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GREENWOOD-PHOENIX AREA,
BRITISH COLUMBIA

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Illustration

GREENWOOD-PHOENIX AREA, BRITISH COLUMBIA

INTRODUCTION.

Greenwood-Phoenix map-area is in southern British Columbia, its southern boundary being 4.8 miles north of the International Boundary. The area is rectangular, and covers approximately 14 square miles. Greenwood, a town of about 200 inhabitants, lies in the valley of Boundary Creek near the western edge of the area, and Phoenix, a former mining town now practically deserted, is 3 miles east of Greenwood and 2,000 feet above it. Grand Forks, the largest settlement in this part of British Columbia, is about 12 miles southeast of Greenwood. The area is characterized by a monotonous succession of rounded ridges and open valleys. Relief is about 2,700 feet: Knob Hill, 1 mile southeast of Phoenix, reaches an elevation of 5,150 feet, whereas Boundary Creek, at Greenwood station, is 2,450 feet above sea-level.

HISTORY

The record of the early development of this part of southern British Columbia is essentially a chronicle of its mining history. In 1890 the discovery of gold-copper deposits at Rossland, some 40 miles east of Greenwood, stimulated prospecting throughout the country, and in the following year large, low-grade copper deposits were discovered near Phoenix. By 1900 all the important mines in the district had been partly developed, a branch of the Kettle Valley railroad had been constructed from Eholt to Phoenix, and smelters at Grand Forks, Greenwood, and Boundary Falls were under construction. The branch line of the Great Northern railroad connecting Phoenix and Grand Forks was completed in 1904. Production from Phoenix district reached its peak in 1913, when 1,250,000 tons of ore were mined and shipped, and slowly decreased thereafter. In 1919, when the available ore reserves were approaching exhaustion, labour strikes in the Crowsnest coalfield cut off the supply of coke for the Granby smelter at Grand Forks and forced the operators at Phoenix to abandon the mines. Phoenix district has produced about 15,000,000 tons of ore averaging slightly over 1.5 per cent copper and about 75 cents a ton in gold and silver.

The principal mining companies in the district were: the Granby Consolidated Mining, Smelting, and Power Company, Limited, formed in 1901 by the amalgamation of several operating companies in Phoenix; the British Columbia Copper Company with mines at Deadwood camp and Phoenix, and smelters at Greenwood and Boundary Falls; the Consolidated Mining and Smelting Company of Canada, Limited, with mines at Phoenix; and the New Dominion Copper Company, Limited, with mines at Phoenix and Deadwood camp. The development of low cost mining and smelting methods by these companies is one of the outstanding achievements in Canadian mining history.

From 1920 to 1933 mining activity in the Greenwood district was limited to desultory development work on a few of the more promising gold and silver deposits that, although discovered early in the history of the district, had never had a large production. In 1933, the rise in the price of gold and the favourable treatment rate for siliceous ores offered by the Consolidated Mining and Smelting Company combined to awaken outside interest in the district, and a number of mines were re-opened. In general this recent development work disclosed lenticular quartz veins with erratic gold content. Results at the Dentonia mine, however, were sufficiently encouraging to justify the installation of a 100-ton flotation mill, which operated until the end of August 1936. In September 1936 the Knob Hill and Ironside mine in Phoenix was re-opened, ore from this mine being hauled to a 50-ton flotation mill situated 1 mile north of Greenwood.

The first work in the area by the Geological Survey was a reconnaissance survey in 1901 by R.W. Brock. In 1902 Brock mapped geologically a belt about 13 miles wide along the International Boundary from Grand Forks to Midway. R.A. Daly, geologist for the Boundary Commission, later mapped a 5-mile belt along the International Boundary. Detailed geological work was done at Phoenix and at Deadwood camp from 1908 to 1910 by O.E. LeRoy of the Geological Survey.

FIELD WORK AND ACKNOWLEDGMENTS

The field work for this report was carried on from June 1 to October 9, 1936. Messrs. W.T. Dempsey, W.L. Redmond, Kenneth de P. Watson, and F. Joubin rendered able assistance in the field.

The writer is also indebted to various mining men of the district for their courtesy and co-operation.

GENERAL GEOLOGY

The oldest rocks in Greenwood-Phoenix area constitute an assemblage of mixed sedimentary and volcanic origin. The sedimentary rocks are argillite and limestone, and are, in part at least, of Carboniferous age. The volcanic rocks are latite and andesite, and are believed to be chiefly flows. Both the sedimentary and volcanic rocks were intruded, in Mesozoic time, by igneous rocks that include, from oldest to youngest, small bodies of peridotite, pyroxenite, gabbro, and diorite, and larger bodies of granodiorite. In the vicinity of Phoenix, Tertiary sediments and volcanic flows overlie the above mentioned sedimentary and igneous rocks unconformably. The youngest consolidated rocks of the area are dykes and sills that range in colour and composition from dark-coloured diorites to light-coloured alkalic syenites.

The Tertiary sedimentary and igneous rocks are younger than the ore deposits with which this report is mainly concerned, and will receive only brief treatment.

Most of the Palaeozoic sedimentary and volcanic rocks have undergone textural and mineralogical changes since their consolidation. They have been partly to completely silicified to form jasperoid and chert over wide areas. This silicification has so completely changed their original character that it is impossible in many places to distinguish altered limestones and argillites from altered volcanic rocks. In addition to having been silicified, the limestones have been partly to completely replaced in the vicinity of Phoenix by lime silicate minerals, notably epidote and garnet. In places these lime silicate rocks contain sufficient sulphides to constitute low-grade copper ore. Neither the silicified rocks nor the lime silicate rocks appear to bear any spatial relation to exposed intrusive rocks.

Most of the Mesozoic intrusive rocks have been altered to some extent. Propylitization, which involves the alteration of dark-coloured minerals to chlorite, epidote, and carbonates and the alteration of feldspars to epidote, carbonates, and sericite, is widespread. Sericitization is common, particularly along mineral-bearing fissures in granodiorite. Intrusive masses of an ultrabasic rock, probably peridotite, have been altered to serpentine. Margins of serpentine bodies and serpentine masses adjacent to younger acidic intrusive rocks are commonly altered to talc and talc-carbonate rocks.

Rock exposures are good on the steep hillsides bordering Boundary Creek and along the interstream ridges, but elsewhere are poor. About 50 per cent of the area is covered by drift.

TABLE OF FORMATIONS

Quaternary	Pleistocene and Recent	Recent ~~alluvium~~ and glacial drift.
Tertiary	Miocene (?)	Masses of alkalic syenite, syenite, and diorite.
		Midway volcanic group: principally augite trachyte.
	Oligocene	Kettle River formation: conglomerate, sandstone, shale.
Mesozoic		Granodiorite, diorite, gabbro, pyroxenite, serpentine.
Palaeozoic	Carboniferous in part	Limestone, argillite, andesite, and latite, in part altered to chert, jasperoid, and lime silicate rock with sulphides.

SEDIMENTARY ROCKS

Patches of Palaeozoic sedimentary rocks occur with jasperoids in the vicinity of Phoenix and elsewhere, and partly silicified phases are associated with volcanic rocks near the intrusive granodiorite body at Greenwood. Tertiary sediments form a narrow, discontinuous band extending northerly from near the War Eagle mine to the Gilt Edge mine near Phoenix.

The Palaeozoic sedimentary rocks correspond in part to the Attwood series as mapped in the Phoenix area by LeRoy.[1] The Attwood series was

1 Geol. Surv., Canada, Mem. 21 (1912).

divided by LeRoy into the Brooklyn formation, consisting of limestone and its altered equivalents, and the Rawhide formation, consisting of argillites. Jasperoids were believed to be chiefly silicified limestone and, consequently, to be a part of the Brooklyn formation. The Rawhide formation was found to overlie the jasperoids, and was, therefore, considered to be younger than the Brooklyn formation.

It has now been found: (1) that limestone, argillite, latite, and andesite have all been altered locally to jasperoid; and (2) that the jasperoids immediately below the argillites that had been mapped with the Rawhide formation were formed by the silicification of argillites, not limestone, and, therefore, do not indicate that the argillites (Rawhide formation) are younger than the limestones (Brooklyn formation). Owing to the doubt as to the relative ages of the limestone and the argillite, the formational names have not been employed in this report.

Limestone

The main exposure of limestone is on the west side of Montezuma ridge just north of Phoenix. Smaller patches of limestone outcrop on Montezuma ridge to the north of the Stemwinder mine, and discontinuous limy bands occur in jasperoid near the northeast corner of the map-area. Several small outcrops of limestone were seen along the northeastern contact of the granodiorite on the Lake, Last Chance, and Yellowstone claims.

The limestone is crystalline, fine- to medium-grained, and white to dark greyish brown. It is massive in most places, but thin-bedded, argillaceous limestones are exposed in a railway cut 2,000 feet west of the Brooklyn mine and also northwest of Providence Lake along the contact of the limestone and jasperoid. Limestones strike north 30 degrees west to north 12 degrees east and dip at high angles. The estimated thickness of limestone in the area immediately north of Providence Lake is 1,500 feet.

Most of the limestone is partly silicified. The thin sections examined are made up of an interlocking mosaic of calcite grains and irregular aggregates of cryptocrystalline quartz.

Chemical Analyses of Limestones[1]

	I	II
	Per cent	Per cent
$CaCO_3$	90.41	98.40
$FeCO_3$	0.16	0.31
$MgCO_3$	tr.	tr.
Insoluble (chiefly silica)	10.00	1.50
	100.57	100.21

I - Limestone, Brooklyn mine.
II - Limestone, Knob Hill-Ironside mine, 300-foot level.

[1] F.G. Wait, analyst. (LeRoy, O.E.: Geol. Surv., Canada, Mem. 21, p. 34 (1912)).

Argillite

Two patches of argillite occur in jasperoid southeast of Phoenix. Small outcrops of argillite were also seen 2,000 feet northwest of the Skylark mine in an almost completely drift-covered area.

The argillites are fine grained and thin bedded. They weather light shades of brown and grey, and are black to grey on fresh fracture. Coarser grained bands in the argillite resemble fine chert conglomerates and parallel or cut across the bedding at a small angle in the exposures along the old railway grades, 600 feet southeast of the Rawhide mine. These siliceous bands are lithologically similar to fine-grained phases of the jasperoid, and some of the bands can be traced from the argillite to the surrounding jasperoids. They are, therefore, regarded as silicified bands rather than original clastic beds in argillites.

The argillites northwest of the Skylark mine strike north 10 degrees west and dip 35 degrees east. The argillites southeast of Phoenix are flat-lying at the argillite-jasperoid contact 500 feet east of the Rawhide mine, but elsewhere they strike from north 40 degrees east to north 50 degrees west and dip westerly at 21 to 42 degrees. The estimated thickness of the band of argillite 600 feet southeast of the Rawhide mine is 300 feet. What may be a poorly preserved fossil plant was found in the argillites 800 feet southeast of this mine.

Kettle River Formation

> "The earliest rocks of the Tertiary are a sedimentary series deposited in the rivers and lakes. The formation, once extensive through the district, is now exposed only in isolated patches, one of which occurs in the Phoenix area, resting unconformably on the Brooklyn formation. The rocks are conglomerates, sandstones, and shales with interbedded tuffs in certain localities. The sandstones and shales locally contain small seams of impure lignite and plant remains of Oligocene age. ....The trend of the strike is northerly and the dips are prevailingly to the east and vary from 10 degrees to 60 degrees, the average being about 35 degrees. The maximum thickness of the formation as determined from logs of diamond drill holes is about 260 feet." [1]

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[1] LeRoy, O.E.: Geol. Surv., Canada, Mem. 21, pp. 27-28 and 42 (1912).

IGNEOUS ROCKS

Both extrusive and intrusive igneous rocks are widely distributed in Greenwood-Phoenix area. The extrusive rocks are of two ages. The older group consists mainly of andesite, and is closely associated with the highly altered Palaeozoic sedimentary rocks. The younger group overlies the Kettle River formation of Oligocene age unconformably and is dated as Miocene by Brock, Daly, and LeRoy. It consists of augite trachyte flows or closely related types. The intrusive rocks include stocks, bosses, and dykes of serpentine, pyroxenite, gabbro, diorite, and granodiorite of Mesozoic age and dykes and sills of diorite and syenite of Tertiary age.

Extrusive Rocks

The Palaeozoic group of volcanic rocks is made up of fine-grained andesite and latite flows. Some of the coarser grained and porphyritic phases of these rocks may be the older series of porphyrites of LeRoy, which he thought might be lavas.

The andesite and latite form a wide northwesterly trending band that extends from the Winnipeg mine to Providence Creek. Smaller outcrops of these rocks occur along the Phoenix branch line of the Kettle Valley railroad northeast of Hartford junction. Many small patches of andesite occur with the highly silicified sedimentary and volcanic rocks exposed northeast of Phoenix.

The Tertiary lavas are augite trachytes or closely related types. They are well exposed on Deadman ridge northeast of Phoenix, and form part of the Midway group.

Andesite and Latite

Andesite and latite cannot be separated in the hand specimen. They are typically massive, green, fine-grained rocks containing hornblende, biotite, and feldspar. Partly silicified varieties near bodies of jasperoid have a distinct fragmental appearance. Those facies exposed east of the granodiorite contact on the Last Chance and Lake claims are dense, massive rocks in which the constituent minerals are too small to be recognized megascopically.

Microscopic study shows that the andesite and latite are made up largely of oligoclase, orthoclase, pargasite, chlorite, and epidote. The latites contain about equal amounts of orthoclase and oligoclase, and the andesites slightly more oligoclase. Carbonate, biotite, and magnetite are present in small amounts.

The andesites and latites are believed to be chiefly volcanic flows. LeRoy[1] described these rocks as they occur in a much altered state

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[1] Geol. Surv., Canada, Mem. 21, p. 31 (1912).

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in one part of the Phoenix area, as being tuffs, breccias, and porphyrites that he considered might be lavas. Volcanic rocks having a fragmental appearance were found by the writer to be confined chiefly to their contact zone with jasperoid. The fragmental appearance, in these localities at least, is due to silicification and is not an original texture.

The age of the andesite and latite is not known. LeRoy[2] included

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[2] Op. cit. p. 30.

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them in his Knob Hill group, which he considered to be older than the limestone and argillite. The volcanic rocks are separated from the limestone and argillite by bodies of jasperoid that may have been derived from either, and thus no direct evidence of their relative age is available. Structural evidence is inconclusive.

Midway Group

The Tertiary, Midway lavas outcrop east of the area of Kettle River beds. The main area of lava ....

> "has a length of a little over a mile and varies in width from 1,100 to 2,000 feet. To the south of the Canadian Pacific railway, the lava is inconspicuous as a topographic feature, but to the north along Deadman ridge it presents steep slopes with low escarpments on both east and west flanks. The thickness, compiled from the logs of diamond drill holes, varies from a few inches to 200 feet, and is probably 300 feet on parts of Deadman Ridge." 3

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[3] Op. cit. p. 44

The lavas are augite trachytes, typically fine grained and porphyritic, with phenocrysts of feldspar and augite. The groundmass consists of laths of orthoclase and plagioclase feldspar, with pale green augite and irregular plates of biotite occupying the interstices.

Intrusive Rocks

About one-quarter of the area is underlain by intrusive rocks, the most extensive of which is granodiorite. Serpentine, pyroxenite, diorite, and gabbro form many smaller bodies throughout the area.

Because of the scarcity of well-exposed contacts the order of intrusion could not be completely established. A rock now altered to serpentine has intruded the highly altered sedimentary and volcanic rocks and has been, in turn, intruded by diorite and granodiorite. Diorite, gabbro, and pyroxenite are believed to be connected genetically with the granodiorite, but may be slightly older. All these rocks are probably of Mesozoic age. The youngest intrusions within the area are dykes and sills of diorite and syenite that intrude the Tertiary volcanic flows.

Serpentine

Intrusive bodies of a nearly completely serpentinized basic rock are common in the southern part of Greenwood-Phoenix area. The largest of these bodies outcrops on the north side of Lind Creek Valley, 2,700 feet east of Boundary Creek. It is about 4,000 feet long and attains a maximum width of 2,400 feet. Smaller bodies of serpentine are exposed above the Argo tunnel near Greenwood, and south and west of Phoenix.

The serpentine varies somewhat in lithological character from place to place. Serpentine from the large stock on the north side of Lind Creek is hard, black on fresh fracture, and weathers light greyish green, whereas that exposed in the vicinity of No. 7 mine and around the Athelstan mine is soft, light to dark green, and has a distinctly greasy feel. It is traversed by numerous shear planes along which the rock is soft and weathers to a light apple-green. Hard "kernels" between the shear planes are elliptical in shape, dark green in colour, range in length from a few inches to several feet, and resemble pillow structure in lava.

Microscopic examination of the serpentine yields very little information as to the original nature of the rock. Most of the sections studied are made up of colourless antigorite and small amounts of talc, magnetite, and a brownish carbonate. Chromite, goethite, and a few relict grains of olivine were also noted. Magnetite is sufficiently abundant in some localities to cause deviation of the compass needle.

Serpentine bodies are commonly altered along their margins to talc and talc-carbonate schists. This alteration is more widespread at the No. 7 and Athelstan mines, where the serpentine is intruded by younger, acidic rocks.

Serpentine intrudes the highly silicified sedimentary and volcanic rocks. It is, in turn, intruded by small stocks of quartz-feldspar porphyry at the Athelstan mine, and by a granodiorite dyke 500 feet southeast of the E.P.U. mine. Similar occurrences of serpentine in the Rossland district of British Columbia are considered to be of Mesozoic age.

Diorite, Gabbro, and Pyroxenite

A group of dark-coloured rocks that range in composition from diorite to pyroxenite form stocks and other small intrusive masses throughout the area. Diorite and gabbro are the most common types, although quartz diorites and pyroxenites are not uncommon. Basic borders occur around many of the larger stocks and grade into the rock of the central core. Diorite, gabbro, and pyroxenite were not observed in contact with granodiorite, and their relative ages are not known. A body of quartz diorite exposed on the boundary between the Dimond fraction and Providence claim is sheared, whereas granodiorite on the Providence claim is massive and may thus be the younger of the two. However, quartz-bearing phases of the diorite do not differ greatly in appearance or mineralogic content from the granodiorite, and they may be about the same age.

The principal outcrops of diorite, gabbro, and pyroxenite lie in a fairly wide, northwesterly trending zone that extends from the Winnipeg mine to Providence Creek. Several small masses of diorite are exposed to the east of Providence Lake.

The diorite in hand specimen is a dark greyish green rock of granular texture, with an average grain size between 2 and 4 millimetres. The visible minerals are green to black hornblende and a greyish white feldspar. Under the microscope the rock is seen to be composed largely of zoned, euhedral to subhedral plagioclase feldspar and partly to completely chloritized amphibole with optical properties approximating those of pargasite. Orthoclase, biotite, epidote, quartz, carbonate, and magnetite are present in small amounts. Partly uralitized augite was noted in one section. The plagioclase feldspars range in composition from labradorite ($Ab_{45}An_{55}$) to oligoclase ($Ab_{80}An_{20}$). The more calcic parts of the crystals are almost completely altered to saussurite and are commonly surrounded by borders of clear untwinned feldspar.

Quartz-bearing phases of the diorite resemble the granodiorite that outcrops in the vicinity of Greenwood, but contain less quartz and orthoclase and have a higher percentage of mafic minerals.

Gabbro and pyroxenite are both dark rocks with prominent subhedral crystals of amphibole and pyroxene as much as 1.5 centimetres long. Microscopic examination shows that the principal minerals of the gabbro are pargasite and a highly altered plagioclase feldspar. The rock is veined by chlorite and carbonate. Aggregates of finely divided, almost isotropic chlorite commonly occupy the interstices between the feldspar and pargasite. The pyroxenite is composed of diallage and bronzite in about equal amounts.

Granodiorite

A granodiorite stock is well exposed on the steep, bare hillsides on either side of Boundary Creek at Greenwood. The eastern part of this stock forms the largest intrusive mass within Greenwood-Phoenix area. It extends about 2 miles from north to south and about 1.5 miles from west to east. The eastern contact is concealed by drift south of the Greenwood-Phoenix road. Several small outlying masses outcrop on both the north and south sides of the stock.

The rock is light grey, shows a uniform equigranular texture, and contains quartz, feldspar, biotite, hornblende, and epidote. Marginal phases are finer grained and in places contain irregular masses of quartz and epidote.

Microscopic examination reveals about 35 per cent plagioclase, 25 per cent orthoclase and microcline, 25 per cent quartz, and 15 per cent mafic minerals. Accessory minerals include apatite, zoisite, and magnetite. The plagioclase feldspars are zoned and show both albite and pericline twinning. They range in composition from oligoclase-andesine ($Ab_{70}An_{30}$) to albite-oligoclase ($Ab_{88}An_{12}$). The central parts of the crystals are altered to turbid aggregates of sericite, zoisite, and epidote, and the marginal shells are of clear untwinned feldspar. Green, pleochroic chlorite is the most abundant mafic mineral and has replaced most of the biotite and almost all of the hornblende. Epidote occurs as grains in the plagioclase feldspar and also as veinlets traversing the rock. It is present in all sections and reaches a maximum of over 20 per cent of the rock. Abundant sericite and some carbonate have been found in the vicinity of quartz veins, and are described under metamorphic rocks.

Tertiary Intrusive Rocks

Bosses, dykes, and sills of porphyritic pulaskite, porphyritic diorite, and related types are common throughout the area. They are typically fine-grained porphyritic rocks, but coarse-grained equigranular types occur in the larger bodies. They intrude the Miocene (?) flows near Phoenix, and are, therefore, the youngest consolidated rocks in the area.

METAMORPHIC ROCKS

The pre-Tertiary sedimentary and igneous rocks of Greenwood-Phoenix area have undergone a wide variety of textural and mineralogical changes since their consolidation. Both dynamic and igneous metamorphism have been effective. Dynamic metamorphism has resulted in the formation of local fault breccias and zones of shearing in some of the volcanic and sedimentary rocks. Changes induced by igneous intrusion have been much more important and include: serpentinization, steatization, propylitization, and sericitization of the igneous rocks; silicification of sedimentary and volcanic rocks; and the formation of lime silicate and metallic minerals in limestone.

Metamorphism of Intrusive Rocks

Entire bodies of an ultrabasic intrusive rock throughout the southern part of the Boundary district[1] have been so completely serpentinized

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1 Geol. Surv., Canada, Map No. 828.

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that it is impossible to determine their original mineral composition. Microscopic study of the serpentine rock shows that it is made up of colourless antigorite, magnetite, chromite, goethite, and a few residual grains of olivine.

Margins of serpentine bodies, and serpentine bodies adjacent to younger acidic intrusions, are altered to talcose rocks containing carbonate and, in places, mariposite. The general term carbonate is used to designate at least two carbonate minerals, probably ankerite and calcite, that commonly occur in the altered rocks. These minerals are coarse grained, and in places constitute over 90 per cent of the talc-carbonate rock. Mariposite is a conspicuous mineral of the rocks exposed in the underground workings of the Athelstan-Jackpot mine. This type of alteration may be of considerable economic importance in that the carbonates formed are susceptible to replacement by mineral bearing solutions. Thus at the Athelstan-Jackpot mine sulphide ore bodies occur as replacement deposits in talc-carbonate, mariposite-carbonate, and carbonate rocks. These rocks occur in serpentine close to intrusive bodies of quartz diorite.

Changes that involved the alteration of mafic minerals to chlorite, epidote, and carbonates, and of feldspars to epidote, carbonates, and sericite have affected in some degree all the intrusive rocks of the area. The effects are most pronounced in granodiorite and diorite and least pronounced in the Tertiary intrusive rocks. Hornblende and biotite in granodiorite and diorite have been replaced by chlorite pseudomorphs or in places by mixtures of chlorite and magnetite. Chlorite also fills fractures in jasperoid and in vein quartz.

Sericite is common in granodiorite along the margins of mineral bearing fissures. The granodiorite is altered to a chalky white rock containing quartz, completely sericitized orthoclase and plagioclase, chlorite, and carbonate.

Silicification has not been a common process in the intrusive rocks. Margins of the large granodiorite stock exposed near the upper Dynamo tunnel are partly altered to a rock made up of epidote and quartz, but elsewhere in the area fresh granodiorite cuts silicified sedimentary and volcanic rocks.

Metamorphism of Volcanic and Sedimentary Rocks

Igneous metamorphism of the volcanic and sedimentary rocks of Greenwood-Phoenix area has been widespread. Jasperoid and chert have been formed in many places, and near Phoenix the limestone, in addition to being silicified, has been partly to completely replaced by epidote, garnet, and actinolite.

Jasperoid

Jasperoid, as defined by Spurr, is a ....

> "rock consisting essentially of cryptocrystalline, chalcedonic or phanocrystalline silica which has formed by the replacement of some other material ordinarily calcite or dolomite. The jasperoid may be white or various shades of red, grey, brown, or black, the colours resulting from different forms of iron in varying proportions."[1]

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1. Spurr, J.E.: Geology of the Aspen Mining District; U.S. Geol. Surv., Mon. 31, p. 219.

Jasperoids formed by silicification of argillites and volcanic rocks and limestone closely resemble one another and consist largely of rounded to angular aggregates of cryptocrystalline quartz.

Jasperoids are widespread in the vicinity of Phoenix. They form a semicircular band that extends from the north side of Providence Creek to the summit of Knob Hill and thence curves to the east and passes under drift east of the Curlew mine. Other masses of jasperoid are exposed near the northeast corner of the map-area, and on the West Kootenay Power line 700 feet east of the Lind Creek-Phoenix road.

The alteration of sedimentary and volcanic rocks to jasperoid in Greenwood-Phoenix area bears no consistent spatial relation to exposed intrusive rocks, and it does not persistently favour any particular horizon. Its distribution is probably controlled by the source of the required solutions and by the available channelways.

In the incipient stages of silicification of limestones and argillites, the alteration has a tendency to follow bedding planes, but may also follow joint and fault planes and thus transgress the bedding.

The jasperoids are grey, greenish grey, or light brownish red, and consist of rounded to angular fragments of grey chert and red or green jasper embedded in a matrix of quartz, feldspar, calcite, and chlorite.

"The individual fragments range in size from microscopic grains to masses 6 inches or more in diameter. Along the contact of the jasperoids and limestone numerous residual fragments of the latter are included in the former. These occur for several hundred feet on either side of the contact, but with a noticeable diminution of the limestone fragments, as the distance from the contact increases. In the field the jasperoids often similate in appearance that of a breccia or conglomerate."[1]

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1 LeRoy, O.E.: Geol. Surv., Canada, Mem. 21, p. 35 (1912).

Fragments of a highly altered, coarse-grained igneous rock resembling some phases of the diorite and fragments of altered andesite occur in the jasperoids in a few localities.

Under the microscope the jasperoids are seen to be composed of rounded to subangular fragments of chert and jasper in a matrix that contains fine to coarsely crystalline quartz, feldspar, epidote, chlorite, biotite, and muscovite. Unreplaced remnants of the country rock were seen in the matrix in several sections. Pyrrhotite, chalcopyrite, magnetite, and pyrite are present in minor amounts. The fragments of chert and jasper are made up of aggregates of microcrystalline anhedral quartz usually less than 0.02 millimetres in diameter. The matrix contains quartz grains ranging from 0.02 to more than 3 millimetres, and lath-shaped crystals of orthoclase and albite-oligoclase that reach a maximum of 4 millimetres. Epidote is relatively abundant in jasperoid derived from limestones.

The rocks have been well fractured. The larger crystals of quartz and feldspar in the matrix are fractured and veined by finer quartz, chlorite, and carbonate, and the coarsely crystalline quartz usually shows strain shadows. The fragments of chert and jasper have been closely fractured and re-cemented by fine comb-quartz, chlorite, and carbonate, and these veinlets may either pass through the fragments and merge with the material in the matrix, or occupy discontinuous cracks within the fragments. Chlorite and carbonate form many small veinlets and are apparently the last minerals to be introduced into the rock.

The origin of jasperoids associated with some of the ore deposits in Utah has been discussed by Lindgren,[2] Gilluly,[3] and Nolan[4]. They agree

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2 Lindgren, Waldemar: Geology and Ore Deposits of the Tintic Mining District, Utah; U.S. Geol. Surv., Prof. Paper 107, pp. 154-159 (1919).

3 Gilluly, James: Geology and Ore Deposits of the Stockton and Fairfield Quadrangles, Utah; U.S. Geol. Surv., Prof. Paper 173, pp. 97-101 (1932).

4 Nolan, T.B.: The Gold Hill Mining District, Utah; U.S. Geol. Surv., Prof. Paper 177, pp. 93-94 (1935).

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that the initial stage in its formation was the replacement of limestone by colloidal silica. Evidence for the colloidal origin of silica is furnished by masses of chalcedony and by the preservation of colloform banding in some of the aggregates of finely crystalline quartz. The second stage was the crystallization of the colloidal mass to form chalcedony or granular quartz. The crystallization involved a considerable contraction of volume and thus led to the formation of openings by shrinkage and brecciation. These openings were filled by fresh supplies of colloidal silica, and the process was repeated. The development and size of quartz crystals is believed to be dependent on the rate of crystallization; where crystallization of the colloidal silica was rapid, fine-grained aggregates of anhedral quartz were produced, but where conditions favoured a slower rate of crystallization larger subhedral to euhedral quartz crystals were formed.

In Greenwood-Phoenix area, jasperoids that have been derived from argillites and volcanic rocks as well as from limestones resemble those described by Lindgren, Gilluly, and Nolan, and are believed to have a similar origin. Evidence of the colloidal silica is furnished by small masses of chalcedony in several thin sections. Evidence of the second stage, that is the crystallization of the colloidal mass and the consequent contraction in volume, is furnished by cracks and vugs in the chert and jasper fragments and by the uniformly brecciated character of large masses of jasperoid.

Chert

The term chert is used in this report to designate a group of fine-grained, siliceous rocks that, like the jasperoids, have been formed by the silicification of sedimentary and volcanic rocks. In part the cherts occur in veins, blobs, and larger irregular shaped masses in the undifferentiated sedimentary and volcanic complex; elsewhere they have so completely replaced the country rock as to leave only a few scattered remnants. Cherts also occur around the margins of jasperoid bodies where they have a faint brecciated appearance near the contact and may have been formed by the coalescing of chert fragments in the jasperoid. The contacts of chert against volcanic rocks and jasperoid are commonly transitional.

The cherts are greyish white, grey, green, or black. The black varieties are carbonaceous. Under the microscope they are seen to be composed of fine- to medium-grained quartz that ranges in grain size from 0.02 to 0.3 millimetres. The larger quartz grains have sutured boundaries and are veined by microcrystalline quartz of two generations. In general, quartz in chert located near the large granodiorite stock is coarser grained than that seen elsewhere.

The origin of chert and its relation to jasperoid is not clear. Contacts between chert and jasperoid are commonly gradational, and the brecciated character of the jasperoid is faintly preserved in the chert. Such chert is believed to have been formed by coalescing of chert aggregates in the jasperoid. LeRoy considered the cherts to be silicified volcanic rocks, and the jasperoid to be silicified limestone. He states,[1] ....

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1 LeRoy, O.E.: Geol. Surv., Canada, Mem. 21, p. 38 (1912).

"the massive limestone appears to be less readily attacked on an extensive scale, and in it the chemical action progressed more slowly along cleavage and minor planes of fracture. The probable porous character of the ash rocks of the Knob Hill group (undifferentiated group of chert and sedimentary and volcanic rocks) presented more favourable conditions for an even and widespread silicification, which accounts for the great thickness of cherts".

The present writer believes that both sedimentary and, locally, volcanic rocks have been silicified to form jasperoid and chert in the Greenwood-Phoenix area, and thus that factors other than the original lithological character of the rocks must have determined the type of replacement that took place.

Undifferentiated Chert, Sediments, and Volcanic Rocks

This group of rocks formed a convenient map unit for masses of partly silicified volcanic and sedimentary rocks wherein chert predominates but does not occur commonly in large enough bodies to be mapped separately. Such rocks are well exposed along the Grand Forks-Phoenix road east of Phoenix. The highly altered rocks along the northern and southern contacts of the granodiorite stock are also included and consist mainly of contorted schistose rocks that contain blobs and lit-par-lit bodies of fine-grained quartz. The quartz was apparently injected into the rocks after folding, for quartz strands cutting across the axial planes of contorted folds of microscopic size do not show any displacement along planes of slippage.

Lime-silicate rocks composed of garnet, epidote, calcite, and quartz occur locally on the Dynamo and Tilby claims on the south side of the stock and are included here. Other types included are the partly silicified and finely banded rocks that outcrop along the east side of Deadman ridge and that are believed to be highly altered sediments.

Lime Silicate Rocks with Sulphides

Limestone at Phoenix has been altered to lime silicate minerals, and in places these minerals are accompanied by sufficient sulphides to constitute low-grade copper ore. Several small masses of lime silicate rock with sulphides were also seen on the Trilby, Mayflower, and Dynamo claims southeast of Greenwood. Although these were too small to be mapped separately, several of them on the Dynamo claim are noteworthy as having been derived from granodiorite instead of from limestone. This alteration of granodiorite appears to be confined largely to the margin of the stock on the Dynamo claim.

The lime silicate minerals and sulphides at Phoenix were studied in considerable detail by LeRoy[1], who states:

[1] LeRoy, O.E.: Geol. Surv., Canada, Mem. 21, pp. 20-21 and 53-70 (1912).

"The extensive deposits of low grade copper ore, which have given rise to the important mining industry at Phoenix, occur in a mineralized area of the Brooklyn limestone which has all the characteristics of a zone of contact metamorphism. This zone is composed essentially of epidote and garnet, together with calcite, quartz and chlorite. Actinolite, tremolite, zoisite, sericite and apatite have been noted microscopically and, with the exception of the first named mineral, occur in very trifling amounts.

"The mineral zone lies in relatively wide and shallow troughs floored by jasperoids, in steep narrow troughs in limestone........., or along the contact between jasperoid and limestone, and between jasperoid and the quartzose rocks of the Knob Hill group........"

"The ore bodies lie at different horizons in this zone though generally favouring the lower and outer portions, and may be considered simply as portions of the mineralized zone in which the copper ore has been sufficiently concentrated to form workable deposits. The ore bodies range in size from lenses about 100 feet long and 20 feet thick to extensive masses like the main ore body of the Knob Hill-Ironside mine, which is about 2,500 feet long and has a maximum thickness of 125 feet and a known width of 900 feet. The attitude of the ore bodies varies in different bodies, and at different points in the same body, from vertical to almost horizontal. There is a pronounced flattening of the dip with depth. The foot-wall is usually jasperoid, occasionally limestone, and, in one instance, the quartzose rocks of the Knob Hill group. As a rule, the commercial foot-wall coincides with the structural. The hanging-wall is almost invariably a commercial one, though the pay ore is usually sharply marked off from the lower grade by a gouge-filled fissure of 'slip'.

"The ore throughout is remarkably uniform and is almost self fluxing. It consists of finely disseminated chalcopyrite, with pyrite and hematite (specularite), in a gangue composed essentially of epidote, garnet, quartz, calcite, and chlorite. Magnetite occurs in distinct masses, or lens-like bodies, both in and along the borders of the main ore bodies. In the case of the Monarch deposit magnetite forms one of the main ore bodies. The chalcopyrite carries all the copper, gold, and silver values, the average ore containing from 1.2 to 1.6 per cent of copper with about $1.00 in gold and silver to the ton".

The paragenesis of the minerals in the lime silicate rocks has been studied at Phoenix[1] and at the Mother Lode and Sunset Mines[2] 3 miles

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[1] LeRoy, C.E.: op. cit.

[2] LeRoy, C.E.: Geol. Surv., Canada, Mem. 19, pp. 36-39, 1913.

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west of Greenwood. It is as follows: epidote, garnet, and actinolite were formed during the early stages of the alteration of the rock. Magnetite is the oldest metallic mineral and is probably in great part contemporaneous with the lime silicate minerals. Chalcopyrite and hematite (specularite) are later than the magnetite and the lime silicate minerals. Pyrite had a wide range in time of deposition, occurring both prior to the chalcopyrite and as the last of the minerals to crystallize. Calcite and microcrystalline quartz are late minerals, and fill fine fractures in the other gangue minerals. If this microcrystalline quartz is of the same age as the silica introduced into the sedimentary and volcanic rocks to form jasperoid and chert it would indicate that silicification took place after the alteration of limestone to lime silicate rock. Field evidence, on the other hand, suggests that silicification occurred prior to the formation of the lime silicate minerals: (1) on the Trilby and Mayflower claims small masses of lime silicate rock occur in the highly silicified complex of sedimentary and volcanic rocks, but do not in themselves show any signs of silicification; (2) on the Dynamo claim, granodiorite has intruded silicified sedimentary and volcanic rocks and the margin of the granodiorite stock is in places altered to garnet, epidote, and coarsely crystalline quartz; (3) near Providence Lake veins and irregular masses of pyrrhotite, magnetite, pyrite, and chalcopyrite occur as fissure fillings and small replacement bodies in jasperoid; (4) specimens collected from the jasperoid lime silicate contact zones in Phoenix show epidote and actinolite veining fragments made up of microcrystalline quartz. It is quite possible that quartz was introduced over a wide range of time, but in the writer's opinion the evidence indicates that the greater part of silicification occurred prior to the formation of silicate minerals.

Summary of Metamorphism

In Greenwood-Phoenix area jasperoid and chert were formed by the replacement of volcanic and sedimentary rocks prior to the intrusion of granodiorite and related rocks, but probably at some time during the general advance of these bodies. Contemporaneous with, or shortly after, the consolidation of the granodiorite certain unsilicified remnants within the intruded rocks, and particularly the limestone remnants, were replaced by lime silicate minerals. Similar alteration affected the margin of the granodiorite stock locally.

Lime silicate minerals, typical of contact metamorphic conditions and undoubtedly formed at high temperatures, are abundant near Phoenix, but bear no consistent relation to exposed intrusive rocks. The writer believes them to be related to an underlying igneous mass, the upward extensions of which may be the exposed stocks of granodiorite, diorite, and gabbro.

ECONOMIC GEOLOGY

Mineral deposits of Greenwood-Phoenix area are of three types:

(1) Quartz veins

(2) Deposits of chalcopyrite, pyrite, magnetite, and hematite.

(3) Deposits of pyrrhotite, pyrite, and arsenopyrite.

QUARTZ VEINS

Quartz veins are common throughout the area, but are particularly numerous in and around bodies of granodiorite. They are lenticular, average about 1 foot in width, and attain a maximum of 5 feet. Pyrite, galena, sphalerite, and chalcopyrite are common, and high assays in gold and silver have been reported. A genetic relation between the veins and the granodiorite and diorite is suggested by their close association in the field, although the veins were, in part at least, formed after the solidification of the exposed parts of the intrusive rocks.

DEPOSITS OF CHALCOPYRITE, PYRITE, MAGNETITE, AND HEMATITE

Deposits of chalcopyrite, pyrite, magnetite, and hematite occur with the lime silicate minerals at Phoenix. Their geological relations are referred to above, and individual properties are described in detail by LeRoy[1].

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1 LeRoy, O.E.: Geol. Surv., Canada, Mem. 21, pp. 71-102 (1912).

Recent developments in the Phoenix camp include the re-opening of the Knobhill-Ironsides and Brooklyn mines in the summer of 1936. Careful sampling of the remaining ore bodies in these mines has shown that the gold content is, in places, considerably higher than the average for the camp, which was about 0.05 ounce to the ton. Recent tests by the Bureau of Mines on concentrates from the Knobhill-Ironsides ore have shown that pyrite contains about half as much gold as chalcopyrite, and, consequently, is not barren as was formerly believed.[1]

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1 Op. cit., p. 61.

DEPOSITS OF PYRRHOTITE, PYRITE, AND ARSENOPYRITE

Replacement deposits characterized by these minerals occur near the margins of bodies of granodiorite and diorite. Deposits of this type, which were worked in the vicinity of Greenwood and Phoenix in the early days, include the Last Chance, Lake, Winnipeg, and Athelstan-Jackpot mines. With the exception of the last, these properties have been abandoned for many years and their workings are inaccessible. The Athelstan-Jackpot mine is described below.

DESCRIPTIONS OF PROPERTIES

Six mining properties are described here. Four of these, namely, Elkhorn, Providence, Dynamo, and Bay mines, are located in Greenwood-Phoenix area, but the No. 7 and Athelstan-Jackpot mines lie to the south. The ore bodies at the Athelstan-Jackpot mine are arsenopyrite-pyrite replacement deposits; those at the other properties lie in quartz veins.

BAY CLAIM

Reference: B.C. Dept. of Mines: Ann. Rept. B.C. Minister of Mines, 1922 and 1934; Lode Gold Deposits of B.C., Bull. 1, 1932.

This claim is owned by R. Foreshaw of Greenwood and is situated 1 mile east of the town at an elevation of 3,350 feet. Recorded production from the property prior to 1930 is 83 tons of ore containing 249 ounces of gold and 114 ounces of silver. The claim has been worked by leasers during the past 2 years and they have made several shipments of high-grade ore to the Trail smelter. Underground openings consist of two inclined shafts and about 200 feet of drifting. Most of this drifting has been done on two levels from the southern inclined shaft, which was full of water during the summer of 1936. Considerable stripping and trenching has been done on the property.

The country rock exposed in these workings is granodiorite intruded by narrow lamprophyre dykes. The granodiorite is the typical massive, medium-grained rock of the Greenwood stock. Shearing and hydrothermal alteration of the granodiorite adjacent to the mineral-bearing fissures have produced a green schistose rock that is composed largely of chlorite, carbonate, and some quartz. The lamprophyre dykes are fine- to medium-grained rocks and are typical of the dark-coloured Tertiary dykes of the area.

The mineral deposit is a quartz vein that strikes north 15 degrees east and dips 35 to 50 degrees east. It has been traced for 500 feet on the surface, and varied from several inches to 3 feet in width. The vein is well defined in surface workings north of the inclined shafts, but elsewhere consists of branching quartz strands that enclose lenses of mineralized country rock.

The northern section of the vein has been offset to the east by a fault that is exposed in surface workings between the inclined shafts. This fault strikes south 70 degrees east and dips 40 degrees south. The amount of offset is not known, as the 100-foot section of the vein between the fault and northern shaft has not been explored. The northern shaft has been sunk on the vein to a depth of 100 feet, and a small amount of "high-grading" has been done from the shaft. Most of the production from the property has come from the inclined shaft that is located on the south side of the fault and has been sunk on the vein to a depth of 65 feet. At a depth of 65 feet the shaft passes from the hanging- to the foot-wall of the southerly dipping fault. Exploration work designed to locate the faulted section of the vein on the under side of the fault was not successful. This work includes a 40-foot drift east from the bottom of shaft, an inclined raise from this drift to the surface, and a shallow winze, all of which are located in the crushed zone along the fault.

Other faults cut the vein but do not displace it more than a few feet. Broken fragments of vein material in the breccia zones and free gold in fault gouge indicate that there has been some post-mineral movement along most of the cross faults. Shearing parallel with or at an acute angle to the walls of the vein, and along thin septa of altered country rock in the vein, fractured the quartz along closely spaced parallel planes before the close of mineralization. These fracture planes served as channelways for later mineralizing solutions and are now occupied in some places by thin seams of metallic minerals, chlorite, and carbonate, giving the vein quartz a distinctive banded appearance known as ribbon structure. Ribbon quartz is a term commonly used to designate quartz possessing this structure.

Pyrite, galena, sphalerite, chalcopyrite, petzite, and free gold comprise the ore minerals in the quartz-carbonate gangue. Finely crystalline petzite with well-defined cubic cleavage has been mistaken for galena in the Bay vein, but may be distinguished by its lighter colour, finer grain, and common association with free gold. Pyrite and an occasional small piece of free gold are found in the altered granodiorite adjacent to the vein fissures. High-grade ore shoots are characterized by minutely fractured vitreous quartz of greenish blue cast, by the presence of finely crystalline petzite, and by the absence of coarsely crystalline galena and sphalerite.

The ratio of ore minerals to gangue varies throughout the length of the vein. The stoped section between the easterly striking fault and the southern inclined shaft contained high-grade ore. Another well-mineralized section of the vein has recently been found in the hanging-wall in the northern inclined shaft. North of this shaft and south of the southern inclined shaft the vein is not as well mineralized, and the future of the property appears to be dependent on finding high-grade ore in the unexplored section of the vein north of the easterly striking fault.

DYNAMO GROUP

<u>References</u>: Ann. Repts. B.C. Minister of Mines, 1922, 1925, 1927, 1931, and 1934.

The Dynamo group of seven claims is situated on the east side of Boundary Creek about half a mile southeast of the Greenwood post office. The property was optioned to the Dynamo Mining and Milling Company, Limited, in 1934, and a considerable amount of development work was done at that time. Very little work has been done since October 1934. About 20 tons of ore shipped to the Trail smelter in 1934 yielded 7.6 ounces gold, 165 ounces silver, and 1,631 pounds lead.

Mine openings consist of three adit crosscuts and a few short drifts totalling about 3,000 feet. A large amount of surface trenching has been done along the veins.

The property lies along the southern contact of the large granodiorite stock. The rocks exposed in the underground workings are granodiorite, serpentine, and the highly altered group of sedimentary and volcanic rocks.

A number of quartz veins have been found within the granodiorite. They are lenticular and probably do not average more than 10 inches in width. Pyrite, galena, chalcopyrite, and sphalerite are the common ore minerals.

ELKHORN MINE

References: B.C. Dept. of Mines: Ann. Rept. B.C. Minister of Mines, 1926, 1927, and 1928; Lode Gold Deposits of B.C., Bull. 1, 1932.

The Elkhorn mine is situated in Boundary Creek Valley about 1 mile north of Greenwood and about 1,400 feet west of the Providence mine. The trans-Canada highway passes through the property. The property consists of one claim and is owned by George White of Greenwood. Recorded production from the mine prior to 1930 is 131 tons, which contained 145 ounces gold, 9,470 ounces silver, and 13,586 pounds lead. An additional 32 tons of ore shipped to the Trail smelter in 1935 yielded 14.7 ounces gold, 3,890 ounces silver, and 2,776 pounds lead. Underground openings consist of a 50-degree inclined shaft 270 feet in length, with levels at 65 and 270 feet, and an adit level at 110 feet. At the time of examination the mine was flooded below the adit level and the 65-foot level was also inaccessible.

The Elkhorn claim lies almost entirely within the belt of highly altered rocks that border the large granodiorite stock. These rocks are silicified sedimentary and volcanic rocks, and are described in some detail in the description of the Providence mine.

The ore occurs in a quartz vein that has an average strike of north 50 degrees east and dips 45 to 65 degrees southeast. The vein has been traced about 250 feet by underground workings, and ranges from a fraction of an inch to 16 inches in width.

The vein is cut by several faults that strike north 30 to 50 degrees east and dip at low angles to the northwest. The hanging-wall has in each case moved down with reference to the foot-wall. Offsets along these faults range from a few feet to 30 feet. On the 110-foot level the vein is cut by two post-mineral feldspar porphyry dykes, and has not been located beyond the dyke that is exposed 135 feet northeast of the inclined shaft. The other dyke, which is exposed in the level at the inclined shaft, has not offset the vein.

Sphalerite, galena, chalcopyrite, pyrite, tetrahedrite, and ruby silver (proustite) are the common ore minerals. Native silver was found above the 65-foot level of the mine.

Commercial sections above the adit level have been stoped. According to Mr. White the vein has not been located in the workings below the adit level.

NO. 7 MINE

References: B.C. Dept. of Mines: Ann. Rept. B.C. Minister of Mines, 1896, 1897, 1900, 1901, 1902, 1903, 1909, 1910, 1912, 1934, and 1935; Lode Gold Deposits of B.C., Bull. 1, 1932. Geol. Surv., Canada, Sum. Repts. 1901 and 1902.

No. 7 mine is situated outside the area on the south side of McCarren Creek about $4\frac{1}{2}$ miles south of Greenwood, at an elevation of 4,400 feet. A fair automobile road passes through the property and joins the trans-Canada highway at Boundary Falls, 3 miles to the west. The property includes three claims, which are owned by the Consolidated Mining and Smelting Company of Canada, Limited, and leased to W.E. McArthur of Greenwood.

The mine was operated intermittently from 1896 to 1910, and, according to P.B. Freeland,[1] the total production for that period was

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B.C. Dept. of Mines: Lode Gold Deposits of B.C., Bull. 1, pp. 84-85 (1932).

7,453 tons, which yielded 1,405 ounces gold, 59,482 ounces silver, and 89,000 pounds lead. W.E. McArthur shipped an additional 2,500 tons of slightly higher grade ore during 1934-36, making a total production of about 10,000 tons. About 5,500 feet of underground development work was done to obtain this comparatively small production. In addition an aerial tramline was constructed from the mine to the railway at Boundary Falls.

Mine workings comprise a 320-foot inclined shaft, adit levels at 40 and 300 feet, and intermediate levels at 100 and 180 feet. Old mine maps show that the underground work on these four levels totals about 5,200 feet. The 300-foot adit level is open from portal to face, a distance of about 1,900 feet, but the other levels are partly caved southeast of the inclined shaft. Other workings include an adit drift 130 feet northwest of the 40-foot (No. 1) adit, a large number of surface pits, and a deep trench along the vein from which some underhand stoping was done.

The surface geology in the vicinity of the mineral deposit is complex, and is partly obscured by overburden northeast of the shaft house. The oldest rocks are green to black, chloritic argillites and quartz-mica schists that outcrop on the northeast side of the vein. These rocks are thinly bedded in places and strike north 65 degrees west and dip 50 to 70 degrees northwest.

The intrusive rocks in the vicinity of the mine comprise serpentine, granite porphyry, and a wide variety of dyke rocks of different ages. Green to black serpentine and its sheared and altered border phase, a yellowish brown talc-carbonate schist, form a northwesterly striking band about 100 feet wide between chloritic argillites on the northeast and granite porphyry on the southwest. Larger bodies of serpentine outcrop south and southeast of the mine. The serpentine is the typical variety found in Greenwood-Phoenix area, the thin sections studied being made up largely of colourless serpentine and carbonate. Magnetite is sufficiently abundant in the serpentine to cause deviation in the compass needle. In places, lenses of hard, green, finely crystalline rock occur in the talc-carbonate schist and serpentine and suggest remnants of original peridotite, but examination under the microscope shows that these rocks have also been completely altered to serpentine.

Granite porphyry forms an irregular, northwesterly trending band that extends across the property and separates the narrow band of serpentine adjacent to the vein from more extensive bodies of serpentine to the south. The granite porphyry is slightly to highly sheared, greenish white on fresh fracture, and is composed mainly of quartz, orthoclase, albite-oligoclase, and chloritized mafic minerals. The rock is veined by microscopic seams of chlorite, epidote, and carbonate.

A conspicuous feature of the geology of the mine is the large number of dykes found close to the ore deposit. These dykes range from biotite-albite lamprophyre to light green quartz trachyte and are believed to be largely post-mineral. A highly sheared and partly silicified lamprophyre dyke along the foot-wall of the vein near the shaft is probably pre-mineral. Most of the dykes occur close to or along the contact of the talc-carbonate schists and the chloritic argillites, and thus trend northwest. Two notable exceptions occur: a biotite-albite lamprophyre dyke exposed in an open pit 350 feet southeast of the shaft house and a quartz-biotite andesite dyke exposed at No. 1 adit cross the contact and have a general northerly trend. These dykes send out apophyses 20 to 50 feet in length along the contact.

Ore bodies occur within a quartz vein that has an average strike of north 65 degrees west and dips 40 to 65 degrees northeast. It has been traced for almost 1,000 feet on the surface, and ranges from several inches to 5 feet in width. The vein follows the contact between the chloritic argillites and the talc-carbonate schist. In places the chloritic argillites form the hanging-wall and talc-carbonate schists the foot-wall of the vein, but usually one of the numerous dykes is present on either the hanging- or foot-wall of the vein.

A large number of northeasterly striking faults displace the vein. Displacements along these faults range from a few feet to almost 200 feet. The maximum displacement was measured on the fault exposed in the southeast end of the 300-foot level and on the surface 200 feet southeast of the long open-cut. The vein has not been located beyond this fault. Movement along these faults has been largely post-mineral. Evidence of some pre-mineral movement is furnished by lenticular seams of unbroken vein quartz up to 8 inches by 10 feet in the fault zone exposed in the southeast end of the 300-foot level. Subsidiary faults of small displacement are part of this same fault zone, and offset both the vein and the post-mineral quartz trachyte dyke. Thus this single fault zone has been the locus of both pre- and post-mineral movements.

The vein is cut in two places by northerly striking lamprophyre dykes, and in several places has been cut at an acute angle by the quartz trachyte dyke that closely follows the contact between the chloritic argillites and the talc carbonate schists throughout the mine workings.

Sphalerite, galena, and pyrite are the common ore minerals in the quartz vein. The most productive section was on the southeast side of the inclined shaft from the 180-foot level to the surface. These workings are now inaccessible. On the 300-foot level the vein is lenticular and of low grade.

All ore in the accessible parts of the mine has been removed. A search for new ore bodies should be preceded by a careful study of the factors that have caused localization of ore deposition in the upper levels of the mine. Accessible stopes in this part of the mine dip at lower angles than the low-grade sections of the vein on the 180- and 300-foot levels. A stope contour map showing the relationship between assays and the altitude of the vein could be prepared from available mine plans and sections. If any consistent relationship between the two could be determined by this method it would be of great value in guiding future development work on the property.

PROVIDENCE MINE

References: B.C. Dept. of Mines: Ann. Rept. B.C. Minister of Mines, 1896, 1897, 1903, 1904, 1905, 1906, 1918, 1919, 1920, 1921, 1924, 1925, 1926, 1927, 1928, 1929, and 1934; Lode Gold Deposits of B.C., Bull. 1, 1932. Geol. Surv., Canada, Sum. Rept. 1902.

The Providence mine is situated on the north side of Providence Creek about 1 mile north of Greenwood. A good automobile road connects the mine with the trans-Canada highway. The property consists of one claim and is owned by Wm. Madden of Greenwood.

The mine has been operated intermittently from 1896 to the present time, and according to P.B. Freeland[1] the total production prior

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[1] B.C. Dept. of Mines: Lode Gold Deposits of B.C., Bull. 1, pp. 84-85 (1932).

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to 1930 was 5,750 tons, which yielded 3,225 ounces gold, 746,951 ounces silver, and 187,689 pounds lead. About 4,000 feet of underground development work was done to obtain this production.

Mine workings consist of five levels served by two inclined shafts. The old shaft, now abandoned, is about 450 feet north of Providence Creek and gave access to levels 1 to 4 inclusive. Levels 2, 3, and 4 were established at 50-foot intervals. An inclined winze connects levels 4 and 5. A new shaft, 100 feet north of Providence Creek and 470 feet southwest of the old shaft, has been sunk to 177 feet on an incline, with levels at 56, 121, and 177 feet. The 56-foot level and the 121-foot level connect with levels 3 and 4, respectively, of the old shaft. Levels 1 and 2, and the old shaft above level 2, are partly caved.

Providence claim lies almost entirely within the highly altered rocks that border the large granodiorite stock. The original nature of ~~most~~ of these rocks has been obscured by shearing and widespread silicification. Some of them resemble silicified argillites, whereas others, which have a granular appearance and are chiefly made up of aggregates of hornblende and biotite in a fine-grained matrix of andesine, are probably of volcanic origin. The rocks resembling silicified argillites strike north 30 to 70 degrees west and dip 30 to 70 degrees northeast. Granodiorite outcrops on the south side of Providence Creek near the Providence-Freemont claim posts, and is widely exposed in the lower workings of the mine. Sheared hornblende-quartz diorite is exposed on the north side of Providence Creek close to the Province-Dimond Fraction claim line. This rock was not recognized in the underground workings. All of these rocks are cut by later Tertiary dykes.

The upper levels, which are partly inaccessible, are largely within the silicified rocks, and No. 5 level, particularly southwest of the inclined winze, is largely within granodiorite. Shearing and hydrothermal alteration adjacent to the mineral-bearing fissures makes the identification of the various rock types difficult.

Ore shoots occur within a quartz vein that strikes north 50 degrees east and dips 40 to 65 degrees southeast. It has been traced underground for more than 1,200 feet, and ranges from a fraction of an inch to 2½ feet in width. Unbroken quartz rarely extends from wall to wall, and more commonly strands of quartz are separated by thin, lenticular bands of altered country rock. The vein is irregular in size and attitude on the lower levels. In a few places these changes can be correlated with the passage of the vein from one rock to another. Thus, in the northeast part of the fourth level the vein pinches to a gouge-filled fissure on passing from the relatively hard silicified rocks to soft chloritic schists. On No. 5 level the vein appears to be more persistent in the silicified rocks than in the granodiorite.

Faults of at least two ages displace the mineral-bearing fissure. The older group, which is pre-mineral in age, strikes north 30 to 50 degrees east and dips gently northwest. Local reversals of dip were seen along several low-angle faults, and rolls in the fault plane were noted in every case where an individual fault could be traced for any distance. In each case the hanging-wall has moved down with reference to the foot-wall, thus indicating normal faulting. Offsets along these faults range from a few feet to 80 feet. The maximum offset was measured along a fault that is now occupied by a post-mineral feldspar porphyry dyke.

Veins are in places slightly enlarged where they intersect these pre-mineral faults, and at other places narrow quartz stringers may follow the fault plane. The younger group of faults strikes north 30 degrees west to north 10 degrees east and dips at high angles. Displacements along these faults are small. They are post-mineral and offset the vein as well as the older group of faults.

Sphalerite, galena, chalcopyrite, pyrite, tetrahedrite (?), and ruby silver (proustite) are the common ore minerals in the quartz-carbonate gangue. Native silver, free gold, and chalcocite were common in the upper levels.

Exploration below the fifth level, particularly in the southwestern part of the mine, will be mainly within granodiorite, and conditions on the fifth level indicate that this makes a less favourable host than the silicified rocks of the upper levels.

Some ore might be found in the upper levels between the hanging-wall of the feldspar porphyry dyke and No. 2 level. This dyke follows a fault that offsets the vein fissures 80 feet on the second level near the old shaft. The same dyke outcrops on the surface 200 feet north of the new shaft and is exposed in the old shaft between the second and third levels and can be traced northeast from there through stopes to the third and fourth levels. The vein has been stoped from No. 2 level to the surface and from the third and fourth levels to the foot-wall of the dyke. A triangular shaped block of ore should exist between the hanging-wall of the dyke and the floor of the second level. Some of this ore may have been removed by underhand stoping from the second level, but no evidence of this could be seen in the accessible parts of the level.

A small amount of exploration work has been done on the third and fourth levels beyond the feldspar porphyry dyke. The rocks exposed by this work are chiefly soft chloritic schists of a type that is probably unable to maintain a fissure for any distance. These schists resemble highly altered phases of the sheared, hornblende quartz diorite that outcrops on the surface above these workings. Exploration work within this quartz diorite on the adjoining Dimond fractional claim failed to locate the northeastern extension of the Providence vein, and it may be that the vein does not continue far into the chloritic schists.

The vein was not examined on the southwest side of the new shaft. It has been stoped from the fourth level to the overlying creek gravels, and the resultant inflow of water necessitated the construction of a concrete bulkhead on the fourth level between the shaft and stope.

ATHELSTAN-JACKPOT MINE

References: B.C. Dept. of Mines: Ann. Rept. B.C. Minister of Mines, 1904, 1910, 1911, 1912, and 1935; Lode Gold Deposits of B.C., Bull. 1, 1932. Geol. Surv., Canada, Sum. Rept. 1901 and 1902.

Athelstan-Jackpot mine is situated about 5 miles southwest of Greenwood on the north side of Taylor Creek at an elevation of about 3,900 feet. It is outside of Greenwood-Phoenix area. Fair automobile roads connect the mine with Phoenix, and with the trans-Canada highway about 10 miles east of Grand Forks. The property is owned by W.E. McArthur of Greenwood. Recorded production from the property prior to 1930 is 36,614 tons, which contained 5,781 ounces gold, 6,757 ounces silver, and 15,965 pounds copper. The mine was operated during the summer of 1936 and produced about 40 tons of ore a month. The ore averaged slightly over one-half ounce of gold a ton. It was hauled 14 miles by truck to Danville, Washington, and shipped from there to Tacoma for treatment.

The present company is an amalgamation of the old Athelstan and Jackpot mines. These properties were developed by independent companies in the early days, and their underground workings were not connected. Considerable development work was done on both mines prior to 1912, but most of the openings are now inaccessible. The Athelstan adit is 1,100 feet to the west and 300 feet above the Jackpot adit. Accessible workings at the Athelstan mine include a westerly trending adit drift about 100 feet in length, and a flat stope. Accessible workings at the Jackpot mine include a westerly trending adit crosscut about 120 feet in length, and an interior inclined shaft sunk to a vertical depth of 56 feet, with levels at 34 and 54 feet. Talc-carbonate rocks, serpentine, and quartz diorite are exposed in these workings. The talc-carbonate rocks occur in serpentine adjacent to bodies of quartz diorite and its porphyritic phase a quartz-feldspar porphyry. The youngest consolidated rocks near the mine are the post-mineral augite porphyrite dykes. Surface exposures are confined largely to prospect pits and caved areas over the old stopes.

The talc-carbonate rocks weather brown and contain talc and ferromagnesian carbonate in various proportions. Their outcrops are marked by limonitic gossan produced by the oxidation of the carbonate. The rocks show some variation in lithological character from one locality to another. Sheared varieties consisting largely of talc and serpentine with subordinate amounts of carbonate are common near the contacts of the talc-carbonate rocks against serpentine. Massive varieties largely made up of a brown-coloured ferromagnesian carbonate, probably ankerite, and some calcite are well exposed around the Athelstan surface workings. Other varieties containing a conspicuous green mica, probably mariposite, are common in the underground workings of the Jackpot mine. Contacts between the talc-carbonate rocks and serpentine are usually gradational. The total extent of exposed talc-carbonate rocks is not known, but they extend from an elevation of 4,200 feet at the top of the hill above the Athelstan adit at least as far as the Jackpot adit and outcrop over a maximum width of about 550 feet.

Talc-carbonate rocks here contain slightly more carbonate than those developed from serpentine elsewhere in the area, but have probably been formed in a similar way by solutions richer in carbon dioxide.

These rocks are traversed by an irregular system of pre-mineral fissures that have strongly influenced the rising ore-bearing solutions by providing channelways for them, and gouge-filled barriers capable of deflecting them.

The talc-carbonate rocks are intruded by quartz diorite east and northeast of the Jackpot adit and by small masses of quartz-feldspar porphyry south of the Athelstan adit. The quartz diorite is a greyish, fine- to medium-grained, equigranular rock containing orthoclase, oligoclase, quartz, and chloritized mafic minerals. Pyrite is common in the form of veinlets and small irregular masses throughout the rock. The quartz-feldspar porphyry has a similar mineral composition, and is believed to be a finer grained, porphyritic phase of the quartz diorite. Along the north side of a caved stope 250 feet south of the Athelstan adit it is bleached and contains appreciable amounts of pyrite. In some places margins of the quartz diorite and the intruded rocks are slightly silicified. Both the talc-carbonate rocks and the ore deposits are cut by numerous veins of calcite with a maximum width of 2 inches.

The ore bodies at the Athelstan-Jackpot mine are arsenopyrite and pyrite replacement deposits in talc-carbonate rocks. The shape and size of several ore bodies that were mined in the early days can be inferred from the accessible mine workings. At the Jackpot mine two of the ore bodies that were mined from the present adit crosscut were crescentric in plan and plunged from 10 to 40 degrees to the east along their longest axis. They ranged in thickness from a few feet to 25 feet and probably averaged 10 feet. They were stoped over a length of at least 100 feet and over a width of at least 40 feet. Narrower parts of these same ore bodies have been mined during the past 2 years. At the Athelstan mine the only accessible stope is about 60 feet long, averages about 40 feet wide, and ranges from 3 to 8 feet in height. A winze, which was sunk in the floor of this stope to a depth of 12 feet during the summer of 1936, is entirely in ore.

The foot- and hanging-walls of the ore bodies commonly follow well-defined fissures, and occasionally such fissures also form the lateral limits of the ore bodies. Sulphides may extend for a few inches beyond these fissures, but are then extremely erratic.

Chemical composition of the wall-rock has also had a marked influence on ore deposition. Those rocks containing a high percentage of carbonates were the most susceptible to replacement by the ore-bearing solutions, whereas those containing appreciable amounts of serpentine were apparently the least susceptible.

The ore deposits are displaced by a number of northeasterly striking normal faults that dip 40 to 70 degrees northwest. One of these faults is well exposed at the western end of the large stope in the Jackpot mine. The bands of ore that have been stoped to the surface on the western or hanging-wall side of this fault are believed to be the down-faulted segments of the ore bodies below the fault. Another northwesterly striking fault is exposed at the western end of the Athelstan stope. Although the direction of movement along this fault is not known definitely, it is reasonable to assume it is similar to the northeasterly striking and northwesterly dipping faults in the Jackpot mine, and is thus a normal fault.

The common ore minerals are pyrite and arsenopyrite. In the zone of surface weathering these are oxidized to limonite and a white arsenious oxide. These oxides form extensive deposits in some places and have been shipped as ore to the Tacoma smelter.