Geology and Copper Deposits of the Boundary District, British Columbia

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Introduction and Acknowledgments

THE RECENT and continuing activity in the Boundary district, British Columbia, makes the publication of this paper timely. The following description and discussions are based on two years' experience in the district as Field Manager and Geologist for Attwood Copper Mines, Limited.

The Attwood project was organized by Dr. D. F. Kidd to re-examine the Boundary mining camp. Thanks are due to Dr. Kidd, both for his intelligent guidance during the project and for his permission to publish this paper.

Much of the data and many of the interpretations presented are credited to the work of, and to discussion with, Dr. W. H. White, Consultant Geologist, who worked for 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 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 15th, 1891, and by the end of the year other prospectors had staked most of the claims covering the valuable orebodies 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 orebodies 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 Consolidated Mining, Smelting and Power Company, 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 Company, the Consolidated Mining and Smelting Company of Canada, and the B. C. Copper Company.

The town of Phoenix was incorporated in 1900. In 1898 the Canadian Pacific Railway, and in 1904 the Great Northern Railway, extended their lines to reach the town.

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 per cent 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, Limited, acquired some of the old properties in 1951 and began intensive exploration. Geological mapping indicated favourable areas and these were tested with the modern techniques of biogeochemistry and geophysics. The resulting 'anomalies' were analyzed and those suspected of indicating orebodies were diamond drilled. The only new orebodies found to date are extensions of deposits discovered by the old-timers.

TABLE OF FORMATIONS

TERTIARY	Midway Volcanics and Hypabyssal Rocks	Dacitic to basaltic flows with associated dykes and sills of syenite (pulaskite in part) and augite porphyry
	Kettle River Arkose, etc.	Arkose, with minor shales and conglomerate, in places containing coal
JURA-CRETACEOUS	Intrusives	Quartz diorite and diorite
LATE PALAEOZOIC	Attwood Series: Brooklyn Formation	Sharpstone conglomerate,* limestone, greywacke and/or andesitic tuff, with minor shale and basalt.
	Rawhide Formation	Shale
EARLY PALAEOZOIC (?)	Knob Hill Formation	Chert and andesite, with minor limestone, shale and serpentine

*A conglomerate formed from stones predominantly angular.

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Early Palaeozoic

Knob Hill Formation

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 one-half inch in diameter. Outcrops in precipitous areas, for example on Deadman's Ridge near the Phoenix-Grand Forks road, 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 termed 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 coarse-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.

Late Palaeozoic: Attwood Series

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 Figure 1). LeRoy states that it "overlies conformably the Brooklyn formation". The shale has well marked bedding, showing light and dark grey laminations and intercalated lenses of sandstone and conglomerate with smoky-grey chert and sparse jasper pebbles. The beds in some places are flat and in other places dip as much as fifteen to twenty degrees west and northwest. At higher elevations toward the west, on the West Kootenay Power Transmission Line, the lenses of conglomerate increase in size and number, and finally the shale disappears until the rock is all chert pebble conglomerate (see Figure 3).

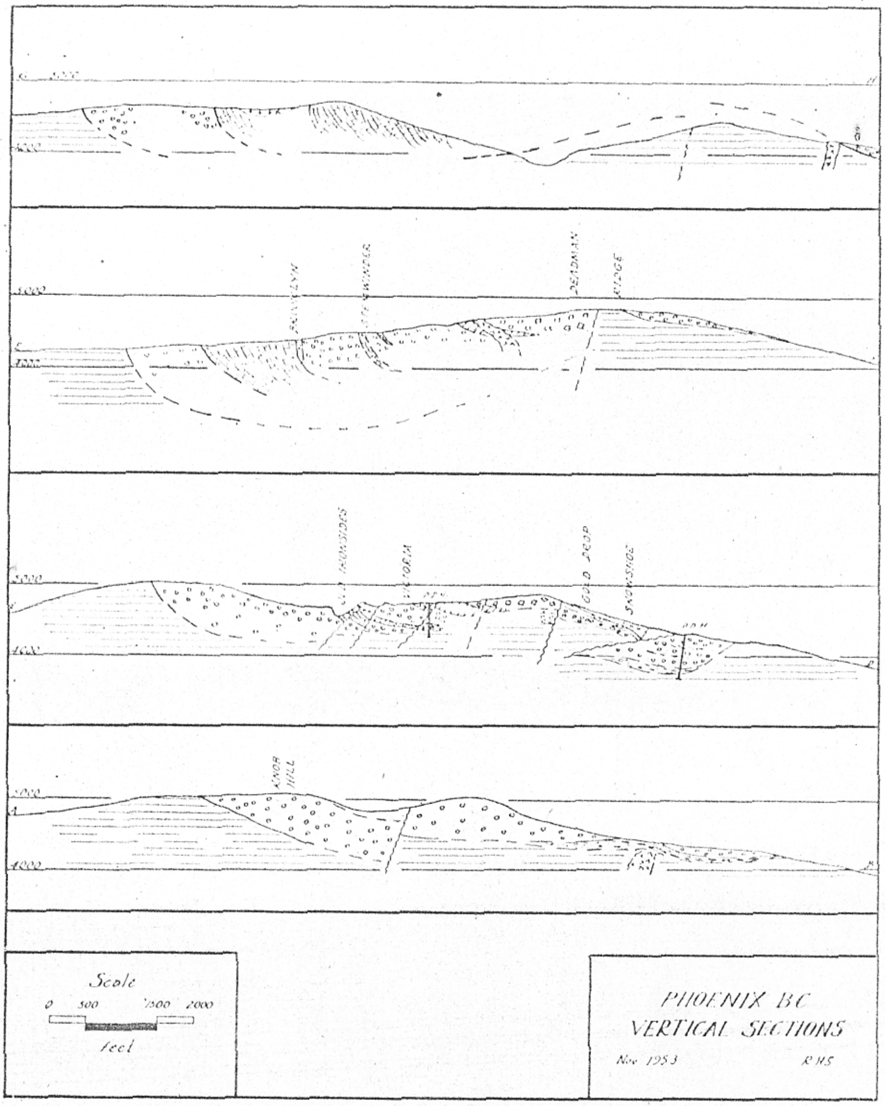

Figure 2.

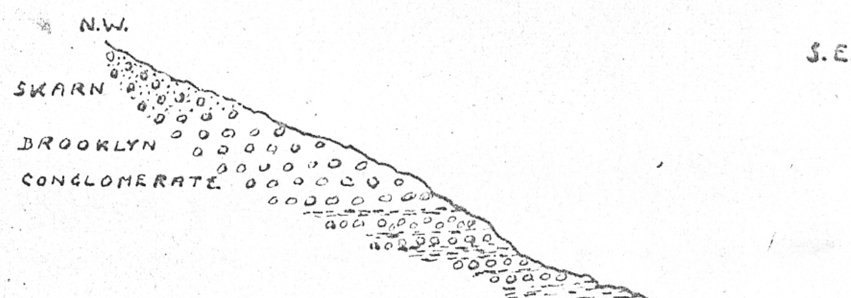

Figure 3.—Section of Rawhide Shale along West Kootenay Power Line.

One small exposure contained truncated symmetrical ripple mark, 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 stratigraphically.

The Rawhide shale lenses out to the southwest and is not found beyond the Gilt Edge workings. Toward 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 fern-like frond.

The Rawhide formation, then, is a lens of shale lying below and

Snowshoe, and Victoria mines. One of these intrusives is cut by quartz-chalcopyrite veinlets in the Stemwinder. The dykes in the Stemwinder mine and in the old railway grade near the Snowshoe mine bear an abundance of disseminated pyrite, but little or no disseminated 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 5,000 feet 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 area 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 says "the Tertiary sedimentary and igneous rocks are younger than the ore deposits . . .", but he 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 sulphides were found — thus the only definite conclusion 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 rock in 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 Oro Denora mine at least, the age of the orebody is Jura-Cretaceous.

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 hanging-wall, 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 severely 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 were deposited in 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 that were 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 the Oro 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 of the largest, Phoenix, and the smallest, the B.C., are close to Jura-Cretaceous 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 to 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

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 feet thick at maximum, of limestone breccia or angular conglomerate called the Stemwinder limestone. As discussed above, this rock may be either sedimentary or a 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 in diameter from a few millimeters to about one foot, and sparse chert fragments ranging in diameter from a few millimeters to about one inch. 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 close packing 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 fifteen hundred feet 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 claims, near Denora townsite in the B.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 two 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 Oro Denora and Emma mines south of Eholt. The relation of these stocks to mineralization is discussed later.

TERTIARY

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 millimeters to fifty feet thick. The thin beds are shale and the thick beds are cross-bedded conglomerates. 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 1,000 feet south to 3,000 feet 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 feet thick and dips easterly at about 50 degrees. Some 1,500 feet east, on the east limit of the north-plunging Tertiary basin, the Brooklyn formation is directly overlain by the post-arkose Midway Volcanics. Underground workings indicate that the arkose flattens and lenses out about 1,000 feet down dip (see Figure 1 and Section C-D Figure 2).

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 basins 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 feet southeast of Victoria shaft. Flow banding was observed in only one outcrop, about 1,000 feet 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, which they thus probably fed. 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 the B.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 'phasy' content of magnetic minerals, making it very difficult to prospect beneath them with magnetic geophysical methods.

STRUCTURE

Knob Hill Formation

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 north-westerly 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 Gold Drop workings, along the old railway grade now used as a road, a few tens of feet 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 the 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 Gold Drop 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; southeast 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 found in 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 the Brooklyn 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 the 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 indicates shallow marine deposition. (A suite of fossils including *Spirifer* (*Spiriferina*), *Terebratula?*, and some pelecepods, was found in the limestone. Since the material is not very diagnostic no correlation was made. A late Palaeozoic or Triassic age was proposed).

Detailed mapping of surface and accessible underground workings, followed by diamond drilling, 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 feet (see Figure 1). These rocks, including the replacement of the limy lens which forms the orebody, dip from 45° to 70° easterly at the surface exposures. Yet, 200 feet below surface, the orebody and the banding in it — which is, with little doubt, original bedding — dip only 10° or 15° easterly.

One thousand feet down the dip the orebody is approximately flat, and the 2,500 feet 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 feet 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 feet. Thus, 2,000 feet 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 of scour and fill were noted, but only one or two exposures show cross-bedding.

The structural evidence, in conjunction with the lithological 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 limy 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 feet 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 Jura-Cretaceous diorite or quartz diorite stocks were found within two miles of Phoenix. Only three dioritic dykes, a few tens of feet thick, were found, one in each of the Stemwinder, 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.

Drilling by Attwood Copper Mines has shown that some remnants of the Knob Hill, etc., orebody remain on the northeast end of the body, about 300 feet 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 the Granby Company. 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 hanging-wall Brooklyn rocks.

Brooklyn-Idaho

The Brooklyn-Idaho workings are on a mineralized zone parallel to Knob-Hill, etc., and about 1,000 feet to the west. The zone follows the hanging-wall 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 feet. Most of the Idaho end of the zone was too low grade to mine. The ore zone pinched out at about 250 feet depth where the limestone footwall apparently flattened markedly from a dip of about 70 degrees easterly (at outcrop) to about 20 degrees. As noted above, the Granby body had a similar flattening downdip. Termination on the north can be observed on surface where the zone pinches gradually to one foot 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 degrees 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 of ore were produced from an orebody 1,250 feet long, up to 550 feet thick, and extending to 500 feet depth on the Motherlode claim. The body lies on the contact of fairly pure limestone 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 claim, in a drift-covered area south of the Motherlode-Sunset group, a magnetometer survey disclosed large and strong 'aomalies'. Bulldozer stripping to 15 feet depth failed to find bedrock but exposed many boulders well mineralized with magnetite and chalcopyrite. Subsequent diamond drilling reached bed-rock, Knob Hill chert, at 80 feet 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 of ore.

The Ora Denora production was chiefly from four or five open pits bounded by fault planes, Tertiary dykes, and the diorite stock. The bedding in limestone is transected by a diorite stock. 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 is parallel to the original bedding and strikes northerly. The orebody was a lens several hundred feet long and up to 25 feet 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. Syenite dykes 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 a geophysical and biogeochemical survey. 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 has produced important quantities of ore.

Bibliography

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and all underlying rocks. The location of the Tertiary basins shows that the topography has changed markedly since Tertiary time. The Tertiary basins are found on what are now ridges. Erosion from Tertiary to Recent time has cut valleys as much as 2,000 feet 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 degrees to the east. Evidence for this tilting comes from the attitude of the arkose beds, which dip up to 45 degrees 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 degrees, and a probable 10 to 20 degrees. Thus the area has been tilted easterly about 30 degrees 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 degrees toward 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 toward the south, as indicated by the following:

(1) The main band of Brooklyn limestone, with nimor shale, grades toward the south into limy shale and greywacke, which in turn finger out into siltstone and conglomerate showing scour and fill.

(2) The Rawhide shale, on the southeast border of the trough, shows ripple mark.

(3) The conglomerates on the southwest 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, the Brooklyn sediments now dip and gently roll at 20 to 30 degrees 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 degrees 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 degrees toward the axial plane. The Monarch-Rawhide-Gold Drop-Snowshoe orebody was almost horizontal. The Brooklyn-Idaho orebody dipped about 45 degrees easterly, and, if the regional tilt extended to Deadwood, the Mother Lode dipped about 30 degrees easterly.

INDIVIDUAL DEPOSITS

Granby-Knob Hill-Ironsides-Victoria, Etc.

The Knob Hill-Ironsides-Victoria orebody produced about 11,000,000 tons, or 50 per cent, of the copper ore mined in the Boundary area. The skarn enveloping the ore extends 3,000 feet from Phoenix townsite south to the War Eagle and Grey Eagle workings, thence arcs to the east through the Monarch, and from there northeast and north through the Curlew and Gold Drop to the Snowshoe. Production from the War Eagle and Grey Eagle was negligible. A few tens of thousands of tons of ore 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 degrees near surface, but flattens to 10 or 15 degrees a few hundred feet down dip. This western limb follows a ridge (Knob hill) which, at the base of the *'U'*, or the 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 degrees, 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 and thus, on lithological correlation, would be basal to the ore zone. The drilling to 600 feet 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 feet plus of Brooklyn formation 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 600 feet west of the faults, and the deep drill hole is 600 feet east of them. (Knob Hill formation outcrops 2,000 feet east of the faults) (see Figure 1 and Sections, Figure 2). 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, 2,000 feet long, up to 150 feet wide, and continuing for about 1,500 feet down dip. Two outcropping orebodies, each about 75 feet thick, coalesced about 200 feet 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 hanging-wall 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, though by a small fault, with barren limestone on strike of the ore zone on the north end of the Victoria No. 2 level workings (now inaccessible). Diamond drilling indicates that this 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 2,000 feet of conglomerate is a large limestone lens, up to two thousand feet wide and about one mile long (see Figure 1). This lens is postulated as an unreplaced remnant by LeRoy. Lying conformably above the limestone is another 1,500 to 2,000 feet 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 jasperoid in contact with the chert of the latter. 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.

"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 jasperiod 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.

"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 diameter. 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 tufts 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. . . Jasperoids, 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 deep-seated 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 reworking 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 an area a few feet in diameter there 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 a few feet thick, and fine and coarse fragmental beds up to a few hundreds 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 Figure 4).

(3).—Several outcrops containing interbedded fragmental rock and siltstone or shaly 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 smoky-grey chert fragments, well sorted, and metamorphosed 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.

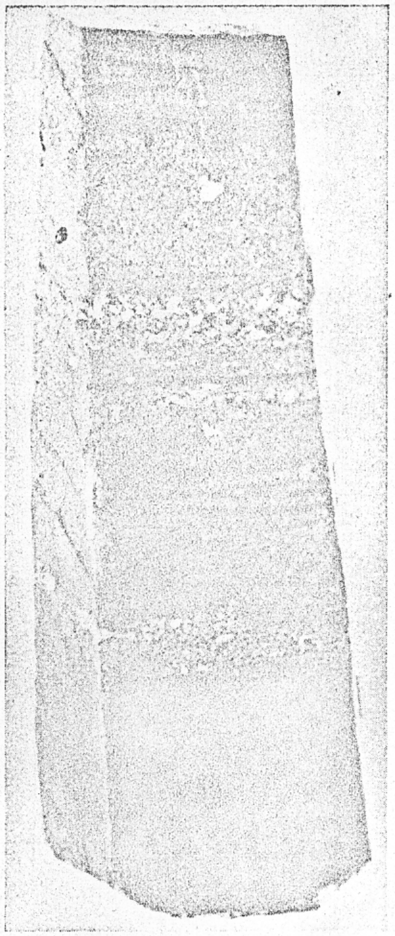

Figure 4.—Bedded Brooklyn conglomerate from footwall of Old Ironsides open pit.

One type of fragmental bed, associated with some of the limestone, is unusual. The rock, termed 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 rounded, frosted, white to light-grey chert fragments of one-eighth to one-quarter inch in diameter in a limestone 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. The 'dumbell' forms mentioned by LeRoy were not observed by the writer. Those which LeRoy noted 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 limestone 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 Figure 1). The individuals are rounded to subangular, and have sharp contacts with the encompassing fragmental chert rock. The writer believes that the limestone 'remnants' are actually pebbles and boulders 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 geological 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 feet. 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 of the Idaho. Unfortunately, the northern termination is drift-covered. The limestone has an apparent thickness of 1,500 feet where it goes under the drift. Beyond the drift-covered area, 2,000 feet farther north, the outcrops are Knob Hill formation. The southern termination, near 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 2,000 feet to near the West Kootenay Power Line (away from the 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 intercalated with and grade into fine-pebble sharpstone conglomerate.