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THE COPPER DEPOSITS OF THE BOUNDARY DISTRICT, B. C.

By

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INTRODUCTION

Many geologists and mining engineers have passed through the ghost towns of Phoenix and Deadwood in southern B.C. and perhaps some have gone as far as looking into the old glory holes and caves. Many others have heard or read of the once famous Boundary Camp. The following description and discussions are based on two years' experience in the camp as Field Manager and Geologist for Attwood Copper Mines Limited.

ACKNOWLEDGEMENTS

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Much of the data and many of the interpretations presented are credited to the work of, and discussions with Dr. W. H. White, Consultant Geologist, who worked two field seasons on the project. However, the author assumes the responsibility for this presentation.

Dr. C.D.A. Dahlstrom worked with the author during the latter stages of the project. His assistance and advice are gratefully acknowledged.

HISTORY

This account of the history is gleaned from old reports and documents which are listed in the bibliography, and from discussions with the old timers of the district.

Prospectors were active in the vicinity of Greenwood in 1891 and in that year staked the Mother Lode, Crown Silver and Sunset. Henry White staked the Knob Hill claim in Phoenix on July 15, 1891 and by the end of the year other prospectors had staked most of the claims covering the valuable ore bodies in the camp. Much surface work done in the early years indicated that the values in copper, gold and silver were low. Large capital investments were required to develop the ore bodies and build smelters. The discovery that the ore was practically self-fluxing greatly enhanced the value of the deposits.

The Miner-Graves Syndicate commenced development on the Knob Hill - Old Ironsides orebody in 1896. This company purchased and merged with other interests until, as the Granby Cons. M.S. & P. Co. it controlled most of the important ground in Phoenix. Granby blew in the first furnace of its Grand Forks smelter in August, 1900. Fourteen million tons of ore were treated in the smelter.

The remaining valuable properties in Phoenix and the Boundary district were controlled by the New Dominion Copper Co., the Consolidated M. & S. Co. of Canada, and the B.C. Copper Company.

Phoenix was incorporated in 1900. The C.P.R. extended its line into Phoenix in 1898 and the Great Northern in 1904.

Production reached its peak in 1913 when 1,300,000 tons of ore were mined and shipped. The camp was abandoned in 1919 when the available ore reserves were approaching exhaustion, and when labour strikes in the Crowsnest coalfield cut off the supply of coke for the smelters. The Boundary Camp had then produced about 22,000,000 tons of ore averaging slightly over 1.5% copper and about 0.03 oz. per ton in gold and 0.5 oz. per ton in silver. Production since 1919 has been only a few thousand tons from spasmodic leasing.

Attwood Copper Mines Ltd. acquired some of the old properties in 1951 and began extensive exploration. Geological mapping indicated favourable areas which were tested with the modern techniques of biogeochemistry and geophysics. The resulting anomalies were analyzed and those suspected of indicating ore bodies were diamond drilled. The only 'ore-bodies' found to date are extensions of deposits found by the old timers.

GENERAL GEOLOGY

Table of Formations:

TERTIARY

MIDWAY - volcanic and hypabyssals, dacitic to basaltic flows with associated dykes and sills of syenite (pulaskite in part), and augite porphyry.

KETTLE RIVER - arkose, with minor shales and conglomerate, in places containing coal.

JURA-CRETACEOUS

quartz diorite and diorite intrusives.

LATE PALAEOZOIC

ATTWOOD SERIES:

BROOKLYN - sharpstone conglomerates, limestone greywacke and/or andesitic tuff, with minor shale and balsalt.

RAWHIDE - shale.

EARLY PALEOZOIC

KNOW BILL - chert and andesite, with minor limestone, shale and serpentine.

LITHOLOGY

Knob Hill

The Knob Hill is a highly contorted formation, predominantly of chert and andesite. The chert is light to dark grey, and so highly fractured that it is difficult in many places to obtain a fragment more than onehalf inch in diameter. Outcrops in precipitous areas, for example on Deadman's Ridge near the Phoenix-Grand Forksroad, indicate that individual chert bodies are at least several hundred feet thick. The andesite in many places is streaked, having the appearance of flow structure, and contains structures which may have been volcanic bombs. Some outcrops show vague feldspar crystals, possibly formed from re-crystallization after deposition.

In many places the rock has been called cherty andesite or andesitic chert; siliceous ooze and andesitic tuff have been deposited either simultaneously or in alternation with later comminution and interflowage to form a melange. In other places, for example near Hartford Junction, the andesites are massive and free of chert. Andesite in outcrops south of the Rawhide Mine is more corase-grained than the "typical" Knob Hill andesite. The rock in these outcrops is a clean, fresh-looking hornblende diorite, most likely a flow or hypabyssal intrusion. This grained rock was grouped with the Knob Hill andesite.

Limestone and serpentine are sparse in the Knob Hill formation. The few outcrops in the area mapped by Attwood are contorted pods a few tens of feet long.

ATTWOOD SERIES

Rawhide Formation

The name "Rawhide Formation" was applied by LeRoy to a bed of shale a few hundred feet thick, which outcrops south of the Rawhide Mine (see Map). LeRoy states that it "overlies conformably the Brooklyn Formation". The shale has well marked bedding, showing light and dark grey laminations and intercaleted lenses of sandstone and conglomerate with smokey-grey chert and sparse jasper pebbles. The beds in some places are flat and in other places dip as much as fifteen or twenty degrees west and north-west. At higher elevations towards the west, on the West Kootenay Power Transmission Line, the lenses of conglomerate increase in size and number, and finally the shale disappears; the rock is all chert pebble conglomerate (see figure below).

One small exposure contained truncated symmetrical ripple marks, of about one inch frequency and one-half inch amplitude. These show that the shale was laid down in water with little or no current, and that the beds are top-side up stratigtaphically.

The Rawhide shale lenses out to the south-west and is not found beyond the Gilt Edge workings. Towards the east it passes under overburden east of the Rawhide mine. East of this overburden all the outcrops found are Knob Hill formation.

The only fossil found in the shale is one imprint that could have been either a graptolite or a fernlike frond. The Rawhide Formation, then, is a lens of shale lying below and transitional to the Brooklyn Formation.

Brooklyn Formation

The Brooklyn Formation is host to all the major orebodies in the Boundary Camp, and therefore has received the most study. The writer disagrees markedly with former workers in the area on the origin and nomenclature of some of the principal members of this formation.

(A) Conglomerate:

The rocks which LeRoy has described as jasperoid (siliceous rocks formed from replacement of limestone) are believed to be sharpstone conglomerate. As discussed later, the sharpstone conglomerate lies, probably unconformably, on the Knob Hill series except where the Rawhide shale forms the base of the Attwood series. Lying conformably above the lower 2000 feet of conglomerate is a large limestone lens, up to two thousand feet wide and about onemile long (see map 1). This lens is postulated as an unreplaced remnent by LeRoy. Lying conformably above the limestone is another 1500' to 2000' of sharpstone conglomerate, in which are intercaled two lenses of limestone breccia or conglomerate, named the Stemwinder limestone by the writer.

LeRoy's description of the series, and his evidence supporting his belief that the chert-breccia rock is a jasperoid, is quoted in considerable detail because his publication is now out of print.

> "The lower or Brooklyn Formation consists essentially of limestone or its replaced equivalents, while the upper or Rawhide Formation consists almost entirely of argillites.....(The Brooklyn) formation lies on rocks of the Knob Hill group, the basal member of the former being jasperiod in contact with the chert of the later. The formation is susceptible of a three-fold division based on the character and degree of alteration and replacement of the limestone. It consists of(a)crystalline limestone with some associated calcareous argillites; (b) a zone of jasperoids with some tuffs, argillites, and altered basic intrusions and (c) a mineralized zone composed essentially of garnet and epidote.
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> The limestone had originally a very extensive development but is now represented by a few isolated exposures, the masses usually resting on a floor of jasperoid rocks ..... A complicated faulting, with shearing and brecciation, has probably been an important factor in assisting the processes which have replaced so large a proportion of the original limestone by quartz and lime-silicates.....
>
> Included in the zone of jasperoids are the jasperoids proper which are replacements of limestone, as well as other varieties derived from tuffs; argillites, and fragmentary masses of intrusive igneous bodies which are occasionally encountered only in the underground workings.
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> The jasperoids consist of oval, rounded, oblong, and subangular pebble-like individuals of light grey and white quartz, grey, pink and brownish cherts, and reddish-brown and bright red jasper in a matrix of smaller forms of the same composition with calcite and chlorite. The individuals vary in size from microscopic grains to masses six inches or more in diemater. Along the contact of the jasperoids and the Stemwinder 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 rock often simulates in appearance that of a breccia or conglomerate. A banding is occasionally noticeable with the rounded cherty individuals in an alignment which coincides in direction with the major jointing of the adjacent limestone. The rock usually weathers light grey and the rounded individuals stand out in relief as a result of the dissolving out of the calcite matrix.

In the field all transitional forms are to be seen between crystalline limestone on the one hand, and typical jasperoid on the other. The replacement takes place along bedding, joint and fracture planes, the jasper growing in bands and tongue-like extensions which increase by coalescing. The replacement also goes on in a more uniform manner throughout the whole mass in the case of some limestone bodies, where the siliceous solutions have followed the finer and almost microscopic planes of parting. In such stages the rock shows the pebble like bodies standing out in high relief on weathered surfaces.

Under the microscope the jasperoid is seen to be composed of oval, rounded, oblong, and sub-angular aggregates of cryptocrystalline or chalcedonic and microcrystalline quartz in a matrix of calcite, with some angular mosaics of quartz and small amounts of pale green chlorite and tuffs of colourless mica (sericite?). The calcite is the predominant mineral of the matrix and may represent part of the original limestone which has been redeposited. The siliceous aggregates are oval, rounded, oblong or sub-angular individuals with smooth and crenulate borders. Some show tongue-like extensions indicating directions of growth, and irregular and rude dumbell forms. A few aggregates hold small granular clusters of calcite grains as inclusions. In some slides quartz crystals of good form have developed freely in the calcite portion of the matrix.... Jasperiods, which were originally medium grained tuffs, possibly more or less calcareous, show in addition to the above mineral constituents, grains and phenocrysts of plagioclase feldspar a few of which show evidence of secondary growth, and fragments of porphyrites, porphyries, aplites and effusive types of igneous rocks with a partially altered glassy base.....

In the transitional types between the limestone and jasperoids the replacement of calcite by silica follows cleavage and contact planes of the calcite grains, the minute grains of quartz occurring as solitary grains or in clusters in the first stage. From this stage all types showing gradual progression toward the typical jasperoid may be seen.

The siliceous rocks of the Brooklyn Formation and the Knob Hill group jasperoids and cherts probably have a common origin as regards the source of the silica. It would appear that the source was a deepseated one, and that the siliceous solutions may have been derived from the main granodiorite batholith during its early stages of invasion...."

The writer is in sympathy with LeRoy's interpretation of the Series, because it does not require an explanation of the very unusual sequence of sedimentation represented by the Attwood Series. However, the writer maintains that the "jasperoids" are beds of angular, or sharpstone, conglomerate in which the chert individuals are original pebbles, rather than siliceous replacements. Subsequent metamorphism has produced a slight regeneration or re-working of some of the quartz and/or chert, but little if any silica has been added to the bulk of the formation since deposition. The reasons for this belief follow:

1. (a) The rock in many places contains chert fragments of different colours, as mentioned by LeRoy, within a few inches of each other. The distribution of these coloured fragments appears completely haphazard. It is doubtful that the original limestone postulated by LeRoy was composed of variously coloured small units in which the colour was maintained by the replacing silica, and even more doubtful that the original limestone was all of one colour, and the replacing silica abruptly changed colour while replacing each small unit.

   (b) Some of the chert fragments are banded, and the attitude of this banding in neighbouring banded pebbles is haphazard.

   (c) The composition of the neighbouring individuals is not uniform.

In a volume a few feet in diameter are, besides the above-mentioned variously coloured chert pebbles, sparse pebbles of igneous rocks as mentioned by LeRoy, small slabs of slate, and rounded fragments of limestone.

This heterogeneity of colour, structure and composition of the fragments composing the "jasperoid" could be maintained only if a banded jasperoid with included remnants of igneous rocks, shale, and limestone were strongly brecciated. However, the "jasperoid" does not show the regional structure of a tectonic breccia.

2. The rock is bedded. Shale, impure limestone, and siltstone beds, a few inches to

to a few feet thick, and fine and corase fragmental beds up to a few hundred of feet thick have conformable contacts wherever observed, except for several outcrops showing scour and fill. Unequidimensional fragments in the fragmental beds are rudely aligned parallel to the bedding (see Plate 1).

3. Several outcrops containing interbedded fragmental rock and siltstone or shaley siltstone show good scour and fill structure.

4. The chert fragments in the fragmental beds which are close to the beds of limestone, shale or siltstone are smaller, more rounded, and better sorted in size than the chert fragments in most fragmental beds elsewhere. Also the fragmental beds associated with limestone etc. are much thinner than most fragmental beds elsewhere.

The fragmental beds associated with the Rawhide Shale are composed predominantly of smokey-grey chert fragments, well sorted, and metamorphozed to a quartzite. Only one or two fragments of jasper were observed in the quartzite. These fragmental beds are lenticular, but were nowhere observed transgressing the bedding in the shale.

One type of fragmental bed, associated with some of the limestone, is unusual. This rock, called the "Peanut-Brittle Limestone" by the writer, is the rock LeRoy postulates as a transitional stage in the silicification of limestone. The rock contains many well founded, frosted, white to light-grey chert fragments of one-eighth to one-quarter inch in diameter in alimestone matrix. The ovoid fragments in any one bed have a very small range in size. The chert ovoids do not touch one another in many of the specimens examined. None of the "dumb-bell" forms mentioned by LeRoy were observed by the writer. Thoese which LeRoy observed could have been formed from two touching chert ovoids. If these chert ovoids were formed by replacement of limestone one would expect them to vary greatly in size and shape, and to be accompanied by veinlets of quartz. The evidence strongly suggests that the chert ovoids are windblown pebbles.

Beds composed of quartz or chert sand in a limestone matrix were found in the area. The sand in these beds is probably windblown.

5. LeRoy mentions that limestone remnants are numerous in the jasperoid near the contact with limestone, and become less numerous as distance from the limestone increases. These limestones individuals or "remnants" are found in great abundance near the two lenses of limestone breccia or conglomerate called the Stemwinder Limestone (see below) outcropping near the Stemwinder Mine (see map). The individuals are rounded to sub-angular, and have sharp contacts with the encompassing fragmental chert rock. The writer believes that the limestone "remnants" are actually pebbles and bounders deposited with the chert fragments. It is realized that clastic limestone is unusual, and can exist only where the sediments have undergone very short transport. However, a short search of geologic literature resulted in finding several other examples of limestone conglomerate.

(B) Limestone:

Overlying the lowest or basal band of the sharpstone conglomerate in the Phoenix area is a lens of limestone reaching a maximum thickness of about 2,000'. The limestone is light-grey to cream, with abundant shale and/or siltstone laminations in places. It is continuous from the "Idaho" mine at Phoenix to near the Great Northern Railway grade, about one mile north. Unfortunately the northern termination is drift-covered. The limestone has an apparent thickness of 1500' where it goes under the drift. Beyond the drift-covered area, 2000' farther north, the outcrops are Knob Hill Formation. The southern termination, hear the "Idaho" mine is similarly abrupt, but underground workings afford good exposure enabling one to examine the termination.

The beds of limestone, with minor shale and siltstone, grade in a few tens of feet along strike, into a zone of alternating carbonate-rich and chlorite-rich bands. These bands of carbonate and chlorite are a few inches thick, and are uniform and persistent. They probably represent bedding. They continue south for about 2000' to near the West Kootenay Power Line (away from mineralized area of the "Idaho" mine the bands are andesitic tuff or greywacke and impure limestone rather than chlorite and carbonate). South of the Power Line they are intercalcated with and grade into fine-pebble sharpstone conglomerate.

Stratigraphically above this large limestone lens is another thousand to fifteen hundred feet of sharpstone conglomerate and intercalated in this upper conglomerate are the two lenses, each about 100' thick at maximum, of limestone breccia or angular conglomerate called the Stemwinder limestone. As discussed above, this rock may be either sedimentary or tectonic breccia, but the association with the sharpstone conglomerate indicates it is more likely the former.

The two lenses of "Stemwinder" limestone outcropping near the Stemwinder Mine have not been described in detail by LeRoy. The lenses are composed of angular to sub-angular fragments of limestone ranging from a few millimeters to about one foot in diameter, and sparse chert fragments ranging from a few millimetres to about one inch in diameter. The matrix is limestone with minor quartz. The fragments are closely packed, and in some places appear to match their neighbours, as if they could be fitted together. This matching is sufficiently rare that it could have occurred either by chance breakage, or by closepacking effected by slight movements, between time of deposition and consolidation.

The writer has not found a completely satisfactory explanation of the origin of the lenses of "Stemwinder" limestone. There is no evidence that they are associated with fault zones. They may be scree. They lie one thousand to 1500' in the hanging-wall of the large bedded limestone band. But there is no evidence of a hiatus between the large band and the Stemwinder limestone; i.e. it is not known how the large band could be eroded to form fragments for the "Stemwinder" limestone. Only a short interval, during which the separating band of chert fragmentals was deposited, could have elapsed between the deposition of the lower large limestone lens and the Stemwinder lenses. The problem is further considered below under the section on Regional History.

(C) Basalt:

A few lenses of andesitic to basaltic rock lie within and unconformably above the Brooklyn Limestone. Outcrops of this rock are found on the road from the Brooklyn mine to Marshall Lake, and east of the Lancashire Lass and Ora Denora mines, near Denora Townsite in theB.C. Basin area. The area near Lancashire Lass has been studied in detail by Dr.W.H.White. A north-trending basin of basalt lies upon a rubbly surface of Brooklyn limestone. The basalt extends at least as far as Wilgress (Loon) Lake, about 2 miles north of the Lancashire Lass. The more andesitic phases of this rock are difficult to distinguish from the massive Knob Hill andesite; consequently the rock may be incorrectly mapped in places.

JURA-CRETACEOUS INTRUSIVES

No Mesozoic sediments or volcanics were deposited in the Boundary District. A batholith of granodiorite reported as Jura-Cretaceous underlies most of the Boundary Creek and Kettle River drainage areas a few miles north of the Greenwood area. Mesozoic Intrusives in the area mapped include the quartz diorite stock which underlies the City of Greenwood, and the quartz diorite stock which outcrops west of the Ora Denora and Emma mines south of Eholt. The relation of these stocks to mineralization is discussed later.

KETTLE RIVER ARKOSE

The Tertiary (Oligocene) Kettle River Arkose forms lenses a mile or two long, and a few hundred feet thick. It is similar in attitude to the underlying Brooklyn formation. The lower contact is marked by a few feet of shale and rubble with coal fragments. Individual beds in the formation range from a few millimetres to fifty feet thick. The thin beds are shale and the thick beds are cross-bedded congolmerates. The conglomerate pebbles in the lens of arkose exposed at Phoenix are composed of arkose only slightly more indurated than the arkose of the matrix.

The arkose is well exposed at Phoenix extending from 1000' south to 3000' north of Victoria shaft. A lens of similar size is cut by the valley of Fisherman Creek, and small outcrops were found in the "Copper Camp". At Phoenix the arkose is notably lenticular along both strike and dip. Near Victoria shaft the arkose is about 200' thick and dips easterly at about 50 degrees. 1500' east, on the east limb of the north-plunging Tertiary basin, the BrooklynFormation is directly overlain by the post-arkose Midway Volcanics. Underground workings indicate that the arkose flattens and lenses out about 1000' down dip (see section).

The arkose was probably formed from erosion of the extensive masses of granitic rocks north of the Boundary District. The basins are probably remnants of basin which were far more extensive before the glacial period.

MIDWAY VOLCANICS:

The Midway Volcanics, which include lava flows of trachyte, andesite and basalt, lie conformably, or with slight disconformity on the Kettle River arkose. The flows are far more extensive than the arkose, and probably obscure many mineral deposits in the area. The bottoms of the flows are, in places, marked by scoriacious breccia, as along the south side of the West Kootenay Power Line 500' south-east of Victoria shaft. Flow banding was observed in only one outcrop, about 1,000' east of Victoria shaft.

Associated with the flows are hypabyssal intrusives of syenite, in places "pulaskite" and augite porphyry. These transect all the older formations and merge into the flows, thus probably fed the flows. In the skarn zone at Phoenix, pulaskite dykes are highly altered to clay and/or allied minerals, and consequently are difficult to distinguish and identify. North of Wilgress (Loon) Lake, in theB.C.Basin, flat-lying syenite bodies are very abundant. They outcrop almost continuously for several thousand feet. Flat sheets of syenite in the B.C. mine are reported to be so abundant that they seriously hindered mining. The flows and hypabyssal intrusives have a high and "phasey" content of magnetic minerals, making it very difficult to prospect beneath them with magnetic geophysical methods.

STRUCTURE

Knob Hill

Neither well-defined bedding nor horizon markers have been found in the Knob Hill Formation. However, zones which may be beds do exist locally. West of Knob Hill, for example, zones predominantly of chert alternate with zones predominantly of andesite. The zones are several hundred feet thick and trend northwesterly for a few thousand feet. Perhaps a few months of diligent and detailed mapping would unravel some of the structures in the Knob Hill Formation, but Attwood did not undertake the task because only small and marginal grade orebodies have been found in the formation.

KNOB HILL - Brooklyn Contact

Only one outcrop, on the southeast slope of Deadman Ridge, was found spanning the contact of the Knob Hill formation and the overlying Attwood series. The Contact here appears conformable; andesite is directly overlain by sharpstone conglomerate with an andesite matrix. The contact is "frozen" with no faulting or distinguishable hiatus. The transition from massive andesite to chert pebble conglomerate with an andesitic matrix occurs within a few inches.

North of the GoldDrop workings, along the old Railway grade now used as a road, a few tens of eet of overburden separate Brooklyn Formation skarn (in an open pit) from Knob Hill outcrops. Similar fracturing and alteration may be observed near the obscured contact of Knob Hill and Brooklyn formations at the Sunset Mine in Deadwood. The fracturing and alteration may be associated with the emplacement of the ore in the GoldDrop and Sunset Mines. Alternately, it may be associated with an unconformity or a large flat thrust-type fault zone between the Knob Hill and the overlying Brooklyn formation.

In summary, the Brooklyn formation is probably unconformable to the Knob Hill formation. The reasons for this belief are;

(1) The Brooklyn conglomerate, as indicated by the angularity of the chert fragments, has been transported only one or two thousands of feet at most. Thus it must be derived from a nearby formation, without doubt mostly from the Knob Hill. The chert fragments in andesitic matrix (Brooklyn formation) may lie upon cherty andesite (Knob Hill formation) and subsequent lithification and metamorphism would make the contact appear gradational and conformable.

(2) The uppermost "strata" in the Knob Hill formation are not everywhere the same rock type. West of the Phoenix Camp the Knob Hill - Brooklyn contacting rocks are chert and sharpstone conglomerate; south they are andesite and sharpstone conglomerate; south-east they are cherty andesite and shale; east, where the outcrops mentioned above span the contact, they are cherty andesite and sharpstone conglomerate. The variations in the rock type of the lowest Brooklyn member can, I believe, be satisfactorily explained by the marked lateral gradation one would expect to find in deltaic deposits of conglomerate and shale. But andesite and chert, such as foundin the Knob Hill Formation in most places do not lens out in a thousand or so feet along strike.

(3) The orogeny that has contorted and shattered the Knob Hill rocks has not involved theBrooklyn formation. Beds and bedding in the Brooklyn Formation can be traced with little change in attitude for several thousand feet.

(4) The fracturing and alteration near the Knob Hill - Brooklyn contact, at Gold Drop and Sunset mines could be caused by three periods of weathering and erosion; early Brooklyn, Mesozoic to Tertiary, and Recent, rather than by faulting.

ATTWOOD SERIES

The thousands of feet of angular fragmental rocks in the Attwood Series must have originated under unusual conditions. The angular fragments are positive evidence of rapid deposition. The presence of limestone and of symmetrically ripple-marked shale indicate shallow marine deposition. (A suite of fossils including "Spirifer" (Spiriferina), "Terebratula"? and some pelece-pods was found in the limestone. Since the material is not very disgnostic, no correlation was made. A later Paleozoic or Triassic age was proposed).

Detailed mapping of surface and accessible underground workings, followed by diamond drill at Phoenix have provided more information pertinent to the problem. West of the Knob Hill - Old Ironsides orebody are exposures of bedded sharpstone conglomerate for 2,500 ft. (see map). These rocks, including the replacement of the limey lens which forms the orebody, dip from 45 deg. to 70 deg. easterly at the surface exposures. Yet 200' below surface the orebody and the banding in it which is with little doubt original bedding, dip only 10 deg. or 15 deg. easterly.

One thousand feet down the dip the orebody is approx. flat, and the 2500' of fragmental footwall rock has completely disappeared. The orebody is here underlain by Knob Hill cherty andesite. The statement that the footwall sharpstone conglomerate is exposed for 2,500' west of the Knob Hill - Ironsides orebody is perhaps misleading. West-dipping normal faults found in the mine workings give in places a duplication in plan of the east-dipping strata, and this fault system may continue into the footwall rocks. However, the sum of the normal movements on the faults mapped underground does not exceed 200'. Thus, at least 2000' or more of sharpstone conglomerate in the footwall of the orebody must lens out and flatten only a few hundred feet down dip.

The data would appear best explained by rapid deltaic deposition. Several good exposures or scour and fill were noted, but only one or two exposures show cross-bedding.

The structural evidence, in conjunction with the lithologic evidence, certainly suggests that the rock is a sediment, an angular chert-pebble, or sharpstone, conglomerate, rather than a silicified limestone later brecciated.

ORE DEPOSITS

The copper orebodies are all replacements of limestone or impure limey rock at or near contacts with other rocks. Chalcopyrite is the ore mineral in all the deposits. Other metallic and sub-metallic minerals are pyrite, specular hematite and magnetite; non-metallic minerals are epidote, carbonate, amphibole, chlorite, quartz, garnet, pyroxene and earthy hematite. Bedding, indicated by bands with varying concentration of the above minerals, is well preserved locally in most of the deposits. The relative percentage of the minerals listed above varies considerably along strike and down dip in each deposit, and some of the minerals are far more abundant in some deposits than in others. Almost all the deposits, particularly those which are more flat-lying,have a hanging-wall of skarn as much as 200' thick. Chalcopyrite mineralization is most abundant in the carbonate-rich bands and in narrow carbonate veinlets traversing the banding. With one or two exceptions, no noticeable increase in chalcopyrite mineralization was found near faults.

Relation to Intrusives and Age of Deposition:

No outcrops of the Laramide diorite or quartz diorite stocks were found within two miles of Phoenix. Only 3 dioritic dykes, a few tens of feet thick were found, one in each of the Stemwinder, Snowshoe and Victoria mines. One of these intrusives is cut by quartz-chalcopyrite veinlets in the Stemwinder. The dykes in Stemwinder and in the old Railroad grade near the Snowshoe bear an abundance of pyrite, but little or no chalcopyrite. Their alteration indicates that they are pre-ore. No increase in mineralization was noted near their boundaries.

The Greenwood quartz diorite stock is in contact with chalcopyrite - bearing skarn in the Deadwood Camp. However, the contact is obscured by drift on surface and is a fault zone in drill core. No relation is apparent between grade of ore and proximity to the intrusive. The Motherlode Mine is 5000' west of this granodiorite contact, but small bodies of granodiorite outcrop a few hundred feet east of the mine workings and were found at depth.

The contact between the Denora diorite stock and mineralized skarn is well exposed in the Ora Denora mine. The garnet-epidote skarn grades into the diorite, and pockets of skarn, mineralized with chalcopyrite, are found several hundred feet within the stock. The grade of ore increases with proximity to the contact. Thus, little doubt exists that the diorite here provided the mineralizing solutions. Since the other orebodies in the Boundary are similar in mineralization, it is probable that they were formed at the same time and that the Jura-Cretaceous stocks were the source of the ore-forming fluids.

McNaughton states "the Tertiary sedimentary and igneous rocks are younger than the ore deposits ...." but gives no evidence to support the statement.

The evidence is as follows:

1. No exposure has been found in which mineralization transects or replaces Tertiary rocks. A few places were noted in which ore appeared to be of higher grade close to Tertiary dykes, but these places may be coincidental, for patches of "high grade" also occur with no apparent relation to the dykes.

2. In the "Copper Camp" secondary copper minerals have been deposited in a trough formed by Tertiary dykes and arkose. However, no primary sulfides were found, thus the only definite conclusions is that the secondary ore is post-Tertiary. Incidentally, the copper oxides are in a hematite gangue in the "Copper Camp" and in a limonite gangue in the other oxidized deposits in the district.

3. It appears in two underground localities that the Tertiary intrusives had picked up inclusions of ore. However, the rockin these places is brecciated and gougey from faulting and thus the ore "inclusions" may be fault drag.

4. The relation of the orebodies to Jura-Cretaceous intrusives has been described in the section above. The evidence strongly suggests that, at the Ora Denora mine at least, the age of the orebody is Laramide.

Data suggesting that the ore deposits may be younger than the Tertiary rocks are as follows:

1. The Eastern, or down dip, extension of the Knob Hill - Ironsides orebody at Phoenix is immediately on the footwall of the Tertiary arkose. Tertiary rock may have provided a "cap" for the mineralizing solutions. Alternately however, Brooklyn Formation, which formerly made the hangingwall, may have been eroded in pre-Tertiary time and the Tertiary arkose deposited after this erosional period. If this is the case, the Tertiary rock may also transect the mineralized zone itself. The other orebodies in the Boundary area show no proximity to the Tertiary sediments and extrusives now exposed.

2. The Tertiary dykes in mineralized areas are strongly altered in places to clay minerals and sericite. No such alteration is found away from the mineralized areas.

3. No detrital ore or skarn has been found in the Kettle River formation sediments.

REGIONAL HISTORY

The solution of the regional history is far from complete, but the main features are believed to be as follows:

The basement Knob Hill Formation of chert and andesite, probably of marine deposition, were partially uplifted and severly folded before Brooklyn time. The uplift must have formed rugged mountains, which were devoid of vegetation, bordered by inlets and bays of the sea.

These bays and inlets were the site of the Brooklyn deposition. Erosion was predominantly mechanical, and very rapid. The conglomerates and minor greywackes and shales were roughly sorted during a short transport and deposited in fairly lenticular beds. The main band of limestone, with minor shale and siltstone, was deposited during a period of less rapid erosion, and in deeper water than the greywacke and fine conglomerate being deposited at the same time. Rapid erosion and deposition later formed the Upper Brooklyn conglomerates and greywacke. The upper limestone "breccia" bands may have formed from erosion of the Lower Brooklyn limestone or of larger bands of Knob Hill limestone than those now exposed.

Volcanic activity during Brooklyn time and continuing into post-Brooklyn is manifested by the thin flows of andesite and/or basalt intercalated with and lying conformably above the Brooklyn.

The Knob Hill and Brooklyn formations were intruded in Jura-Cretaceous time by diorite and quartz diorite. These intrusions were accompanied by mineralization. Many small precious metal lodes were formed near the border of the Greenwood stock. The limestone at Ora Denora and Emma mines was metasomatized to form economic orebodies containing chalcopyrite and magnetite with skarn minerals. As discussed previously, all the camps in the district, with the exception ofthe largest, Phoenix, and the smallest, the B.C., are close to Laramide intrusives. The intrusions were doubtless accompanied by folding. In the B.C. Basin tight folds in limestone were noted, with no apparent relation to faults, and several thousand feet from intrusive contacts. The "syncline" at Phoenix, as discussed above, may be an old topographic basin rather than a syncline formed by folding. The steepness of the western limb may be due to folding, but as discussed below, is more likely due to Tertiary tilting. Both fold and basin axes in the Boundary area plunge northerly at 10 or 15 degrees. The Brooklyn Formation may have been far more extensive in pre-Laramide time than now. If the Brooklyn outcrops in Phoenix were continuous to those in Deadwood, then the Greenwood stock has uplifted the Brooklyn on its roof, and subsequent erosion has stripped the uplifted area.

Early Tertiary basins at Phoenix and on Fisherman Creek, a few miles north of Phoenix, were filled or partially filled by arkose. The bedding and cross-bedding in the arkose shows that this sediment was derived from the west, and the composition indicates that it was formed from Jura-Cretaceous granitoid rocks. Late Tertiary flows were laid down on top of the arkose, and associated hypabyssal intrusives, feeders to the flows, cut the arkose and all underlying rocks. The location of the Tertiary basins shows that the topography has changed markedly since Tertiary time. The Tertiary basins are foundon what are now ridges. Erosion from Tertiary to Recent has cut valleys as much as 2000' deep.

Post Tertiary diastrophism is evident from the many faults found cutting the Tertiary rocks. Accompanying the folding was a regional tilting of at least 30 deg. to the east. Evidence for this tilting comes from the attitude of the arkose beds which dip up to 45 deg. easterly, both at Phoenix and on Fisherman Creek. The initial dip (dip at time of deposition) of these arkose beds would be a maximum of 30 deg. and a probable 10 to 20 deg. Thus the area has been tilted easterly about 30 deg. since Miocene time.

In pre-Tertiary time then, the Brooklyn beds at Phoenix must have lain in a nearly symmetrical trough, with the limbs dipping about 30 deg. towards the vertical or almost vertical axial plane. This attitude could have been maintained as initial dip by the beds of angular conglomerate.

The higher end of this trough was towards the south, as indicated by the following:

1. The main band of Brooklyn limestone, with minor shale, grades towards the south into limey shale and greywacke, which in turn fingers out into siltstone and conglomerate showing scour and fill.

2. The Rawhide shale, on the south-east border of the trough, shows ripple marks.

3. The conglomerates on the south-west border of the basin are more coarse than elsewhere.

The lensing-out and flattening of the Brooklyn beds at a few hundred feet depth can now be explained. Rather than lensing out with depth, the lensing out probably occurred where the sediments met the east rim of the basin at time of deposition. East of the Phoenix basin theBrooklyn sediments now dip and gently roll at 20 to 30 deg. easterly down to the B.C. Basin. These sediments must have been relatively flat-lying in pre-Tertiary time.

The orebodies would also have to be tilted about 30 deg. westerly to show their attitude immediately after deposition, assuming that they are Jura-Cretaceous in age. The Knob Hill - Old Ironsides orebody, then occupied the trough of a shallow syncline, with limbs dipping about 20 deg. towards the axial plane. The Monarch - Rawhide - Gold Drop - Snowshoe orebody was almost horizontal. The Brooklyn - Idaho orebody dipped about 45 deg. easterly, and if the regional tilt extended to Deadwood, the Mother Lode dipped about 30 deg. easterly.

Individual Deposits, Granby - Knob Hill - Ironsides -Victoria etc.

The Knob Hill - Ironsides - Victoria orebody produced about 11,000,000 tons, or 50% of the copper ore mined in the Boundary area. The skarn enveloping the ore extends from Phoenix townsite, 3000' south to the War Eagle and Grey Eagle workings, thence arcs to the east through the Monarch, and thence north-east and north, through the Curlew and GoldDrop to the Snowshoe. Production from the War Eagle and Grey Eagle was negligible. A few tens of thousands of tons were mined from the Monarch, and continuous ore from there to the Snowshoe provided about 4,000,000 tons.

In plan then, the mineralized zone forms a "U" with the open end to the north. The base, to the south, was too low grade to make ore. The west limb of the "U" dips easterly at about 60 deg. near surface, but flattens to 10 or 15 deg. a few hundred feet down dip. This western limb follows a ridge (Knob Hill) which, at the base of the "U", or south end, slopes down to the south, causing the outcrop to swing easterly. West dipping normal faults accentuate the flattening of the deposit and thus also the easterly swing. A west dipping normal fault, stronger than those mentioned above, near the Monarch, brings the mineralized zone relatively up on the east. East of the Monarch, the ore zone and the hillside dip and slope easterly, almost paralleling one another, on the eastern limb of the "U". The axis of the "U" plunges northerly about 10 deg. under a capping of the Tertiary arkose and volcanics.

West and south of the mineralized zone, Lower Brooklyn and Knob Hill rocks are well exposed.

East (down dip) of the mineralized "U" zone is a swampy area with very few outcrops. The underground workings in the Snowshoe show two strong faults, one dipping flatly west and the other steeply east, forming the eastern termination of the ore zone. The rock found in outcrops and drill core east of these faults is sharpstone conglomerate with chert pebbles in a chert matrix, the pebbles being barely distinguishable from the matrix. This conglomerate is similar to that found intercalated with the Rawhide shales, thus on lithological correlation would be basal to the ore zone. The drilling to 600' depth failed to find either an indication of the skarn zone or definite Knob Hill or Rawhide footwall rocks, thus structural correlation across the east terminal faults is lacking. Assuming that the 600' plus of BrooklynFormation found east of the faults is lower Brooklyn formation, basal to the ore zone, gives an anomalous thickness to the lower Brooklyn here, for only a few tens of feet of lower Brooklyn rocks lie between the ore zone and the Knob Hill formation west of the east terminal faults. However, the locality where the lower Brooklyn thickness can be ascertained is six hundred feet west of the faults, and the deep drill hole is 600' east of the faults. (Knob Hill formation outcrops 2000' east of the faults), see Maps and Sections C andD. A local basin may have existed here before Brooklyn deposition, accounting for the anomalous thickness found in the drilling.

The west limb of the U was the Knob Hill - Ironsides - Victoria orebody, 2000' long, up to 150' wide, and continuing for about 1500' down dip. Two outcropping orebodies, each about 75' thick, coalesced about 200' down dip, and the body gradually flattened and thinned down dip to the east. The skarn between the two outcropping bodies, and forming the gangue of the hangingwall body is thinly banded (a few inches average width per band) carbonate - epidote - chlorite rock, originally probably a thin-bedded impure limestone. The banding is continuous and regular except for minor drag folds near the stronger faults. The footwall outcropping orebody showed very little banding, but contained on-strike lenses of quartz-carbonate rock, particularly near the north end of the mined zone. Before mineralization these quartz-carbonate bodies could have been either fairly pure limestone into which quartz was later introduced or "peanut-brittle" limestone in which the quartz was later reworked. LeRoy shows the ore zone in contact, through by a small fault, with barren limestone on strike of the ore zone on the north end of the Victoria #2 level workings (now inaccessible). Diamond drilling indicates that this limestone is the Stemwinder Limestone breccia or conglomerate, and that it is continuous north of the ore zone, through the valley of Twin Creek to where it outcrops near the Stemwinder workings. The Stemwinder is thus on the same ore-making structure as Knob Hill - Ironsides - Victoria.

Attwood drilling has shown that some remnants of the Knob Hill etc. orebody remain on the northeast end of the body, about 300' vertically below the surface. The skarn zone extends north and east beyond this mineralization under the capping of Tertiary rocks. Skarn and copper mineralization are exposed in the Gilt Edge workings northwest of the Tertiary capping. The area inside the U was intensively explored, and in part mined by Granby. However, only one or two holes were drilled by Granby through the Tertiary volcanics north of the U. In summary, the Granby skarn zone has not been explored to its north and east limits, the Stemwinder has not been explored down dip, and the Gilt Edge zone has not been prospected down dip under the Tertiary capping southeast of the workings. These three mineralized zones could be parts of the same zones, obscured in part by the Tertiary rocks and in part by hangingwall Brooklyn rocks.

Brooklyn-Idaho

The Brooklyn-Idaho workings are on a mineralized zone parallel to Knob-Hill etc. and about 1,000' to the West. The zone follows the hangingwall contact of the main band of Brooklyn limestone. The ore zone outcropped on both the north (Brooklyn) and south (Idaho) side of Twin Creek, and was continuous under the creek valley, giving a total length of about 1,800'. Most of the Idaho end of the zone was too low grade to mine. The ore zone pinched out at about 250' depth where the limestone footwall apparently flattened markedly from a dip of about 70 degrees (at outcrop) to a dip of about 20 deg. easterly. As noted above, the Granby body had a similar flattening down dip. Termination on the north can be observed on surface where the zone pinches gradually to 1' in width before it is obscured by overburden. The southern termination has been discussed in connection with the disappearance of the main band of limestone to the south. The ore tails out with the main limestone band into banded chlorite and carbonate. Actually, however, the ore zone has not been explored south of a fault on the footwall of a pulaskite dyke dipping 15 or 20 deg. northerly. Drag folding on the hanging-wall of the dyke indicates that the ore zone south of the fault has moved easterly. However, the zone is too low grade to merit prospecting beyond the fault.

Motherlode - Sunset

The gangue in the Motherlode-Sunset orebodies differs from that in the Phoenix orebodies in that it contains little, if any, hematite, either earthy or specular, but contains abundant actinolite. Nearly 4,000,000 tons were produced from an orebody 1,250 ' long, up to 550' thick and extending to 500' depth on the Motherlode claim. The body lies on the contact of fairly pure limestone with

with impure banded limestone on the steep west limb of a shallow syncline. In general, the mineralization has followed bedding, but in detail the lenses of good grade ore were separated by bodies of lower grade sub-ore. The body was terminated at depth by Knob Hill rocks forming the base of the syncline and by granodiorite.

The Sunset lies in a highly fractured small outlier of Brooklyn limestone on the shallowly dipping east limb of the syncline. The outlier caps a small knoll. It is underlain by Knob Hill chert.

The Brooklyn rocks are exposed for at least a mile to the north of the mine workings to where they disappear under Tertiary volcanics. No mineralization of importance was found in them. The syncline must plunge to the north, for the mine workings are bounded on the south by Knob Hill cherts.

On the Peacock claims, in drift-covered area south of the Motherlode Sunset group, magnetometer survey disclosed large and strong anomalies. Bulldozer stripping to 15' depth failed to find bedrock, but exposed many boulders well mineralized with magnetite and chalcopyrite. Subsequent diamond drilling reached bedrock, Knob Hill chert, at 80' depth. Erosion must have removed many tons of ore from the Motherlode and Sunset lodes.

Ora Denora, Emma and B.C.

The Ora Denora, Emma and B.C. mines in the B.C. Basin area, each produced about 100,000 or 200,000 tons.

The Ora Denora production was chiefly from four of five open pits-bounded by fault planes, Tertiary dykes and the diorite stock. The bedding in limestone is transected by a diorite stock. ~~Thexbeddingxinxlimestonexis transectedxbyxaxdioritexstockx~~ Old records show that diamond drilling explored the skarn zone below the mine workings, but did not intersect economic mineralization. The principal skarn mineral is garnet, but pods of magnetite, several feet in diameter, were noted.

The Emma mine also lies on the contact of the stock with limestone. The contact of the stock is parallel to the original bedding and both strike northerly. The orebody was a lens several hundred feet long, and up to 25' wide dipping almost vertically. It is bounded on the west and south by diorite, on the east by skarn, and to the north it pinches into barren limestone. No information on the structure at depth is available. Garnet and magnetite are the chief skarn minerals.

The B.C. mine lies on the contact of basalt and limestone. It is similar to the Emma in size and shape. Syenitedykes are reported to cut off the orebody at depth. Old reports indicate that diamond drilling failed to find extensions to the south. The zone to the north has been explored by geophysics and biogeochemistry. One drill hole to the north intersected syenite dykes and sharpstone conglomerate, indicating that the overlying limestone is discontinuous. No mineralization was intersected.

Several other mineralized properties were examined in the B.C. Basin, including the Lancashire Lass, Jumbo, Mountain Rose and R.Bell, but none have produced important quantities of ore.

R. H. Seraphim

Vancouver, B.C.
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