NICKEL, URANIUM, ETC.

CARNOTITE IN RIO BLANCO COUNTY, COLO.

By Hoyt S. Gale.

INTRODUCTION.

In September, 1906, while the writer was engaged in a survey of coal fields in the upper valleys of White and Yampa rivers in northwestern Colorado, his attention was called to the reported occurrence of an ore of uranium that was then and is now attracting considerable interest from various parts of the State. The prospects lie just east of the border of the Danforth Hills coal field and the material occurs in rocks the study of whose stratigraphy has formed an important part of the writer's field work for the last two seasons. In the spring of 1906 a party, including Mr. E. L. White, State commissioner of mines, and Prof. Herman Fleck and W. G. Haldane of the school of mines at Golden, Colo., visited these prospects, and their report is expected at an early date.

LOCATION.

The prospects lie near the valley of Coal Creek, about 14 miles by wagon road northeast of Meeker, the county seat of Rio Blanco county. Meeker is usually reached by stage from Rifle, a station 45 miles distant on the Denver and Rio Grande Railroad, the trip occupying a day. The claims now located (eight or ten in number) are situated 1½ miles east to southeast of the locality known as "The Transfer," on Coal Creek, where lumber hauled from the mills on Sleepy Cat Mountain is transferred to the larger wagon loads to be taken into Meeker.

CARNOTITE.

The name carnotite was given in 1899 by E. Cumenge and C. Friedel to a canary-yellow ocherous pigment that was found impregnating a siliceous sandstone in Montrose County, Colo.[a] Carnotite has also been discovered in San Miguel and Mesa counties in Colorado and in adjacent counties of Utah.

[a] Merrill, G. P., The Nonmetallic Minerals, 1904, p. 322.

The mineral carnotite is of use as a source of the rare elements uranium and vanadium. It is also reported to have been tested and found to contain the rarer element radium.[a] It is readily dissolved in acids and may be treated in this way for the commercial production of uranium salts. The chief use of uranium is as a pigment in painting on porcelain, in photography, and as a color in glass manufacturing.[b] It has been employed experimentally in the manufacture of alloys of iron and aluminum. It increases the hardness and elasticity of steel and also of aluminum, but as yet has not been put to much practical use for this purpose.

A description of the carnotite occurrences in western Colorado and a discussion of the chemical nature of the mineral will be found in a paper published by Hillebrand and Ransome in August, 1900.[c] In this paper the following conclusions as to the general nature of carnotite are reached:

> The body called carnotite is probably a mixture of minerals of which analysis fails to reveal the exact nature. Instead of being the pure uranyl-potassium vanadate, it is to a large extent made up of calcium and barium compounds. Intimately mixed with and entirely obscured by it is an amorphous substance—a silicate or mixture of silicates—containing vanadium in the trivalent state, probably replacing aluminum. The deposits of carnotite, although distributed over a wide area of country, are for the most part, if not altogether, very superficial in character and of recent origin.

The Rio Blanco County carnotite is found in the Dakota sandstone, a group of sandstone ledges of which several are very massive, interstratified with some shaly beds. This formation has a thickness of 700 feet or more. The carnotite is found at the summit of the hogback ridge formed by the lowest and most massive of the sandstones. In the principal group of deposits seen the carnotite occurs in association with fossil or silicified wood. This fossil-wood layer is apparently an original stratum of the Dakota sandstone, for it may be traced along the strike of the beds for a mile or more. The carnotite itself is in the form of a bright-yellow film or crust with the appearance of having been deposited from solution, coating the silicified wood and filling cracks in it and to a less extent in the neighboring sandstone. In only one place the mineral was found as an impregnation in the Dakota sandstone apparently without association of silicified wood.

The mineral itself, scraped from the rock to a glass slide, immersed in liquid and covered with a thin glass, shows on magnification minute granular patches, transparent and yellow in color. W. T. Schaller examined some of this material in the Geological Survey laboratory and found a few crystals showing minute hexagonal form

[a] Eng. and Min. Jour., vol. 77, 1904, p. 673.

[b] Eng. and Min. Jour., vol. 76, 1903, p. 46.

[c] On carnotite and associated vanadiferous minerals in western Colorado: Am. Jour. Sci., 4th ser., vol. 10, 1900, p. 120.

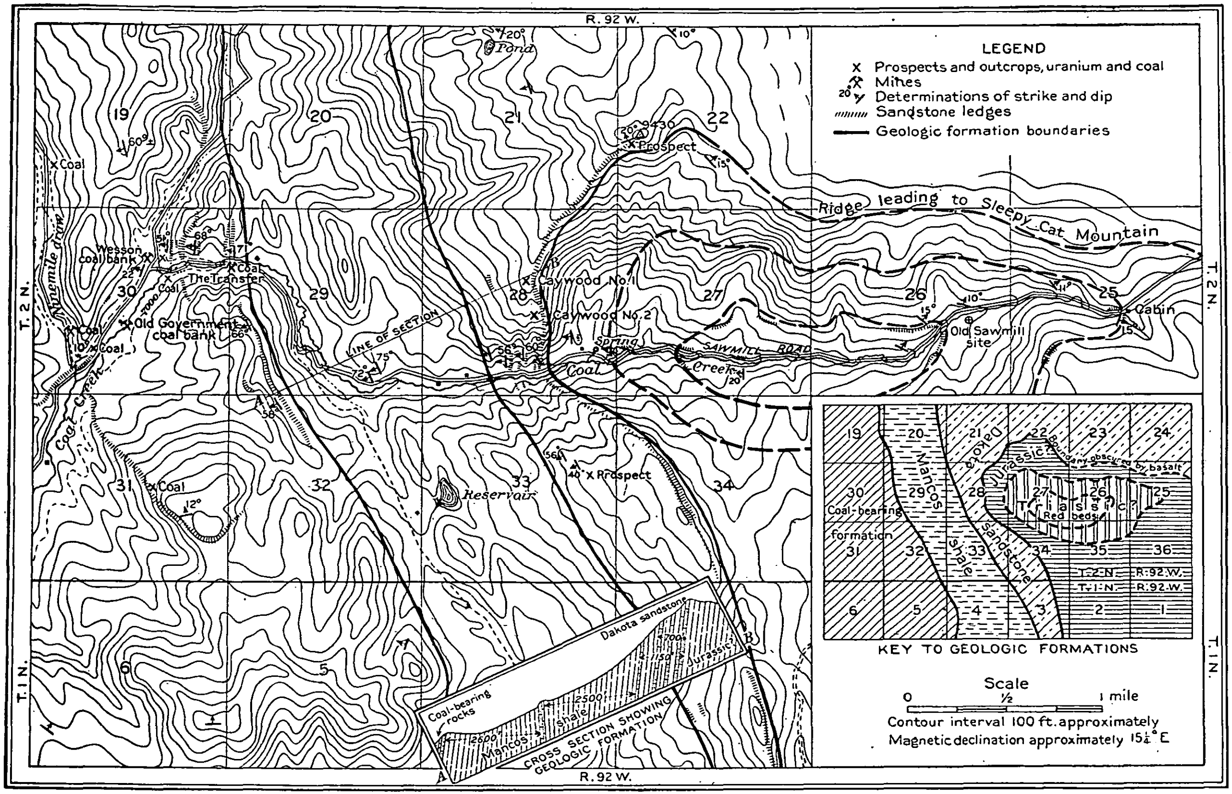
and an appreciable thickness, but too minute to give interference figures. In this respect it probably varies in character from the Montrose County carnotite, which is reported to be composed of "exceedingly fine, dust-like particles without crystal outlines and acting so faintly on polarized light as to at first seem almost amorphous," although a few exceedingly minute crystals are also mentioned in the description of that material.

The Montrose County carnotite is reported to be found in the La Plata sandstone, which is of Jurassic age, and the mineral therefore occurs in an older geologic formation than the carnotite of Rio Blanco County, which is found in the Dakota sandstone. Since, however, in both localities the carnotite was evidently deposited in these rocks long after the time of their formation as such, this difference has no especial significance relating to a differing mode or time of formation of the mineral itself.

GEOLOGY OF THE COAL CREEK DISTRICT.

The summit of Sleepy Cat Mountain is a peak of about 10,800 feet elevation, capped by basaltic lava representing a succession of surface flows that probably took place in late Tertiary time. The bowlders of this basalt strew the spurs and ridges surrounding the peak and obscure much of the structure of the underlying sediments. Coal Creek rises on the west flank of Sleepy Cat Mountain and flows nearly due west for 6 miles in a rather deep, narrow valley. About midway in this portion of its course the creek has cut its valley into the crest of an anticlinal fold or dome in the rock strata, exposing formations that are doubtless of Triassic age. (See geologic map, Pl. III.) Along the upper half of this stretch of Coal Creek the rocks dip to the east or northeast, toward Sleepy Cat Mountain. Down the creek bed west of the fold these same rock beds may be recognized dipping westward, in the direction the creek is flowing, and as they pass beneath water level they are covered by successively younger formations. At the lower end of its narrow valley the creek passes through a gateway in large ledges of white quartzite and sandstone, west of which it emerges into a long, straight, northwest-southeast valley. The white sandstone ledges represent, in part at least, the formation so widely known as the Dakota sandstone. The depression immediately east of this sandstone and quartzite ridge is formed upon shaly strata showing in outcrops of various colors, in the main shades of pink and red. It is suggested that these underlying strata may be of the same age as the Gunnison formation of the Anthracite-Crested Butte area.[a] The fact that, so far as the writer knows, no identifiable fossils have as yet been collected from the formations including and below the Dakota in this locality or near vicinity causes some doubt as to the

[a] Eldridge, G. H., Geologic Atlas U. S., folio 9, U. S. Geol. Survey, 1894.



GEOLOGIC MAP OF UPPER COAL CREEK VALLEY AND VICINITY, RIO BLANCO COUNTY, COLO.

proper designation of these lower formations. The rock strata, however, form a series fairly comparable with the formations known east of the Rocky Mountain ranges, and it is on the basis of similarity of character of the rocks themselves that the geologic names are given.

Below the gap in the Dakota ledges Coal Creek emerges into an open valley, from which, after making a short turn toward the north, it once more turns westward and cuts into the sandstone hogbacks of the coal field. Half a mile or so beyond, it turns to the south toward White River. The valley between the coal-field hogbacks and the Dakota hogback is about $1\frac{1}{2}$ miles wide and is eroded on a formation of comparatively weaker shales. It is divided about midway by a minor hogback ridge due to the presence of some harder sandy layers. The total thickness of these shaly strata is considerably over a mile. Just above the Dakota ledges the shale is very black, dense, and in many places slaty, and in this position on the north slope of Sleepy Cat Mountain a number of fossils were found that are known to be of Benton age. The geologists of the Hayden survey mapped this whole predominatingly shaly formation (except a few hundred feet at the top that were placed with the Fox Hills formation) as the Colorado shale. As a single unit the whole group of strata above the Dakota sandstone and below the coal-bearing formation has been called the Mancos shale in the report on the Yampa coal field.[a]

Above the Mancos shale the coal-bearing sandstones and shales attain a thickness of something over a mile, and in other parts of the field these rocks are succeeded and overlain by still later formations. The lumber camp known as "The Transfer" is in the rocky gorge where Coal Creek enters the lowermost ledges of the coal-bearing beds. All of these rocks, occupying the interval from the beds below the Dakota ledges up to the sandstone ledges near "The Transfer," dip westward at rather high angles, varying from about 55° to 75°. (See cross section, Pl. III.)

PROSPECTS.

CAYWOOD CLAIMS.

A number of claims on which only prospect pits had been dug were visited in company with Mr. Gilbert Wesson, of Meeker. The best showing of carnotite was in a shallow pit, said to be known as the Caywood No. 1 claim. This is situated on the ridge summit at an elevation of 1,100 feet above Coal Creek, about half a mile north of the point where the creek flows through the Dakota sandstone ledges. In this and some other pits near by there was an apparent abundance of fossil wood, coated with bright-yellow pigment. This coating is very conspicuous and contrasts markedly with the dark iron-brown

[a] Bull. U. S. Geol. Survey No. 297, 1906.

rock on which it is found. Specimens from the Caywood No. 1 claim have been tested by George Steiger in the laboratory of the United States Geological Survey, and are reported by him as containing uranium and vanadium and as being probably carnotite. There is practically no doubt that the mineral is actually carnotite, as it has already been so determined by a number of authorities who have examined material from this locality. Material for a complete analysis has now been sent to the Survey laboratory and will probably be studied later.

The specimens collected were the better pieces among those lying out on the dump, together with some hammered from the ledges near their surface outcrop. The ore shows very clearly the original woody structure in the silicified gangue, which is now of a rusty-brown color and filled with seams and cracks. Some small pieces of coal were also found, but these were fragments or small patches and not a continuous seam. As is explained more fully on page 116, the yellow carnotite is evidently a surface coating, filling fractures and impregnating the neighboring sandstone.

A prospect pit said to be known as Caywood No. 2 is situated about 300 yards from Caywood No. 1 in a southerly direction along the ridge summit, but about 300 feet lower down. Here the sandstone showed a green stain for 4 or 5 feet down from the surface of the ledge on the ground, especially along the jointing planes in the rock. This prospect apparently contained no yellow ore, but a streak of fossil wood was exposed, embedded in the massive sandstone, which carried much green stain. This proved on testing [a] to be a copper stain and showed no trace of vanadium or uranium. The whole prospect pit was in massive though much broken sandstone. Below the Caywood No. 2 down the ridge to the bed of Coal Creek fragments of silicified wood were noted, apparently marking a single continuous stratum in the Dakota ledges.

OTHER PROSPECTS.

On the south side of Coal Creek, along the southerly continuation of the hogback ridge that has just been described, another prospect pit was found. This is about half a mile in a straight line south of Coal Creek and 1,200 feet or so above the main creek valley. No carnotite has been discovered here, but the silicified wood noted at the other prospects, as well as the associated strata, seemed at the time of visit to mark this pit as being at a horizon in the Dakota ledges almost, if not exactly, identical with that of the prospects already described. However, inasmuch as the plotting of this locality on the map seems to show its position as at some little distance west of the main sandstone ridge, the first conclusion as to its identity of

[a] By George Steiger, in laboratory of United States Geological Survey.

horizon with those to the north may not have been correct. West of the pit, down the hill slope, the outcrops of beds representing strata overlying the fossil-wood layer were noted as follows: Near the pit is a band of very red soil, thought to indicate a calcareous bed; beyond which a few feet of white granular sandstone or quartzite shows, dipping 40° W. Above this stratigraphically, although outcropping farther down the hillside, is a bed of conglomerate containing angular pebbles, many of which are limestone. Next is a bed of quartzite dipping 56° W., and then an interval of 100 feet or more of hill slope covered by vegetation and loose rock. Below this there is an outcrop of dark-green, compact, almost slaty shale, and scattered about in the soil are nodular masses of radial columnar calcite, ranging from a few inches in diameter to the size of a pumpkin, which some of them somewhat resemble in shape.

A little over a mile northeast of the Caywood No. 1 claim another prospect pit was found high up on the ridge, showing yellow carnotite ore in a mode of occurrence somewhat different from those already described. This prospect is near the top of a peak that was occupied in 1876 as a triangulation station by the topographic corps of the Hayden survey, who give its elevation as 9,430 feet. The pit itself is about 500 feet southeast of the summit and nearly as high. The ore seam lies 6 feet or so below the surface of the ground. The rock is the Dakota sandstone, much jointed and having a dip of about 20° a little west of north. Around this point the outcrop of Dakota ledges, together with the strata above and below, swings off toward the east, dipping in a northerly direction toward Thornburgh Mountain and Axial Basin and conforming in general with the anticlinal structure farther south, already noted in the section along the upper valley of Coal Creek. (See Pl. III.) The ore seen at this place is a seam an inch or so thick between two sandstone strata. The overlying bed is about 20 inches and that below about 4 inches thick. The ore seam itself is an irregular filling in what appears to be a stratification plane of the rock. This may possibly have been at one time the channel through which mineralized solutions have passed. The yellow pigment impregnates the inclosing sandstone on either side of the ore seam, producing sandy ore similar to that described from Montrose and San Miguel counties. No fossil wood was observed at this locality.

EXTENT AND ORIGIN OF THE DEPOSITS.

In view of the lack of development on the properties at the time they were visited little can be said as to the extent of these deposits in depth. By analogy with similar and better known deposits farther south in the same State it may be expected that these deposits will be found to be superficial in character. The occurrences seen had the aspect of surface deposits, being mere coatings or films of an apparently secondary mineral in joints and fractures of the country rock, and this observation is corroborated by a closer examination of the ore itself. Under the microscope thin sections of material from the Caywood No. 1 claim show the cellular structure of the silicified wood, but no trace of impregnation with mineral within its mass, most of the carnotite with which the specimen had been coated having been lost in the grinding of the thin section. Evidently the silicification of the wood was fully completed before the carnotite was introduced. The hand specimen shows the same evidence, only the outer surface and coarser fractures of the comparatively impervious wood appearing to contain the yellow pigment.

It thus seems likely that carnotite is a surface or alteration product, representing in a secondary form some other original minerals from which its substance has been derived. As it has probably been deposited from solution in ground water it is very likely that the source of the rare elements which the deposits contain may have been at some considerable distance, and it is possible that the primary minerals were widely disseminated in minute quantities, of which the present deposits are a product of concentration.

Doctor Hillebrand suggests in a personal communication that—

> Coal is a possible source of the vanadium and perhaps uranium in carnotite and other evidently secondary minerals that contain one or the other of these elements. This suggestion is based on the repeated finding of vanadium in coal ashes and the observation of uranium in anthracitic bitumen in Sweden and in nodular forms of carbon from the oldest sedimentaries of that country,[a] in grahamite from "North America,"[a] and in carbonaceous material from a pegmatite dike in Quebec.[b] Further, in the San Rafael Swell, in the eastern part of Utah, vanadium has been found by me in relatively large amount in the carbonaceous material accompanying and impregnating sandstone, and at Cerro de Pasco, Peru, carbonaceous matter very rich in vanadium occurs.[c] These facts are so indicative of a relation between vanadium and possibly uranium, and certain coals and carbonaceous materials that an examination of the coals and bitumens of western Colorado and eastern Utah for a possible content in these elements seems desirable. If found in them, the question of ultimate origin would still remain.

In this connection it may be pointed out that in all probability the coal seams formerly extended over and far beyond the position of the present uranium deposits; that these strata have since been removed by erosion; and also that the coal seams of the vicinity are at present largely burned along their outcrop. On the other hand, it seems that had these rare elements been derived from the coal seams we should now find traces of minerals containing these elements among the sandstones of the coal-bearing strata, rather than in deposits separated from the coal beds by a thickness of approximately a mile and a half

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[a] Nordenskiöld, A. E., Comptes rendus, vol. 116, 1893, p. 677.

[b] Obalski, J., Jour. Canadian Min. Inst., vol. 7, 1904, p. 243; Eng. and Min. Jour., vol. 77, 1904, p. 441.

[c] Hewett, Foster, Eng. and Min. Jour., vol. 82, 1906, p. 385. Bravo, José J., Inform. y Mem. Bol. Soc. Ing. [Lima], vol. 8, 1906, p. 171.

of sedimentary rocks. No occurrences of carnotite have been observed or, so far as the writer knows, reported within the coal field itself. The only other suggestion that can now be offered to explain a possible source of uranium and vanadium is that they may have been derived from the basalt of Sleepy Cat Mountain, bowlders of which lie scattered over the Dakota sandstone ridges.

VALUE.[a]

In the absence of knowledge as to the nature and extent of the deposits in depth very little can be said of their probable commercial value. An announcement in the Engineering and Mining Journal of March 3, 1906, reporting the discovery of the properties that have been described in the foregoing pages, stated the intention of the owners to ship 10 tons of ore from these claims to Denver for treatment. It is not known whether this intention has been carried out or not, but to provide a sound basis for an estimate of values available the sample should represent more than the present shallow workings, and, as need hardly be stated here, should be a fair average of the actual run of prospecting that has been sufficiently extensive to warrant further commercial development in case the values are found satisfactory.

[a] An article in the Mining Magazine for February, 1906, describes a method of treating this ore in a commercial way.

NOTE ON A MINERAL PROSPECT IN MAINE.

By George Otis Smith.

Within the past few years there has been a revival of interest in mineral deposits in eastern Maine. In several localities where small copper, zinc, or lead mines were opened thirty years ago, the properties have been reexamined and in a few places shafts have been pumped out. At other places metalliferous veins have been prospected to determine whether the ore can be mined with profit under modern methods of ore treatment.

At the request of the Maine State Survey Commission the writer visited one of these prospects during the last season, and the following note is published, as it is believed that the deposit is somewhat typical of the disseminated sulphides of this region, so that the conclusions reached here may at least suggest the value of other similar deposits. The locality visited is in the town of West Pembroke on the farm of B. S. Sinclair, about a mile southeast of Ayers Junction on the Washington County Railroad. During 1906 considerable prospect work was done here, and shallow openings have been made at a dozen places on the hillside.

The country rock is metamorphic and of volcanic origin, much of it being a greenstone breccia with amygdaloid fragments. The bedding of the volcanic deposits appears to be represented by the sheets of varying texture, which have an east-west strike and steep dip. The rock is thoroughly silicified and more or less jointed.

The metalliferous minerals are sphalerite, galena, pyrite, and chalcopyrite, with quartz and calcite as gangue minerals. Oxidation has penetrated the rock for only 1 to 2 inches, and copper carbonates were seen at one place. These sulphides are scattered throughout irregular bands of the greenstone, the mineralized and unmineralized portions of the rock not being sharply contrasted. In no place is any well-defined vein exposed, although at one opening, No. 2, the more compact greenstone contains several small lenticular areas of quartz, including small bunches of chalcopyrite. These cut across the sheeting of the rock. Where the breccia character of the greenstone is well shown the sulphides occur more generally in the matrix, and in the amygdaloidal phases the metallic minerals are found in the amygdules.

A sample of ore was collected at the small opening designated the No. 6 prospect. Care was taken to procure a representative sample, with the view of determining the value of the material such as would necessarily be mined and shipped from a deposit of this type. Such selection was made to secure a good sample of the possible shipping product. The same quality of mineralized rock occurs at most of the openings, but at none could any commercial quantity of better grade ore be mined. On this account the sample is believed to be representative of this deposit and probably also to a large extent of other bodies of mineralized rock in this region.

The assay of this sample by Ledoux & Company of New York, follows:

Assay of ore from West Pembroke, Me.

Copper by electrolytic assay	per cent.	0.08
Zinc	do	1.26
Lead	do	.51
Silver (per ton 2,000 pounds)	ounce	.13
Gold (per ton 2,000 pounds)		Trace.

While this assay indicates a total content of between $2 and $3, under the present high prices of metals, the values are so distributed among the four metals that this valuation expresses little. No commercial process is known that would win all these metals, and with any treatment now in use the cost of the recovery of any two of them would doubtless exceed the value of the very small content in this rock. It can therefore be stated with confidence that the cost of mining and treating an ore of this type would be prohibitive.

NICKEL DEPOSITS OF NICKEL MOUNTAIN, OREGON.

By G. F. Kay.

INTRODUCTION.

For more than twenty-five years hydrated nickel magnesium silicates have been known to occur on Piney or Nickel Mountain near Riddles, in Douglas County, Oreg., and it has been hoped that development would prove the presence of these minerals in sufficient quantity for economic purposes. There seemed to be reason for this hope, since the deposits are in mineral content, in modes of occurrence, and in their associations very similar to the deposits of New Caledonia, whose mines are the second largest producers of nickel in the world. But as yet no commercial ores have been produced.

During the summer of 1906 Mr. J. S. Diller and the writer were engaged in mapping, for folio publication, the rocks of the Riddles quadrangle, in which the nickel silicates occur. In connection with this work, the writer made a special study of the ores, in order to get, if possible, a clearer idea of the modes of occurrence and the probable extent of these interesting deposits.

Thanks are due to Mr. W. Q. Brown, of Riddles, for kindness in the field and for information in regard to the development and other features of the ore bodies.

The literature on these deposits is as follows:

Clarke, F. W., Some nickel ores from Oregon: Am. Jour. Sci., 3d ser., vol. 35, 1888; pp. 483–488; Bull. U. S. Geol. Survey No. 60, 1890, pp. 21–26.

Analyses are given of the nickel silicates of the country rock (Saxonite), and of the olivine of the country rock. J. S. Diller gives the results of a microscopical study of the saxonite and of the ore. The evidence points to the saxonite as the source of the nickel.

Von Foullon, H. B., On Riddles, Oreg.: Jahrbuch K. k. geol. Reichsanstalt, vol. 42, Vienna, 1892, p. 223.

The minerals, their associations, and their probable origin are described. The ores are thought to have resulted from the decomposition, by superficial weathering, of the country rock, which he calls harzburgite. The processes of alteration are fully discussed.

Austin, W. L., The nickel deposits near Riddles, Oreg.: Proc. Colorado Sci. Soc., January, 6, 1896.

The location of the deposits, their method of occurrence, the development work, the probable origin of the ores, and the metallurgy of the ores, are fully discussed. The theory of deposition from ascending thermal waters is advanced.

LEDOUX, A. R., Notes on the Oregon nickel prospects: Canadian Min. Rev., vol. 20, 1901, pp. 84-85; Jour. Canadian Min. Inst., vol. 4, 1901, pp. 184-189.
Describes the geologic relations of the ore bodies and gives a chemical analysis of the ore.

GEOGRAPHY AND HISTORY.

Nickel Mountain is one of many peaks and ridges of moderate elevation near the northeastern base of the Klamath Mountains in southwestern Oregon. It is about 3½ miles west of Riddles, a small village on the Southern Pacific Railroad, about 225 miles south of Portland. Riddles is 713 feet above sea level, and the highest point of Nickel Mountain is 3,513 feet above sea level. The nickel silicates are known to occur only on the southern slope of the mountain, above an elevation of 2,000 feet. A good wagon road about 7 miles in length runs from the village to a point within 200 feet of the summit of the mountain. All the important prospects are reached by this road.

Although these deposits were discovered about 1864, their true nature was not recognized until 1881. Soon after that time, under the management of W. Q. Brown, the original owner, development work was commenced, being continued in greater or less degree until 1900, when all work was suspended. Numerous surface openings were made, shafts sunk, and tunnels run. The longest tunnel, 320 feet in length, was completed in 1897 by the Oregon Nickel Mines Company. The deepest shaft, 83 feet deep, was sunk by the same company about the same time. In all, there are more than 600 feet of tunneling. Owing to the caving in of the walls, many of these workings are not now accessible except at the entrances. It is estimated that between 3,000 and 4,000 tons of material were taken from the various openings and placed on the dumps, where it still remains, much of it considerably leached and of low grade, the nickel minerals having been dissolved and carried away. Only a few small shipments of ore were ever made to the smelters, and these merely for experimental purposes. In 1893 the International Mining Company shipped considerable smelting machinery to Riddles, but it was never used. About the same time this company also erected, near the deposits, a brick engine and boiler house, a sawmill, a carpenter shop, a blacksmith shop, and other buildings, all of which are now in a more or less dilapidated condition.

GEOLOGY.

The nickel deposits are associated with saxonite or harzburgite, a variety of peridotite, a basic igneous rock consisting chiefly of olivine and enstatite. Olivine constitutes more than two-thirds of the whole rock. Chromite and magnetite are in general present as disseminated grains, though in places within the peridotite area there are segregations of almost pure chromite. The peridotite readily breaks down to a dark-greenish serpentine, a rock that in the Nickel Mountain region is widely distributed as small isolated patches and elongated masses, the trend of which is northeast and southwest. Such an elongated mass of serpentine extends for several miles both to the northeast and to the southwest of Nickel Mountain. In some places the band is narrow; in others it is more than a mile in width. The serpentine has but a thin covering of soil, which is comparatively free from vegetation.

Other igneous rocks in this region are less basic than the peridotite and may be designated as greenstones and dacite porphyries. The greenstones comprise several types of rock, all of which are more or less dull green in color. They vary in texture from fine-grained and compact to coarsely granular. Most of them are considerably altered, but where fresh are usually found to consist essentially of pyroxene and soda-lime feldspars. The dacite porphyries are rather fine-grained, light-colored rocks and are much less abundant than the serpentines and greenstones. The chief minerals present are quartz and soda-lime feldspars, both of which in many places form distinct phenocrysts. Ferromagnesian minerals are subordinate.

The peridotite appears to have cut up through the greenstones, but was itself intruded by the dacite porphyries.

The sedimentary rocks are Mesozoic and Tertiary in age. The systems represented are Jurassic, Cretaceous, and Eocene. The Jurassic consists chiefly of sandstones and subordinately of shales, conglomerates, and cherts. The rocks as a rule show veining and pronounced lithification. Fossils are scarce, but the distinctly Jurassic form *Aucella erringtoni* has been found. The Cretaceous rocks consist chiefly of conglomerates, sandstones, and shales, and their fossils correspond to those of the Knoxville and Horsetown of California. There is evidence of a slight unconformity between the beds representing these two formations. The Knoxville rocks are lithified, but for the most part not nearly so strongly as the rocks of the Jurassic. The Eocene deposits consists of yellowish sandstone, shale, and conglomerate, the stratification of the rocks being well preserved.

A great unconformity can be traced between the Jurassic and the Cretaceous, and a somewhat less important unconformity separates the Cretaceous and the Eocene.

All the igneous rocks of the region are younger than the Jurassic, some are younger than the Cretaceous, and all are older than the Eocene.

THE ORE AND THE GANGUE.

Practically all the known occurrences of nickel silicate in this region are within an area of $1\frac{1}{2}$ square miles, lying on the slopes to the south, southwest, and southeast of the mountain. The thin soil peculiar to this area is composed almost entirely of iron oxides, which give it a distinctly reddish-brown color. The ores occur chiefly as flat-lying deposits on the surface of the peridotite and subordinately as veinlets in the peridotite or its decomposition product, serpentine. Only one nickel mineral is known to occur in these deposits, namely, genthite, which is a soft hydrous nickel-magnesium silicate. The proportions of the nickel and magnesium vary considerably in the best specimens obtainable, as shown by the subjoined analyses:

Analyses of nickel silicates from Riddles, Oreg.

	1.	2.	3.	4.
Loss at 110° C.	8.87	6.63	7.00	12.29
Loss on ignition	6.99			
$Al_2O_3+Fe_2O_3$	1.18	1.38	1.33	.06
SiO_2	44.73	48.21	40.55	48.82
MgO	10.56	19.90	21.70	18.49
NiO	27.57	23.88	29.66	19.04
	99.90	100.00	100.24	98.70

1. Clarke, F. W., Am. Jour. Sci., 3d ser., vol. 35, 1888, p. 484.
2-3. Hood, Dr., Mineral Resources U. S., 1882, U. S. Geol. Survey, 1883, p. 404.
4. Von Foullon, H. B., Jahrbuch K. k. geol. Reichsanstalt, vol. 42, 1892, p. 272.

There is probably every gradation from material with compositions like those of the foregoing analyses to pure silicate of magnesium. Von Foullon[a] states that he was able by washing to separate from the green ores of Nickel Mountain a light-colored material which on analysis proved to be magnesium silicate, containing no nickel. The color of the genthite varies with the nickel content from a pale green to a deep green—the more nickel present the more intense the color.

For the sake of comparison some analyses of the best nickel silicates of New Caledonia are given herewith:

Analyses of New Caledonia nickel silicates.[b]

	1.	2.	3.	4.	5.	6.	7.
H_2O	15.40	15.55	10.34	15.83	17.97	17.60	12.73
$Al_2O_3+Fe_2O_3$	.89	.50	1.68	1.57	.55	.11	3.00
SiO_2	42.61	35.45	44.40	37.78	38.35	37.49	47.90
MgO	18.27	2.47	3.45	10.66	10.61	14.97	12.51
FeO			.43				
CaO	....	....	1.07	....	....	....	....
NiO	21.91	45.15	38.61	33.91	32.52	29.72	24.00
	99.08	99.12	99.98	99.75	100.00	99.89	100.14

[a] Jahrbuch K. k. geol. Reichsanstalt, vol. 42, 1892, p. 232.

[b] Annales des Mines, 10th ser., vol. 4, 1903, p. 368.

From all the analyses thus far published of the nickel silicates of New Caledonia and of Riddles it appears that the average content of nickel in the New Caledonia minerals is higher than that in the genthite of the Riddles deposits. Perhaps sufficient amounts of the Riddles ores have not been smelted to permit safe estimates to be made of their average nickel content; but the treatment by different methods of about 20 tons of the ore, which constituted the shipments made by the Oregon Nickel Mines Company, gave results varying from 5 to 8 per cent in nickel. Two specimens, taken by the writer as average samples of the ore, were analyzed in the Survey laboratory by George Steiger. The results were 5.35 and 4.94 per cent of nickel. Each of the two analyses also showed 0.11 per cent of cobalt. The New Caledonia ores now being shipped to the smelters contain between 6 and 7 per cent of nickel.

The gangue consists of quartz, iron oxides, and serpentine. The quartz, the most abundant of these minerals, is in general of a whitish color, but the surface of much of it has a yellowish to brownish-red tint, due to a coating of iron oxide. The quartz appears to be chiefly chalcedonic, but in places it has a weak greenish color, resembling chrysoprase, a mineral that has been shown to be present in these deposits.[a] The iron oxides are of a distinctly yellow to reddish-brown color, and the evidence is clear that these oxides represent one of the final products of decomposition of the serpentine, which is itself produced by the alteration of the peridotite.

THE DEPOSITS.

The deposits, which lie flat, occur as brecciated and conglomeratic irregular masses on the surface of the peridotite and consist of silica, nickel silicate, iron oxide, and serpentine, with a very subordinate amount of chromite. The most striking feature of the ore is the green color of the nickel silicate. Where the ores have been exposed to weathering action for a considerable time, these nickel silicates have been dissolved and carried away and a honeycombed quartz skeleton remains. In some of the cavities of this skeleton are found pulverulent iron oxides, which can readily be shaken out, only the siliceous cement of the former brecciated or conglomeratic mass being left. Such materials lie on the surface of a considerable part of the nickel area and have served as a guide to prospecting. A portion of this material has been transported mechanically to its present location. In some places the brecciated ore consists of irregular-shaped fragments of serpentine breaking down to hydrated iron oxides. The fragments are cemented by silica and nickel silicate, which were prob-

[a] Kunz, G. F., Gems and Precious Stones, p. 122.

ably deposited at about the same time. Here and there these cementing materials do not fill all the spaces between the fragments. In such places the cavities are lined with a thin film of silica having a mammillated surface. This thin film appears to have been deposited later than the general mass of cementing quartz and nickel silicate.

The distinctly conglomeratic ore differs from the brecciated ore in that the constituents are rounded rather than angular. This is particularly well shown by the nickel silicate itself, which consists of rounded concretions varying from the size of a pin's head to that of a walnut. When broken open, these are usually found to consist of homogeneous, apple-green, amorphous-looking nickel silicate, which on close inspection is seen to be penetrated by minute films of white silica; but in some of the ore the nickel silicate forms only a shell on the outside of the pebble, the inside consisting of decomposed serpentine or of brecciated ore, in which the small fragments of nickel silicate, iron oxide, and serpentine are plainly seen. Many specimens of the ore, both brecciated and conglomeratic, show slickensided surfaces, indicating movement subsequent to the formation of the ores.

The ore found beneath the flat-lying deposits occurs as small veins and minute veinlets in the peridotite, which contains innumerable fractures. These veins and veinlets run in various directions, forming an irregular network, but in the main they appear to be related to zones of fracture and brecciation that have a general northeast-southwest direction. These zones are of considerable width, but the individual fractures are narrow, the largest vein observed being not more than 6 inches wide and most of them less than 1 inch. The vein filling consists of nickel silicate and silica, but iron oxides are also present, and in some places the material is of the nature of a cemented breccia. Between the veinlets in the fractured zones the material is chiefly hydrated iron oxide in which rounded, bowlderlike masses of fairly fresh peridotite occur. In places the fractures are still unfilled, the walls being of peridotite but little altered.

Fault planes with slickensided surfaces were observed at several places within the nickel area. The relations of many of these fault planes to the ore bodies indicate that movements have taken place subsequent to the forming of the general mass of the ore.

ORIGIN OF THE ORES.

The field evidence strongly suggests that the nickel silicates are a decomposition product of the peridotite with which the ores are so intimately associated. The evidence derived from chemical analyses supports this view.

The nickel, which is by analysis found in small quantities in the fresh peridotite, appears to be associated with the constituent olivine rather than with the enstatite. Clarke's analyses [a] of the rock and of the olivine are as follows:

Analyses of peridotite and olivine from Nickel Mountain, Oregon.

	Rock.	Olivine.		Rock.	Olivine.
Loss on ignition	4.41	0.57	NiO	0.10	0.26
SiO_2	41.43	42.81	MnO		
Al_2O_3	.04		CaO	.55	
Cr_2O_3	.76	.79	MgO	43.74	45.12
Fe_2O_3	2.52	2.61			
FeO	6.25	7.20		99.80	99.36

The rock analyzed was more than two-thirds olivine. The olivine analyzed was not entirely free from chromite and enstatite. Von Foullon analyzed the olivine of a peridotite from this region and found it to contain 0.32 per cent of nickel oxide; about 80 per cent of his rock was olivine. His analysis of the rhombic pyroxene of the peridotite gave only 0.05 per cent of nickel oxide.

Analyses of the serpentines which have been derived from the peridotite also show the presence of nickel. For example, Von Foullon states [b] that a specimen of serpentine taken near the border of the peridotite area contained 0.45 per cent of nickel oxide. A specimen taken by J. S. Diller from Iron Mountain, in the Port Orford quadrangle, more than 25 miles west of Nickel Mountain, yielded 0.13 per cent of nickel oxide.[c] A specimen obtained by the writer from a large serpentine area northeast of Nickel Mountain and analyzed by George Steiger showed 0.26 per cent of nickel, equivalent to 0.33 per cent of nickel oxide. Indeed, when we consider that the rocks containing nickel in small quantities are so widespread in this region, it is surprising that the deposits of nickel silicate appear so scanty. The writer has no definite evidence to account for the fact that the serpentines derived from the peridotite on the southern slope of Nickel Mountain are further decomposed into nickel silicate, silica, and iron oxide, whereas elsewhere they show no such alteration. It may be that the rocks in the vicinity of the deposits contained many more minute fractures and fissures than the rocks in other places. If so, weathering action must have been more effective and the decomposition of the rocks more complete near these deposits than where the fractures were fewer.

The field study of the nickel deposits and their associations reveals the various stages from the fresh peridotite to the final products of decomposition. The peridotite, under the ordinary atmospheric weathering processes, has been decomposed into serpentine, which in turn was further decomposed, the resulting products being hydrous

[a] Clarke, F. W., Am. Jour. Sci., 3d ser., vol. 35, 1888, p. 485.
[b] Jahrbuch K. k. geol. Reichsanstalt, vol. 42, 1892, p. 233.
[c] Geologic Atlas U. S., folio 89, U. S. Geol. Survey, 1903, p. 4.

nickel-magnesium silicate, silica, and iron oxides. The hydrous nickel-magnesium silicate and silica were dissolved, carried out, and redeposited in the cracks and crevices so abundant in the peridotite. The iron oxide, unless transported mechanically, remained behind in the spaces formerly composed of peridotite or serpentine. It is probable that much of the material now found in the veins and veinlets in the peridotite has been leached from deposits formed higher up, carried down, and redeposited. Some material has probably been carried down mechanically.

This theory of origin is in accord with that advanced by Von Foullon [a] after a careful study of the deposits. A similar view has recently been presented by Glasser [b] in explanation of the nickel-silicate deposits of New Caledonia.

If this theory is correct, the downward extension of the main deposits will be limited to the depth of decomposition of the peridotite. On the other hand, if the theory of deposition by ascending thermal waters, as advanced by Austin, is correct, the deposits may extend locally to greater depths, but of this there is no favoring evidence on the surface. The depth of the deposit appears, from present evidence, to be comparatively shallow.

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[a] Jahrbuch K. k. geol. Reichsanstalt, vol. 42, 1892, pp. 224-233.
[b] Annales des Mines, 10th ser., vol. 4, 1904, pp. 448-464.

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