A GOLD-PLATINUM-PALLADIUM LODE IN SOUTHERN NEVADA.

By ADOLPH KNOFP.

INTRODUCTION.

The discovery of platinum-bearing gold ore at the Boss mine, in southern Nevada, was brought to the attention of the Geological Survey by Mr. F. A. Hale, jr., in September, 1914. Some samples of the ore were submitted at the same time. These were assayed and found to be extraordinarily rich in gold, platinum, and palladium. A brief announcement of the discovery, based on the returns of these assays and on information courteously supplied by Mr. Hale, appeared on October 3, 1914, in an advance chapter of Mineral Resources for 1913. Early in October an examination of the deposit was made by the writer, the results of which are here given.

LOCATION.

The Boss mine is situated in the Yellow Pine mining district, Clark County, Nev., near the extreme southern part of the State. The main settlement of the district is Good Springs, distant 8 miles from Jean, a station on the San Pedro, Los Angeles & Salt Lake Railroad. Good Springs lies on the east side of a desert range known as Spring Mountain, but the mine is situated on the west slope, 12 miles from Good Springs, by a road which crosses the range through a low pass. A few miles from the mine is the abandoned settlement known as Sandy (Ripley post office), at which was situated the cyanide plant of the Keystone mine. From a well at this place water of good quality is obtained for domestic use at the Boss mine and neighboring prospects. An ample supply is said to be available for milling purposes.

HISTORY.

The deposit on the Boss claim was discovered some 30 years ago, having been located for copper, the presence of which is plainly indicated by chrysocolla and other oxidized copper minerals. In

the nineties the property was bonded and a leaching plant was built at Good Springs to treat the oxidized copper ores, but, the process proving a failure, the property reverted to its original owners. Not until recently has the gold and platinum content of the ore been recognized. The owners, Messrs. Yount & White, discovered the high gold content by sampling and assaying, and the Boss Gold Mining Co. was organized in March, 1914.

The failure to recognize previously the auriferous character of the ore needs explanation. It seems to have been due in part to the fact that, although the ore can be shown by assays or chemical means to carry considerable gold, the presence of the gold, as the writer has verified personally, is not evident on panning. Moreover, some extraordinarily rich material (the plumbojarosite, described on p. 8, assaying as high as $6,000 to the ton in gold) yields when panned a black residue which might easily be thrown away as worthless black sand. This unpromising-looking black residue when strongly scoured by rubbing it in the pan with a piece of iron rolls out into yellow flakes and quills, and its identity as gold becomes manifest. The discovery of the platinum content of the ore is due to the acumen of Mr. H. K. Riddall, chemist for the Yellow Pine Mining Co. In running assays of the Boss ore he noticed that the gold buttons, instead of being smooth, had rough, cauliflower-like surfaces. He suspected that the buttons might contain platinum, and this suspicion was strengthened by the fact that solutions obtained on parting, instead of being colorless as is the rule when the gold is alloyed with silver only, showed yellow and brown tints, indicating the presence of platinum and palladium. By systematic tests these metals were then proved to be present. This result was soon verified by a number of other assayers, although one supposedly reliable assaying firm in Los Angeles reported that the ore contained no platinum. Two samples sent to the Geological Survey by Mr. Hale were submitted for assay to Ledoux & Co., of New York, who reported on September 9, 1914, as follows:

<table>
<thead>
<tr>
<th>Assays of ore from Boss mine.</th>
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<tr>
<td></td>
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<tr>
<td>Platinum</td>
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<td></td>
</tr>
<tr>
<td>Gold</td>
</tr>
<tr>
<td>Palladium</td>
</tr>
</tbody>
</table>

Note.—Concentration by panning shows that the metals are in the free state, being apparently alloys of gold and platinum metals. Owing to uneven distribution, assaying is very difficult and the above results can only be considered as approximately correct. Assay for palladium was omitted on No. 1, but the sample contains 1 or 2 ounces of this metal. A little iridium is present in No. 2.

Prior to the discovery of the platinitiferous character of the ore some small shipments of high-grade copper ore and of high-grade
gold ore had been sent to the smelter at Salt Lake City, but after the platinum content was recognized production was suspended, pending arrangement for the advantageous disposal of the platinum and allied metals.

In October negotiations were under way for the treatment of certain lots of high-grade ore by the Pacific Platinum Works, of Los Angeles, whereby this firm agreed to pay $46 an ounce for the combined platinum and palladium content, after deducting a treatment charge of $300 a ton.

Late in the year the mine was sold by the Boss Gold Mining Co. to W. C. Price and associates for $150,000, according to O. J. Fisk, former manager of the company.

The great interest that attaches to so unusual and remarkable an occurrence of platinum and palladium in a gold-bearing lode hardly needs comment. As is shown on pages 13–17, in the review of the known distribution of platinum in veins, the Boss vein is one of the few primary deposits in which metals of the platinum group occur in more than traces and, with one possible exception (the New Rambler mine in Wyoming), is the only primary deposit of economic importance in which these metals are the constituents of predominant value.

GENERAL GEOLOGY OF THE DISTRICT.¹

SEDIMENTARY AND IGNEOUS ROCKS.

The prevailing rocks of the district are stratified dolomites of middle Carboniferous age. (See Pl. I.) They are considerably though not acutely folded and are broken by faults. This formation is economically the most important assemblage of rocks in the district, as all of the ore deposits occur in it or in the dikes cutting it.

Limestones of Pennsylvanian age and red sandstones and shales of probable Mesozoic age are also present in the district, but they are of no special concern here, as they lie at a considerable distance from the area in which the Boss mine is situated.

Intrusive igneous rocks are not common in this district; in fact, the areas occupied by them are so small as to be barely perceptible on the geologic map. They consist of sills and short dikes of quartz monzonite porphyry and granite porphyry, as a rule considerably altered. The age of intrusion has not been established, but is thought to be at least as recent as post-Jurassic.

Some horizontal sheets of biotite andesite cap the summit of Table Mountain, southwest of Good Springs. This is the only noteworthy occurrence of extrusive rocks in the district.

**METALLIFEROUS FEATURES.**

The principal metalliferous deposits of the district are bodies of lead-zinc ores inclosed in dolomite or limestone. The prevailing minerals are smithsonite and cerusite; galena occurs to some extent, but zinc blende, presumably the parent of the oxidized zinc ores, is present in only one mine. The genesis of the primary minerals of these deposits is as yet unknown.

Gold deposits were formerly of some importance in this district, the Keystone mine, the most productive, being credited with an output of $1,000,000. At this mine the gold is disseminated through quartz monzonite porphyry, which has been highly altered by the development of sericite and siderite. In general the deposits are closely associated with the porphyry dikes and may stand in genetic relation to them. Certainly the chemical alteration produced in the porphyry dikes indicates that the ore-forming solutions were ascending thermal waters.

Some copper deposits have also been developed. They consist predominantly of oxidized copper minerals forming irregular replacement bodies. Tetrahedrite, which has been recognized in the gold ore of the Lavina mine, and chalcocite are the only copper-bearing sulphides found in the district.

Finally, brief mention should be made of the so-called vanadium deposits. On the Bill Nye claim, for example, a dolomite breccia cemented by a copper-bearing lead vanadate, probably cuprodesclozie, forms a tabular deposit 18 to 24 inches thick, which has been exposed by an incline to a depth of 12 feet.

The Yellow Pine district is the most productive zinc and lead district in Nevada. In 1913 it yielded 29,060 tons of ore, containing $1,268 in gold, 192,339 ounces of silver, 283,592 pounds of copper, 6,204,065 pounds of lead, and 14,369,709 pounds of zinc, valued in all at $1,239,081.¹

**THE BOSS MINE.**

**GENERAL GEOLOGIC FEATURES.**

The country rock at the Boss mine consists of dolomite in beds ranging from a few inches to several feet thick. The beds comprise a dark-gray or black variety, fetid with hydrogen sulphide on fresh fracture, and a more prevalent pale-buff variety. They not uncommonly carry crinoid fragments and are of late Mississippian or early Pennsylvanian age—that is, middle Carboniferous.

The rocks strike east and dip gently to the north. The structure is that of a broad anticlinal arch, whose crown has been more or less

fractured and broken by faults. In the immediate vicinity of the mine the rocks are practically horizontal.

A small mass of granite porphyry or dike of no great linear persistence occurs 600 feet north of the mine. This rock is characterized by numerous large corroded phenocrysts of quartz and kaolinized feldspars embedded in a fine-grained groundmass. It accordingly resembles the small masses of intrusive granite porphyry and quartz monzonite porphyry scattered throughout the district. The porphyry is highly altered and has been considerably prospected for gold, but has proved of too low grade to be profitable, carrying at best only a few dollars in gold to the ton.

The ore bodies so far developed may be briefly characterized as oxidized copper shoots and gold-platinum-palladium shoots. The copper ores consist largely of chrysocolla and colloidal complexes of chrysocolla and limonite; these ores are reported to carry only minor amounts of the precious metals. The gold-platinum-palladium shoots consist of fine-grained siliceous ore carrying a small quantity of a bismuth-bearing variety of plumbojarosite (a hydrous sulphate of iron and lead). There is no fixed ratio between the content of gold and the platinum metals, nor between the content of platinum and palladium. This variability seems to be a result of the prevailing oxidized condition of the ore. The palladium, according to reliable figures furnished to the writer, is probably in excess of the platinum.

The copper shoots and the precious-metal shoots can be mined separately, it is said. The segregation of the metals into separate shoots that makes this feasible will assuredly be found less and less complete as depth is attained on the deposit.

The ore bodies of the Boss mine occupy a nearly vertical zone of fracturing in the horizontal strata of dolomite. At the surface this zone is 30 feet wide, but the precious-metal shoots are confined to the 12 feet resting on the footwall. The length of the mineralized zone exposed on the surface is about 100 feet, but the ore bodies do not extend continuously over this distance. At the portal of the upper tunnel the footwall strikes N. 5° E. and the hanging wall strikes N. 25° E. The principal ore shoot, so far as the present workings disclose, forms an irregular pipe pitching at a low angle to the northeast.

The dolomite within the zone of fracturing has recrystallized to a coarse white spar, and this dolomite spar makes up the rock inclosing the ore shoots.

DEVELOPMENT.

The principal development consists of three tunnels driven along the zone of mineralization. (See fig. 1.) They are known as the upper, middle, and lower tunnels. The middle tunnel is about
30 feet below the upper, and the lower is about the same distance below the middle tunnel. The richest ore is exposed in the "ore winze," which was sunk from the upper tunnel and is connected with the middle tunnel. Estimates of the total amount of ore exposed in the mine range from 1,000 to 2,000 tons, but at the time of visit an accurate estimate was not possible.

A development tunnel was started some years ago several hundred feet below the upper group of tunnels, but no work has been prosecuted on it recently.

**MINERALOGIC FEATURES.**

The essential features of the deposit are well shown in the irregular open cut at the portal of the upper tunnel. Here there is a considerable mass of somewhat cupriferous gossan. Below it, at about the tunnel level, is an irregular pocket of light-gray material, which crumbles to a fine gray sand; and beneath this sandy material is a porous dark-gray to blackish siliceous rock. The ore carries gold and platinum metals, and a winze was sunk
LIST OF MINES

1. Potosi
2. Green Monster
3. Keystone
4. Oro Amigo
5. Whale
6. Bill Nye
7. Hoodoo
8. Springer and Tiffen
9. Hoofer
10. Milford
11. Addison
12. Ninety-nine
13. Contact
14. Ninety-three group
15. Red Cloud
16. Prairie Flower
17. Yellow Pine
18. Alice
19. Porphyry Canyon
20. Lavinia
21. Columbia
22. Frederickson
23. Monarch
24. Lincoln
25. Porter
26. Monte Cristo
27. Accident
28. Bonanza
29. Anchor
30. Boss

LEGEND

SEDIMENTARY ROCKS
- Gravel, sand, and recent wash
- Light-colored cross-bedded sandstone
- Red sandstone and shale

IGNEOUS ROCKS
- Buff to pink limestone with conglomerate and some sandstone
- Light to dark gray dolomite

MINERAL DEPOSITS
- Intrusive quartz monzonite and granite porphyries

MINE SYMBOLS
(Numbers refer to list of mines)
- 25 Lead-zinc
- 6 Copper
- ✦ Gold
- ✦✧ Platinum

SKETCH MAP OF YELLOW PINE MINING DISTRICT, CLARK COUNTY, NEV.
here to the tunnel below, but the ore shoot is reported not to have persisted to the lower level. About 6 feet farther in toward the mouth of the tunnel, lying under a mass of earthy red hematite, is another streak of gray sandy material, containing a middle band, three-fourths of an inch wide, of a soft greenish-yellow powder. This greenish-yellow mineral, identified as a new variety of the rare species plumbojarosite, is extraordinarily rich in gold and platinum metals; in fact, the evidence indicates that the distribution of the precious metals, especially of those of the platinum group, is dependent on the presence of this mineral.

A sample of the gray sandy material essentially free from admixed plumbojarosite, taken by the writer from a point near the winze mentioned above, was submitted to the Bureau of the Mint and assayed by F. P. Dewey, who reports as follows: Gold, 0.44 ounce to the ton; platinum metals remaining insoluble on boiling the silver lead in strong sulphuric acid, 0.01 ounce to the ton. If palladium was present it was not determined.

The gray sandy material proves to consist largely of perfectly formed crystals of quartz, averaging 0.1 millimeter in diameter; doubly terminated crystals are common. Some of this quartz sand, after repeated evaporation with hydrofluoric acid, left a small residue consisting of minute crystals of adamantine, almost metallic luster. These crystals comprised octahedrons and square tabular forms, averaging a few hundredths of a millimeter in size. Their crystal habit, together with the fact that they gave a strong titanium reaction after fusion with potassium bisulphate, suggested that they were octahedrite (anatase), and their identity as octahedrite was conclusively established by Dr. H. E. Merwin by the determination of their optical properties. Dr. Merwin reports as follows:

The grains are mostly single crystals, slightly tabular normal to an optic axis (uniaxial, negative). The refractive index \( \omega \) was found to be 2.51+0.01 for lithium light. Measured on six crystals, \( \omega - e \) is 0.070+0.003. The value for \( \omega \) is the same as all observers have found for anatase (ranging between 2.515 and 2.521) and \( \omega - e \) is the same as later investigators have found for this mineral (0.066-0.073).

A few prisms and knee-shaped twins of rutile occur with the octahedrite. The octahedrite and rutile are subordinate constituents, but they are the only gangue minerals in the deposit other than quartz.

A particularly rich shoot of ore has been developed by a winze sunk from a point near the end of the upper tunnel. In this shoot are small masses of what is locally known as greenish talc. Some of these were mined separately and two shipments aggregating about 1 ton were sent to the smelter at Murray, Utah. On a control sample of this ore Ledoux & Co. report as follows: Gold, 111 ounces to the

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CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1915, PART I.

ton; platinum, 99.08 ounces to the ton; palladium, 16 ounces to the ton; iridium, trace.

The "greenish talc," determined chemically and microscopically, proves to be a bismuth-bearing variety of the rare mineral plumbojarosite. It is a greenish-yellow mineral of smooth, unctuous feel, which under the highest power of the microscope is seen to consist of perfect hexagonal tablets averaging 0.01 millimeter in diameter. It carries considerable mechanically admixed gold and platinum metals. An analysis of the purest obtainable material was made in the laboratory of the United States Geological Survey by R. C. Wells, with the following results:

### Analysis of bismuthic plumbojarosite from the Boss mine.

<table>
<thead>
<tr>
<th></th>
<th>Fe₂O₃</th>
<th>Al₂O₃</th>
<th>SO₃</th>
<th>PbO</th>
<th>H₂O</th>
<th>H₂O+</th>
<th>CaO</th>
<th>MgO</th>
<th>K₂O</th>
<th>Na₂O</th>
<th>CO₃</th>
<th>As₂O₅</th>
<th>SiO₂</th>
<th>TiO₂</th>
<th>Au</th>
<th>Pt</th>
<th>Pd</th>
<th>Ir</th>
<th>Ag</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>32.24</td>
<td>.14</td>
<td>24.08</td>
<td>16.75</td>
<td>.02</td>
<td>8.55</td>
<td>1.97</td>
<td>6.34</td>
<td>6.06</td>
<td>.14</td>
<td>.22</td>
<td>.09</td>
<td>0.06</td>
<td>0.37</td>
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Reduced to ounces a ton, the analysis shows gold to be present to the extent of 234 ounces, platinum 15 ounces, and palladium 64 ounces. Assays of similar material are reported to show as high as 575 ounces of gold, 230 ounces of platinum, and 30 ounces of palladium. The silica and titania shown by the analysis represent an admixture of quartz and octahedrite.¹

The gold and platinum metals can be partly separated from the plumbojarosite by panning, but long before a clean separation can be effected fine gold and especially platinum pass into the tailings, in spite of the utmost precaution. The gold is extraordinarily rough and spongy; delicate platy forms are common, and some is intergrown with quartz and plumbojarosite or is molded around minute quartz crystals. It is more or less blackish, and aggregates of the finer particles look like so much black sand. Treatment with hydrochloric acid and annealing, however, bring out the normal yellow color of gold. Some of the larger particles after being treated thus were analyzed by R. C. Wells, as follows:

### Analysis of gold from the Boss mine.

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<table>
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</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>97.8</td>
</tr>
<tr>
<td>Silver</td>
<td>2.2</td>
</tr>
<tr>
<td>Platinum metals</td>
<td>Trace</td>
</tr>
</tbody>
</table>

100.0

¹ Further study of the material analyzed shows that it contains 20 per cent of beaverite, CuO.PbO. FeO₂.SiO₂.4H₂O. (See Knopf, Adolph, Plumbojarosite and other basic lead-ferric sulphates from the Yellow Pine district, Nev.: Washington Acad. Sci. Jour., vol. 5, pp. 497-503, 1915.)
Qualitative tests on other gold particles always showed the absence of platinum metals, and the inference of Ledoux & Co. that the metals are present "apparently as alloys of gold and platinum metals" is therefore not borne out. The platinum and palladium occur in extremely small particles, which even at high magnification under a binocular microscope are indistinguishable from the dull blackish particles of gold; in all material examined by the writer chemical tests were necessary to establish the presence of the platinum and allied metals. By cleaning the precious metals in molten sodium carbonate, particles of gray metal (platinum and palladium, or an alloy of these) become distinguishable from yellow gold. The possibility was entertained that sperrylite might be present in the residue of the pannings from the plumbojarosite or elsewhere in the ores of the Boss mine, but no trace of this mineral, which, according to its discoverer, is characterized by a wonderfully brilliant luster, was found.

The pockets of plumbojarosite occur in a porous, fine-grained siliceous gangue, which is a replacement of the dolomite country rock. The pores and cavities evidently resulted from the leaching of sulphides formerly present; they are now partly filled with malachite in small botryoidal groups, or more commonly with powdery plumbojarosite. A thin section cut from a specimen selected for assay shows quartz, commonly euhedral, and plumbojarosite scattered throughout the material, perhaps to the extent of 10 per cent. This specimen was submitted to the Bureau of the Mint for assay, and F. P. Dewey reports as follows:

Gold, 4.12 ounces to the ton; platinum metals remaining insoluble on boiling the silver bead in strong sulphuric acid, 3.35 ounces to the ton. I made no determination of palladium, but the sulphuric-acid solution was strongly colored, indicating that much palladium had gone into solution.

This determination of the platinum metals (mainly platinum with some iridium) is therefore a minimum for this particular sample. The ore, despite its extreme richness, shows no free gold or platinum metals. The writer was unable to pan any precious metal from this ore, or to separate any with heavy solution, but on evaporation with hydrofluoric acid an extremely fine black residue remained, containing gold, platinum, palladium, and octahedrite.

A composite of 22 samples taken in the winze connecting the upper and middle tunnels and on the intermediate level yielded the following return, in ounces to the ton: Gold, 3.46; silver, 6.4; platinum, 0.70; palladium, 3.38. It is probable that there are several hundred tons of ore of this grade, which, with platinum and palladium at $45 an ounce, has a value of $256 a ton.

1 Data furnished to the writer by a mining engineer who examined the mine under an option that was not exercised.
The only sulphide-bearing ore exposed in the mine at the time of visit was in the sublevel below the upper tunnel. Here, in particularly tight ground, about 3 feet of copper ore rich in chalcocite had been opened. An average sample of this ore, as reported by the management, showed copper 15.1 per cent and platinum metals 0.40 ounce, gold 0.13 ounce, and silver 1.2 ounces to the ton.

The chalcocite, which is of the steely kind and shows conchoidal fracture, occurs as small blebs and finely disseminated particles embedded in a close-grained siliceous gangue. It is partly altered to brochantite, the basic sulphate of copper, which forms small glassy emerald-green prisms implanted on the sulphide from which it was derived. Examination of this ore under the microscope shows that it is an aggregate of quartz, chalcocite, and brochantite, with octahedrite present as a rare accessory mineral; the brochantite occurs in partial replacement of the quartz and is somewhat more abundant than would be estimated from inspection by the unaided eye. An oxidized bismuth compound, whose identity was not established, is associated with some of the chalcocite.

**GENESIS OF THE ORE.**

The Boss deposit represents in the main an irregular siliceous replacement of dolomite along a series of vertical fractures. On account of the prevalent oxidation and the inconsiderable depth to which the workings have penetrated, primary sulphides have not yet been reached. The chalcocite, the only sulphide so far found, most probably originated as a precipitate from downward-moving solutions whose copper was derived from primary sulphides formerly exposed to oxidation near the surface.

The deposit yields as yet no especially strong evidence concerning the genetic conditions that prevailed at the time it originated. Some clue is perhaps afforded by the presence of the titanium oxide minerals, octahedrite and rutile. Both of these are rather uncommon in metalliferous deposits. Of the two rutile is the more common. It is, for example, somewhat abundant in certain of the auriferous deposits of the Juneau gold belt, which are veins that originated at high temperature; in fact, according to W. H. Emmons,\(^1\) rutile is restricted to high-temperature veins. Octahedrite occurs in the tourmaline-bearing copper veins of Las Condes, Chile;\(^2\) in tin veins of Saxony- associated with apatite, fluorite, and chlorite; and in fissure fillings in the Alps,\(^3\) but these veins are not notably metalliferous. The Alpine veins are, thought to have formed at tempera-

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\(^1\) A genetic classification of minerals: *Econ. Geology*, vol. 3, p. 625, 1908.


\(^3\) Koenigsberger, Johann, *Transformations and chemical reactions in their application to temperature measurement of geologic processes*: *Econ. Geology*, vol. 7, p. 697, 1912.
tures between 250° and 400°. In view of the affiliation generally shown by the octahedrite and rutile with deposits of high-temperature origin, the suggestion is advanced that the primary ore of the Boss deposit was formed under conditions of moderately high temperature.

The facts at hand can not of themselves be held to prove that the ore deposition was genetically connected with the intrusion of any particular dike or igneous mass now visible at the surface. It is probable, nevertheless, that the mineralization followed as a sequel to the intrusion of the magma from which the granite porphyry dikes were derived, for these are the only intrusives that penetrate the rocks of the district.

The deposit, as already described, is highly oxidized and contains abundant oxidized copper compounds and plumbojarosite. These minerals indicate that the primary sulphides will be found to carry copper, iron, lead, bismuth, and precious metals. The extraordinary richness in gold, platinum, and palladium of ore containing notable quantities of plumbojarosite raises an important problem. It is of course not impossible that the plumbojarosite may have originated essentially in place by simple oxidation of sulphides that were extremely rich in precious metals. A partial analogy for this supposition is furnished by the development of the brochantite in the chalcocite-bearing ore; the brochantite appears to have formed in place from the chalcocite without any important migration of copper.

For the origin of the plumbojarosite, however, the following explanation appears to fit the known facts more closely. B. S. Butler, who has recently shown that in the oxidized ores of Utah plumbojarosite is rather common, although heretofore unrecognized, believes that in the occurrences studied by him the plumbojarosite was produced by the action of ferric solutions on galena; the lead has remained essentially in place, but the iron may have come from some distance. It is therefore suggested that in the Boss ore body descending solutions rich in ferric sulphate attacked primary galena, forming the plumbojarosite, and that this reaction caused the concomitant precipitation of the gold, platinum, and palladium. According to this explanation an efficient solvent for the precious metals was active and in this connection the fact established by R. C. Wells, during the chemical investigation of the plumbojarosite, that the precious metals are rather soluble in hydrochloric acid in the presence of plumbojarosite is highly suggestive.

On the whole, then, it is likely, in view of the probable mode of origin of the plumbojarosite and of the evidence of leaching indicated by the porous nature of the siliceous ore, that a certain amount of redistribution of gold, platinum, and palladium has taken place by

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1 Occurrence of complex and little-known sulphates and sulpharsenates as ore minerals in Utah: Econ. Geology, vol. 8, pp. 315-316, 1913.
the action of descending surface solutions. It would follow, then, that in depth, below the zone of oxidation, the pockets of extremely high-grade ore, such as are now being extracted, will be found to give way to ore of moderate grade.

AZURITE MINING CO.'S CLAIMS.

The claims of the Azurite Mining Co. adjoin those of the Boss group, and some work is in progress here. The Rosella prospect, situated several hundred feet north of the Boss mine, is in a coarsely crystalline white dolomite; the metalliferous deposits consist of small irregular bodies of oxidized lead-zinc ore. Of interest is the occurrence of pure lumps of the rare mineral plumbojarosite, consisting of minute hexagonal tablets, having a maximum refractive index of 1.83, and reacting for lead, ferric iron, water, and sulphate. Curiously enough the plumbojarosite is not a bismuth-bearing variety, as at the adjoining Boss mine. In places a porous siliceous gangue is found, but this has not been shown to be platiniferous.

On the Azurite claim a body of oxidized copper ore inclosed in coarsely crystalline dolomite has been opened. The gangue is siliceous and, in addition to carrying the oxidized copper minerals, locally contains chalcocite.

ORO AMIGO MINE.

At the time of the writer's visit to the Yellow Pine district, metals of the platinum group were known to occur only at the Boss mine. Since then they have been found in the ore of the Oro Amigo mine, the property of the Oro Amigo Platino Mining Co., which is situated between 1 and 2 miles northeast of the Boss mine. Mr. H. K. Riddall, to whom the writer is indebted for specimens of the ore, reports as follows:

**Assay of ore from Oro Amigo mine.**

<table>
<thead>
<tr>
<th>Ounces to the ton.</th>
<th>Gold.</th>
<th>Platinum metals.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample No. 1, width 3 feet</td>
<td>0.11</td>
<td>0.10 Small</td>
</tr>
<tr>
<td>Sample No. 2, width 6 inches</td>
<td>.51</td>
<td></td>
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</tbody>
</table>

Sample No. 1, as examined by the writer, consists essentially of limonite; it carries no bismuth nor admixed plumbojarosite and is therefore quite unlike the ore of the Boss mine. This may indicate that the distribution of the platinum metals is more widespread in the Yellow Pine district than is now known and that it is not restricted to the peculiar mineral association shown by the Boss deposit. Sample No. 2 is a siliceous rock, holding numerous small angular fragments of chert, and is coated and permeated with limonite.
A GOLD-PLATINUM-PALLADIUM LODE IN NEVADA.

GEOLOGIC OCCURRENCE OF PLATINUM.

REVIEW OF KNOWN LODE OCCURRENCES.

To afford a basis for comparison of the platiniferous deposit at the Boss mine with other occurrences of platinum in lodes, a short summary is given in the following pages, describing, so far as they are known, the geologic features of some of the more important occurrences of platinum in lode deposits.

The bulk of the world's supply of platinum, as is well known, is obtained not from lodes but from placers, those in the Ural Mountains of Russia alone furnishing 95 per cent of the entire annual production. Minor quantities are derived from Colombia, California, and New South Wales. In the Ural Mountains the platinum-bearing gravels have resulted from the erosion of a broad belt of basic plutonic rocks trending parallel to the axis of the range. The platinum, traced to its bedrock source, is found as an original constituent of dunite, or rarely of pyroxenite, and as such has crystallized from a molten state, most commonly in association with chromite. The metal occurring thus, however, is too dispersed to be economically valuable. Certain segregations of chromic iron in the dunite contain considerable amounts of platinum, but even these are so small and irregularly distributed that they do not admit of profitable exploitation. The output of platinum in the Ural region is therefore derived solely from the placers. These are now worked mainly by dredges, and this industry is regarded as likely to show an expansion in the future.

The platiniferous gravels of other districts, such as those of Colombia, have essentially the same geologic relations as those of the Ural Mountains. The platinum obtained as a by-product of the gold-dredging industry of California is shown by Lindgren to be derived from the erosion of the serpentine, peridotite, and gabbro masses occurring in the auriferous region.

Although platinum occurs in metalliferous lodes at a number of places in several parts of the world, no lode deposit is worked solely for its platinum content. In fact, the platinum in those deposits from which it is obtained forms but an insignificant fraction of the total metallic content, either in quantity or in value, and is recovered as a minor by-product. There are, however, a few platiniferous lode deposits which, under more favorable commercial conditions, may possibly become productive and in which the platinum is the metal of predominant value.

Platinum and palladium occur in the copper-nickel ore of the Sudbury region, Canada, and small quantities of these metals are recovered annually from the electrolytic muds formed during the refining of the nickel. In 1902 no less than 2,375 ounces of platinum and 4,411 ounces of palladium were recovered, but the production has since decreased very considerably, and no figures are available for the years after 1904.  

The platinum occurs in the ores of the Sudbury region as the arsenide, sperrylite, the only known natural compound of the metal. This mineral was, in fact, first discovered in the gossan of the Vermilion mine. Although palladium is present in larger amounts than platinum, no palladium compound has yet been recognized. Sperrylite forms small cubes and octahedrons of brilliant tin-white color and resists weathering completely; hence it becomes concentrated in the gossans of the oxidized sulphide masses. In the unoxidized ore it is associated mainly with chalcopyrite, from which it can be isolated by treatment with acid. The Sudbury deposits, consisting of pyrrhotite, pentlandite, and chalcopyrite, resulted from the separation of these minerals from a body of molten rock before cooling was complete; the associated platinum and palladium are therefore of direct magmatic origin.

Sperrylite has also been recognized in the ore of the Rambler mine, Wyoming. The deposit consists of covellite, chalcopyrite, chalcopyrite, and pyrite inclosed in a highly decomposed diorite. The sperrylite is particularly associated with the covellite in extremely minute crystals, the largest isolated by Wells and Penfield measuring only 0.12 millimeter in diameter. Considerable palladium is associated with the platinum. A special investigation was made by T. T. Read to determine the condition in which this palladium occurs in the ore. He concluded that it is either in the tetrahedrite, which he showed is a constituent of the Rambler ore, or may be present as some definite palladium mineral soluble in nitric acid or caustic soda. No evidence was obtained that the palladium is present as an arsenide analogous to sperrylite. In recent years an experimental mill has been built at the Rambler mine and the recovery of the precious metals attempted.

2 Idem, p. 29.
3 Idem, pp. 44-55.
7 Concentration of platiniferous copper ore at the Rambler mine, Wyoming: Met. and Chem. Eng., vol. 9, pp. 75-78, 1911. This article describes the methods of investigation and treatment, the experimental mill, giving its flow sheet and assays of the different table products and the assay methods employed.
was made,\textsuperscript{1} but in 1912 the plant was shut down. An assay of a general sample on the stope level of the Rambler mine is reported to show 1.3 ounces of precious metals (mainly platinum and palladium) to the ton and 6 per cent of copper.\textsuperscript{2} On account of the profound metamorphism of the Rambler deposit, due to oxidation and sulphide enrichment, the genesis of the deposit has not been satisfactorily established.

The platinum-bearing peridotite dikes near Bunkerville, Clark County, Nev., 25 miles east of Moapa and 100 miles northeast of the Boss mine, are described by Howland Bancroft.\textsuperscript{3} The dikes, as determined on fairly fresh material from the Great Eastern prospect, consist chiefly of augite, olivine, biotite, and enstatite and contain pyrrhotite, probably nickeliferous, chalcopyrite, and magnetite. The sulphides are apparently of pyrogenic origin. A shipment of 91,600 pounds from the Key West dike showed a content of 2.3 per cent of copper, 1.79 per cent of nickel, and 0.13 ounce of platinum metals to the ton. As a result of careful experimentation Dickson\textsuperscript{4} concluded that the platinum does not exist as sperrylite in this ore; it occurs apparently in a form soluble in nitric acid, caustic soda, or hydrofluoric acid.

A platiniferous deposit of contact-metamorphic origin in Sumatra is briefly described by L. Hundeshagen.\textsuperscript{5} The deposit consists of wollastonite, garnet, and bornite and is regarded as having resulted from the metamorphism of a limestone lens by granite. Slightly decomposed wollastonite containing no copper proved to be richest in platinum, carrying 0.17 ounce to the ton, besides 0.11 ounce of gold.

A remarkable deposit of palladium-gold occurs at Candonga, in Minas Geraes, Brazil.\textsuperscript{6} Gold and palladium-gold (an alloy of gold containing about 8 per cent of palladium) are found in a rock consisting of an intergrowth of pyroxene, actinolite, chondrodite, calcite, magnetite, and ilmenite. This lime-silicate rock was beyond question derived from a limestone lens in itabirite, as a result of the contact metamorphism produced by the intrusion of granitic and pegmatitic masses.

The Gongo Socco mine, also in Minas Geraes, produced 390,337 ounces of gold carrying approximately 4 per cent of palladium. This

\textsuperscript{1} Horton, F. W., Platinum: Mineral Industry, 1911, p. 597, 1912.
\textsuperscript{2} Met. and Chem. Eng., vol. 9, p. 76, 1911.
deposit, like that of Candonga, is regarded by Hussak as having originated as a result of the metamorphism exerted by granitic intrusions on a limestone layer in the itabirite series.

The Ruwe gold lode, in the Belgian Kongo, consists of a bed of sandstone in a series of sandstones and quartzites. It carries gold, platinum, palladium, and silver, said to average $17 to the ton. Gold and platinum are present in the metallic state, and with them are associated a number of lead and copper vanadates, together with pyromorphite and malachite. The origin of this deposit has not yet been established.

The occurrence of platinum in quartz veins is recorded from a number of localities, but none of these appear to be of commercial importance. The platiniferous character of certain pyritic gold-quartz veins which traverse crystalline schists near the Rio Bruscus, in the State of Pernambuco, Brazil, has been demonstrated by Williamson.

In New Zealand some small quartz veins cutting mica schists and phyllite have been found to be platiniferous by J. M. Bell; the best, however, carries only 0.17 ounce of platinum to the ton. The associated sulphides are pyrite and chalcopyrite, and silver is present in the ratio of 7 parts of silver to 1 of platinum. The veins occur near altered magnesian plutonic rocks and are believed to have originated as a result of the intrusion of these rocks.

As early as 1806 Vauquelin had established the presence of platinum in the ore of a silver mine at Guadalcanal, Spain. The mineral analyzed was tetrahedrite, or some mineral closely resembling it, and was found to contain copper, lead, antimony, iron, sulphur, silver, and some arsenic. The platinum content proved to be irregular, ranging from a trace to as much as 10 per cent. The veins are inclosed in mica schist and have a gangue of calcite, barite, and quartz.

Other examples of lodes in which platinum has been detected might be cited, but those already mentioned serve to illustrate the salient features of occurrences of platinum in veins. A. Eilers has recently placed on record a table which gives the amount of platinum, palladium, and other elements contained in the blister copper from a number of the larger smelteries. Although these two metals are present in extremely minute proportions they are recovered during refining in the electrolytic muds, where they accumulate as valuable by-products. The palladium is generally more abundant

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than the platinum. The blister copper from the Steptoe smeltery, which treats the porphyry ore of Ely, Nev., contains 0.01 ounce of platinum and 0.044 ounce of palladium to the ton.

Of further interest in connection with the geology of platinum are the observations of Hussak on the solution, migration, and redep-osition of this metal by waters of surface origin. He believes that certain botryoidal, stalactitic nuggets of platinum were deposited from solutions that resulted from the oxidation of platiniferous sulphides or of sperrylite. The suggestion concerning the derivation of the metallic platinum from the oxidation of platiniferous sulphides is probably well founded, but that concerning the sperrylite seems not to be supported by the prevalence of this mineral in the gossan of the Vermilion mine in the Sudbury district.

CONCLUSIONS AND COMPARISON OF THE BOSS DEPOSIT WITH PREVIOUSLY KNOWN DEPOSITS.

The bedrock occurrences of platinum show that this element is concentrated mainly by magmatic processes, but these processes seem rarely or never to have gone far enough to produce deposits of economic value. As a rule, platinum is restricted to magnesian plutonic rocks, mainly dunites and allied varieties. It is present, however, as a minor constituent of some magmatic copper or copper-nickel ores, of which those of the Sudbury region are the most prominent examples; further, it occurs, as the table given by Eilers shows, in practically all types of copper ores, although in extremely minute quantities. This fact emphasizes the conclusion, first drawn by Kemp after summarizing the information concerning the known distribution of platinum, that platinum "does appear sometimes in veins with other metals, especially with copper. It would follow that platinum migrates in solution." It is not improbable, therefore, that copper-bearing deposits may occasionally be found in which platinum forms an economically important constituent.

The association of platinum with siliceous igneous rocks is not wholly unknown. At Copper Mountain, British Columbia, platinum occurs as sperrylite in a pegmatite dike which carries bornite, probably as a pyrogenic constituent. The pegmatite cuts gabbro, however, instead of granite, thus differing from normal pegmatites. In Sumatra a platiniferous deposit of contact-metamorphic origin has been recognized; it is thought to be genetically associated with granitic intrusions, but this relation has not been decisively established. In Brazil palladium-bearing gold deposits, also of contact-

metamorphic origin, are related to the intrusion of granite and pegmatite.

In short, then, primary deposits containing platinum in noteworthy quantities are mainly of igneous origin, but some of hydrothermal origin have been discovered and are mainly copper-bearing deposits. It is perhaps most reasonable to expect that platinum should occur, as a rule, in high-temperature copper veins—an expectation partly borne out by the Sumatran occurrence—but this supposition seems to be opposed by the fact that platinum in certain other recognized occurrences is associated with tetrahedrite, a mineral not characteristic of high-temperature zones.

From the foregoing discussion it is apparent that the gold-platinum-palladium deposit at the Boss mine is not closely similar to any other deposit carrying metals of the platinum group heretofore described. Its cupriferous character links it, however, with most of the other known platinum-bearing lode deposits. The occurrence of abundant gold together with palladium, on the other hand, is suggestive of the Brazilian deposits, as is also its probable genetic connection with siliceous igneous rocks.