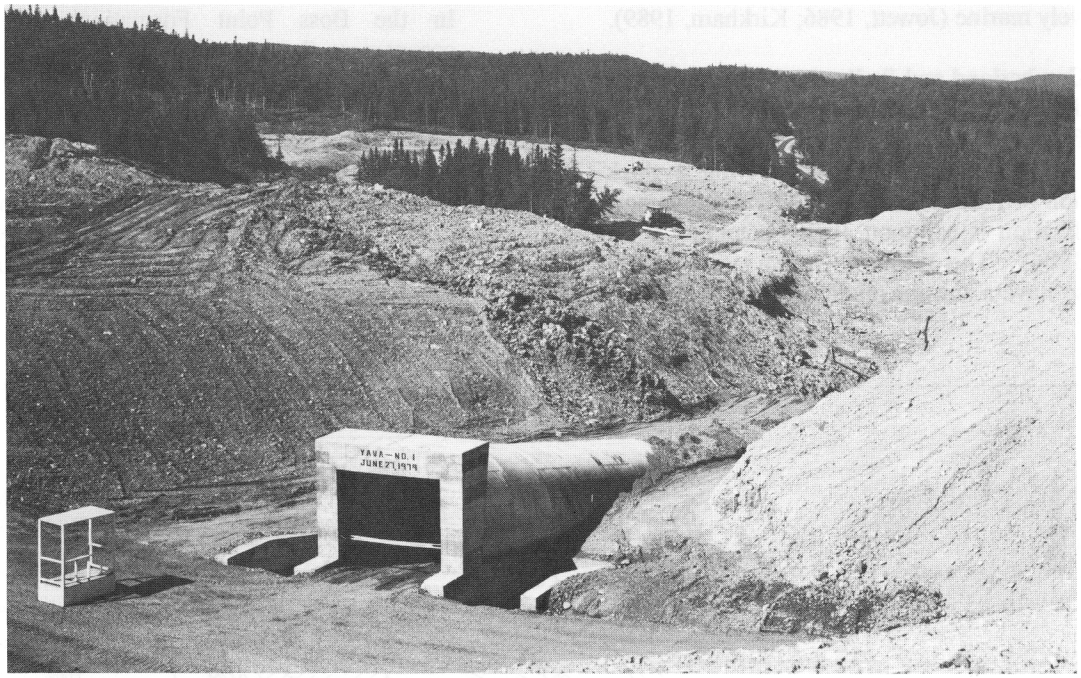
7. SANDSTONE-HOSTED DEPOSITS: YAVA (SALMON RIVER)



Yava mine site.

7.1 INTRODUCTION

Sandstone-hosted base metal deposits are known from a wide stratigraphic range, from late Proterozoic to Triassic, and have a world-wide distribution. The host rocks range from true sandstones, as at Laisvall and Vassbo (Sweden), L'Argentiere (France), Yava and George Lake (Canada), and Bou Sellam (Morocco), to shales as at White Pine (Michigan), the Kupferschiefer deposits of Europe, and the massive copper deposits of Dzhezkazgan in the former USSR. Deposits in this class are major contributors to the world base metal inventory, characteristically being large tonnage but low grade. The White Pine copper deposit in Michigan has an "ore reserve" of 560 Mt @ 1.29% Cu (Seasor & Brown, 1986) and has experienced closure during periods of low copper prices. Thus such deposits are susceptible to fluctuations in metal prices, though the silver content, which in some instances (Mexico) can be very significant, will have a positive economic impact.

Within Nova Scotia this deposit class includes both the coarse and fine clastic-hosted deposits in the Glengarry Half Graben (Boehner & Prime 1985) of Cape Breton Island and the Cumberland Basin of northern mainland Nova Scotia. Those in the Cumberland Basin have been well described by Ryan (1991) and essentially comprise the following types of deposits:

(1) redbed, solution front type Cu, Ag, Zn, Pb, Au, Ba stratiform occurrences of diagenetic origin found proximal to reduction zones;

(2) uranium roll fronts;

(3) unconformity "Kupferschiefer" type (redox) Cu-Ag, occurring where carbon-rich strata overlie a thick redbed succession; and

(4) fault-related mineral occurrences.

Kupferschiefer-type mineralization occurs where there are organic-rich grey strata overlying a predominantly red succession of clastic sedimentary rocks. The Cumberland Basin examples of this type of mineralization differ from

the European Kupferschiefer because both marine and terrestrial strata may act as the hosts for the Cumberland Basin deposits (Ryan and Boehner, 1986), whereas in Europe the host rocks are exclusively marine (Jowett, 1986; Kirkham, 1989).

In the Cumberland and Stellarton basins grey beds of continental origin, which are part of the Boss Point Formation of late Carboniferous age, are usually the first grey horizon overlying a thick succession of redbeds of Early Carboniferous age. Mineralization is common at this boundary (Stea et al., 1986). The Windsor Group marine strata may also have a similar relationship to red clastic rocks of the Horton Group; however, this part of the stratigraphic section is rarely exposed at surface within the area.

In the Boss Point Formation's shale-hosted occurrences the ore mineralogy is almost exactly the same as the solution front deposits in the area. The Cu minerals are chalcocite and bornite with minor associated digenite and covellite. They occur as nodules or as replacement of coalified plant material within the grey siltstones and shales. The Cu minerals are usually closely associated with pyrite, and some traces of sphalerite are also present.

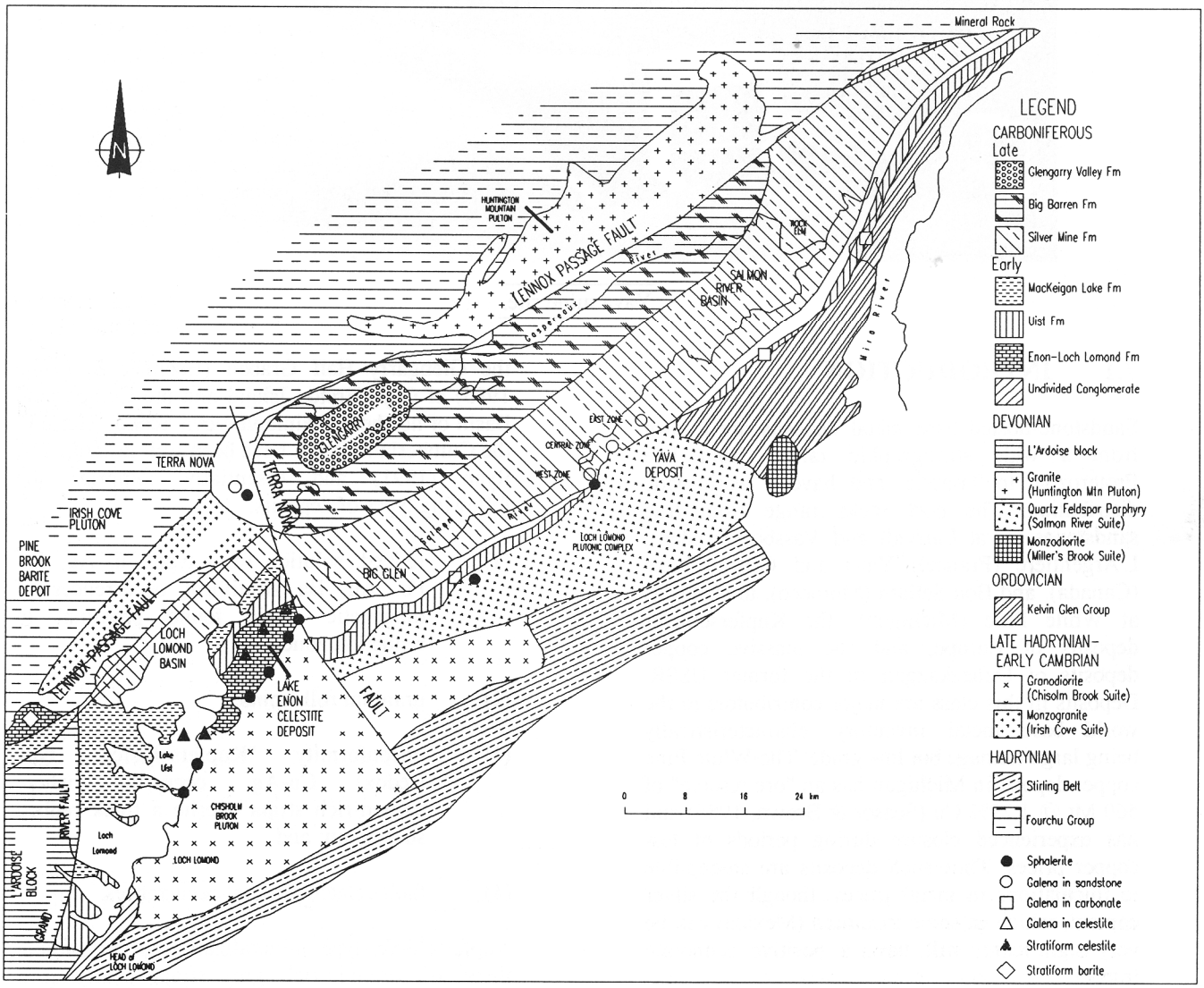


Figure 23. *Geology and mineralization in Salmon River and Loch Lomond basins, Cape Breton Island (modified after Boehner and Prime, 1985).*

The **Donaldson's Mill Brook** occurrence (Ryan, 1991), located south of Canfield Creek within the Cumberland Basin of northern Nova Scotia, is hosted in a 3 m thick grey silty shale, of the Boss Point Formation, which overlies red siltstones and sandstones. The mineralized horizon is approximately 50-100 m stratigraphically above an unconformity with red conglomerates of Early Carboniferous age. The mineralization occurs as a 1-3 m thick horizon that contains chalcocite and bornite nodules up to 2 cm in diameter, and as coalified plant stems that have been mineralized by pyrite, chalcocite and bornite. The occurrence has an outcrop strike length of 45 m and samples by Ryan from three assay channels delineated a 110 cm zone of 1% Cu with 0.25 oz. per ton Ag. High grade grab samples from the occurrence contain up to 17 oz. per ton Ag. Sandstone-hosted mineralization, predominantly pyrite but with some zinc oxide minerals, occurs over a 25 m intersection in a nearby drillhole (AN 4) and suggests potential for a Cu/Zn deposit.

The actual sandstone-hosted deposit type is exemplified by the Yava and Terra Nova deposits in the Glengarry Half Graben in Cape Breton Island and the **Yava** deposit has been selected to illustrate this class.

7.2 LOCATION

The Yava (Salmon River) Pb deposit is located at Salmon River, Cape Breton County, NS on NTS Map Sheet 11F-16B and at latitude 45^{o} 51'30" N, longitude 60^{o} 24'50" W, and approximately 42 km (by road) southwest of Sydney. The deposit is situated on the southeast flank of the Carboniferous Salmon River Basin, (Fig. 23) which has been referred to as the Glengarry Half Graben by Boehner and Prime (1985).

7.3 EXPLORATION AND MINING HISTORY

Documented activity in the Salmon River area dates from 1928 when W. W. Goodwin reported on exploration by Aconda Mines on showings of argentiferous galena in limestones and basal Carboniferous conglomerates known since the 1880s. This work showed weak vein galena mineralization in the Windsor Group of Lower Carboniferous age. Two diamond-drill holes were completed on the "Mindus Smith Prospect" in 1952 and these intersected vein type galena mineralization in the basement rhyolites.

The discovery, in the late 1950s, of argentiferous base metals associated with the Windsor Group-hosted massive barite mine at Walton, Nova Scotia, led to an extensive exploration program by Talisman Mines along the Horton/Windsor contact in the province. This program, a joint venture between Talisman (77%), Gunnex Limited (20%) and Lehman Bros. (3%), soon met with success in the Salmon River Basin. Geochemical indications were followed up by a drilling program which intersected disseminated galena in the sandstones immediately overlying the Windsor Group shales. Talisman completed 28 drillholes over a strike length of 3000 m and a down dip extension of 600 m. The tonnage potential of the discovery caused Phelps Dodge Corp. of Canada to acquire a 57.8% interest in the deposit in September 1962. Between 1962 and 1969 Phelps Dodge completed 24,700 m of drilling in 219 holes and undertook numerous feasibility studies examining various production options. The project did not proceed to production.

In 1975 Barymin Explorations, having acquired Gunnex Limited in 1972, bought out the Phelps Dodge share and in 1977 acquired 100% ownership of Yava Mines by purchasing the Talisman interest. In the same year the mothballed Kaiser concentrator at Enon (Fig. 23), some 11 km southwest of the Yava deposit, and which had processed the celestite ore from the Enon deposits, was purchased by Yava. During 1977 Barymin completed 4255 m of drilling in 69 infill holes and outlined higher grade areas in the West zone.

Regular commercial production was achieved from the West zone in June 1979 and in the period to September 1981 388,000 tonnes were mined at a head grade of 4.69% Pb. During 1980 and 1981 Yava Mines completed 5300 m of drilling in 48 holes. Financial difficulties in mid-late 1981 caused production to be halted and in late 1981 Yava Mines declared bankruptcy.

Ownership of the property reverted to the province and during 1986 and 1987 a limited drilling program, comprising 917 m in 23 holes, was carried out by the N. S. Department of Natural Resources. This program demonstrated the potential for zinc deposits in the vicinity of the mined area.

In 1989 a Special Licence was issued to 656593 Ontario Ltd. to permit investigation of the possibility of in-situ leaching of the deposit. Initial drilling on this project began in 1992.

7.4 REGIONAL GEOLOGICAL SETTING

The Yava deposit is situated (Fig. 23) on the southeast flank of the Salmon River sub-basin (the Glengarry Half Graben of Boehner & Prime, 1985), an outlier composed predominantly of Late Carboniferous continental clastic deposits of Namurian and Westphalian ages. The outlier, 30 km long in a northeasterly direction and 10 km wide (maximum), plunges gently to the southwest.

The northwestern flank is controlled by the regional northeast-trending Lennox Passage Fault, while the sediments on the southeastern flank dip gently northwest at 14 - 15^{o}. Boehner and Prime (1985) define the western boundary of the Glengarry Half Graben as the junction between the Salmon River and the Loch Lomond Basin, which is marked by the northwesterly-trending Terra Nova Fault, the largest of the northwesterly-trending faults within the map area.

The basement rocks to the southeast and northwest comprise late Proterozoic and early Cambrian metasediments and metavolcanics which are intruded by granitic and dioritic complexes. The age relationships of these intrusive phases are uncertain though the general concensus assigns them to a range from late Precambrian to pre-Devonian.

The Early Carboniferous Windsor Group is represented by marine shales and carbonates in a narrow linear strip along the southeastern margin, whereas faulting along the northwestern basin margin has caused the Windsor to be patchy or absent. The Late Carboniferous is represented by a monotonous sequence of sandstones, conglomerates and shales interpreted as being of continental origin.

In gross terms the basal Windsor Group units represented in the Loch Lomond Basin are absent from the Salmon River Basin and the mineralized brown-tan coloured dolomitic limestones in the Big Glen area, to the southwest of Yava, are absent in the mine area. These limestones are younger than the mineralized limestones in the Loch Lomond Basin.

7.5 DEPOSIT GEOLOGY

The initial stratigraphy within the mine area was determined by the excellent work of Phelps Dodge geologists Mudford (1964 and 1969) and Watson (1963) during the intensive exploration phase of the 1960s. The detailed M.Sc. thesis research of Bonham (1983), using information compiled during the underground mining phase in the 1979-81 period, has greatly assisted in understanding the deposit.

At the Yava Mine the footwall **Windsor Group** unit is a conglomerate or talus breccia comprising highly angular and closely packed pebbles of the underlying 'rhyolite', or more correctly quartz-feldspar porphyry, set in a green clayey matrix. A red and green shale forms the footwall in the area of the mine and passes transitionally downwards into a black shale with evaporites. The top of the red/green shale member is marked by a zone of weathering represented by a soft green clay, which has been referred to as a paleosol or calcrete.

The host rocks to the mineralization are the basal clastics of the Late Carboniferous **Silvermines Formation** (Riversdale Group, Boehner & Prime, 1985; or possibly the Canso Group, Bonham, 1983). The Silvermines Formation comprises grey-green arenaceous sandstones with interbedded conglomerates, shales and mudstones. Coalified plant material is common throughout this unit which was estimated by Mudford (1964) to be 240 m thick in the mine area. Overlying the Silvermines Formation are the clastics of the Morien Group.

7.6 PALEOGEOGRAPHIC ENVIRONMENT

Bonham (1983) recognises four different depositional environments for the sediments in the Salmon River basin and outlined the following palaeogeographic history.

The pre-Carboniferous topography was a series of hills and valleys along parts of the southeastern margin of the basin. The breccia-conglomerate, which partially infilled the pre-Carboniferous topography, is interpreted as a sub-aerial scree accumulation rather than an alluvial fan as proposed by Scott (1980). The late Visean transgression resulted in the deposition of Windsor

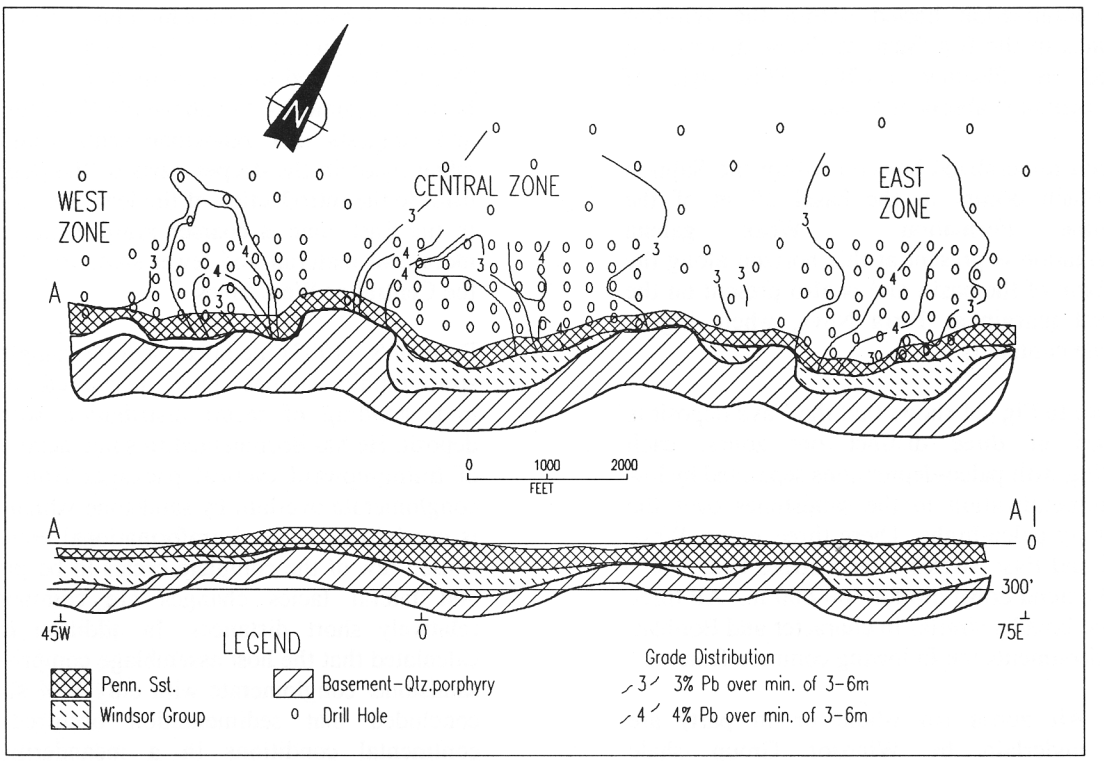


Figure 24. *Yava deposit - showing relationship between basement topography and mineralized zones.*

Group shales and siltstones with interbedded limestones and evaporites. Within the vicinity of the mine the limestone component of this McKeigan Lake Formation is minor and increases southwestwards toward Big Glen and the Loch Lomond Basin. The calcrete and palaeosol horizon marks a period of emergence at the end of Visean times. This was followed by a lengthy period of deposition of continental-derived clastics in a fluvial environment. These deposits, initially confined to the already partially filled depressions, eventually accumulated to the extent of 1500 m and include coal horizons.

7.7 DISTRIBUTION OF MINERALIZATION

In the vicinity of the Yava deposit the basement porphyry forms a palaeotopographic high which extends along strike for 3 km. Within this high are three main depressions, or palaeovalleys, within which a sandstone-dominated clastic sequence was deposited above the Windsor disconformity (Fig. 24). Lead mineralization is contained within the basal 25 m of this 240 m thick sandstone unit, the actual location varying relative to the proximity of the basement topographic highs.

Though the main lead horizon at Yava is near the base of the Silvermine Formation sandstone, galena has been recorded from other stratigraphic levels in the vicinity. Mudford (1964) describes the galena mineralization within the porphyry (rhyolite) and talus breccia as follows:

"Galena occurs in the rhyolite (porphyry) talus breccia and, where the underlying rhyolite is heavily fractured, it often extends into the rhyolite occurring mainly as thin smears along fracture planes. Occasionally, where narrow stringers and blebs were present the grade approaches economic significance, and grades up to 6.65% Pb/ 6 ft. were reported by Watson (1963) in one drillhole."

Mudford relates this to the old showings which created the initial interest in the area in the 1880s and concludes that such occurrences would have very little economic potential.

The mineralization hosted within the Windsor carbonates in the Big Glen, to the west, was first recorded by Fletcher (1878). This style of mineralization is absent at Yava.

The main mineralized horizon within the Salmon River Basin occurs in the basal 25 m of the Silvermine Formation. Weak galena mineralization is present at this horizon along the south flank of the basin and is also present on the northwest margin at Terra Nova, where higher sphalerite content is noted.

Reference to Fig. 24 shows that the Yava deposit is composed of three distinct ore zones, each coinciding with paleo-depressions separated by low grade mineralization in the sandstones over the intervening paleo-highs. These three zones, West, Central and East, stretch over a strike length of 3 km and extend down dip for 500-600 m. All three zones are broadly similar in character and Bonham (1983) documents the following common features:

1- All zones (in whole or in part) are underlain by Windsor Group shale footwall,

2- A higher grade central core passes out progressively through lower grade material to a surrounding halo of weak mineralization,

3- The thickest ore (5-7 m) coincides with the highest grade areas,

4- The styles of mineralization are similar in all three zones,

5- The host rock sandstone assemblage comprises laterally discontinuous beds of conglomerate, sandstone and shale. Mineralization is generally most abundant in the sandstone and absent in the shales, and

6- The mineralization occurs as a cement within the sandstone.

Differences between the zones relate mainly to the location of the mineralization. In the West zone the ore rests directly on a Windsor footwall while in the Central and East zones the ore horizon may rest on Windsor shales, porphyry basement or be underlain by sandstone. The nature of the footwall relates to the position of the basement high and the amount of sedimentation which had occurred prior to the mineralizing event. Thus in the centre of the Central zone and in part of the East zone the ore horizon is some 5 - 9 m above the Windsor contact and suggests that sandstone sedimentation had taken place in the deeper parts of the depressions prior to the introduction of the lead. The sandstone in the East zone is coarser grained and contains more coal material and fewer shale interbeds than the Central or West zones.

Bonham's (1983) detailed sedimentological and stratigraphic studies have permitted a better understanding of metal distribution within the deposit. He has documented in some detail a series of fining-upward cyclical packages from a basal conglomerate overlain by sandstone which in turn is overlain by shale. Intraformational erosion has caused few of the complete cycles to be preserved and lateral facies changes are common over relatively short distances. In addition Bonham calculated that the host assemblage comprises 89% sandstone/ conglomerate with only 11% shale. He concluded that sedimentation occurred under continental conditions in a meandering river system and concurs with Patterson (1979) that mineralization was introduced in the late stages of diagenesis.

7.8 STYLES OF MINERALIZATION

Bonham (1983) described three main styles of mineralization. **Style 1** (the majority of the mineralization) is concordant, disseminated mineralization associated with both microscopic (seven different sub-styles) and macroscopic features. **Style 2** mineralization is also disseminated but is discordant with respect to the sedimentary fabric (foresets) but concordant with respect to the partings between groups of foresets. **Style 3** mineralization is very minor in distribution and is represented by remobilized coarse galena occurring with pyrite and calcite in fractures.

It should be noted that where seen in the West zone, the mineralization is discordant with respect to host rock stratigraphy. It passes laterally through the overstepping sedimentary sequence in order to follow the basal unconformity with the footwall Windsor Group rocks. Ore grade is highest at the footwall and decreases upward.

7.9 ORE MINERALOGY

Galena is the dominant sulphide present and is widespread in distribution. Sphalerite and pyrite occur locally and are concentrated around coalified plant remains. Chalcopyrite and marcasite occur as rare isolated crystals associated with other sulphides. Though macroscopic sphalerite was not noted within the main zones, Patterson (1986,1987 & 1988) reported macroscopic, very pale coloured sphalerite in drill core from an area west of the West zone. Bonham (1983) reports that a typical Yava ore, as derived from a study of drillcore assays, using a 3.5% Pb cut-off, would contain 5.9% Pb, 0.36% Zn and 5.8 ppm Ag.

7.10 ORE GENESIS

Textural considerations indicate that galena mineralization represents the last diagenetic phase (Bonham, 1983) and pre-dates Hercynian tectonism. Analogies with other sandstone-hosted sulphide deposits suggest low temperature diagenetic mineralization in the presence of organic-rich anoxic conditions. Bonham concludes that a model involving basinward migration of saline groundwater containing lead and zinc in chloride complexes along the floor of an aquifer would be suitable.

Supporting evidence for a late diagenetic age of the mineralization is the occurrence of calcareous concretions (calcite plus siderite), devoid of galena but containing pyrite. These features, which can be perfectly round and range from centimetres to 1.5 m in diameter were sealed prior to lead deposition. High grade galena can occur in the enclosing sandstone and can be smeared along the concretion/ sandstone contact. Recognition of these features helps explain non-correlation of high grade ore zones between closely spaced (30 m) drillholes. Bonham (1983), and Sangster and Vaillancourt (1990) describe the sulphide mineralization associated with the coalified plant remains. Three textures associated with coal plant mineralization were described ranging from open cellular fill, through deformed or cataclastic to fractured. The sulphide-filled, undeformed cellular structure led to the conclusion that mineralization had occurred in part before compaction of the weak plant structures.

7.11 PRODUCTION HISTORY AND DATA

Mining commenced from the West zone in mid 1979 and to the termination of operations in September 1981 some 388,000 tonnes at a mill head grade of 4.69% Pb were mined and milled. At the time of closure daily mine tonnage was 1080 tonnes with a record daily production of 1540 tonnes having been achieved. Mine access was by means of a zig-zag -17% decline which crossed the dip of the orebody at an oblique angle. Trackless equipment was used in the room and pillar mining operation. Headings ranged from 6.5 to 9 m in width and the mining height ranged from the minimum 3.7 m to a maximum of 7.6 m.

The Yava mill was located at Enon, 12 km to the west of the mine site. The mill, operating 7 days per week, had a rated capacity of 770 tonnes per day and on occasions exceeded 1000 tpd. With an average millhead grade of 4.70% Pb, some 25,700 tonnes of Pb concentrate were produced at an average grade of 67% Pb (plus 68 g Ag/t) representing a recovery rate of 92%.

7.12 EXPLORATION POTENTIAL

As noted above Yava is one of several mineral occurrences known in the Loch Lomond-Salmon River basins. Deposits include the former producing carbonate-hosted celestite (Lake Enon) and barite (Pine Brook) deposits, both with associated sulphides. Lead mineralization has been known in the dolomitized carbonates in the Big Glen for many years and drilling has returned short (0.5 m) sections of up to 10% Pb. Minor Windsor carbonate-hosted mineralization occurs to the northeast of Yava at Rock Elm. Upper Carboniferous sandstone-hosted mineralization is known at Terra Nova in the northwest of the Salmon River Basin, at the boundary with the Loch Lomond Basin and zinc values in excess of 3% (which is much higher than at Yava) have been intersected.

Exploration potential exists in the immediate vicinity of the Yava deposit and the following targets are proposed.

7.12.1 Down Dip - West Zone

Previous investigators (Metallgesellschaft, 1981; Bonham, 1983) stated that the West zone had been closed off down dip. However, Patterson (1987, 1988) demonstrated that the sharp cut-off in grade down dip coincided with a basement topographic ridge running parallel to the basement margin (Fig. 25). He states:

"the paleoridge rises steadily to the northwest and there is a suggestion, in the most northwesterly part, that the relief may be dropping down again into a depression. If a parallel depression exists to the west of this ridge then possibilities also exist for a renewed development of ore grade material in this depression".

If this contention can be verified then similar potential may exist in the other zones.

7.12.2 Central Zone

Metallgesellschaft (1981) stated that the Central zone mineralization occurred at two stratigraphic levels. The first level is near the Windsor or basement contact close to the topographic highs whereas the second zone is contained within the sandstone at some distance (5 - 10 m) above the contact. It is proposed that this is one zone only with the sandstones in the centre of the depressions having been lithified before the mineralizing process and therefore acting as a non-porous footwall to the mineralization. Thus, at the time of mineralization, sandstones had already been deposited in the basin centre while basement rocks were still exposed along the flanking basement topographic highs.

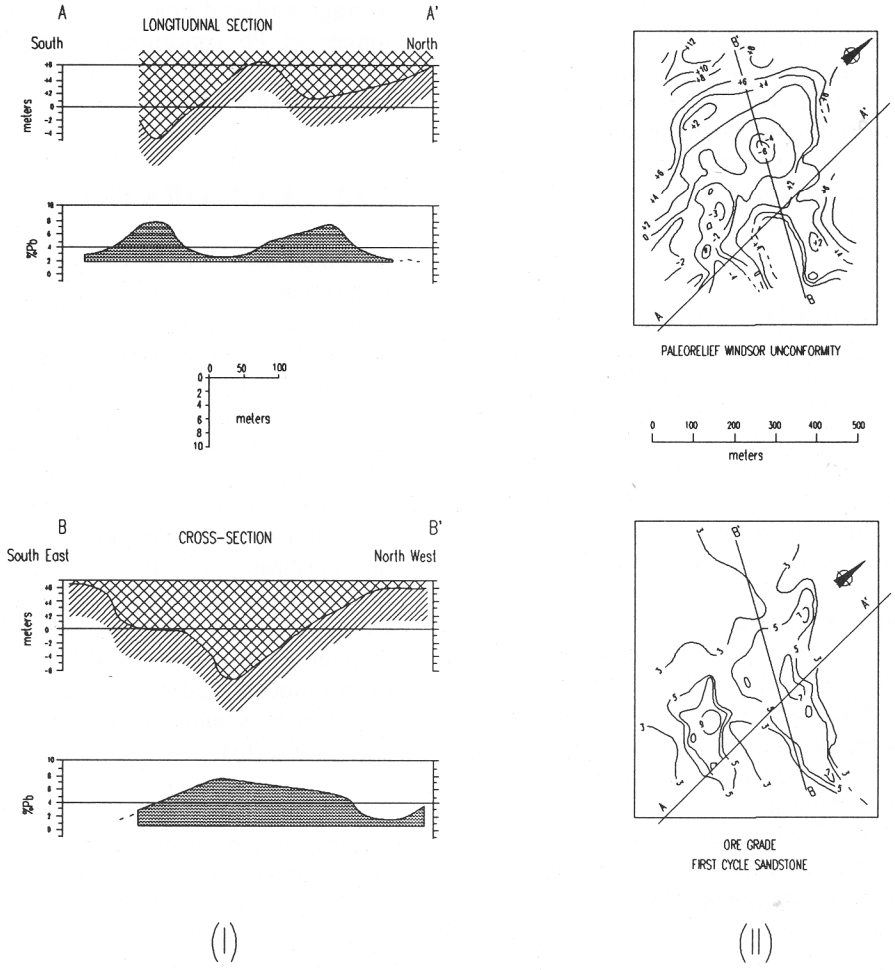


Figure 25. *Yava deposit. West zone. Controls to mineralization and exploration potential (modified after Bonham, 1983, and Patterson, 1988).*

7.12.3 Zinc Potential

Analogies have been drawn with the Laisvall sandstone-hosted Pb/Zn deposit in Sweden, where a large tonnage Pb deposit passes down dip into a Zn deposit which has no surface expression (Rickard et al., 1979). At Yava, Scott (1980), and Bjorlykke and Sangster (1981) had indicated a small enrichment in zinc at slightly higher stratigraphic levels. Drilling by US Borax in 1980 (Burton, 1980) reported 3.32% Pb, 2.26% Zn and 1.09 oz. Ag/t over approximately 2 ft. in a coaly horizon some 800 ft. above the contact with the Windsor. Patterson (1986, 1987 & 1988) followed up this hypothesis with two drilling programs and outlined a coherent area of relative zinc enrichment west of the West zone (Fig. 26). Very pale, finely disseminated, interstitial sphalerite was encountered in sandstone with the best Zn intersection for disseminated sphalerite being 1.02% Zn/2.9 m. The highest Zn value, 2.2%/0.75 m, is associated with pyritic sandstone containing coal debris.

7.13 CONCLUSIONS AND EXPLORATION POTENTIAL IN OTHER BASINS

The Yava Pb deposit is an example of the sandstone-hosted class of base metal deposits. Previous exploration and mining activity at Yava has demonstrated the presence of large tonnage, low grade deposits in this environment and the ability to successfully exploit these deposits.

Potential still exists within the immediate mine area and other potential has been demonstrated within the Salmon River Basin as a whole. The demonstration of a zinc 'enrichment' down dip at Yava and the higher zinc grade of the Terra Nova deposit suggest that the search for a mixed Pb/Zn deposit, similar to Laisvall, is warranted in this environment.

Analogies can be drawn with similar deposits elsewhere in North America, Sweden, France, N.

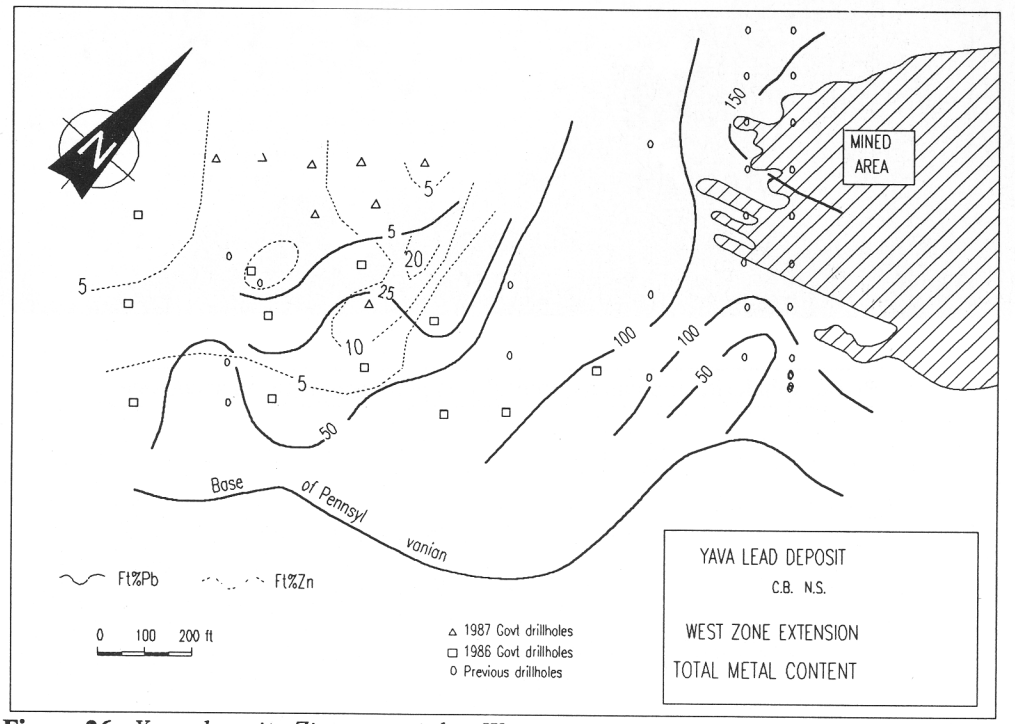
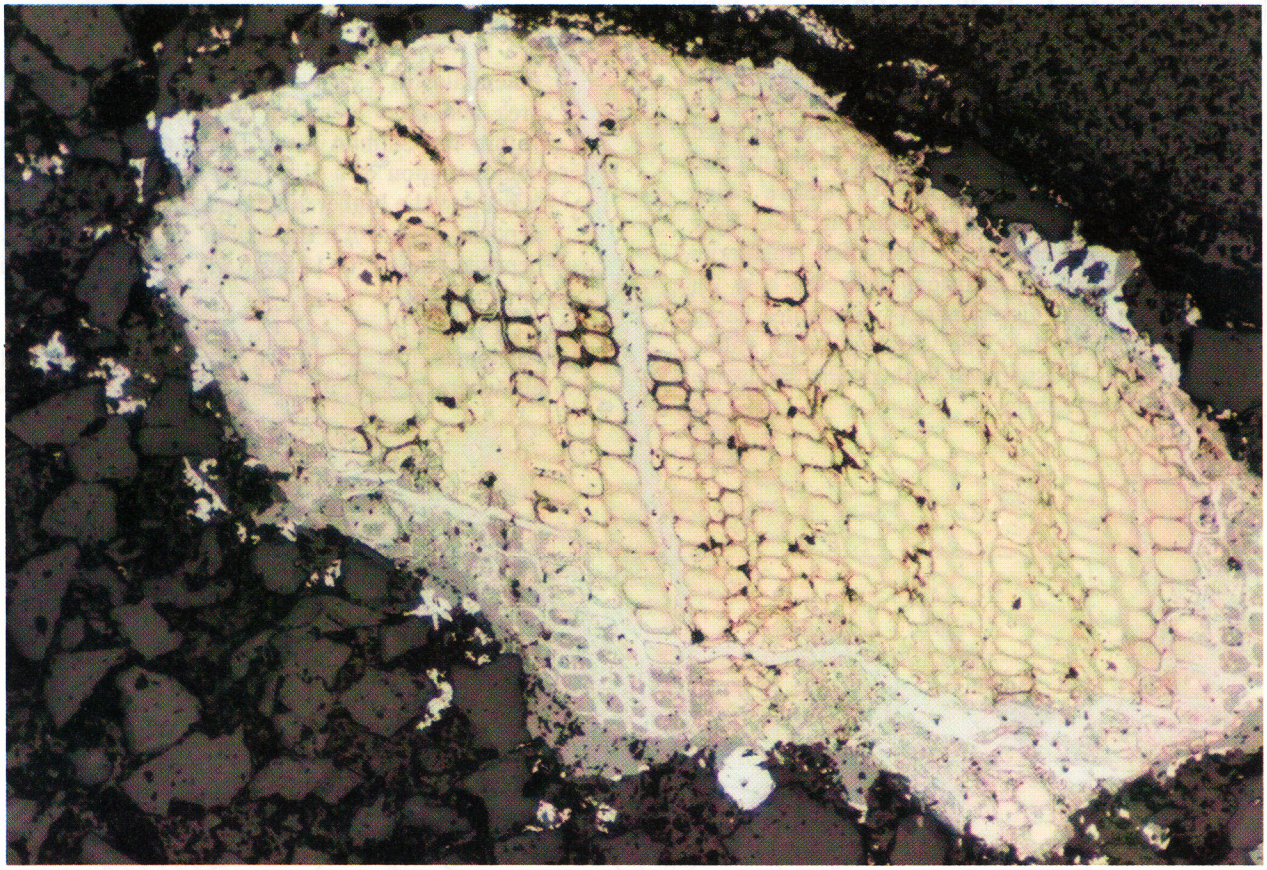


Figure 26. *Yava deposit. Zinc potential in West zone extension (Patterson, 1988).*

Africa and Germany and demonstrate the widespread, both geological and geographical, distribution of such deposits. Some of the occurrences in the Cumberland Basin of northern mainland Nova Scotia bear similarities with the Yava setting and the intersection of 25 m of disseminated pyrite with indications of zinc mineralization in a sandstone unit in DDH AN 4, drilled by Gulf Minerals near Donaldson's Mill Brook, is encouraging. Though analogies with the prolific Kupferschiefer deposits of Poland may be more appropriate for many of the Cumberland Basin showings, it is considered that further exploration in this environment for both shale- and sandstone-hosted metalliferous deposits could be rewarding.



Pyrite, sphalerite and galena, in coalified plant fragment, in sandstone.