CIM

GEOLOGY AND ORE DEPOSITS

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# Western Mines— Myra, Lynx and Price deposits

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## ABSTRACT

*Western Mines Limited produces gold, silver, copper, lead and zinc from a number of Paleozoic volcanogenic deposits near Buttle Lake on Vancouver Island. The deposits were emplaced along a series of submarine linear volcanic ridges that extended for at least 6,000 metres in a northwesterly direction.*

*Rock types mapped include: andesitic, dacitic and rhyolitic flows and volcanic breccias; detrital breccias, tuffs and hematitic silts; black and green cherts; and a variety of dykes and sills, including quartz porphyry and diorite. Orebodies are associated invariably, and in places intimately, with quartz-sericite schist and rhyolitic rocks. The ore is complex, varying in mineralogy and tenor both within each deposit and from one deposit to another.*

*Recent studies have increased our knowledge of the structure and left no doubt that the orebodies were deposited both within the throats of the linear vents and on paleoslopes adjacent to these vents.*

### R.H. Seraphim

R.H. (Bob) Seraphim, a native British Columbian, received his Ph.D. from the Massachusetts Institute of Technology in 1950 and has explored for new mines in the Cordillera almost continually since then. He was instrumental in determining the geology of the Phoenix Mine, leading to its reopening, and he instigated and supervised the initial exploration on Newmont's Ingerbelle (Similkameen) mine at Princeton. He worked for many years for Highland-Bell and affiliated companies, and as western representative for Moneta Porcupine Mines Ltd. prior to 1966. He has been a consulting engineer, based in Vancouver, since then, and is a member of the CIM, SEG, GAC, AIME and the Professional Engineers of B.C.

Dr. Seraphim is a CIM Councillor (1979-81) for District 6. A few years ago, he instigated the compilation of and served on the editorial committee for CIM Special Volume No. 15, "Porphyry Deposits of the Canadian Cordillera."

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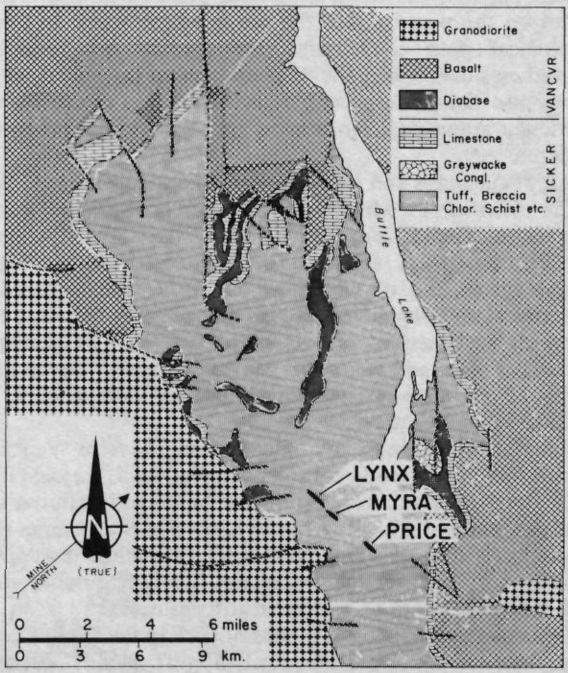
## Introduction

Western Mines Limited operates an 850-tonne-per-day mine, located 85 km south of Campbell River, B.C. The mine is at approximately 400 metres elevation, near the south end of Buttle Lake on Vancouver Island (Fig. 1). It has operated since early 1967 and produced 3,650,000 tonnes with an average grade of 1.9 g (0.06 oz) gold, 93 g (3.0 oz) silver, 1.6 per cent copper, 1.0 per cent lead and 7.5 per cent zinc per tonne by the end of 1978. Current reserves are 1,157,000 tonnes of 2.7 g (0.09 oz) gold, 117 g (3.8 oz) silver, 1.2 per cent copper, 1.2 per cent lead and 8.0 per cent zinc per tonne (December 31, 1978).

ORE

Ore from one zone, known as Myra High-Grade, is mined and milled separately because of its grade. Ore milled prior to December 31, 1978, plus reserves, 180,715 tonnes of 6.6 g (0.21 oz) gold, 554.5 g (17.7 oz) silver, 0.8 per cent copper, 3.2 per



REGIONAL GEOLOGY OF BUTTLE LAKE AREA

– ADAPTED FROM GEOL. SURV. CAN. MAP 2, 1965

**FIGURE 1. The Lynx, Myra and Price eruptive centres or vent zones occur in the Middle Myra Formation of the Sicker rocks. The overlying rocks do not reflect the trend of the zones, except in their immediate vicinity.**

MASSIVE SULPHIDE

WESTMIN - Myra
Lynx
Price

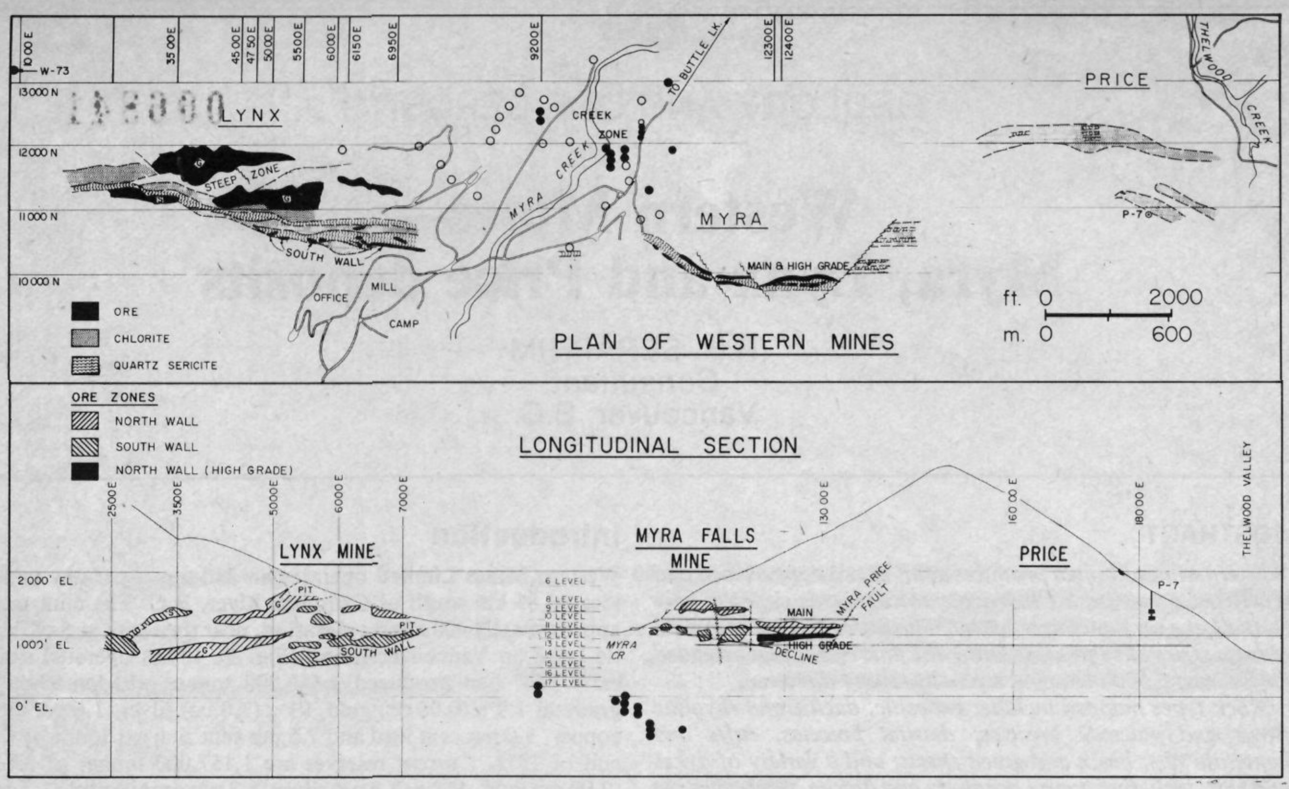


**FIGURE 2. Diamond drilling in Myra Creek Valley indicates continuity between Lynx and Myra vent zones, but the Price is believed to be a separate zone. Price has yielded some drill intercepts of ore grade, but no production to date.**

cent lead and 10.6 per cent zinc are included in the figures listed in the preceding paragraphs.

This paper is the result of several years of intensive study based on the premise that the ore is volcanogenic in origin. Geological data re-affirming the premise are described. Hypotheses concerning the emplacement of the numerous ore zones and thier subsequent deformation are discussed with particular attention given to structure, but without laboratory research.

All of the maps and sections presented herein except Figure 1, are oriented to "Mine North", which is 48 degrees east of true north. The sections look toward "Mine West", which is actually northwest (Figure 1). The status of geological knowledge is that of December 31, 1977, and is based on methodical and objective mapping compiled by the mine staff on plans and sections at 1 inch to 20 feet. (The geological legend for plans and sections is shown on Fig. 9.) The location of the 'Creek Zone', becoming important late in 1979, has been added on Figure 1.

The staff at Buttle Lake originally used the term 'Vent Formation' for the 'chaotic zone' as desribed by J. Lajoie (1977) in his description of stratigraphy associated with eruptive centres. The plans and sections of the Lynx and Myra mines (Fig. 2) disclose, however, that the 'Vent Formation' contains a complex of cross-cutting intrusions, uncomformable strata and alteration zones as well as stratiform rocks.

Some of the least altered bodies of rock in the 'Vent Formation' were, in mine parlance, called 'tuff islands'. Belts of schistosity, differing from place to place in width, intensity and dip, occur between the 'tuff islands'. These belts were mapped as quartz-sericite and/or quartz-chlorite schist. Their structure remains a subject for further study. Bodies of rhyolite, in some places massive and in other places breccia, are interspersed with the 'tuff islands' and schistose belts, particularly on the north flank of the 'Vent Formation'. Three rhyolite strata in the Lynx Mine ('G', 'G Hanging Wall' and 'G Footwall'), each with associated sulphide mineralization, and one or more flows with abundant epidote and chlorite, were used as markers on the north flank of the 'Vent Formation'.

A number of mineralized bodies, diverse in shape, size and mineralogy, but conformable with schistosity in the steeply dipping schistose belt or belts forming the 'South Wall' of the 'Vent Formation', made the south flank particularly complex. The best markers would be orebodies if they could be identified as stratiform.

One steeply dipping tabular mineralized zone in the Myra Mine had been recognized to display the characteristics of a volcanic vent, and was named the 'fumarole?'.

Geologists experienced in volcanogenic mineral deposits deduce that rhyolitic masses, whether flow or breccia, and spatially associated mineralization, emanate from or remain within a volcanic vent (Spence and de Rosen-Spence, 1975; Larson and Webber, 1977; Turner and Gustafson, 1978; Ohmoto, 1977). This deduction is accepted in the following text.

Chaotic zones at Buttle Lake include the Lynx, Myra and Price belts of pyritic quartz-sericite schist and several tens of spatially closely associated orebodies, diverse in mineralogy, size and configuration. At least several rhyolite bodies with associated ore-type sulphides and with apices laterally and vertically separate from the three above-mentioned rhyolite strata can be observed in the Lynx open pit. Each rhyolite stratum or rhyolite body with a separate apex is deduced to emanate from either a separate part of a vent or from a separate vent. Consequently, the author deduces that a number of separate or subsidiary vents and/or a series of stratigraphically higher apices of one or more vents existed within the chaotic zones. A number of these vents are believed to be obscured in varying degrees by subsequent development of schistosity. Therefore, in keeping with the mine term 'Vent Formation', the parts of the chaotic zones at Buttle Lake that include (1) steeply-

**FIGURE 3. A variety of breccias characterize the chaotic zone near the eruptive centres.**

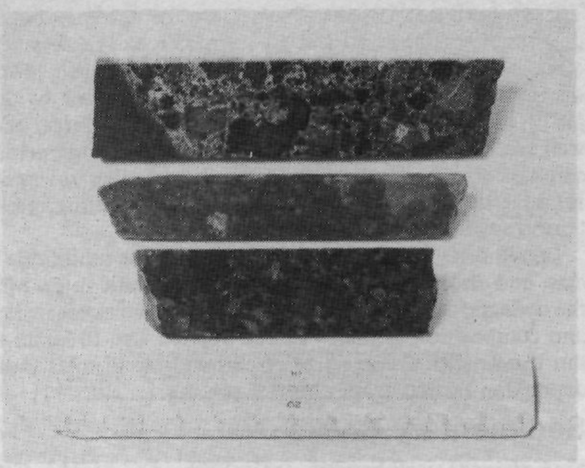


**FIGURE 3(a). The uppermost core is 'purple and green' multilithic breccia with jasper and rhyolite fragments in a matrix with abundant chlorite and epidote. This type is found some tens of metres above or flanking the eruptive centres. The middle core is ore from 'G' zone, and consists of fragments of grey porphyritic rhyolite breccia in a matrix of ore sulphide (clasts are monolithic). The lowest core is multilithic breccia with clasts of rhyolite porphyry, dark green andesite or dacite porphyry and also clasts of ore sulphides in a pale green (epidote-rich?) matrix. The scale is 15 cm (6 in.) long.**

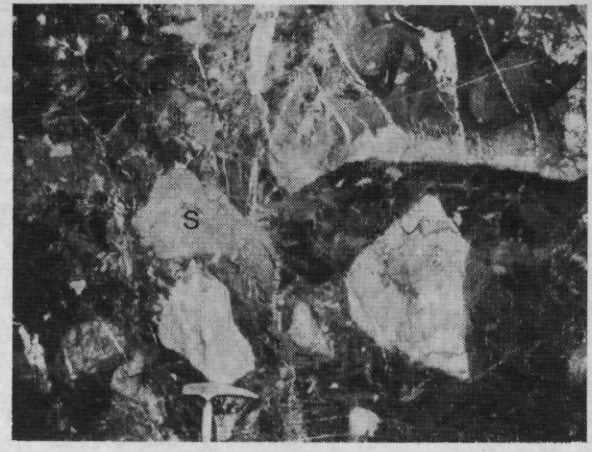


**FIGURE 3(b). This multilithic breccia includes clasts (cobbles?) of rhyolite and of massive sulphide(s). The photograph is taken underground approximately 10 metres in the footwall of 'G' zone. (The head of the geologist's hammer provides scale.)**

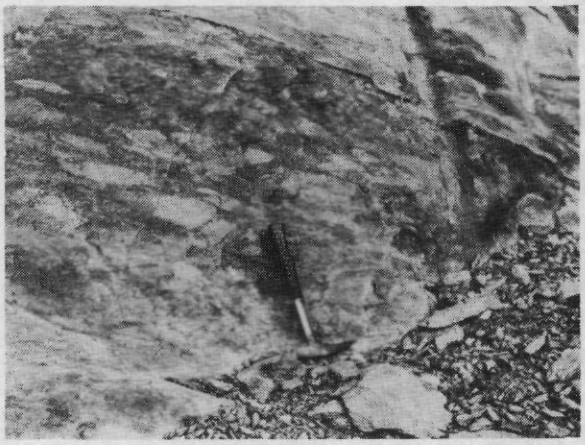


**FIGURE 3(c). Monolithic breccia consisting of clasts of sericitized rhyolite? in a sericitic and pyritic matrix, found a few tens of metres south of 'G' zone. The long axes are parallel to the dip of 'G' zone. Similar rock in Precambrian volcanogenic deposits has been called 'mill rock' (Lajoie, 1977).**

dipping belts of pyritic quartz-sericite and quartz-sericite schist, (2) pyritized, rhyolite (monolithic)* breccias with large clasts, (3) the apices of rhyolite flows or other rhyolite bodies and (4) orebodies are called vent zones in the following description and discussion.

The difference in interpretation of structure and stratigraphy from that described by Muller and others (in press) also is discussed.

## Regional Setting

The Lynx, Myra Falls and Price mineralized zones lie in predominantly volcanic rocks of the Middle Myra Formation (Ordovician?) of the Sicker Group (Fig. 1) (Gunning, 1930; Muller, 1980).

Northwesterly trending piles of submarine calcalkalic volcanic rocks composed of andesite, diabase, dacite and rhyolite are accompanied in the mine area by belts of schistosity, faulting, alteration and mineralization. The vent zones with abundant silicification, quartz-chlorite and sericite schist, coarse rhyolite breccia and steeply dipping sulphide bodies (Fig. 2) described above are believed to be lineal eruption centres similar to those described by Lajoie (1977).

The vent zones are overlain and flanked by: dacitic and andesitic flows; breccias composed mostly of volcanic fragments; tuffs and cherts; and finally limestone and chert of the Buttle Lake Formation. This sequence of Sicker Group rocks is overlain by submarine tholeiitic volcanic rocks of the Triassic Karmutsen Formation.

## Rock Types

### Volcanic Sequence

The dacitic, andesitic and diabasic rocks are predominantly green, and composed of augite, andesine feldspar and quartz, with accessory magnetite and apatite. Mafic minerals are uralitized and feldspars are albitized. Most of the rocks are multilithic** volcanic breccia (epiclastic) and tuff, but some of the coarser-grained rocks are dykes, sills and flows. Some of the rocks may be aquagene flows (with fragments similar in composition to their matrix). Dacitic and diabasic rocks, most prevalent above the sequence containing the rhyolite bodies and ore zones, are predominantly altered, with the development of epidote and chlorite.

Dacitic volcanic rocks are abundant in the mine workings. The rocks are predominantly light green to grey green, mostly aphanitic to finely prophyritic and in places brecciated. Brecciation is more prominant near flow tops.

The term "rhyolite", as used at the mine, includes a variety of rock types, some of which are probably primary in origin and others a product of alteration. Much of the pale cream to grey-coloured rock that may have been rhyolite, dacite or andesite is altered to quartz-sericite schist. Quartz "eyes" and feldspar phenocrysts are observed, some in small exposures of "porphyry" and some in clasts in multilithic breccias. Some rhyolite flows, particularly those such as the "G" flow on the north flank of the Lynx vent zone, where schistosity is less predominant, display brecciation with cream-coloured rhyolite fragments in a grey matrix that is locally abundant in sulphide.

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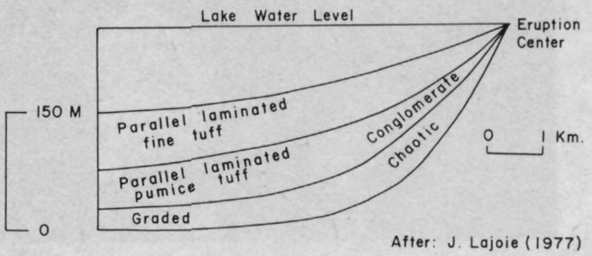
* Breccias comprised of one type of rock fragment.

**Breccias comprised of a number of types of rock fragments.

## Clastic Sequence

The termination of volcanism and the beginning of erosion and sedimentation in the mine area are recognized as overlapping processes. Consequently, the boundary between epiclastic and volcaniclastic rocks is not clear. Although multilithic breccias (Fig. 3a) may be formed by "pick-up" of detrital or ejected fragments on the bottom or top of flows, the author prefers to classify most multilithic breccias at Buttle Lake as volcaniclastic and/or sedimentary and believes them to be formed by the mixing of clasts from several volcanic sources. These multilithic breccias have clasts of many sizes, many degrees of sorting and great diversity of rock type. Some have clasts of sulphide as large as 50 cm in diameter (Fig. 3b). The distribution of clasts is very like that described by Lajoie (1977) in that those proximal to vents tend to be larger and less well sorted (Fig. 4). The presence of rhyolitic fragments and sulphide clasts at Buttle Lake (as well as in other volcanogenic sulphide deposits) indicates that an area of venting merits intensive exploration (Sangster, 1972).



After: J. Lajoie (1977)

**FIGURE 4. The stratigraphy at Buttle Lake conforms closely to that presented above, but the conglomerate is called multilithic breccia in mine terminology. The rocks in the chaotic zone at the mine also contain abundant monolithic (rhyolite or dacite) breccia, usually found closer to the eruptive centres and ore zones.**

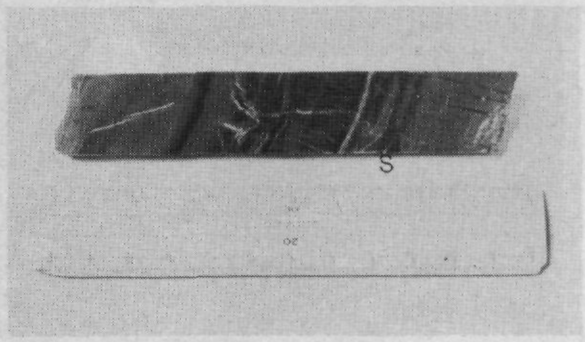


**FIGURE 5. 'Sharp banded' tuffs. The core is milky green interbedded tuff and chert with a sulphide band (S). Some cores with similar banding contain hematitic chert (jasper).**

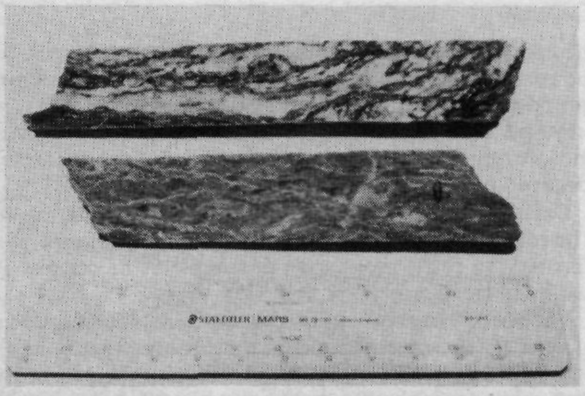


**FIGURE 6. The upper core is quartz-chlorite schist with white quartz and carbonate veining in green chlorite. The core is from a very old Price vertical hole which obviously was drilled parallel to the vent zone structure. The lower core is quartz-sericite schist with tan-coloured sericite and/or talc, and cream-coloured quartz, also from a vertical hole in the Price vent zone and drilled parallel to the structure.**

Lapilli tuffs are found intercalated with the multilithic breccias, and also with the fine-grained to aphanitic tuffs. Most of the deductions applied to the multilithic breccias regarding size and composition of clasts can be applied also to lapilli tuffs, but the smaller average size of clasts in lapilli tuffs indicates deposition farther from areas of venting.

## Sedimentary Rocks

Fine-grained, well-banded tuffs (Fig. 5), named "sharp-banded" tuffs are distributed even farther from the vents. These tuffs locally contain thin bands of pale green chert, and also pyrite bands up to a few centimetres thick, as in the Delbridge deposit (Boldy, 1968, p. 1045). Some strata mapped as chert are very similar in appearance to flow-banded glassy rhyolite. Bands of hematitic chert (jasper) are found stratigraphically above the bands containing sulphide; hematite and sulphides are generally mutually exclusive. Black carbonaceous chert or graphitic siltstone, classified as argillite in some of the mine records, and perhaps grading into argillite in places, has been found at several locations.

## Intrusions

Quartz-eye porphyry has been observed in several localities and, like rhyolite, may also be an altered predecessor of some of the quartz-sericite schist. The author did not outline individual quartz-eye porphyry bodies at the mine. Some of these bodies may be metasomatic rather than intrusive. (Carvalho, p.67, 1979).

A body of Jura-Cretaceous granitic-textured intrusive rock, identified as quartz diorite (Jeffery, 1946), outcrops approximately 2 kilometres west of the Lynx mine, and a dyke of similar rock is exposed in the western part of that mine.

## Alteration

Silicious, sericitic and chloritic rocks (Fig. 6) are widespread near areas deduced to be vents. Pyrite is abundant in most of the zones that contain quartz veinlets or quartz-sericite schist. Some rhyolite flows, particularly near their tops, contain abundant quartz, sericite and pyrite; distinguishing the alteration associated with such flow tops from that associated with their deduced vents may be subjective. Alteration appears to follow the configuration postulated by Sangster *(op. cit.)* and described by Roberts and Reardon (1978), with quartz, sericite and pyrite being particularly abundant within a few tens of metres of the apices of deduced vents, and chlorite being abundant both at depth and as broad haloes around the pyritized quartz-sericite rocks.

Some of the rocks mapped as "chlorite schist" are only weakly schistose, with ghosts of clasts evident in places. Consequently, depending on the decision at the time, rock might be mapped as either "chlorite schist" or breccia (Fig. 7).

"Carbonatization, chloritization and epidotization occurred contemporaneously, and were the dominant processes involved in propylitic alteration of the mafic and mafic-intermediate rocks of both hanging and footwalls. The alteration was apparently not related to the ore-forming processes. Rather, it resulted from burial metamorphism of these mafic and mafic-intermediate volcanic rocks and associated subvolcanic rocks, including gabbro-diabase sills and dykes" (Carvalho, *op. cit.)*.

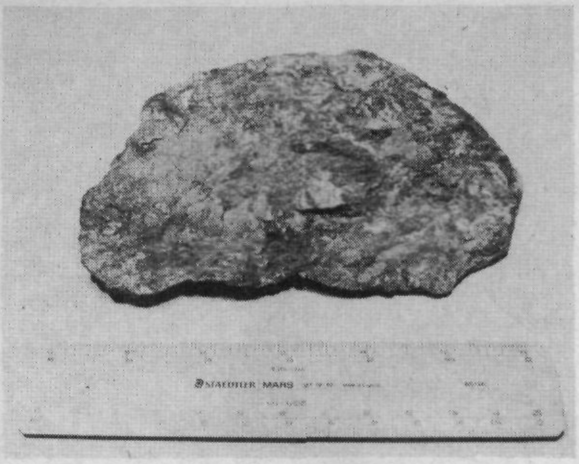


FIGURE 7. A flat piece of schistose rock, from the Price Zone, which could be called either quartz-chlorite schist or, because of the deformed ghosts of clasts of rhyolite and dacite (pale grey), a schistose multilithic breccia. Clasts are not determinable on the other face of the specimen.

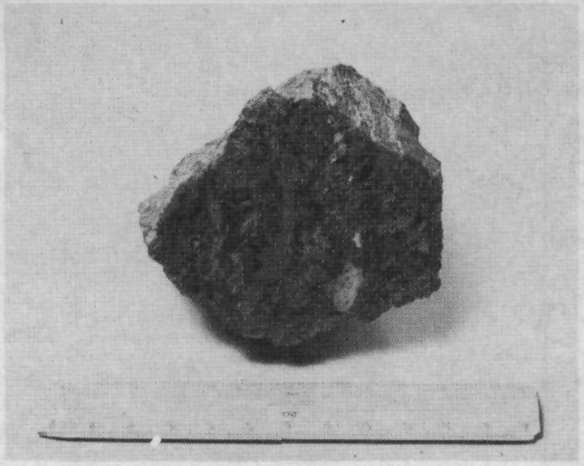


FIGURE 8(a). Ore from Myra vent as shown in Figure 21. Bands of chalcopyrite (medium grey in the photograph) and sphalerite (dark grey) swirl around fragments that are talc and/or sericite.

## Mineralization

Valuable sulphides include sphalerite, chalcopyrite, galena and tetrahedrite-tennantite with minor bornite and covellite. Native gold, native silver and electrum are present. The gold and silver content recently became more valuable than the zinc content of the ore. Pyrite, barite and minor pyrrhotite are abundant locally. Quartz, sericite and chlorite are found interspersed within some orebodies. Caravalho *(op. cit.)* describes the mineral assemblages as follows:

"As early as 1970, Horikoshi and Sato (1970) divided the Tertiary Kuroko deposits of Japan into six distinct mineral assemblages. Five of these are analogous to the sulphide assemblages described in the Western Mines district. The six assemblages are: (a) basal stringer pyrite-chalcopyrite, called Keiko ore, analogous to the vent assemblage described at Western Mines; (b) massive pyrite or Ryukako ore, analogous to the massive pyrite at Western Mines, but seldom present in the vent zone; (c) massive pyrite-chalcopyrite or Oko ore, comparable to the massive yellow ore at Western Mines, and common in the vent zone; (d) banded to weakly banded galena-sphalerite-pyrite, called Kuroko ore, comparable to the massive black ore at Western Mines; this occurs in both flank and vent environments and contains minor or trace amounts of barite, rarely exceeding three percent; (e) monomineralic barite, comparable to the massive barite of Western Mines, where it occurs only in the flank zone; (f) finally, an upper zone of fine-grained hematitic chert and variable pyrite not reported in the Western Mines district, although hematite-pyrite-bearing, red chert fragments are occasionally observed in both distal and proximal facies of the Tuff Unit."

Bands of hematitic chert (jasper), apparently not observed by Carvalho, were logged by the author in holes drilled distally and stratigraphically higher in the section; therefore all of the six mineral assemblages found in Kuroko deposits are represented by those found at Western Mines.

Distinguishing between ore believed to have been emplaced within a vent from stratiform exhaled ore aids in effective planning and exploration development of a particular mineralized body; thus, criteria related to these modes of emplacement were studied in detail. Although stratiform ore in many volcanogenic deposits is shown to contain a higher proportion of grey and black sulphide (kuroko) relative to yellow sulphide (oko) (Ishihara *et al.*, 1974; Sangster, 1972), this relationship is not clear in the Buttle Lake deposits. The relative abundance of the ore minerals does change markedly

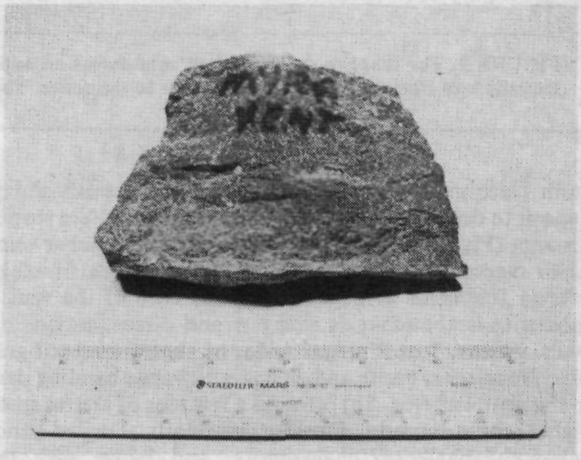


FIGURE 8(b). Ore from Myra main vent as shown in Figure 21. Sugary grains of sphalerite, barite and galena are vaguely banded in a zone a metre wide along a wall of the vent several tens of metres below its apex.

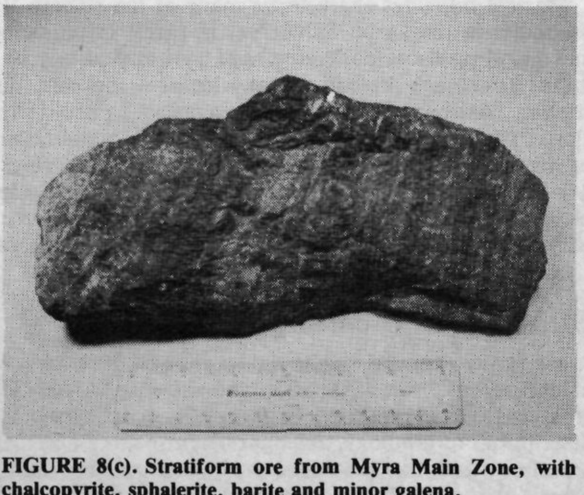


FIGURE 8(c). Stratiform ore from Myra Main Zone, with chalcopyrite, sphalerite, barite and minor galena.

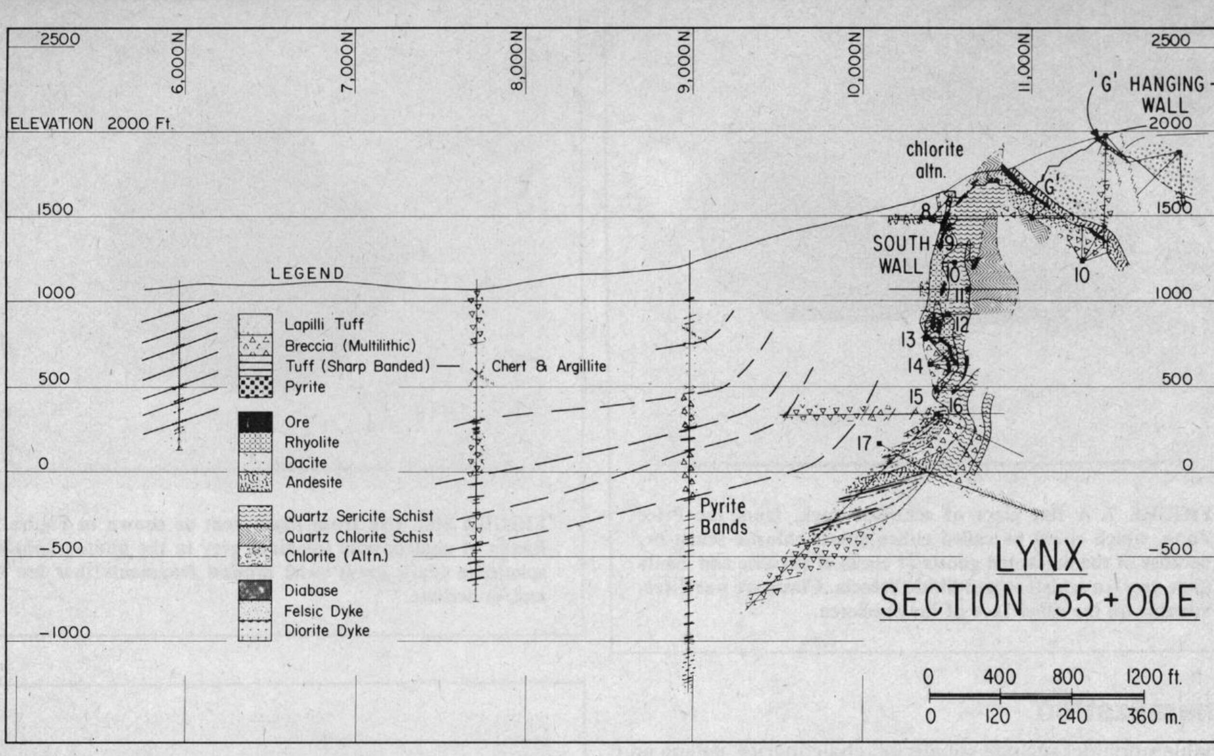


**FIGURE 9. The eruptive centre or vent zone forms an anticlinal-like structure with flows and coarse breccias near the core grading laterally into fine-grained tuffs a kilometre to the south. The legend shown applies to most of the following figures.**

from place to place both within a specific deposit and from deposit to deposit. However, in the Main Myra Vent stope, for instance (Fig. 2, 8a, 21), chalcopyrite predominates as veinlets, small masses and disseminations in the matrix of schistose breccia fragments at depth within the core of the vent, and sphalerite is abundant as stringers and disseminations on its walls. A lens, 1 or 2 metres wide, of sugary-textured grey to black sphalerite, barite and galena with vague banding parallel to the vent wall (Fig. 8b) is found a few tens of metres spatially higher within the vent. Fine but irregularly shingled bands of pale-grey sphalerite, chalcopyrite, and pyrite with minor galena (Fig. 8c) are deposited as stratiform orebodies several metres thick near the vent apex and extending 120 to 130 metres down the north flank of this vent. The vent and flanking bodies of stratiform ore, described above, extend along strike for 350 metres. If the mineralized zones offset to the west (Fig. 2) are faulted parts of the same structure, then the Myra vent zone has a lateral extent of at least 900 metres.

Massive sulphides characterize many of the "South Wall" orebodies in the Lynx. Sphalerite, in places cream-coloured and in other places dark grey, and pyrite, chalcopyrite and minor galena are present in many lenses as delicate, but irregular, bands and in other lenses as matrix to ovoid rhyolite clasts. These sulphides are also disseminated in quartz-sericite or rhyolite in various parts of the 'G' and 'S' zones (Figs. 11, 24). Fine-grained pyrite is the principal constituent of sulphide bands, a few centimetres wide, interbedded with "sharp banded" tuffs 500 metres or more out on the north flank of the Lynx and Myra vent zones.

## Structure and Stratigraphy

A composite plan and longitudinal section of the known zones of mineralization and alteration and showing the location of cross sections is presented in Figure 2. As discussed in the descriptions of lithology, distinguishing rhyolite flows that are brecciated and foliated from the quartz-sericite schist and breccia that are believed to characterize the vents producing the rhyolite flows is difficult, unless the configuration of these flows and vents is known. The series of cross sections presented in Figures 9 (55 + 00E), 10 (60 + 00E), 11 (35 + 00E), 12 (45 + 00E), 13 (47 + 50E) and 14 (92 + 00E) illustrate the continuous change in configuration of the vent zone and associated strata along the trend of the volcanic pile, which is postulated to have formed as a submarine volcanic ridge.

## Lynx

At least three gently dipping rhyolite flows are identified on the north flank of the Lynx vent zone. These strata are called "G", "G Hanging Wall" and "G Footwall" (Fig. 12). "G" rhyolite has been explored in great detail because the associated sulphide ('G' Zone) is a major source of ore. Both "G Hanging Wall" and "G Footwall" rhyolite have associated mineralization, but none of sufficient tenor and bulk to constitute ore unless correlation is made with rhyolite strata in the Creek Zone (Fig. 2).

Figure 9 shows the rhyolitic flow with which "G" zone is associated. The rhyolite and quartz-sericite schist, hosting the cluster of orebodies on the south flank of the Lynx antiform, apex at approximately the same elevation and at intervals within a hundred metres to the south. This section displays a much greater than normal width of quartz-sericitic and chloritic rocks in the vent zone, and shows the greatest abundance of 'South-Wall' orebodies.

Although the "G" ore zone is not shown to extend to the same elevation as the "S" ore zone in Figure 11, it does so on sections farther to the east. In fact, the "G" Zone and the uppermost of the "South Wall" zones (of which "S" Zone is a member) formed a continuous or almost continuous antiform-type structure near sections 5500 to 6000 E (prior to open pitting), as shown in Figures 9 and 10.

Figure 11 shows the relation of the "S" zone, the only well-defined stratiform zone of rhyolite and ore on the south flank of the vent zone, to the "G Hanging Wall" zone. These two zones have apices at approximately the same elevation and appear to form structural mirror images of one another. The mine geologists postulate that the north flank of the vent zone

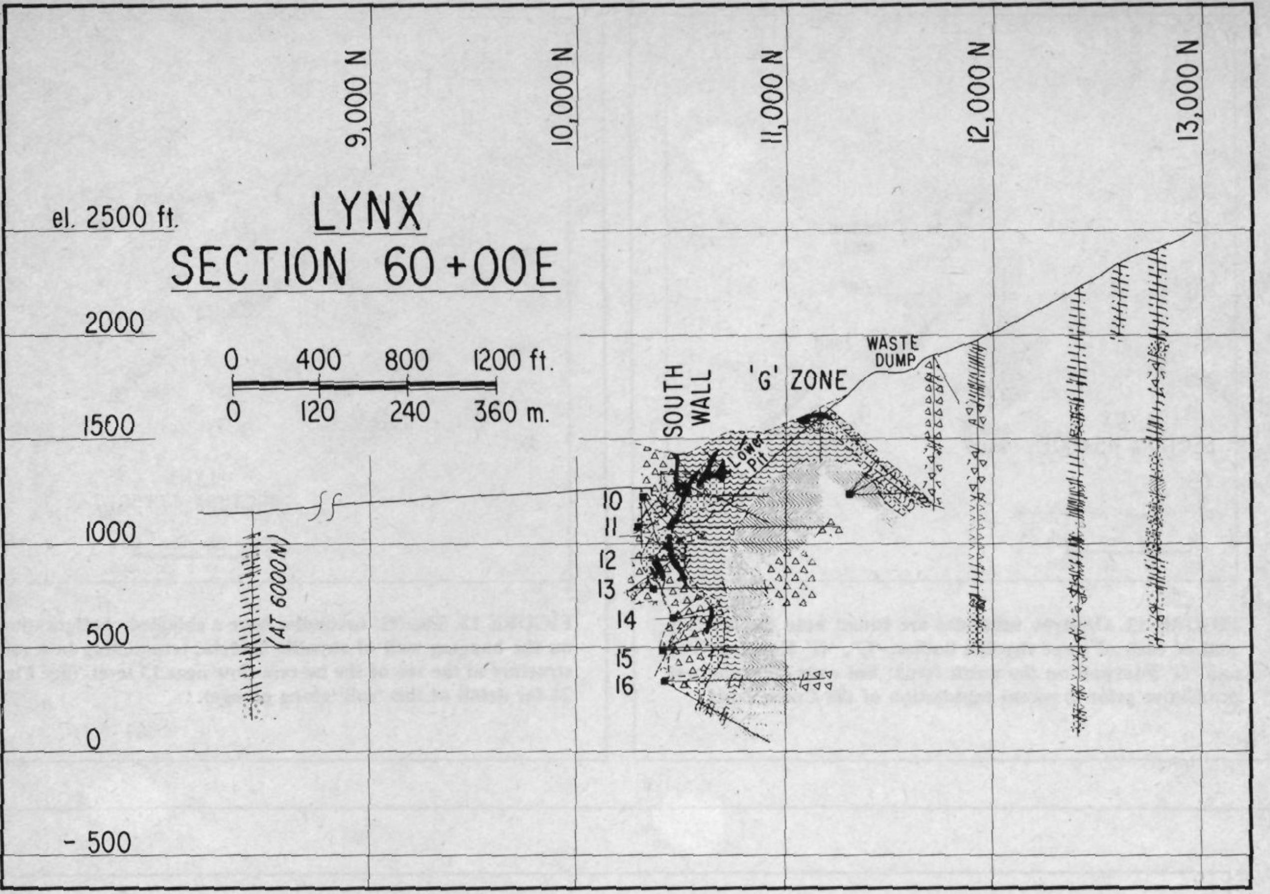


FIGURE 10. Similar to Figure 9, but showing north flank.

has been down-faulted approximately 200 metres, offsetting the "G" zone from the "S" zone. The author prefers the hypothesis that the "G" zone and the "S" zone remain in approximately the same relative locations as they were when originally emplaced.

The sections are based both on drill-hole information and on extrapolation and interpolation from exposures, including mine workings. The formations follow the regional northwesterly strike (i.e. mine east-west) in all exposures examined. However, most of the tuffaceous rocks on the north flank of the vent zone are observed to dip southerly, and in places are unconformable to north-dipping volcanic strata within the same outcrop. Also, the strata several hundred metres north of the vent zone (Fig. 14) contain more abundant and larger flows than those on the south flank. For these reasons, the writer concludes that the strata distal to and on the north flank of the Lynx, Myra and Price vent zones are interfingered in a trough, with some strata derived from sources north of the Lynx vent zone and some from the vent zone itself. Muller (in press) states: "The Myra Creek Formation and its strata-bound massive sulphide deposits has been folded into an asymmetrical, sharp-crested, northwest-striking fold with a shallow plunge", but the author prefers to interpret the major structure to have formed as a submarine volcanic ridge, with little subsequent deformation. Muller has identified soft-sediment 'load or sag structures' and states that 'convoluted slump structures are also fairly common' elsewhere in the Myra Formation. This might indicate that basin and ridge topography, i.e. abundant relief, existed at the time of deposition.

Strata within a few tens of metres south of the south flank of the Lynx vent zone are observed to dip much more steeply than those on the north flank. However, the south flank strata

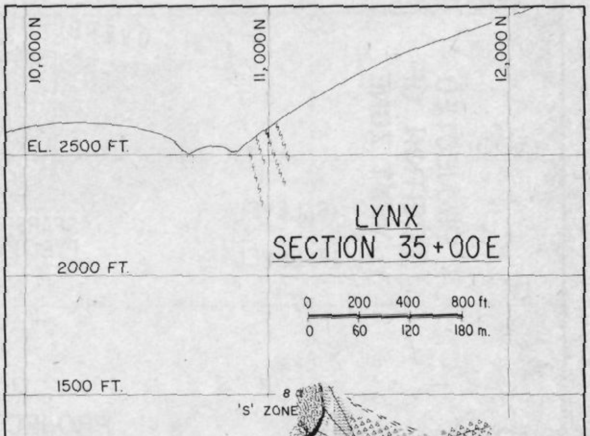


FIGURE 11. Showing the spatial relation of the lowest part of 'G' Zone to 'S' Zone. The latter was discovered recently as exploration continues to the west.

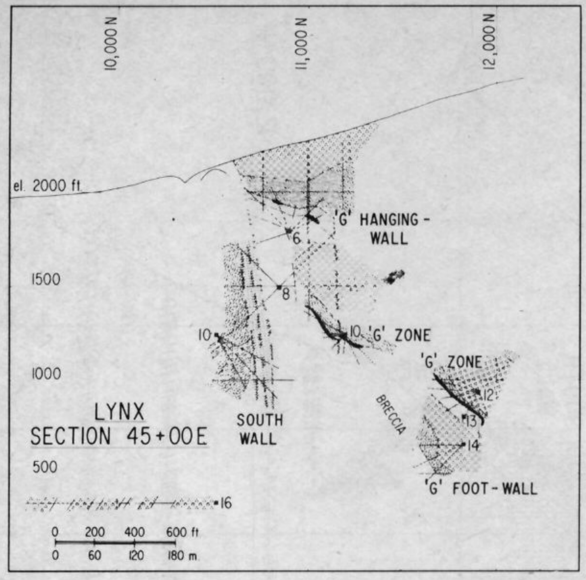


**FIGURE 12. Ore-type sulphides are found near the hanging wall of each of three rhyolite bodies, 'G', 'G' Hanging Wall and 'G' Footwall on the north flank, but only 'G' zone was productive prior to recent exploration of the Creek Zone.**

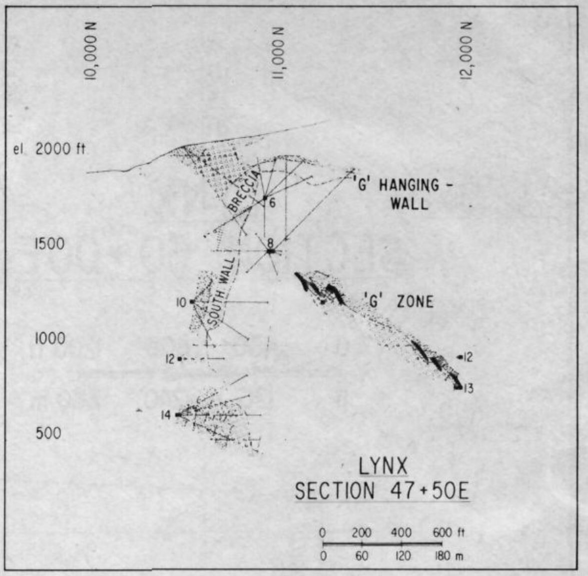


**FIGURE 13. The 'G' orebodies have a shingled configuration on the hanging wall of rhyolite breccia, terminating in a roll structure at the toe of the breccia flow near 13 level. (See Fig. 24 for detail of this 'roll' along plunge).**

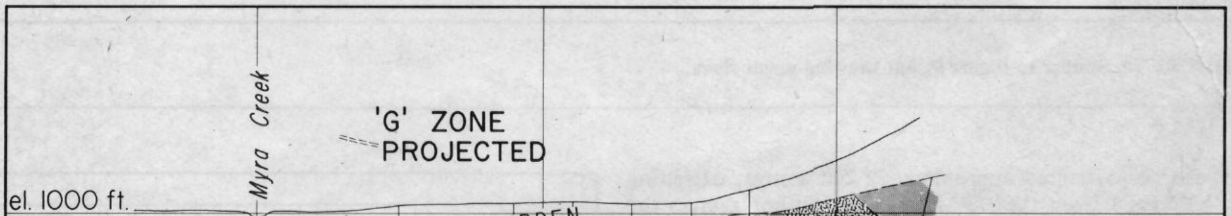


**FIGURE 14. Massive sphalerite-chalcopyrite-pyrite ore was drilled at depth several hundred metres below 'G' zone and well out on the north flank of the vent zone.**

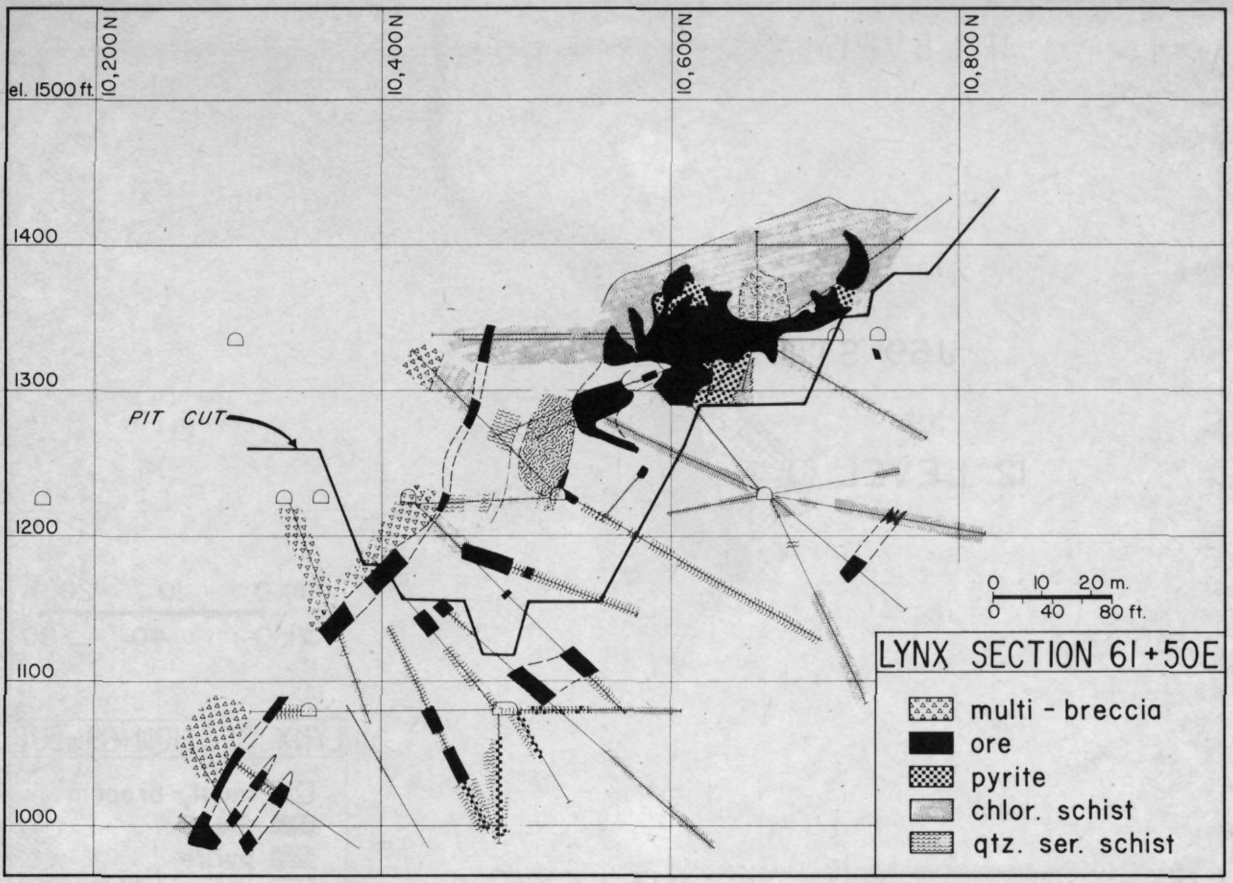


**FIGURE 15. This irregular 'mushroom' ore zone typical of many volcanogenic deposits was found only near surface at Buttle Lake, and at the uppermost level of the mine. The difficulty experienced in interpolation and extrapolation of ore in drill intercepts is obvious and probably contributed to the decision to mine this part of the Lynx by open pitting.**

a few hundred metres south of the south flank lie almost horizontal in accordance with the structure of eruptive centres as described by Lajoie (1977). Locally intense alteration and schistosity preclude determination of most of the stratigraphy within the Lynx vent zone itself. Because orebodies are fully explored, they provide the most reliable stratigraphic information. Figure 15 is presented, with minimal interpolation or extrapolation of mineralized intercepts, to illustrate chaotic structure and/or stratigraphy within or flanking the Lynx vent zone. Unfortunately, the geology of the pit (Fig. 16) is not mapped completely. Mining some of the individual Lynx "South Flank" orebodies showed an unusual configuration in that the lower limit of the ore rolled into a disrupted synform (Fig. 17), but none of these 'rolls' is still available for observation. A multiplicity of interpretations for the structure of some orebodies obviously is possible, prior to mining, particularly when individual drill holes deviate from their initial bearings and when schistosity obscures the original nature of the rock.

**FIGURE 16. The Lynx Pit. The ore continues on plunge directly into the mountain, as shown in Figure 2. (The white fringe on top is snow.) This pit has abundant exposure and consequently provides an almost unique opportunity to observe the geology of a volcanogenic deposit.**

## Myra

The Myra vent zone is similar to that of the Lynx, and drilling in Myra Creek Valley discloses quartz-sericite schist and breccia on strike between the two mines. Thus, Myra probably is in part a continuation of the same vent zone as the Lynx. The over-all form, with a steeply dipping south flank and more gently dipping north flank, is similar (Fig. 18). Intercepts with ore-grade stratiform mineralization, rhyolite, quartz-sericite schist and ore clasts are all found north of the zone of chloritization at depth in the new 'Creek Zone'. The apex of the quartz-sericite schist and ore (Fig. 19) is even more abrupt than that in the Lynx vent zone, but chloritic alteration *precludes determination of primary lithology and structures* close to the apex.

The configuration of Myra "High-Grade" ore has been the subject of intensive study in view of its high grade. The plan (Fig. 20) and section (Fig. 21) show that the ore forms several

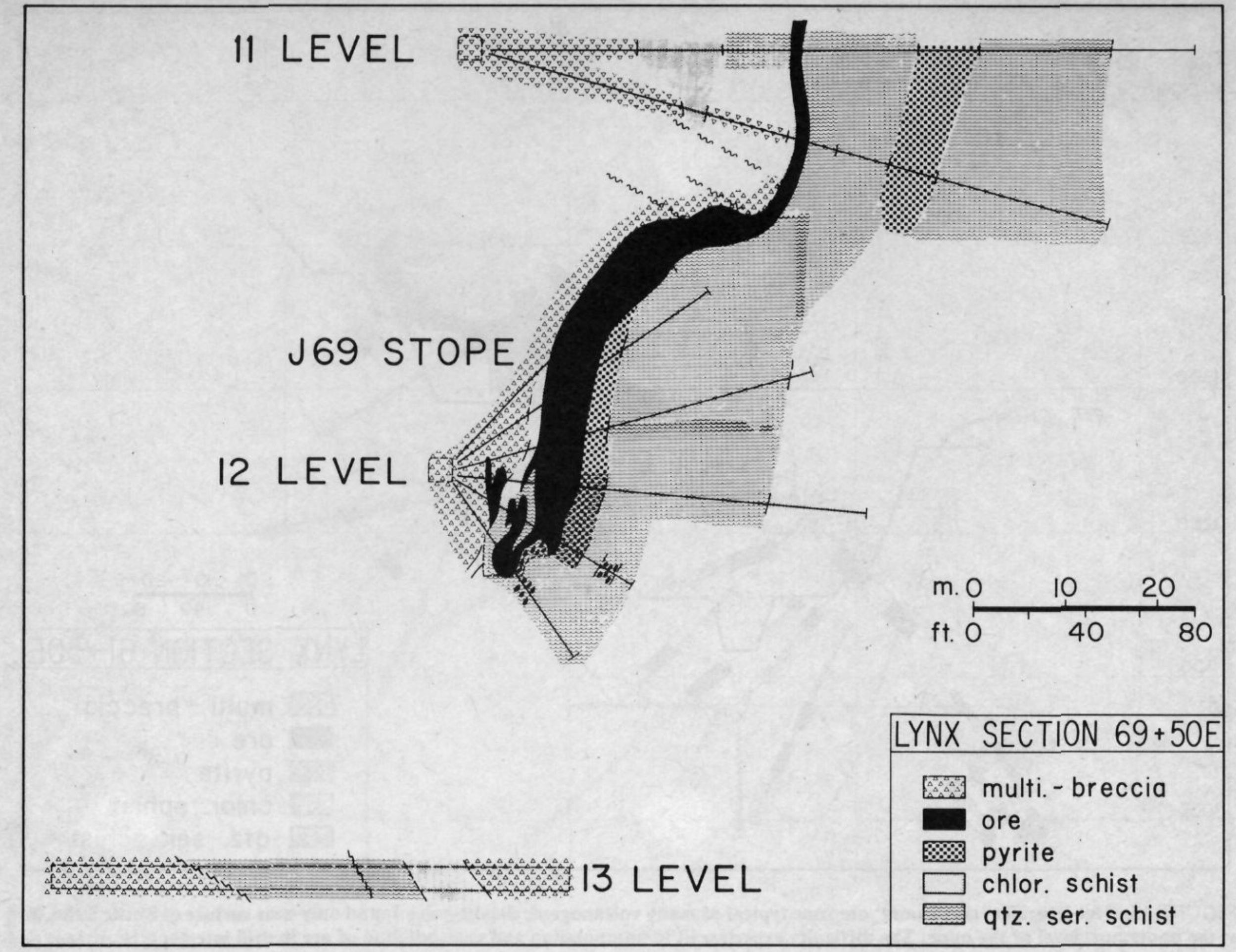


**FIGURE 17. The roll of ore and quartz-sericite schist at the bottom of J-69 stope may represent the toe of a flow.**

lenses, with the tops and bottoms feathering out into quartz-sericite schist. These lenses merge, along strike to the west, into the ore zones shown as Myra "Main".

Myra "Main" orebodies are also well explored and are being studied in particular detail during current mining. An orebody, believed to be a mineralized vent, and an associated orebody, believed to be an exhaled stratigraphic lens, are both being stoped upward toward a common crest zone. The change in nature of mineralization with increasing elevation in the assumed vent was described under 'Mineralization'.

## Price

The Price vent zone has received sporadic exploration which disclosed mineralization approaching ore grade, but individual mineralized bodies are not yet explored in sufficient detail to determine their extent. Consequently, the structure of the zone is not as well understood as that of the Lynx and Myra. Several lenses of pyritic quartz-sericite schist mapped by Carson and others (unpublished) are flanked on the north by multilithic breccias and by banded tuffs that dip gently to the south. Several outcrops in the vicinity of the "Lower Price" disclose unconformities where flows and breccias of undetermined genesis unconformably overlie south-dipping sedimentary rocks, and also transect schistosity in underlying mineralized rhyolite. Interfingering of strata is thus very similar to that described above for the Lynx Zone.

## General

Schistose zones are abundant in and near the vent zones, but both intensity and attitude differ from place to place. Strongly schistose, en-echelon bands of predominantly steeply-dipping quartz-sericite mark the south boundary of the Lynx Vent zone and a similar band marks the south (upper) limit of the "G" ore zone. The strike of schistosity in the south flank swings from westerly to northwesterly and the dip ranges from vertical to as little as 30 degrees northerly or southerly. Strongly schistose bands of quartz-sericite, in places showing diverse attitudes, characterize much of the rock within the vent zones, including that hosting mineralization at the Upper and Lower Price showings.

Schistosity has the configuration of an inverted 'V' in several structures observed near the apices of rhyolite bodies exposed in the Lynx pit. Similar structures, mapped in the Price mineralized zone, might be interpreted either as folds or as the tops of vents (Fig. 23).

Bands of quartz-chlorite schist and chlorite schist are found in many places on the flanks of the quartz-sericite schist. Isolated bands are mapped within a hundred metres south of the Lynx vent zone, within the Lynx vent zone itself, on the north side of the upper parts of the Myra vent zone and in the Price area.

In spite of evidence of tectonic activity indicated by the number of zones and diversity of attitude of schistose rocks, slickensides are not prevalent within the orebodies. The schistosity almost invariably rolls to parallelism with orebodies. Shearing may stretch individual orebodies, but has not been observed to shred them beyond the degree depicted in Figures 15, 19 and 21. Fragments in many of the breccias, and massive rock within many of the flows, do not show any deformation. One outcrop area at the Price displayed undeformed

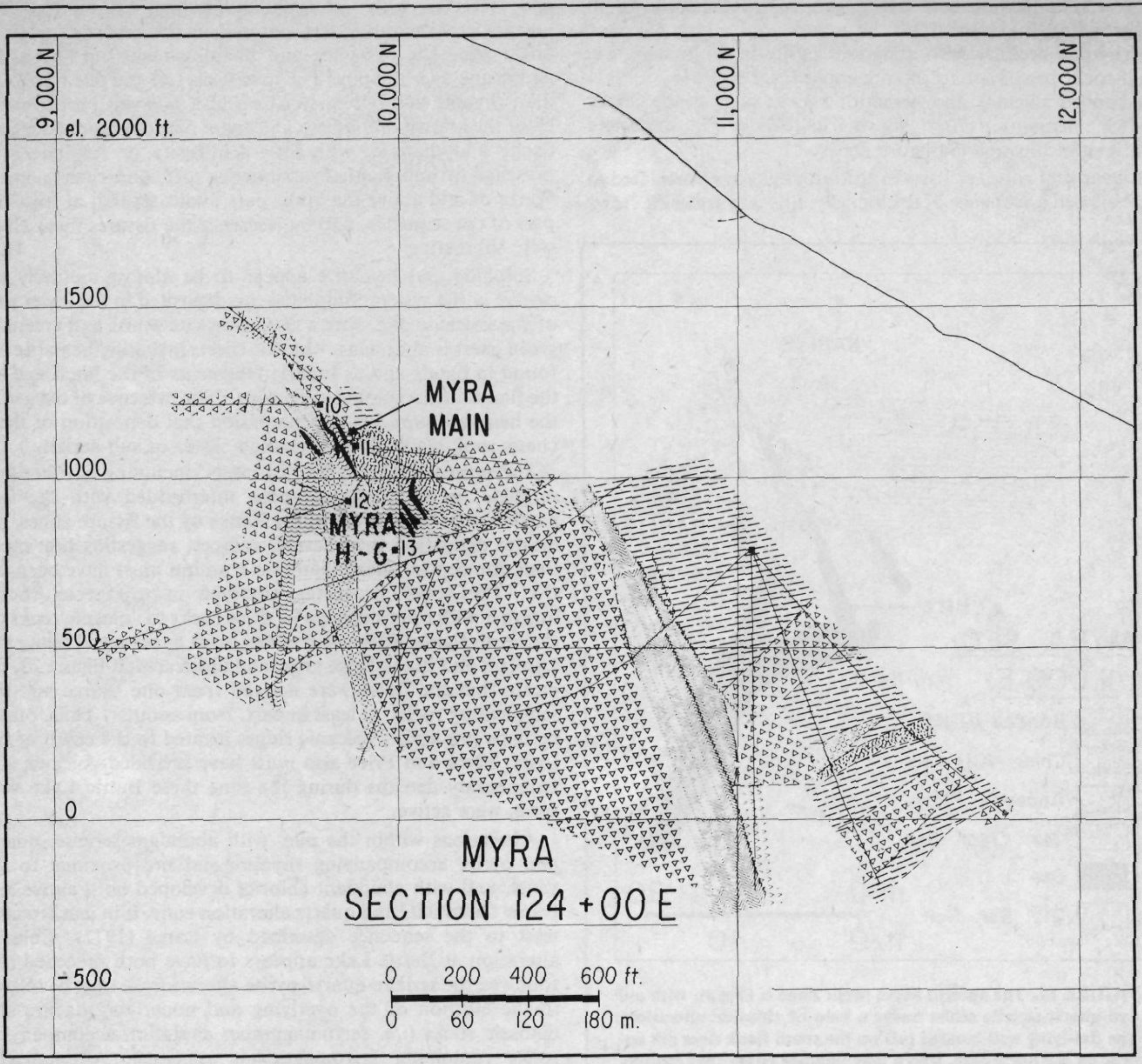


**FIGURE 18. This section through the middle of Myra Zone indicates the configuration of the vent zone is similar to that at the Lynx. Myra Main and Myra High-Grade zones coalesce along strike to the west.**

rhyolite clasts in a moderately schistose sericitic matrix, giving the texture of an augen gneiss. The schistose bands described above decrease markedly in intensity, and in many places disappear within a distance of a few metres to a few tens of metres in the rocks that overlie the quartz-sericite and rhyolite of the vent zones (Fig. 19).

Carvalho (*op. cit.*, p. 151) describes the temporal relation of deformation to mineralization as follows:

"Textural relationships in the graphitic black siltstone at Western Mines indicate that pyrite was present before rock deformation and that it was formed independently from the pyrrhotite which was generated later during the vent deformation stage. The pyrite is not deformed and is oriented parallel to the bedding, whereas the pyrrhotite is deformed and oriented parallel to the vent foliation. If the pyrite is stratiform and undeformed it may be diagenetic and older than the pyrrhotite, as suggested by the presence of idiomorphic pyrite surrounded by flattened aggregates of pyrrhotite. No evidence of pyritic replacement by pyrrhotite is observed, and it is suggested that pyrrhotite was formed during deformation and development of the vent foliation probably by later exhalative-hydrothermal processes throughout the contiguous vent zone."

## Discussion on Synthesis and Genesis

Volcanogenic mineral deposits are characterized by a number of well-defined geological features. The writer concurs with Carvalho *(op. cit.)* that most of these are present at Western Mines. Those present and described above include:

(a) an association with volcanic rocks, i.e. Sicker Group as described;

(b) ore zones in stratabound bodies overlying or adjacent to hydrothermally altered and mineralized pipes, here interpreted to be flanking orebodies, such as 'G' zone, adjacent to the lineal vent represented by the steeply dipping schistose zone with rhyolite breccia and very abundant pyrite, both of which can be observed in the Lynx pit;

(c) stringer or breccia ore such as occurs in the Myra Main Vent stope (Fig. 21) and shown in Figure 8(a);

(d) stratiform primary banding in 'massive' ore, such as shown in Figure 8(c);

(e) clasts of ore or massive sulphide in breccias, such as shown in Figure 3(b);

(f) transition from pyrite-chalcopyrite mineralization within vents to sphalerite-galena mineralization near the vent apex and thence to complex stratiform (exhaled) ore with gold and

silver mineralization and barite gangue, such as shown in Figures 8(a), (b), (c) and 21;
(g) rhyolite breccias with abundant pyrite in the matrix, i.e. 'mill-rock' proximate to the ore zones (Fig. 3(c));
(h) banded silicious and hematitic rocks, such as the jasper and/or hematitic chert shown in Figure 5, deposited stratigraphically above the ore zones.

Linear vent zones or fissures at Buttle Lake are postulated to have ejected a sequence of dacitic, rhyolitic and andesitic flows and breccias with intercalated proximal sulphides. The volcanic rocks, the oldest exposed in the region, formed a linear pile. The overlying and flanking rocks lap up against and drape over the pile. The lowest part of the pile has abundant rhyolite and quartz-sericite schist, and this part contains all of the known orebodies. The upper part has more abundant dacite and diabase, with little schistosity or sulphide. The presence of well-banded subaqueous tuffs and cherts, on the flanks of and above the lower part, indicates that at least this part of the sequence, and by inference the fissures themselves, were submarine.

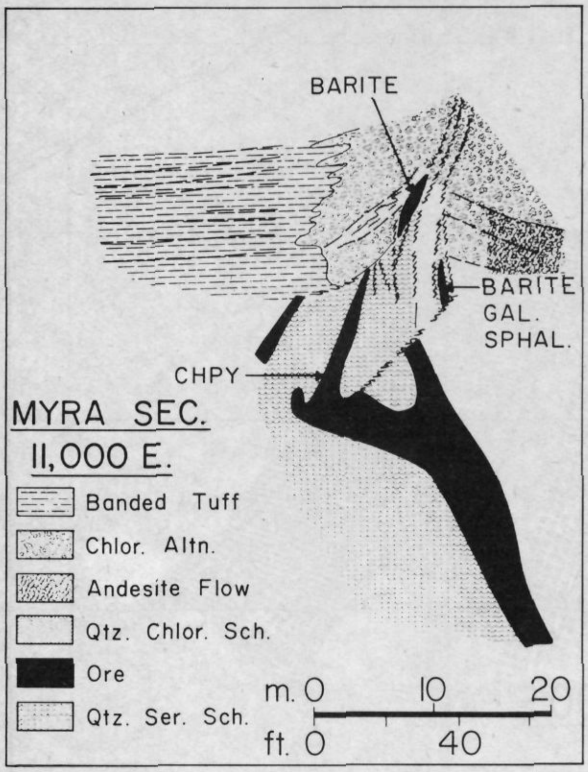


**FIGURE 19. The apex of Myra Main Zone is abrupt, with ore and quartz-sericite schist under a halo of chloritic alteration. The flat-lying well-banded tuff on the south flank does not appear on the north side, which may indicate either that faulting occurred along the ore flanks or that the vent-zone formed a ridge.**

Sulphide and hematite appear to be almost mutually exclusive in the system. Sulphides are deposited in the lower part of the volcanic pile, where quartz-sericite schist and cream to green chert is abundant, whereas cherts including hematite are found in bands and as breccia fragments in the hood and on the flanks of the sulphide-rich core. (The presence of oxygen in the hematite supports the contention that deposition of these cherts took place either in shallow water or sub-aerially.)

The presence of a variety of clasts, including rhyolite and sulphide, in multilithic breccias interbedded with the fine banded tuffs and flows on the flanks of the fissure zones, indicates derivation from several sources, suggesting that more than one vent or more than one eruption must have been active. The scour structures observed in tuffaceous rocks, together with opposing dips of these rocks to volcanic rocks on the north flanks of the vent zones, such as observed above the Lynx pit and in the Price area, and illustrated in Figure 22, indicate that the flows were derived from one source and the sedimentaty rocks, at least in part, from another. Thus, other, perhaps sub-aerial, volcanic ridges located to the north of the Lynx, Myra and Price also must have provided volcanic and sedimentary detritus during the time these Buttle Lake vent zones were active.

Alterations within the pile, with abundant sericite, quartz and pyrite accompanying rhyolite and ore proximal to the vents, and with abundant chlorite developed both above and below the sericite and quartz alteration zone, is in marked contrast to the sequence described by Large (1977). Chlorite alteration at Buttle Lake appears to have both preceded and followed the sericite-quartz-pyrite alteration. It may be related to the ejection of the overlying and underlying dacitic and diabasic rocks (i.e. ferromagnesian alteration accompanying rocks containing ferromagnesian minerals). Alternatively, chlorite may have formed in underlying rocks by redistribution of their iron and magnesium content during eruption of the rhyolitic sequence. Chlorite formation in overlying rocks,

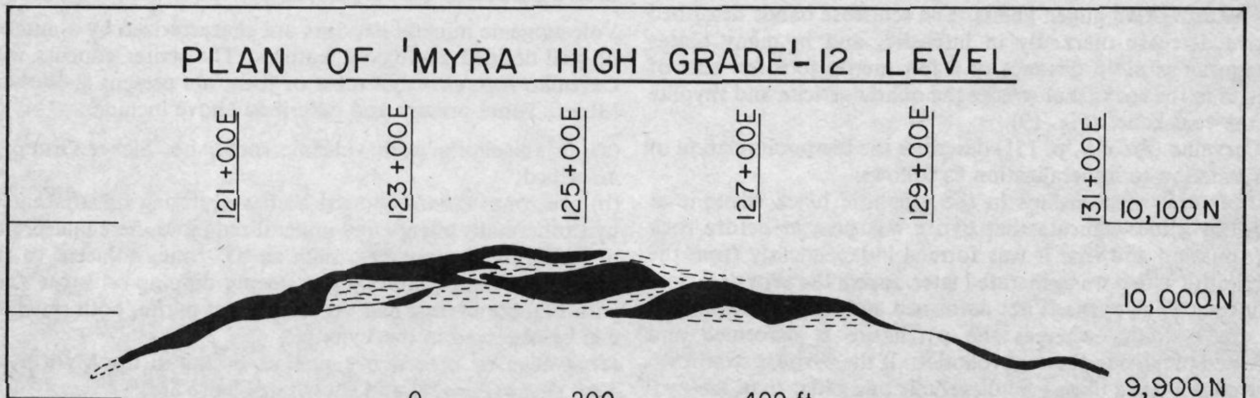


**FIGURE 20. The weakly mineralized sections are quartz-sericite and/or rhyolite, and the entire zone has the configuration of a lenticular stratum. The zone dips steeply, therefore this plan is actually a longitudinal section of the stratum.**

however, must have occurred later in the sequence, after the deposition of those rocks (perhaps as described in the quotation from Carvalho).

The banding and distribution of the conformable massive sulphide provides some evidence of its mode of formation. Uniform and fine grain size indicates that deposition was probably in part through chemical precipitation as described by Turner and Gustafson (1978). The vague banding of the sugary grains of grey sulphides parallel to the wall of the Myra Main vent (Figure 8(b)) indicates *that this material was* deposited by encrustation on the wall of the postulated vent. (If deposited by chemical precipitation, i.e. sedimentation, the banding would be transverse to structure.) The well-banded, but imbricated, separate laminae of barite, sphalerite, chalcopyrite and galena in the associated stratiform deposit indicates precipitation continuing during periods when the composition of the source, or the physical chemistry of the solution medium, was changing markedly. The imbrication, similar to cross-bedding in some places, and the evidence of rolling and slumping, interpreted as 'soft rock' deformation in other places (Figs. 13, 17, 24), indicate that deposition was on a sloping surface. The evidence supplied by banding leads to the deduction that some sulphides were solid or semi-solid prior to ejection from the Myra vent.

Three rhyolite flows, "G", "G Hanging Wall" and "G Footwall", each with associated sulphides deposited within a stratigraphic interval of 300 metres, have been identified on the north flank of the Lynx (Fig. 12). Because ore sulphides are present mostly (but not entirely) within the upper part or above these flows, and have invariably a close spatial relation to an individual flow (Figs. 14, 24), these sulphides are assumed to have been emitted partly simultaneously with, and partly *later than, each flow. In essence, the upper parts of the 'G'* flow contain locally abundant ore sulphides, and in places these parts are of sufficiently high grade to constitute ore. (The plan of 'Myra High Grade', Fig. 20, depicts a similar occurrence, the ore being partly flow.) The flows and orebodies have larger dimensions along their shallow plunges than down their dips.

The three strata mentioned above provide ample evidence that at least three apices, separate spatially and temporally, existed within the Lynx vent zone. Ejection of material along the rifts probably was spasmodic and irregular in place and time. Recent exploration has shown that the rhyolite and/or quartz-sericite bodies do not have apices consistently along a uniform plunge line, thus indicating that rhyolitic material and

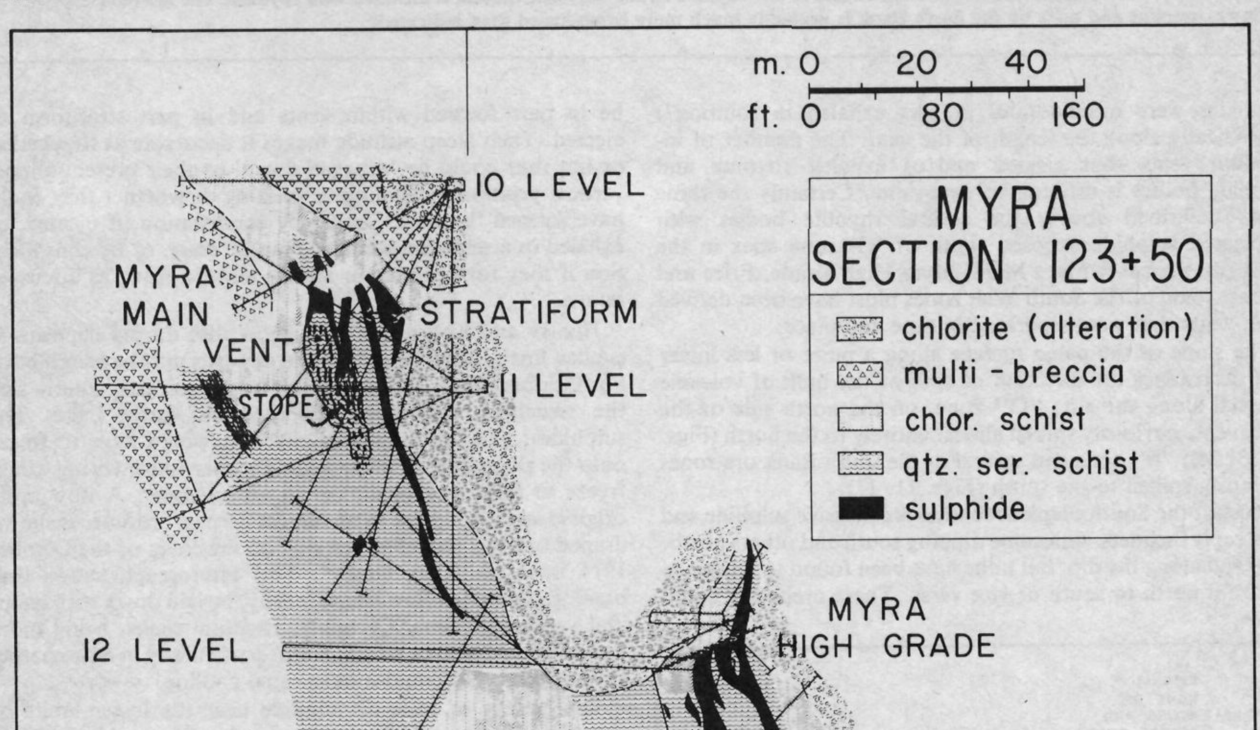


**FIGURE 21. Myra High-Grade and Myra Main have been postulated by some geologists to be faulted offsets of the same structure. Certainly many faults occur in the vicinity, but as mining progresses these have all been found to produce only minor displacements. Alternatively, the chloritized andesite-filled synform between Myra High-Grade and Myra Main should have formed a local basin if Myra High-Grade is a separate vent within the general vent zone. In this event, and if ore deposition is believed to be entirely through sedimentary processes, this local basin should have made an excellent site for ore deposition.**

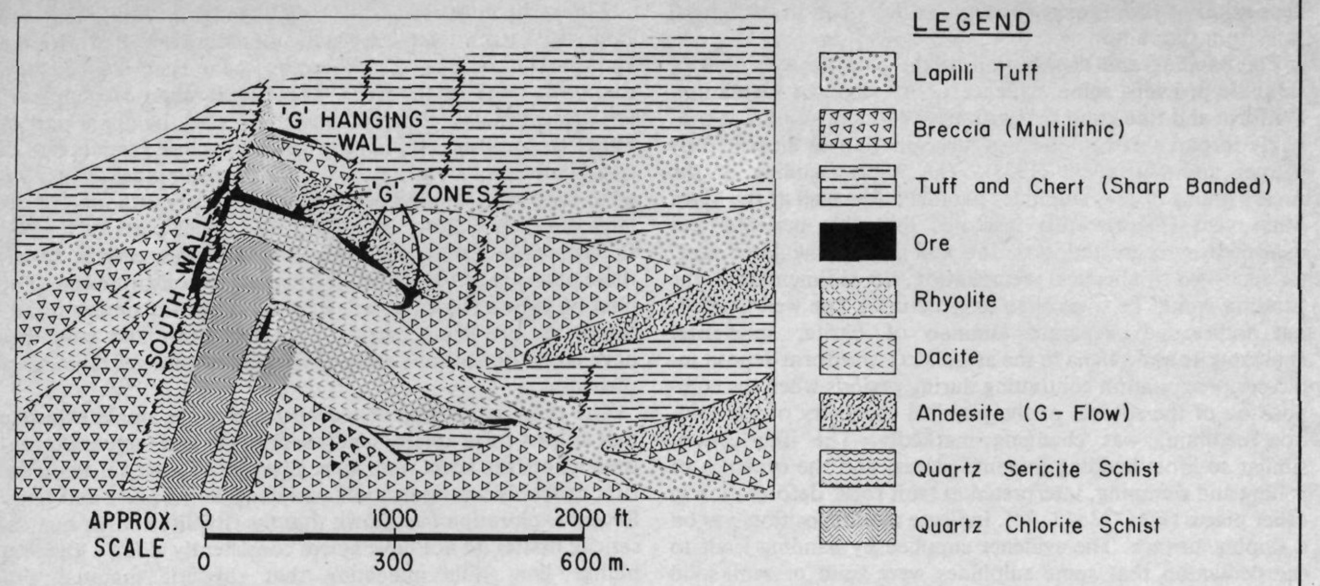


**FIGURE 22. Schematic representation of the volcanic pile at Buttle Lake, showing the relative positions of the mineralized zones to the schistose area at and near the eruptive centre and to the rhyolite strata. Rhyolite breccia is included with rhyolite. The interfingering of flows, breccias and tuffs on the north flank is probably much more complicated than indicated.**

sulphides were ejected (and in part exhaled in solution?) sporadically along the length of the vent. The number of individual vents that ejected and/or exhaled rhyolite and sulphide bodies is difficult to determine. Certainly the three flows described above, the several rhyolite bodies with associated sulphide exposed south of 'G' zone apex in the Lynx pit, probably Myra Main, Myra High Grade, Price and at least some of the South Wall zones must have been derived from vents that were separated in time and place.

The slope of the paleo surface along a more or less linear vent determines the direction of spill of the bulk of volcanic material along the rift. "G" zone, on the north side of the Lynx vent, obviously spilled almost entirely to the north (Figs. 12, 13, 24); "S" zone and several of the south flank ore zones obviously spilled to the south (Figs. 11, 17).

Most of the South Flank orebodies are massive sulphide and are steeply inclined, with some dipping south and others north. They roll along the dip, but none have been found to reverse in dip from north to south or vice versa. These orebodies could be in part formed within vents and in part stratiform or ejected. Their steep attitude makes it debatable as to whether or not they could be 'dragged down' to their present almost vertical position by folding or faulting or whether they could have formed 'in place', either by encrustation, if ejected, or exhaled in a semi-consolidated 'sandy' state, or by consolidation if they formed part or almost all of a flow, as discussed above.

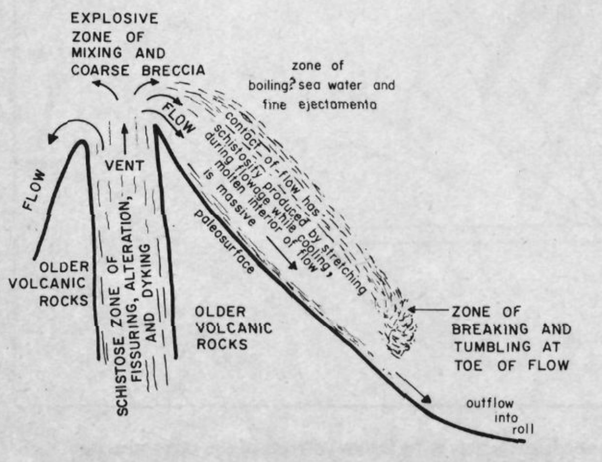


**FIGURE 23. Schematic representation of a submarine vent to show how schistosity might be produced at diverse angles, depending on the attitude of the vent and the slope of the paleo surfaces on its flanks.**

Henley and Thornley (1979) show that during deposition, similar fine-grained ore in kuroko deposits may have existed as hot fluidized beds. This condition would suit particularly well the structural conditions observed at Buttle Lake. The sulphides, and the associated rhyolite, would have to freeze onto the slope, just as water issuing from a linear spring would freeze to form a ridge during an arctic winter. A flow in its original state, solidifed in an almost vertical attitude, is shown draped over an Hawaiian sea cliff on the cover of the October 1974 issue of "Geo Times". This photograph shows that basaltic submarine flows may, locally, be laid down with an initial vertical attitude. Certainly, rhyolitic rocks, being more viscous, could also be so emplaced, particularly in a submarine environment that could induce rapid cooling.

The genesis of rolls of sulphide near the lower limits of several orebodies, such as that depicted in Figures 17 and 24, is debatable. Sedimentary strata, such as the overlying lapilli tuff, are not folded along with the ore, and thus the roll is deduced to have formed prior to deposition of the overlying rock. Ore sulphides have not slumped into and filled the quartz-sericite schist synform shown in Figure 17. Major fault or gouge zones are not present either there or at the base of the ore shown in Figure 24. Consequently, the rolls are suspected to be produced by tumbling at the front or toe of a rhyolitic flow that has abundant sulphide on its upper surface. Perhaps extruded or exhaled sulphide can be deposited by accretion on steep slopes flanking a vent, in similar fashion to their deposition by encrustation on the walls within vents, as discussed above.

The author differs with Muller (in press) and others who interpret the ridge or ridges formed by the vent zones as anticlinal folds. The reasons are:

(a) The detailed geology of the 'rolls' described above precludes their formation as minor folds on the flanks of anticlines.

(b) The 'sense' of the rolls, such as mapped in Figure 17, is discordant to that of minor folding on the flank of an anticline.

(c) Formations do not match on each flank of the structure. Neither clearly defined equivalents to 'G', 'G Footwall' or 'G Hangingwall' rhyolite flows nor equivalents to the 'andesite' flows mapped in Figure 14 appear on the south flank of the G Vent Zone.

(d) Many of the exposures of 'sharp-banded' tuffaceous rocks north of the vent zones (well exposed in Myra 124 cross-cut, Fig. 18), as well as multilithic breccias in abundance north of the Price, show southerly dips.

(e) Pyritized rhyolite breccias or 'mill rock' (Fig. 3 (c)), reported to be typical of volcanogenic domes (Sangster, *op. cit.*), are present near the apex of the rhyolitic sequence.

(f) There is a lack of folds of similar height and width as the ridge, in the vicinity of the mines.

The almost complete lack of folding or schistosity in the outcrops of flat-lying well-banded sedimentary rocks found a few hundred metres out on the flanks of the vent zones indicate that, other than intrusion of Jura-Cretzceous granodiorite, post-vent tectonic activity has been minimal in this region. The volcanic pile itself is essentially the locus of tectonic activity, and appears to be little affected by superimposed events. Hence, the author prefers to class it as a submarine 'paleo-ridge'.

The flat-lying strata in the hoods and on the flanks mask the much more steeply dipping strata (including the ore zones) within the lower part of the volcanic ridge. Exploration for ore by drilling has the best chance of success if conducted with drill holes at appropriate inclinations, other than vertical, after the approximate position of mineralized rocks on each flank is known.

Strong schistosity precludes determination of the number of rhyolite flows that were extruded on the south flank of the Lynx. If one postulates that each sulphide body on the south wall was associated with a separate rhyolite flow (as appears to be the case on the north flank), certainly many individual flows must have been extruded. The building of the ridge must have been a lengthy process. Much disruption was undoubtedly produced within the ridge by material of each successively later eruption moving up through the earlier deposited (lower and inner) flows and orebodies. The rhyolite associated with the uppermost orebodies, "G" zone and "S" zone, has little schistosity or other fabric indicating such disturbance.

The origin of the strong and predominantly steeply dipping schistosity that characterizes parts of the vent zone is not clear. The lack of continuity of strong schistosity in many places into the hoods of the rhyolitic and ore-bearing zones indicates that most of the stresses producing schistosity must have waned soon after the ejection of the rhyolite and the ore, and were not imposed by later tectonic events. More detailed mapping of the strength and attitude of schistosity might provide a better understanding of its origin.

The author suggests that the schistosity in the steeply dipping, pyritic, quartz-sericite schists was produced mainly by *the upward streaming of volatile-rich material that carried* and/or accompanied the rhyolite and the sulphides. Such upward streaming would originate near the molten core of the erupting volcanic ridge and proceed upward in channelways through the overlying cooler zone of more viscous consolidating lava and thence into the boiling sea water at or near the linear vents, as depicted in Figure 23. The continuing differential upward movement could produce most of the predominantly steeply dipping schistose bands. The occurrence of steeply dipping pyritic quartz-sericite schist is, in the author's observation, common in association with similar mineral deposits in the Cordillera. Examples include the Twin J. mine near Duncan, B.C., the Homestake north of Kamloops, B.C., the Premier near Stewart, B.C. and the Bully Hill near Shasta Lake in California. Hence, as considered in preceding paragraphs, the association, in the author's opinion, is genetic rather than superimposed.

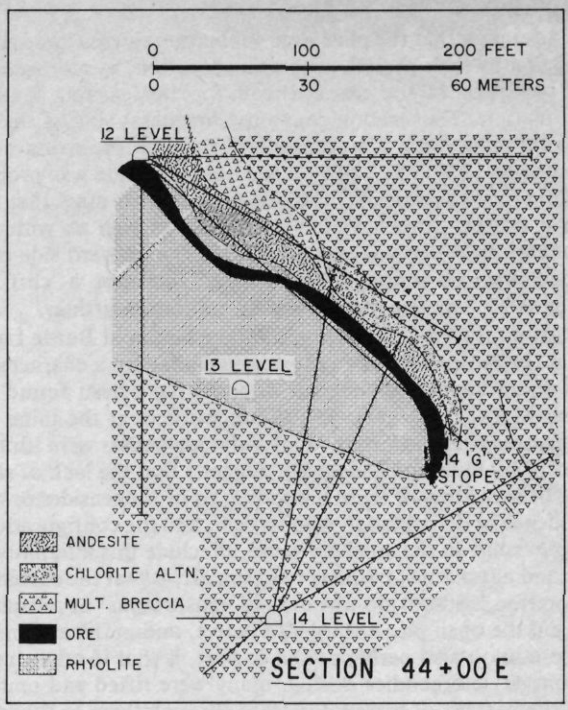


**FIGURE 24. 'G' ore zone, rhyolite and andesite flow showing their relation and coincident termination down dip. Note that some of the ore zone lies within the rhyolite stratum.**

A second cause of shistosity might be provided by differential movement within the submarine rhyolite flows. Certainly the top and bottom of a flow would be cooled and consolidated prior to the core. The lava tubes found in Hawaii are evidence that the hot core material in subaerial basalt flows continues to move down slope beyond the consolidated shell. Rhyolite is known to be even more viscous, thus when extruded onto steep slopes as postulated herein, differential movement of viscous core relative to solidifying contacts could provide schistosity within the flows, as depicted in Figure 23.

A third cause of schistosity in the area might be provided by differential consolidation during diagenesis. Compaction of the soft, water-lain sediments accumulating on the flanks of the volcanic pile would be greater than that of the previously solidified volcanic rocks within the pile. Consolidation, compaction and perhaps tilting likely would be greatest on the seaward (south) flank. Differential and gradual movement downward because of continued compaction of the soft, wet sediments relative to the lithified volcanic rocks within the pile could produce schistose zones within the water-lain tuffs lapping against the 'South Wall'.

Steeply dipping zones of schistosity within the rhyolite could have formed in part by continued or renewed movement along the previously active rifts within the vent zones themselves. These rifts probably continued to be zones of structural weakness, but, as described previously, schistosity does wane markedly upward into the rocks in the hood. The north flanks of the vent zones appear to be further compacted by a series of block faults, as shown in Figure 22.

The soft sedimentary rocks in the hood of the vent zone would tend to be pierced, during their compaction and slumping, by the harder volcanic rocks forming the submarine ridge. Such continued faulting up into the hood rocks can be observed in outcrops on the mountain top west of the Lynx pit, and appears to mark the approximate position of the crests of the vent zones.

Assuming that the piles were submarine ridges, these ridges, judging by their present geographic location, must have formed southwest of and seaward from the then-existing continental margin. The strata close to the northeast side of the submarine ridge have a more shallow dip than the strata on the southwest side. The basin on the northeast side was probably filling in with sediments derived from a land mass that must have existed farther to the northeast, as well as with ejectamenta from the volcanic pile itself. The seaward side of the ridge was obviously much steeper, perhaps a cliff that originated and was maintained by continued rifting.

An unusual feature of the sulphide bodies at Buttle Lake is that the mushroom-like cross sections that are a characteristic of undeformed volcanogenic deposits have been found only near Myra Valley (Fig. 15). Other workers at the mine have suggested that the 'South Wall' sulphide bodies were 'dragged down' by faulting. The author suggests that the lack of shearing or shredding of these orebodies, or of slickensides or other evidence of deformation within them, and the configuration of some 'rolls' in the contrary sense, preclude this alternative. A second alternative, perhaps valid in part, is that the current exploration methods do not expose 'mushrooms' as adequately as did the open pit. A third alternative, and in the author's interpretation also perhaps valid in part, is that if other 'mushroom'-style orebodies existed, many were rifted and removed by the passage of material upward through them to the top of the then-existing volcanic pile. The clasts of ore found in the flanking multilithic breccias may be some of the remnants of such a process.

## Acknowledgments

The plans and sections presented herewith are based in large part on very detailed and accurate mapping by the mine geologists, B. Duna, C. Pearson, R. Tschach and their predecessors. Some of the information on rock types was supplied by Ilson Carvalho.

Many of the concepts presented herein are derived from discussion with these geologists, with other staff geologists and with visiting geologists. Critical readers include V.F. Hollister and T. Lisle, whose improvements are appreciated. The author assumes responsibility for the concepts expressed here, and thanks Dr. G.M. Furnival for permission to publish.

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# Western Mines—Myra, Lynx and Price deposits: a discussion

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The paper, "Western Mines—Myra, Lynx and Price Deposits", by R.H. Seraphim, presents a view of the geology of the Western Mines' deposits. It is based on Dr. Seraphim's experience as a consultant for Western Mines during 1976 and 1977, in which period he examined the property and mine records on many occasions. His personal work contributed to the geological data accumulated by numerous geologists since before production began in 1967.

This discussion is based on my experience with Western Mines over the past two years. During this time, I have been involved in an exploration program on the mine property. This work has been based on relogging of core, and mapping, as well as on new drill-hole data.

The property has a long and varied history which encompasses many changes in geological interpretation, the most fundamental being a shift from the hydrothermal replacement model to the syngenetic, massive sulphide model in the late 1960s. Dr. Seraphim's elaboration of a syngenetic model is an original contribution which in many aspects does not reflect the varied interpretations, past and present, of Western Mines' geologists. The purpose of this discussion is to address only the more fundamental points of difference between Dr. Seraphim's view and alternative interpretations.

Dr. Seraphim argues that the present form and distribution of rock types is primary, and that post-ore deformation has been minimal. I will argue that tectonic deformation has modified primary geological relationships and that reconstruction on a geological history requires distinction among stratigraphy, ore-related alteration, metamorphism and tectonic deformation. From this basic difference in view flow many specific points of disagreement which will not be addressed *here.*

The Sicker Group rocks in the mine area comprise a heterogeneous sequence of volcanic rocks, both massive and clastic, with subordinate chemical sediment. Volcaniclastic rocks predominate and vary from monolithic to heterolothic. Texturally, the volcaniclastics range from thick, massive beds of coarse breccia to fine, bedded sediments with variable but subordinate components of chemical sediment in the form of *chert, carbonaceous argillite and sulphides. The entire sequence* appears to be subaqueous, without recognizable epiclastic components or subaerial erosion surfaces.

The stratigraphic interval of greatest interest is a zone approximately 400 to 500 metres thick which contains all the known occurrences of rhyolite and ore sulphides in the mine area. This stratigraphic zone has been informally called the "Vent Formation" since B.E. Spencer coined that term in the *early 1970's. The term "Vent Formation" was not restricted to* rocks close to the ore zones, to sulphidic rocks, to rhyolitic rocks or to altered rocks. It applied to a complex heterogeneous sequence extensive throughout the mine property. It is characterized by great diversity in compositional and textural varieties of rock which can be interpreted as both proximal and distal with respect to volcanic or explosive, phreatic vents. This complex stratigraphic interval is bedded, but individual *bedding units are lensoidal and discontinuous. Despite significant* lateral variations, the "Vent Formation" can be subdivided into recognizable stratigraphic zones based on combinations of compositional and textural characteristics. These ordered subdivisions of the "Vent Formation" have been recognized throughout the mine property and have been used to predict stratigraphy prior to drilling. The "Vent Formation" appears to have been largely constructed by *deposition of volcaniclastics from subaqueous density flows* with subordinate turbidite phases. Mafic flow units and massive to in-situ brecciated, felsic dome phases are distributed laterally and vertically within the "Vent Formation".

The "Vent Formation" is overlain by a stratigraphic zone locally called the "Sharp Banded Tuff Formation" (S.B.T.). This zone is a few to several hundred metres thick and is *laterally continuous throughout the mine area. The S.B.T. is* characterized by distinct alternating beds of tuff, cherty tuff and chert with units of massive mafic rock, variously interpreted as flows and sills. The sequence appears to be constructed predominantly of thin- to medium-bedded, volcaniclastic turbidites and chemically precipitated, greenish to grey chert. The volcaniclastic component is basic to intermediate, commonly heterolithic, with a clast size varying from very fine *to several millimetres. Chert and cherty tuff usually comprise* more than 30% of the bedded units, and commonly more than 50%.

Bedded tuff-wacke, cherty tuff and chert similar to the "Sharp Banded Tuff Formation" occur locally throughout the underlying "Vent Formation". The contact between the two major stratigraphic zones is an interbedded transition through which the general character of the volcaniclastic changes from *more proximal to more distal. The S.B.T. does not lie unconformably* on the "Vent Formation". It lies above the "Vent Formation", not lateral to it.

In short, a broad ordering of stratigraphic zones is recognized in the mine area despite substantial lateral facies variations within the " Vent Formation". The most important of these facies variations involve the presence of rhyolite at various stratigraphic levels in the "Vent Formation". Rhyolite units *are mostly volcaniclastic, with a few notable occurrences of* massive bodies thought to represent domes with laterally equivalent clastic rhyolite beds. Most of the rhyolite units referred to as flows by Dr. Seraphim are actually volcaniclastic beds, with a sorted lapilli-tuff to tuff texture predominant.

In the past, the most important rhyolite unit has been the host rock for the ores of the Lynx and Myra mines. The ore-bearing Upper Price rhyolite recently has been recognized as the fault-offset continuation of the Myra rhyolite. Correlation of the principal ore-bearing rhyolite through the Lynx, Myra and Price mines indicates an essentially continuous zone in excess of 6000 metres long parallel to the northwest regional strike. This unit is localized in the upper half of the "Vent Formation" and ranges from about 130 metres to at least 900 metres in dip length. Thickness ranges from 1 to perhaps 60 metres. This rhyolite is predominantly tuff to lapilli tuff with coarse breccia and massive phases near the southeast end of the Lynx Mine in the area of the Lynx pit. This is also the area where the rhyolite unit attained maximum thickness and is thought to represent the main volcanic centre for the Lynx-Myra-Price rhyolite. Away from this inferred volcanic centre, both northwest and southeast, the rhyolite comprises principally sorted tuff and lapilli tuff. Through the length of the Myra and Price mines, this rhyolitic clastic sediment forms a thick lens no more than 150 metres wide in plan projection, but continuous along a horizontal, northwest trend line for 1700 metres.

Clearly, the Lynx-Myra-Price rhyolite was originally a linear element within the stratigraphy. Its linearity is paralleled by certain other stratigraphic elements correlated through the mine property. This northwest-southeast linearity is thought to reflect a synvolcanic structural trend which influenced volcanism, sedimentation and ore-forming hydrothermal activity. Today we recognize this direction as both a stratigraphic and synmetamorphic structural trend in the mine area.

All of the Sicker Group rocks in the mine area have been metamorphosed to the lower greenschist facies. Schistosity is variably developed and is most intense along greenschist facies. Schistosity is variably developed and is most intense along the axis of the Lynx-Myra-Price zone as well as near the base of the "Vent Formation" elsewhere. Schistosity generally strikes northwest-southeast and dips steeply northeast or southwest. Schistosity characterizes the ore wallrock environment and typically conforms to ore contacts (envelopes of schistosity). A penetrative, flat to shallow-plunging lineation characterizes the schistosity surfaces and conforms to the general plunge of typically elongate orebodies and other rock units. The degree of schistosity development appears to reflect both primary rock composition and ore-related, hydrothermal alteration. Potassic or potassium-altered rocks, now represented by sericite and sericite-chlorite schists, appear to have localized the development of schistosity during dynamothermal metamorphism. Chlorite schist is more restricted in extent and is associated with sericitic schists. Schistose and non-schistose rocks display a penetrative lineation defined by stretched rock fragments. The stretch direction *parallels the lineation on schistosity surfaces and together they* represent a b-lineation with flat to shallow plunge trending northwest-southeast. The stretched, non-schistose volcaniclastic rocks could be considered b-tectonites.

In cross sections oriented northeast-southwest, the Lynx zone has the form of a flat to shallow-plunging, assymetric anticline with a near-vertical southwest limb and a 35-degree dipping northeast limb. The southwest limb is locally overturned *and dip varies from 60 degrees southwest to 70 degrees northeast.* The average vertical attitude of the southwest limb has been documented over an elevation range of 500 metres. The southwest limb and core zone of the anticline are strongly schistose, and schistosity intensity diminishes to the northeast away from the fold axis. Sericite schist is the principal host rock for the many irregularly folded massive sulphide bodies in the southwest limb. This sericite schist is inferred to be *deformed rhyolite and is probably continuity of the ore zone* over the crest of the anticline from the southwest limb to 'G' zone as observed in the open pit (R. Tschach, personal communication). Sericite-chlorite schist predominates in the core zone of the anticline and is considered to be deformed, altered, heterolithic volcaniclastics which originally lay beneath the rhyolitic host rock. Abundant disseminated pyrite is common in the schists on the northeast side of the southwest limb orebodies, and is thought to represent pyritization of the altered host rock immediately beneath massive sulphide bodies.

In Myra Mine, the same anticlinal structure is more tightly compressed and varies from isoclinal at the northwest end of the mine to asymetric at the southeast end of the zone. In the Upper Price zone, the fault-offset extension of the Myra zone, the anticline is recognized as a more open fold in the stratigraphy above and below the rhyolite lens, but more detailed drilling is needed to define the cross-sectional shape of the rhyolite along the strike of the zone. One section drilled in detail near the southeast end of the Price zone (172 + 00E) indicates that here the rhyolite unit, which hosts ore, is a single, thick lens lying on the northeast-dipping limb of the anticline.

The anticline, which is coincident in trend and plunge with the long axis of the Lynx-Myra-Price rhyolite, appears to be a stratigraphically localized structure controlled by the anomalous lithology of the immediate ore environment. The anticline is recognized in the stratigraphy above and below the ore environment, but is tighter in the rhyolitic rocks and associated ore-related alteration. This is a reflection of the mechanism of folding in the lower greenschist facies environment. Potassic rocks in particular are more susceptible to deformation by shear folding through schistosity development and thus localized deformation both laterally and vertically. The entire lithologic assemblage was subjected to the same tectonic stress as indicated by the stretched fabric of non-schistose (non-potassic) rocks, but folding was localized within and adjacent to those rocks most susceptible to schisting. I believe this is a feature common in massive sulphide deposits in greenschist facies rocks.

The mine area in general, and the immediate ore environment in particular, was affected by brittle deformation manifested by faults and shear joints with a wide range of attitudes. These structures are characterized by slickensides, gouge seams and variably developed zones of gouge and broken ground. This deformation was post-metamorphic and effected both schistose and non-schistose rocks. It appears that more than one period of post-metamorphic deformation is represented. Wallrock to ore is commonly gouged and sheared to an extent that produces ground control and dilution problems for the miner. As an example, 'G' zone ore on the northeast limb of Lynx, which represents the least deformed ore and the best ground conditions, is characterized by a hanging-wall gouge zone commonly one to several feet thick. Associated slickensides are dip-slip in contrast to strike-slip slickensides associated with steeply dipping cross faults.

Perhaps there can be a meeting of minds between the past generation of hydrothermalists and the current generation of syngeneticists. Before the advent of the syngenetic model, geologists recognized that massive sulphides in greenschist facies rocks were commonly localized in "shear zones" (i.e. schist zones) and that the immediate ore environment commonly constituted a structural anomaly within the regional terrain. The hydrothermal model held that structure controlled ore. The syngenetic model suggests that ore-related lithology controlled structure. Regardless of one's angle of approach, the correlation between ore and structure can and has been used to find ore.

Let us not lose track of the contribution made by earlier geologists who viewed the Buttle Lake deposits as hydrothermal replacements in a "shear zone". Let's not forget the basis of the mine mapping system in which schists are the paramount map units. The important question is whether these rocks are tectonically deformed or not. I suggest that they are, and that the Lynx-Myra-Price zone is both a stratigraphic and a structural feature. It is unnecessary and implausible to suggest that massive sulphides in the "south wall zone" formed by freezing of sulphides on vertical and overturned slopes from magmatic flows or fluidized beds, or by encrustation.

Rather than a volcanic ridge, I view the Lynx-Myra-Price zone as a lithologic zone characterized by a rhyolite volcanic centre near the east end of Lynx, with a linear unit of rhyolite volcaniclastic sediments deposited in a narrow, fault-controlled, topographic trough to the southeast. Toward the northwest, the rhyolite and orebodies extended over a width greater than 900 metres normal to the northwest trend prior to folding. Synmetamorphic, tectonic deformation was most intense along the pre-existing, lithologic trend due to inhomogeneity within the rock mass.

An important distinction should be made between volcanic vent and hydrothermal vent. The two are not synonymous. Ambiguity arises in Dr. Seraphim's paper regarding the use of the terms vent and vent zone, as they are used interchangeably for volcanic and hydrothermal vents as well as for structural features. It appears that both a hydrothermal and a felsic volcanic vent existed at the southeast end of Lynx Mine in the area of the Lynx pit. The hydrothermal centre in Myra Mine, termed the "fumarole" by B.E. Spencer, does not appear to be coincident with a volcanic vent. Metal distribution patterns suggest that ore-forming hydrothermal activity occurred along a synvolcanic structural trend away from the felsic volcanic centre as well as coincident with it. The mine property encompasses other rhyolitic volcanic vents and other hydrothermal vents at different stratigraphic levels away from the Lynx-Myra-Price trend.

I hope that this discussion draws attention to problems associated with massive sulphide deposits both at Buttle Lake and elsewhere. If nothing else, it suggests the disparity of opinion which can exist among workers studying the same sequence of rocks. I wish to acknowledge the essential contributions made by many people to the progressive developement of the mine geology picture. Most notably they include: B.E. Spencer, R. Tschach, C. Pearson and B. Duna. I thank the management of Western Mines Limited for permission to publish this discussion.

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# Western Mines—Myra, Lynx and Price deposits: a reply

## R.H. SERAPHIM

The purpose of my paper was to bring knowledge of the mine geology up to date in the light of rapid advances in the understanding of volcanogenic (or exhaled) mineral deposits, so that exploration funds could be utilized to better advantage to disclose new ore reserves. I believe that the purpose is achieved in various ways. This reply to 'A Discussion' by R.R. Walker will refer to some of the statements which I believe to be debatable, and will suggest avenues where further research might answer some of the many questions that remain unanswered.

*Paragraph 1.* A point of information—Most of my investigation was toward determination of the structure of the entire environment of mineralization. The reason for the abrupt terminations of many strata, including orebodies, was of major concern. Examinations of the mines were coupled with the logging and rechecking of logs of more than 84,200 feet of core. These examinations disclosed that most strata terminations were due to simple 'pinch-outs' rather than to faults. The core-logging was predominantly of holes drilled on the flanks of the vent zone(s). Almost all of this work was with the assistance of one or more of the mine geological staff and led to many discussions with staff members. One of these members assisted in making and checking the new sets of plans and sections that form the basis of and are in part presented in the paper. (In fact, the early drafts of the paper were edited by several staff members as junior authors, but changes in opinion, coupled with difficulty in liaison, apparently led to their decision to decline participation in the final version.) The paper, nevertheless, presents what remains in my mind as the interpretation most likely, after considering all proffered opinions, to withstand the test of time.

RE: R.R. WALKERS'S 'DISCUSSION':

*Paragraph 5.* "The entire sequence appears to be sub-aqueous, without recognizable epiclastic components...."

(a) The presence of rocks containing hematite in the hood and flanks of the vent zone, and the fact that "hematite and sulphides are generally mutually exclusive", lead to the belief, as discussed in the paper, that the volcanic pile (which includes the vent zones) probably grew to at least near sea level, where oxygenated water was present.

(b) How epiclastic is epiclastic? The cover of the October 1974 issue of *GeoTimes* shows lava draped over a sea cliff, with vertical and in places 'overdraped' initial dip. (See also "Volcanoes" by M.B. Lambert, published by Douglas & McIntyre, Vancouver.) *National Geographic* Vol. 156, No.5, November 1979, shows a "Strange World Without Sun" photographed by scientists in the submarine *Alvin.* Vertical and 'overhung' lava pillars, and submarine chimneys exhaling solutions that deposit iron, copper and zinc sulphides are shown in photographs. The structures depicted are obviously unstable. When in a shallow-water environment, subject to submarine currents, deep wave action and repeated earthquakes related to continuing volcanic activity, would not disintegration and mixing be expected of a variety of volcanogenic and exhalative products derived from various vents in the general area of the pile? If so, should the resultant strata, formed of a number of types of rock, perhaps including sulphide fragments, be called multilithic breccia, multilithologic breccia or heterolithic breccia? None of these names appear in the A.G.I. Glossary of Geology. Should we coin a new word, use the old term 'epiclastic' or the even older term 'sharpstone conglomerate' which does appear in the Glossary?

*Paragraph 6.* Re paragraph six concerning the 'Vent Formation'. Does not the definition in the A.G.I. dictionary make the use of the term 'formation' unsuitable for the complex described in the opening paragraphs of the subject paper? Do the sections not show the complex to be much too diverse in lithology, and the location of upper and lower boundaries much too dependant upon opinion, to classify it as a formation?

*Paragraph 8.* Re paragraph 8: "The S.B.T. does not lie unconformably on the "Vent Formation". It lies above the "Vent Formation", not lateral to it." Reference is made to the opening sentence regarding 'Clastic Sequence' in the original paper which states: "The termination of volcanism and the beginning of erosion and sedimentation are recognized as overlapping processes." Does not the sequence of interfingering of sharp banded tuffs, lapilli tuffs and multilithic breccias logged in the drill holes below 17 level (0 to 500 feet below sea level) and depicted in Figure 9 show that some of the sedimentary rocks must in part have been deposited while the volcanic pile was still growing? What happens to the fine particles exhaled by the black smokers and the dissolved or colloidal material exhaled by the vents observed by the scientists from the submarine *Alvin (National Geographic, op. cit.)?* Would not at least some be deposited contemporaneously as sedimentary strata, including banded tuff (S.B.T.) and chert in less turbulent water on the flanks of the producing vent or vents? Also, can chert be differentiated everywhere from rhyolite when silicious lava and silica-laden fluids probably were exhaled either intermixed or almost contemporaneously? Perhaps the scientists utilizing *Alvin* eventually will explain more fully how the sorting of the breccias, tuffs and cherts is accomplished and how they lie in spatial relation to the vent or vents that provided them originally.

*Paragraph 10.* "The ore-bearing Upper Price rhyolite" may or may not be recognized as the fault-offset continuation of the Myra rhyolite. I hope that Price ore does continue as far west as the Myra Price fault (Fig. 2), but would prefer to leave the correlation to the test of time while Myra and Price structures are traced as individuals.

*Paragraph 11.* "Through the length of Myra and Price mines this rhyolitic clastic sediment forms a thick lens." Figure 21 shows two separate apices of quartz-sericite schist (rhyolite?) and ore in the Myra Mine, one called Myra Main and the other called Myra High-Grade. Since the philosophy of multiple vents is accepted in Walker's statement: "The mine property encompasses other rhyolitic volcanic vents and hydrothermal vents" (paragraph 20), should not Myra Main and Myra High-Grade be accepted as separate, though in part linked vents, and should not the associated quartz-sericite schist (rhyolite?) be classed as semi-separate lenses produced by separate vents within the vent zone, with the Myra High-Grade vent on the flank of Myra Main? Is not the new H.W. orebody related to a separate vent, perhaps correlating with the vent system that produced the three rhyolite strata and associated mineralized bodies labelled 'G' (Fig. 2 and 12)?

*Paragraph 12.* "All of the Sicker Group rocks in the mine area have been metamorphosed to the lower greenschist facies."

(a) The writer's recollection is that the chloritized andesitic rock in the trough between Myra High-Grade and Myra Main is devoid or almost devoid of schistosity, as is the andesite above 'G' zone rhyolite and as are some of the rhyolitic rocks and some of the sedimentary rocks within the vent zone. Should not the mineralogy of chloritic rocks make them as susceptible, or more susceptible, to the development of schistosity under tectonic stress as is the rhyolitic rock?

(b) "Stretched rock fragments"—The rock fragments shown in Figures 3(a) and 3(b) clearly are not stretched; those in Figure 3(c) clearly are stretched. Are those in 3(c) (monolithic rhyolite breccia stratigraphically in the footwall of 'G' zone) flattened because they were semi-molten when they were deposited, and were they loaded from above before they cooled? Are those in Figures 3(a) and (b), multilithic breccia, not flattened because they were formed as detritus (sharpstone conglomerate) stratigraphically on the hanging wall of 'G' zone? Do these illustrations not provide evidence that much of the lineation and/or schistosity is limited to the parts of the vent zone that were very close to the individual vents in time and place, rather than evidence of a superimposed tectonic event?

*Paragraphs 13 to 15.* With the above in mind, is an anticline, superimposed upon the complex linear dome-like zone of vents and related volcanic pile or piles, necessary to interpret the structures that can be observed? The paper provides six other points of debate that are contrary to the interpretation of an anticline.

*Paragraph 16.* "The mine area in general, and the immediate ore environment in particular, was affected by brittle deformation ...." No debate is necessary here. The unstable nature of the primary volcanic structures, as described previously in this reply, when intercalated and loaded with unconsolidated water-soaked sediments, would make them particularly susceptible to brittle deformation during the diagenesis of the sedimentary members.

*Paragraph 18.* "To suggest that massive sulphides in the "south wall zone" formed by freezing of sulphides on vertical or overtuned slopes from magmatic flows or fluidized beds, or by incrustation ....... is unnecessary and implausible." This brings us back full circle to the discussion on Paragraph 5. The subject paper left the alternatives open. However, the 'overdraped' (rather than overturned) lava on the sea-cliff in Hawaii, and the black smokers, where minerals precipitate out to form chimneys and blanket slopes at their base in the "Strange World Without Sun", provide irrefutable evidence of primary structures similar to those mapped by Western Mines staff geologists and shown in Figure 17. Why add an extraneous event other than diagenesis of the associated sediments? "The present is the key to the past." Need the unlocking of the past be complicated here be encumbering it with hypothetical events other than diagenesis?

Perhaps the development of the new H.W. orebody will provide evidence to answer some of the foregoing questions, and we will be given the benefit of the knowledge through a new paper.

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# International Association for Hydrogen Energy

Martin Hammerli, of the Chemistry and Materials Division of Atomic Energy of Canada Limited, was recently reappointed for a further two-year (1980-82) term to the advisory board of the International Association for Hydrogen Energy (IAHE) to represent Canada. He passes on the following brief history of the organization.

## History of IAHE

Although the origins of the hydrogen energy system concept go back in history, it was about 1970 or thereabouts when proponents of a "hydrogen energy system" were first heard in any numbers. Significantly, the idea was promoted in several corners of the world almost simultaneously. In March 1974, The Hydrogen Economy Miami Energy (THEME) conference was presented by the Clean Energy Research Institute of the University of Miami. Over 700 scientists, engineers and other interested persons representing some 25 countries attended the 3-day meeting, which served as a distinct landmark occasion. This was a convincing indication that there was both substantial and worldwide interest in the hydrogen energy system concept, with all of its facets.

During the course of the THEME conference, several leading representatives from several nations met together to consider steps toward the formation of a permanent professional society to serve this expressed interest in hydrogen energy. It was agreed to form such an association and, under the leadership of Dr. T.N. Veziroglu, director of the Clean Energy Research Institute, the International Association for Hydrogen Energy (the name selected by the founding group) was incorporated in the State of Florida in early 1975.

The Association has sponsored numerous conferences, symposia and workshops in its brief history. Listed below are its purposes and goals.

## Purposes and Goals

- To foster scientific and technological developments leading to the worldwide application of hydrogen energy.
- To promote public information and education concerning all areas relating to hydrogen energy and its ultimate benefits.
- To act as a forum for local, regional, national and international interchanges of information and cooperative planning in the hydrogen energy field.
- To compile and disseminate information on all facets of hydrogen energy via its official journal and other communication means.
- To advance the cause of hydrogen energy generally.

Interested readers are requested to direct inquiries regarding the IAHE to Dr. Hammerli at: (613)-687-5581.

# New volume on world uranium geology and resource potential

This 524-page volume, by the Joint Steering Group on Uranium Resources of the OECD Nuclear Energy Agency and the International Atomic Energy Agency, contains an incredible amount of data on uranium occurrences and potential for as yet undiscovered resources throughout the world. In addition to deposit descriptions, it gives detailed summaries of the geology of those countries with good uranium potential.

This is the report of the International Uranium Resources Evaluation Project, prepared by the Joint Steering Group on Uranium Resources of the OECD Nuclear Energy Agency and the International Atomic Energy Agency. It is an edited, updated and expanded version of the expert study that was the basis for the OECD/NEA publication *World Uranium Potential: An International Evaluation.*

The NEA/IAEA Steering Group on Uranium Resources extends the knowledge of uranium resources by this expert study to better define the possible extent and location of uranium resources commercially mineable below a cost of (U.S.) $59.00/lb U ($130/kg U). To serve as a basis for the study summarized in this volume, data on 185 countries were obtained and evaluated as to: general geography; geology in relation to potentially favourable uranium-bearing areas; past exploration; uranium occurrences, resources and past production; present status of exploration; and potential for new discoveries.

An excellent summary section gives readers an introduction to the geologic setting of uranium deposits, ranks speculative resources by continent and provides an overview of each continent's geology. The main features of the six categories of ore types in which major uranium resources of the world can be found are then described more fully, with intercontinental correlations examined.

The main body of this book is made up of very complete and detailed reports on the geology fully explained. Each country with good potential for undiscovered resources is then described in terms of geography, geology, uranium resources and production, areas of uranium potential and status of exploration. Additional countries with limited potential are briefly noted.

Illustrated with over 130 geologic maps and diagrams, World Uranium Geology and Resource Potential is a very important and useful book for uranium explorationists.

The report is available, at a cost of (U.S.)$50.00, exclusively from *World Mining,* Book Department, 500 Howard Street, San Francisco, Calif. 94195, U.S.A.