXIII DECEMBER 1, 1939 No. 5

GEOLOGY AND MINING SERIES No. 32

Nickel Deposits In Cottonwood Canyon, Churchill County, Nevada

By H. G. FERGUSON
Geologist, U. S. Geological Survey

PREPARED AND PUBLISHED BY NEVADA STATE BUREAU OF MINES IN COOPERATION WITH UNITED STATES GEOLOGICAL SURVEY

PRICE 25 CENTS

PUBLICATION OF THE NEVADA STATE BUREAU OF MINES AND THE MACKAY SCHOOL OF MINES
JAY A. CARPENTER, *Director*

158

PUBLISHED QUARTERLY BY THE
UNIVERSITY OF NEVADA
RENO, NEVADA

Entered in the Post Office at Reno, Nevada, as second-class matter under Act of Congress, July 16, 1894. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized April 21, 1919.

STATE PRINTING OFFICE — JOE FARNSWORTH, SUPT.

UNIVERSITY OF NEVADA BULLETIN
GEOLOGY AND MINING SERIES

PUBLICATIONS OF THE NEVADA STATE BUREAU OF MINES AND THE MACKAY SCHOOL OF MINES

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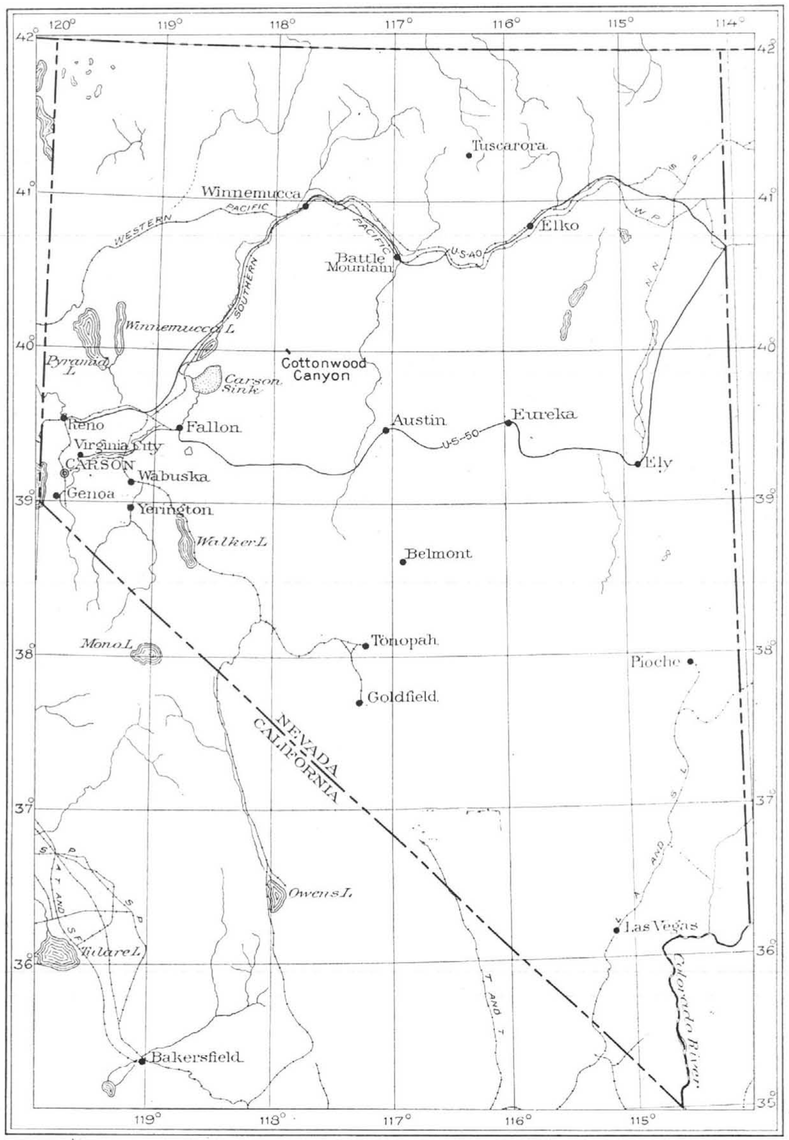

FIGURE 1. Index map showing the location of Cottonwood Canyon, Churchill County, Nevada.

The final stage of mineralization by the magmatic solutions in the Cottonwood Canyon area is believed to have been the introduction of sulphides and arsenides of nickel, cobalt, and copper, with subordinate pyrite and gangue minerals along small fissures in the already altered country rock. At the Nickel mine, at least, this was not a simple process, for the sulphide, millerite, appears to have been first formed, followed by its almost complete replacement by the arsenide, niccolite. The paragenesis of the even more complex ores of the Lovelock mine is unknown, nor can any explanation be offered as to why only nickel minerals are found at the Nickel mine, whereas the similar fissures of the nearby Lovelock mine contain a greater variety of metals.

It is thought that the relation of the nickel and nickel-cobalt ores to the diorite roof indicates that the deposition of these ores was the last observable event in an unusual and complex sequence of end products of the diorite magma, but, as Ransome[15] has pointed out, the possibility of a Tertiary age for these deposits, though it seems unlikely, cannot be completely excluded.

It is possible that the silver-lead ores in the northern part of the district mentioned by Lincoln[16] may represent more usual types of sulphide mineralization at a greater distance from the margin of the intrusive.

OUTLOOK FOR FUTURE PRODUCTION

It seems probable that the titanium content of the aplitic dikes of Corral Canyon is too low to justify any hope of immediate commercial exploitation. On the other hand, the gold-bearing quartz associated with these dikes gives promise of future production, the scale of which will depend on the degree of continuity of the valuable portions as determined by future development.

The data available concerning the nickel and cobalt deposits of Cottonwood Canyon do not warrant a dogmatic statement regarding the possibility of future production, but the inference is that no large output is to be expected even under conditions much more favorable for operation than the present. On the other hand, parts of the area are not easily accessible and prospecting may not have been sufficiently intensive to eliminate the possibility of new discoveries.

[15]Ransome, F. L., Notes on some mining districts in Humboldt County, Nevada: Geol. Survey Bull. 414, pp. 58, 71, 1909.

[16]Lincoln, F. C., op. cit., p. 12.

parts of the diorite. Albitization was widespread both at Cottonwood Canyon and at Corral Canyon, but the succeeding mineral changes differed in the two areas, perhaps owing to differences in distance from the source, for at Cottonwood Canyon the down-faulted roof of the diorite batholith is preserved, whereas at Corral Canyon erosion has reached a deeper level below the original cover of the diorite.

Although sericitization was widespread, the principal later stages of hydrothermal alteration at Corral Canyon were confined to the dikes and their immediate vicinity. The first stage was the introduction of the titanium-bearing minerals with accompanying dickite, sericite, and quartz and calcite. The titanium crystallized first as sphene, in much larger crystals than the original sphene of the diorite and the unaltered aplite dikes. Later, but presumably during the same stage of hydrothermal alteration, this sphene was replaced by an aggregate of anatase crystals. Possibly the early calcite and quartz, which accompany the anatase, were formed from the breaking down of the sphene with release of lime and silica during the transformation. The last stage of the mineralization at Corral Canyon involved the introduction of the gold-bearing quartz along the margins of the altered dikes with accompanying continued sericitization and calcitization of both the dikes and the diorite.

In the Cottonwood Canyon area the effects of the presumed earlier stages of mineralization are less marked. Albitization of the dikes and adjoining parts of the diorite took place, as in the Corral Canyon area, but the introduction of anatase into the dikes took place on a much smaller scale.

There was also an introduction of silica in the Cottonwood Canyon area. Quartz veins cut the diorite in places. The limestone, and probably to some extent the aplite near the Nickel mine were partly replaced by fine-grained silica and the greenstone became irregularly silicified as in the craggy outcrops on the north wall of the canyon. Quartz veins also cut the diorite but, as far as known at present, gold did not accompany the quartz in the Cottonwood Canyon area. As in the Corral Canyon area, sericite and calcite were deposited in the diorite, even where no alteration effects are apparent in the field.

The platy hematite in the greenstones was presumably in part the result of alteration of iron-bearing minerals originally present in these basic rocks, but the large amounts present in places where the original rock has been almost completely replaced, implies introduction of iron.

NICKEL DEPOSITS IN COTTONWOOD CANYON, CHURCHILL COUNTY, NEVADA*

By H. G. Ferguson

ABSTRACT

Nickel and cobalt deposits, formerly productive, occur in Cottonwood Canyon at the northern end of the Stillwater Range. A large mass of diorite, with accompanying smaller masses and dikes of aplite, has intruded into and altered sedimentary and overlying volcanic rocks. The nickel and cobalt minerals occur in small fissures in the altered rocks. Near Corral Canyon, five miles south of Cottonwood Canyon, veins and lenses of gold-bearing quartz are associated with altered aplitic dikes that contain anatase (octahedrite). As little could be seen of the old workings of the nickel deposits, no definite opinion can be offered as to possible future production, but the ore-bearing fissures are small and discontinuous and there is little ore in sight. The titanium-bearing dikes do not contain a sufficiently high content of TiO_2 to warrant exploitation at present. The gold-quartz veins, on the other hand, are being developed with encouraging results.

INTRODUCTION

During the summer of 1938, a short visit was paid to the nickel and cobalt occurrences in Cottonwood Canyon, Churchill County, Nevada (see Figure 1).† The work was done, under grant from the Public Works Administration, as part of a general investigation of strategic minerals. In the study of the geology, to which four days were devoted, the writer was assisted by A. E. Granger and George P. Sopp. The work included a brief visit to the titanium and gold deposits near Corral Canyon, five miles south of Cottonwood Canyon.

The topographic and geologic map (Figure 2) is controlled by points fixed by a plane-table traverse made by R. M. Dreyer, with the assistance of George P. Sopp and Craig Moore. The writer is indebted to Mr. C. S. Ross for study of the rock and mineral specimens collected and to R. C. Wells and J. G. Fairchild

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†It is possible that the nickel and cobalt mines described in this report are, at least in part, within Pershing County.

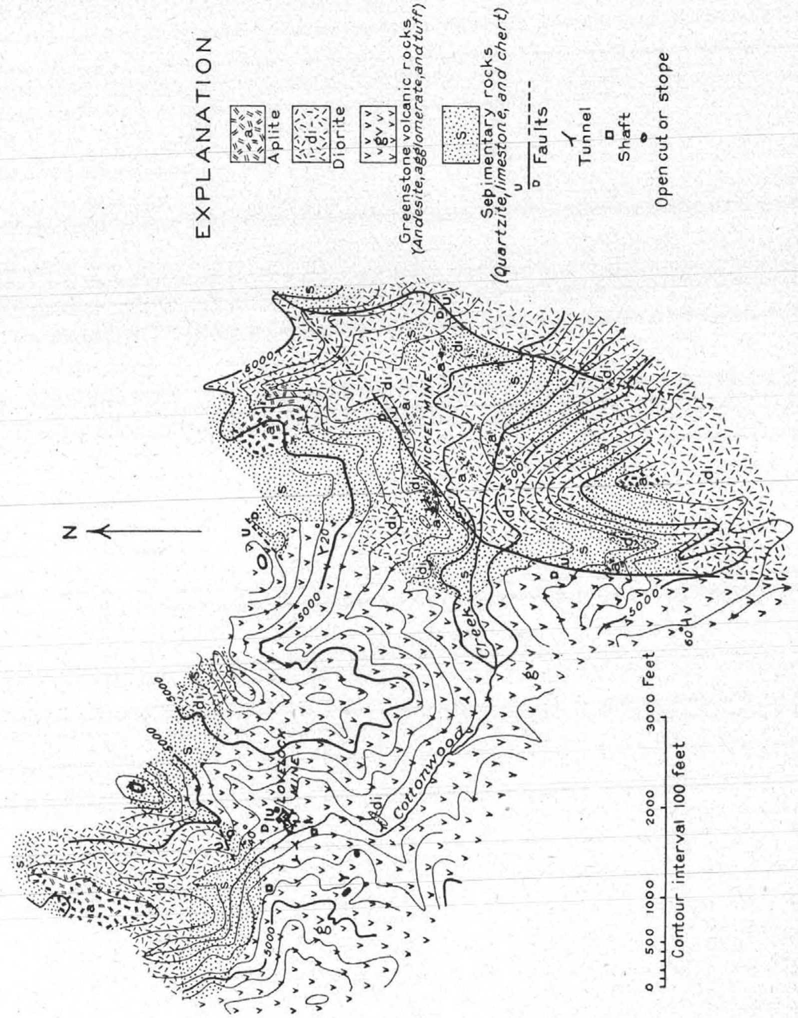


FIGURE 2. Geologic map of part of Cottonwood Canyon near Nickel and Lovelock mines.

only minor replacement by calcite and sericite. In most of the dike rocks in the small area examined the original minerals have been completely altered. The only feldspar present is albite, probably a replacement of the original feldspars of the dike, and the rock consists essentially of dickite, quartz, anatase (octahedrite), calcite, and sericite, named in approximate order of their abundance. The anatase is sporadic in its distribution. In places it forms over 5 percent of the rock and in small segregations a much larger proportion; elsewhere it may be lacking or present only in small specks. Where most abundant it forms sharply outlined lozenge-shaped masses, the largest nearly 2 inches in length, which suggest that it was formed by the replacement of earlier sphene.

The quartz that is now being mined for its gold content forms very elongate lenticular bodies within and along the margins of the dikes. Single quartz masses a few feet in width may be traceable for as much as 100 feet. There has, however, been complex later faulting close to the range front and it has not been determined to what extent discontinuity of the outcrops of the dikes and quartz veins may be due to later faulting.

The quartz is milky white and of medium grain, and some calcite is also present. The only visible metallic minerals are pyrite and very rare sphalerite. There is also everywhere more or less brown iron oxide, presumably the result of oxidation of pyrite. The gold is free but so finely divided that it is visible only in the pan. Assays of samples taken from the outcrops are reported to show a tenor of about an ounce to the ton along ore shoots as much as 75 feet in length. A little ore mined by lessees from one of the faulted segments close to the range front yielded a return of a little over $21 a ton. Assays show a ratio of gold to silver of about 10 to 1.

ORIGIN OF THE DEPOSITS

It is thought that the origin of both the nickel and cobalt deposits of Cottonwood Canyon and the titanium and gold deposits of Corral Canyon is closely related to the intrusion of the diorite. The sequence seems to have been as follows:

Intrusion of the aplite dikes closely followed that of the diorite. In their original form the dikes consisted essentially of quartz and sodic plagioclase. The sphene present in both the dikes and the parent diorite suggests a relatively high content of titanium in the original magma. Following the consolidation of the dikes came widespread albitization, resulting in nearly complete alteration of the feldspars, not only in the dikes but in the adjacent ore deposition may have followed faulting; if they are pre-Tertiary, there may have been renewed movement on an older fault, and the mineral-bearing stringers may be associated with the original major fracture.

There are numerous small prospect tunnels in the hills bordering Cottonwood Creek between the two mines, but in those that were accessible there was nothing seen to indicate the likelihood of any mineral deposit of commercial promise. Most of these tunnels follow iron-stained fissures with only here and there a little green stain. It is doubtful, however, whether the area has been so intensively prospected as to eliminate the possibility of new discoveries. The writer, for example, found an unexplored small copper-bearing stringer in the altered greenstone near the crest of the steep ridge about half a mile northwest of the Nickel mine. Except for the Nickel mine, where the mineral deposits are in the sedimentary rocks at the diorite contact, the fissures sufficiently well defined to encourage prospecting are all within the greenstone and the great majority of them are in the portion of the greenstone that shows replacement by hematite. The silicified zones in the greenstone, which form the craggy outcrops on the ridges north of Cottonwood Creek, show no nickel or copper stains.

CORRAL CANYON

GOLD AND TITANIUM DEPOSITS

Part of a day was devoted to a visit to prospects close to the front of the range near Corral Canyon, about 5 miles south of the mouth of Cottonwood Canyon. No attempt was made to study the geology in any detail, nor was the intervening area examined. The writer is indebted to C. S. Ross for mineralogic and petrologic determinations of material collected.

The country rock of the region is diorite, presumably a part of the same mass as that of Cottonwood Canyon. The diorite is cut by a number of dikes, originally of feldspathic rock, which contains abundant anatase (octahedrite) and are associated with veins or segregations of gold-bearing quartz.

The white, fine-grained dikes have a general northerly trend and stand out sharply against the surrounding diorite. It is probable that here, as in the Cottonwood Canyon area, the dikes originally consisted of an aplitic rock, composed of feldspar with a little quartz, and their present peculiar mineral composition is the result of pegmatitic and hydrothermal alteration. A specimen from the apparently least altered part of one of the dikes was found to consist essentially of microcline and oligoclase, with

for identification of the ore minerals and analyses of the ore of the nickel mine.

LOCATION

The nickel and cobalt mines of Cottonwood Canyon are in the Table Mountain district, also known as the Cottonwood or Boyer district, which occupies part of the Stillwater Range in Churchill and Pershing (formerly a part of Humboldt) Counties. According to Lincoln,[1] the district contains a wide variety of mineral deposits, including nickel, cobalt, copper, silver, lead, gold, kaolin, oil shale, and gypsum. Except, however, for the gold and titanium deposits near Corral Canyon, discovered since the publication of Lincoln's compilation, the present investigation was confined to the nickel and cobalt deposits of Cottonwood Canyon.

Cottonwood Canyon, in the northern part of Churchill County, cuts the steep, eastern flank of the Stillwater Range. The mouth of the canyon can be reached by automobile over roads that are passable in good weather, either by a route about 55 miles in length through Dixie Valley from Highway U S 50 or one about 70 miles southward from Winnemucca on U S 40, through Grass and Pleasant Valleys. In the fall of 1938 work was planned on a road to connect the two east-west highways through Dixie, Pleasant, and Grass Valleys. Completion of this road will render the district much more easily accessible. There was formerly a road up the canyon to the mines, but it has been completely washed out and the mines at present can be reached only on foot through the steep-walled canyon.

The Stillwater Range and its northern continuation, the East Range, rise abruptly from the valley in a steep, eastward-facing scarp. Two or 3 miles north of the mouth of Cottonwood Canyon, the horizontal distance between the 4,000- and 7,000-foot contours is less than $1\frac{1}{2}$ miles, as shown in the southern-most part of the topographic map of the Sonoma Range quadrangle. Cottonwood Creek flows through a narrow box canyon, crossing the ridge that borders the front of the range. Near the mines, 2 or 3 miles back from the front of the range, the canyon is much wider, and west of the Lovelock mine it becomes a shallow valley cut only slightly below a broad bench that has an altitude of about 5,500 feet. This bench is apparently about coincident with the position of the contact of the older rocks and overlying Tertiary lavas. To the west these lavas, which form the crest of the range, rise to an altitude of about 7,500 feet.

[1]Lincoln, F. C., Mining districts and mineral resources of Nevada, pp. 11–13, Reno, Nevada, 1923.

PREVIOUS WORK

Cottonwood Canyon lies within the area covered by the maps of the Fortieth Parallel survey, but it is doubtful whether the geologists of this survey actually visited the locality. The nickel and cobalt deposits, as well as the copper deposits near the crest of the range south of the canyon, were visited by Ransome in 1908. The present writer can add little to Ransome's description of the deposits.[2] The map of the area around the two mines and the notes on the recently discovered gold and titanium deposits near Corral Canyon are the principal new contributions to the geology of the district. The copper deposit, not visited by the writer, has been described by Carpenter.[3] Lincoln's compilation[4] gives notes on mining developments and a concise summary of earlier publications.

GEOLOGY

COTTONWOOD CANYON

ROCK FORMATIONS

The rocks of the area studied include highly altered sedimentary and volcanic rocks cut by a large mass of diorite and by aplitic dikes, all of which are now highly altered.

The oldest rocks in the vicinity of the nickel deposits are sedimentary and consist chiefly of quartzite, but they also include altered limestone, in part silicified, together with a white chert-like rock, that may be either bleached chert or silicified limestone. The total thickness is uncertain, but probably is not over a few hundred feet.

Overlying the sedimentary rocks is a considerable thickness of altered volcanic flows, with smaller amounts of agglomerate and obscurely bedded tuff. The flows were probably of andesitic composition originally, but are now so highly altered that it seems preferable to describe them by the noncommittal term of greenstone. Little remains of their original texture. Over much of the area, particularly near the two mines shown in Figure 2, a considerable part of the rock has been replaced by platy hematite. In part, this hematite is hydrated to a brown iron oxide. Elsewhere, as on the ridge north of the two mines, they have been impregnated with fine-grained silica and the silicified rocks form bold craggy outcrops.

[2]Ransome, F. L., Notes on some mining districts in Humboldt County, Nevada: Geol. Survey Bull. 414, pp. 55–58, 64–66, 71, 1909.
[3]Carpenter, A. H., Boyer copper deposits, Nevada: Mining and Scientific Press, vol. 103, pp. 804, 805, 1911.
[4]Lincoln, F. C., op. cit., pp. 11–13.

the inaccessible cross-cut north of the diorite. The entire production apparently came from the upper workings. In the lower tunnel, near the face of the eastern branch, the silicified limestone close to the intrusive diorite west of the fault is cut by small iron-stained fissures, which, here and there, contain a little green stain, probably due to nickel. Elsewhere the accessible workings of this level are completely barren. Although such work as has been done on this level seems to eliminate the possibility of any large body of ore, it is not unlikely that other small nickel-bearing stringers may be encountered on this level below the productive zone in the upper workings.

Should further work be undertaken, the area east of the lower tunnel should be explored as far as the fault, as the upper workings indicate that the stringers, though not continuous, may be rich in nickel. This may have been the intention of the last operators when they started the east branch at the northern end of the lower tunnel.

It is not known how much work was done below the lower tunnel. There are several winzes in the northern part of the lower tunnel, and the shaft also extends below the tunnel level, but these deeper workings were not accessible. No further deep work would appear justified without better indications at the level of the lower tunnel than now appear.

It is believed that the fault is post-mineral and that the ore deposition was pre-Tertiary. If so, no exploration is justified along the fault itself. This belief is based on the apparent late Tertiary age of the fault, as shown by its inferred northerly extension; also by the complete lack of primary mineral deposits along the fault itself in the vicinity of the mine, both at the surface and in the small tunnel along the fault. North of the mine, however, there are small prospect pits along the fault in which the fault gouge contains a little limonite and faint green stains, which may be due to either nickel or copper. These may be the result of supergene deposition, which is shown in the mine itself by the presence of secondary millerite and marcasite. Ransome,[14] however, points out that, as copper ores occur in the Tertiary tuffs near the crest of the range south of the canyon, a Tertiary age of these deposits cannot be excluded. As will be shown below, this suggestion appears to be unlikely, but there remains the possibility that the association of the nickel-bearing stringers with the fault is not fortuitous. If the ores are of Tertiary age,

[14]Ransome, F. L., op. cit., pp. 58, 71.

Similar discontinuity of fissuring was observed in the prospects between the Nickel and Lovelock mines and in the workings south of the creek. The workings of the Lovelock mine were inaccessible, but according to Ransome,[13] "comprise a labyrinth of superficial burrowings by which miners have followed or sought for the small erratic veinlets of ore, and a precarious shaft that no attempt was made to explore." A stope about 50 feet by 20 feet, open at the surface, trends N. 75° W., but, as far as could be observed, the stringers remaining on the walls have no consistent direction.

It seems probable that individual mineral-bearing fissures are at least as discontinuous in a vertical direction as in the outcrop. According to Ransome, the shaft of the Lovelock mine is apparently not much more than 100 feet deep. The accessible part of the lower tunnel of the Nickel mine (Figure 4) does not cross mineral-bearing fissures such as have been stoped in the tunnel about 60 or 70 feet above.

The inaccessibility of the workings of the Lovelock mine prevents any speculation as to the possibility of renewed production from this mine. According to Ransome, considerable work has been done in the 100-foot zone above water level, both in following the mineralized fissures and in searching for others. Apparently nothing was found to justify exploration at greater depth. It was observed, however, that the stope and nearly all the small tunnels and inclines are east of the main shaft, and that at the shaft itself there was a steep fault with northerly strike which separates the highly altered and mineralized greenstone from less altered rock on the west. It is possible, therefore, that here, as at the Nickel mine, there has been post-mineral faulting with downthrow on the west, and that the extension of the productive zone is west of the shaft and at greater depth than present workings have reached.

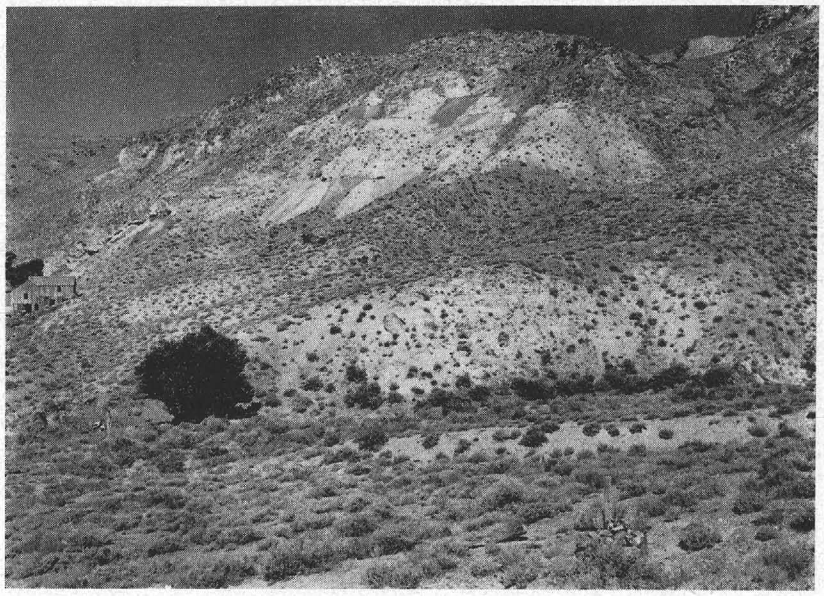
The ore deposit of the Nickel mine (Figure 4), on the other hand, occurs within a downfaulted segment of a mineralized area, the eastern portion of which has been eroded. The major production seems to have been derived from a gently-dipping stringer, which has been stoped above the upper tunnel and possibly also between the upper and lower tunnels. It does not, however, extend to the lower tunnel 60 or 70 feet below. Similarly, the steeply-dipping stringer to the north, on which there has been some stoping, was not cut in the lower level unless in

[13]Ransome, F. L., op. cit., p. 58.

The age of these volcanic rocks is unknown; they bear a certain resemblance to interbedded sedimentary and volcanic rocks of Permian age in the north part of the Sonoma Range quadrangle. (Recent areal studies in the Sonoma Range quadrangle suggest that these rocks may be of Pennsylvanian rather than Permian age.) Less metamorphosed sedimentary rocks, also cut by diorite, crop out at the mouth of the canyon, about 2 miles southeast of the Nickel mine. These include limestone, slate, and conglomerate, and bear some resemblance to rocks of known Lower Triassic age in the Sonoma Range quadrangle.

Diorite is the principal rock of the area. The canyon for the 2 miles between the Nickel mine and the range front is cut in diorite. The same mass extends southward along the range front and is probably continuous with that at the titanium prospects near Corral Canyon, 5 miles south of Cottonwood Canyon. Diorite also cuts the sedimentary and volcanic rocks north of the Lovelock mine. The diorite varies greatly in texture and composition, but is, in general, coarse- to medium-grained. Plagioclase, augite, hornblende, and biotite are present in varying amounts, with sphene, magnetite, and apatite as primary accessories. All of the rock examined in thin sections by Mr. Ross was altered. The feldspars are everywhere partly sericitized. Other secondary minerals include dickite (one of the kaolin minerals), clinozoisite, chlorite, quartz, and calcite. Replacement of plagioclase by albite is also common, and near some of the aplite dikes there appears to have been nearly complete replacement of the original rock by albite accompanied or followed by calcite, sericite, quartz, and dickite.

At the margins of the diorite mass there are small dikes of a fine-grained, white feldspathic rock (aplite). These crop out within the diorite mass and are in contact with the sedimentary rocks close to the diorite. None was found in the altered volcanics in the central part of the mapped area nor in the main mass of diorite in the lower part of Cottonwood Canyon. Essentially, the aplite is a fine-grained aggregate of feldspar and a little quartz. In one of the specimens examined by Mr. Ross the feldspar proved to be a mixture of oligoclase and microcline; in all the others examined, albite is the only feldspar present. In most of the specimens examined additional later minerals include dickite, quartz, calcite, sericite, and anatase. The anatase where present is in extremely small crystals, so well scattered through the rock that Ransome, who did not see the much more altered



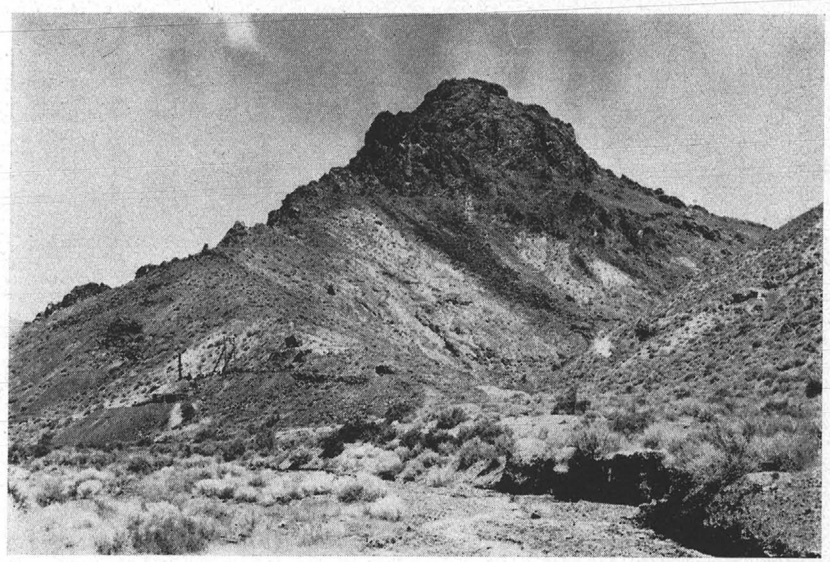


FIGURE 3. A. View of Nickel mine from east. Foreground consists of diorite cut by aplite dikes. The workings are in the more resistant altered sedimentary rock west of the fault shown in Figure 2. B. View of Lovelock mine from south. In foreground is greenstone. High hill to south consists of quartzite.

a flat fissure with a dip of about 20° to the southwest. This has been followed along the strike for about 100 feet and stoped over about one-half this distance. Probably this stringer yielded a relatively large amount of nickel, in spite of its small length,

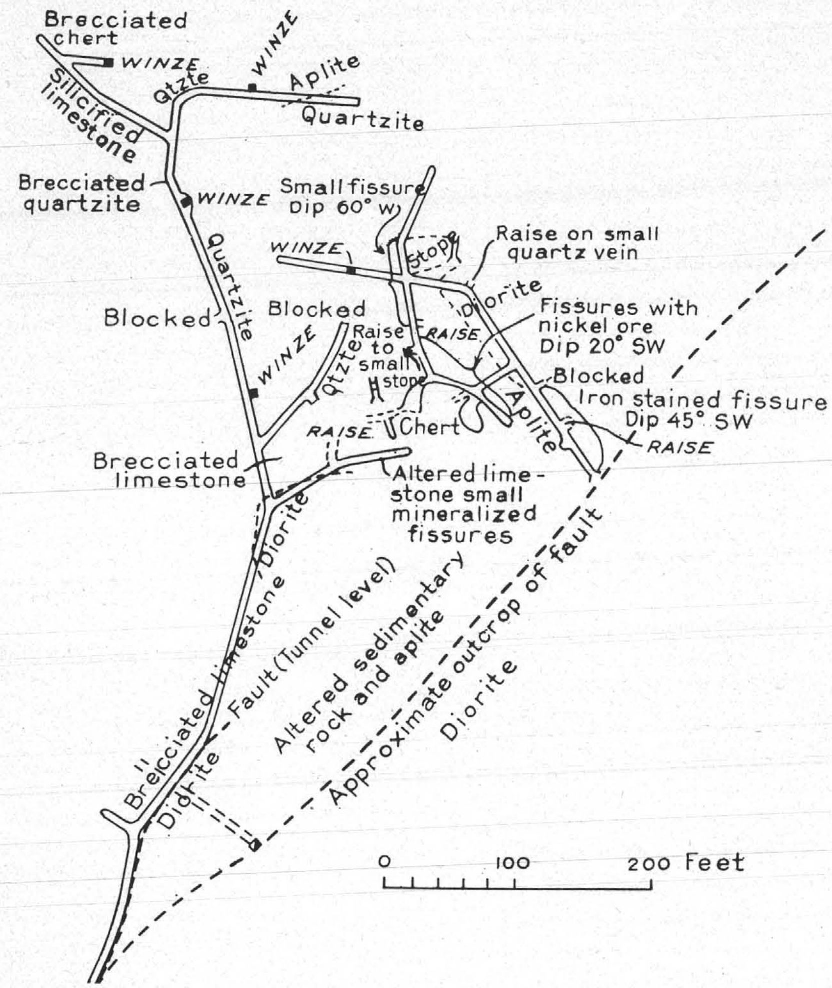


FIGURE 4. Map of a portion of the workings of the Nickel mine, based on a pace and compass survey. Relative positions of the different workings are approximate only.

for the sample taken from a 4-inch vein of green material left at the end of the stope assayed 23.3 percent nickel. Nearby, in the same tunnel, a stringer with a northerly trend and a westerly dip of 60° to 70° has been followed for about 80 feet, and has been stoped for about 30 feet.

"From the summation of the calculated percentages it appears that the reduction has been too great. This might be explained in part by the presence of garnierite, which was not allowed for, or by a partial dehydration of the hydrated minerals previous to analysis. If the proportion of water had been higher, the calculation would have resulted in more annabergite and less of the last two arsenides, bringing the summation closer to 100. Water was determined by the Penfield tube, using sodium tungstate as a retainer of the arsenic and sulphur. The ore carried 23.30 percent nickel expressed as metallic nickel."

The low iron content shown by this analysis is not representative of the deposits as a whole. Most of the stringers show abundant brown iron oxide with, here and there, green streaks, indicating the presence of nickel, whereas others show only limonite and a little quartz.

In the greenstone area between the Nickel and Lovelock mines in the prospects on the hill west of the Lovelock mine the filling of the small fissures is predominantly iron oxide, with, here and there, a little green copper sulphate and carbonate, but no nickel minerals.

At the Lovelock mine the mineral composition is more complex; ores of copper, cobalt, and arsenic are all present, and, according to reports, nickel ore was mined as well. According to Ransome,[12] "The minerals recognized are tetrahedrite, erythrite (cobalt bloom), azurite, and green crusts that, according to Mr. Schaller, contain copper and nickel arsenates and sulphates and consequently may be a mixture of annabergite and brochantite." Specimens from a small pile of picked ore at the mouth of a tunnel leading to the open stope of the Lovelock mine and from stringers on the walls of the stope were examined by J. G. Fairchild, of the Geological Survey. He reports as follows: "A basic sulphate of copper, resembling brochantite, is the abundant green mineral. Cobalt bloom, or erythrite, was identified chemically in two specimens. No nickel mineral was identified. The light-green mineral is also a basic sulphate of copper with some arsenic, possibly chalcophyllite. An oxide of manganese is present in dark-brown seams and black patches." The approximate metal content of the material, according to Mr. Fairchild, is 9 percent copper, 1 percent arsenic, 1 percent cobalt, and 0.6 percent nickel.

No consistent orientation of the mineralized fractures is apparent. In the Nickel mine (Figure 4) the principal stopes are along

[12]Ransome, F. L., op. cit., p. 58.

dikes of the Corral Canyon area (pp. 15, 16), considered it an original mineral.[5] The chemical analysis given by Ransome shows only 0.97 percent TiO_2. In a dike near the Nickel mine, however, anatase apparently replacing sphene was found completely enclosed in calcite.

STRUCTURE

The altered volcanic rocks, cut by the diorite, lie in a syncline bordered on the west, north, and east by the altered sedimentary rocks. Their southward extension is unknown, but apparently they crop out on the high ridge that separates Cottonwood Canyon from the next canyon to the south.

There are two faults of northerly trend, both with downthrow on the west, in the eastern part of the mapped area. The western fault cuts off the mineral-bearing fissures of the Nickel mine and probably branches out from the eastern fault in the valley northeast of the mine. Its dip averages about 45° to the west. The eastern fault also has a westerly dip, but is steeper and probably everywhere dips over 60°. Over most of its course within the mapped area, it is traceable only as a shear zone in the diorite, but on the north bank of Cottonwood Creek it forms the boundary between a downfaulted roof pendant of quartzite and the main mass of the diorite. The amount of displacement along these faults is not measurable, but may amount to several hundred feet, for the greenstone crops out only in the area west of the western fault.

A fault that is the apparent continuation of that crossing Cottonwood Canyon displaces middle or late Tertiary bedded tuffs[6] a short distance north of the area mapped. Therefore, it is probable that the faults within the district may also be of late Tertiary age.

Probable faults of smaller throw, inferred from the nature of the contacts rather than from direct observation, form the boundaries between the sedimentary and volcanic rocks at one place north of the Nickel mine and between the sediments and diorite at one place northwest of the Lovelock mine. The shaft of the Lovelock mine is along a fault that separates heavily hematitized greenstone from less altered rock.

NICKEL AND COBALT DEPOSITS

According to Lincoln,[7] the nickel and cobalt deposits of Cottonwood Canyon were discovered by George Lovelock and Charles

[5]Ransome, F. L., Notes on some albitite dikes in Nevada: Washington Acad. Sci. Jour., vol. 1, pp. 114–118, 1911.
[6]Muller, S. W., personal communication.
[7]Lincoln, F. C., op. cit., p. 11.

Bell about 1882. Production began shortly afterwards, and the early volumes of "Mineral Resources" contain notes on production. Apparently the larger part of the earlier production was derived from the Lovelock mine and continued until about 1886. According to "Mineral Resources":[8] "Since the first opening of the mines in 1883 about 200 tons were shipped for reduction to England, of which 90 tons were shipped during 1885. * * * The general average of the 200 tons shipped to England was said to have been 12 percent nickel and 14 percent cobalt." Ransome[9] says that the mine is reported to have shipped a total of about 500 tons of high-grade nickel-cobalt ore. The mine was reopened about 1898 by an English company and an attempt made to smelt the ore, but little or no production was made.

The ore deposits of the Nickel mine were probably discovered at about the same time as the Lovelock mine, but, so far as known, less work has been done on this deposit. According to Ransome[10] the principal period of activity was between 1882 and 1890, and at least one car of ore, with a content of 26 percent nickel, was shipped to Camden, N. J. The mine was reopened in 1904 and an attempt made to leach the ore with sulphuric acid. A small smelter was also built, but the production was very small, probably not over 50 tons of matte, according to Ransome.[11] The mine has been idle since 1907. In 1936 the patented claims covering the property were purchased at a tax sale by the present owners.

As far as could be observed, the nickel and nickel-cobalt ores of the two mines occur as small discontinuous stringers that cut the rocks immediately surrounding the diorite. These stringers are composed essentially of ore minerals and iron oxide with very little quartz. At the Nickel mine such stringers cut a highly altered rock that was probably an aplite dike originally, and also cut the adjoining altered sedimentary rocks; at the Lovelock mine the stringers cut highly altered greenstone. No stringers of this type were found within the diorite, though veins of white quartz cut the diorite and have been prospected in places, apparently without success.

Although the type of mineralization seems to have been the same throughout the area, the mineral content of the small stringers varies greatly in the different mines and prospects. At the

[8] Mineral Resources of the United States for 1885, p. 361, 1886.
[9] Ransome, F. L., op. cit., p. 58.
[10] Ransome, F. L., op. cit., p. 57.
[11] Ransome, F. L., op. cit., p. 12.

Nickel mine the ore minerals present are combinations of nickel, arsenic, iron and sulphur.

The nickel minerals present in the stringers are almost completely oxidized and consist principally of the hydrous nickel arsenate, annabergite, the sulphate, morenosite, possible garnierite, and an unidentified bright-green nickel-bearing mineral. Sulphide present in one of the stringers was identified by C. F. Park as dominantly niccolite, which, however, by its crystal form, appears to have replaced millerite. Millerite occurs in part as rare residual grains within the niccolite and in part as thread-like veinlets, probably accompanied by a little marcasite, that cut the niccolite and apparently the annabergite also. The second mode of occurrence is presumably supergene, but the total secondary enrichment thus indicated is negligible. Gangue minerals are not abundant and include limonite, quartz, and dickite. The following analysis by R. C. Wells of a sample cut from a 4-inch stringer at the end of the principal stope, indicates the composition of the purest ore obtainable:

Analysis of Nickel Ore
(R. C. WELLS, Analyst)

	Determined		Calculated
SiO_2	14.78		14.78
Al_2O_3	1.61		1.61
Fe_2O_3	.71		.71
NiO	29.67	NiO	18.37
		Ni	8.49
As_2O_5	36.20	As_2O_5	22.07
		As	9.21
MgO	1.27		1.27
CaO	.83		.83
Na_2O	.22		.22
H_2O-	2.56		2.56
H_2O+	11.04		11.04
TiO_2	Trace		Trace
S	1.70		1.70
SO_3	1.83		1.83
	102.42		95.19

Mr. Wells comments on the analysis as follows:

"The calculated composition shown is based on subtraction of assumed constituents in the following order and percentages:

	Percent
Water-soluble As_2O_5	4.07
Water-soluble morenosite, $NiSO_4.7H_2O$	5.33
Millerite, NiS	4.82
Annabergite, $Ni_3As_2O_8.8H_2O$	46.50
Niccolite, NiAs	8.04
Violarite, $NiAs_2$	6.54