The origin and economic potential of sandstone-hosted disseminated Pb-Zn mineralization in pyritic shale horizons of the Mid-Proterozoic Newland Formation, Montana, USA

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Abstract. Pyritic shale horizons of the Newland Formation (Belt Series, Mid-Proterozoic) show striking similarities to Proterozoic pyritic shales elsewhere that are host to major lead-zinc deposits, such as Mt. Isa and McArthur River. However, in contrast to these deposits the pyritic shales of the Newland Formation contain only minute quantities of lead and zinc. Elevated concentrations of lead and zinc are only found in pore spaces of intercalated sandstone beds. Petrographic and geochemical data indicate that pyritic shale deposition and elevated lead-zinc concentrations in sandstone beds are unrelated, that base metal mineralization is controlled by initial porosity, and that iron and base metals were derived from different sources.

Petrographic studies show that base metal sulphides are diagenetic and resemble disseminated mineralization described from sandstone hosted lead-zinc and copper deposits in the Belt basin and elsewhere. The absence of orebodies of disseminated lead-zinc mineralization in sandstones of the Newland Formation may be due to a comparatively thin sedimentary sequence below the sandstone occurrences, as well as to unfavourable geometry and small volume of sandstone bodies.

The Mid-Proterozoic Belt basin (Fig. 1) contains several mineral deposits and mining districts of major importance, among them Sullivan (Zn, Pb, Ag, Sri), Coeur d'Alene (Pb, Zn, Cu, Ag), and Troy (Cu, Ag). Numerous occurrences of sediment hosted base metal mineralization were found in a long history of mineral exploration (Reynolds and Harrison 1981; Lange and Eby 1978; Connor et al. 1981; Rye et al. 1981). Huge pyritic shale horizons, recognized in the late 1970's in the Helena embayment (Fig. 1), were intriguing exploration targets because of their great similarity to pyritic shales that host the Pb-Zn-Ag deposits of Mt. Isa and McArthur River in Australia. Yet more than ten years of drilling activity yielded not a single Pb-Zn ore body. A study by Schieber (1985) led to the conclusion that these pyritic shales are probably pyrite mineralized microbial mats, that the iron was carried into the basin by continental runoff (Schieber 1987, 1989, 1990), and that pyritic shale hosts of above Australian deposits may have the same origin and are unrelated to Pb-Zn mineralization. In this paper diagenetic mineralization in pyritic shale horizons of the Newland Formation is described. It will be demonstrated that diagenetic Pb-Zn mineralization is porosity controlled and independent of the formation of pyritic shales.

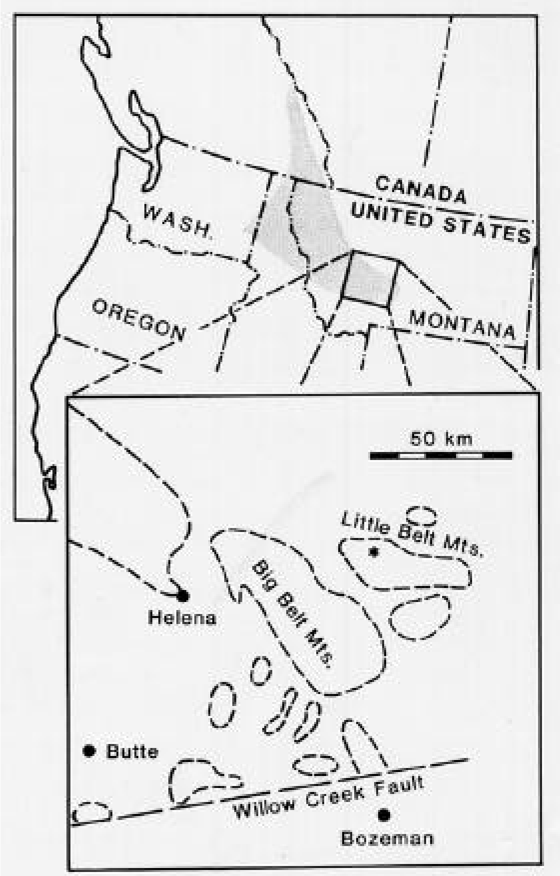


Fig. 1. Location of study area. Present day outline of Belt basin indicated by stipple pattern. Enlarged portion of map shows outcrop areas of Belt sediments in the Helena embayment. Star symbol: location of pyritic shale horizons, southern Little Belt Mountains

Geologic setting

The Newland Formation of the Helena embayment (Fig. 1) correlates with the upper portions of the Prichard Formation in the central and western Belt basin (Harrison 1972), and is subdivided (Nelson 1963) into a lower (dolomitic shales) and upper member (alternating shale and carbonate packages). A sandstone bearing transition between lower and upper member is informally called the Newland Transition Zone or NTZ (Schieber 1985, 1987). The pyritic shale horizons mentioned above occur in the upper portion of the NTZ. Further information on the geologic background of the Newland Formation can be found in Schieber (1985, 1987 b, 1989).

Of particular interest for this study are interbeds of sandstone (well sorted calcarenaceous subarkose) and conglomerate (shale and carbonate clasts in sand matrix) in shales of the Newland Formation, because they contain the more conspicuous examples of base metal mineralization. These coarse elastic beds are most abundant in the NTZ.

Mineral paragenesis

Sediments of the Newland Formation show a well defined sequence of diagenetic minerals, including pyrite (Py), sphalerite (Shl), galena (Gn), chalcopyrite, silica, dolomite, and calcite. Pyritic shales show the same mineral paragenesis as observed elsewhere in the Newland Formation.

Pyrite diagenesis

Five distinct types of pyrite (Py-A through Py-E) are present and are always arranged in the same succession, even though the sequence of pyrite generations is commonly incomplete. All Py types with exception of Py-A (earliest) can be found to overgrow other diagenetic minerals. Py-A is the fine crystalline Py (1-10 gm in size) that is typical for laminated Py beds of the pyritic striped shales (Schieber 1985, 1989, 1990). It is whitish-yellow in polished specimens and shows no changes when etched with HN03.

Py-B forms overgrowth rims on Py-A, ranging in thickness from 1 [Lm to tens of ìm If Py-A grains are spaced closely, Py-B overgrowths can coalesce and fill most of the space between Py-A grains (Fig. 2). Etching with HN03 causes this Py variety to darken slightly to a yellow colour.

Py-C has a radial fibrous habit and grows as single spherules (Fig. 3) or as encrustations on earlier Py accumulations (crusts 5-30 ìm thick) and appears yellowishbrown when etched with HN03.

Py-D occurs mostly as overgrowth rims of blockymassive (Figs. 2 and 3) to radial-bladed (Fig. 3) Py (1050 ìm thick). It is the dominant form of Py in pyrite concretions and appears medium brown when etched with HN03.

Py-E commonly forms euhedral crystals (up to 2 mm in size) and occurs as single cubes, clusters of cubes, and as overgrowths on earlier Py generations (Fig. 2). It is of bright yellow colour and does not change when etched with HN03. Emplacement of Py-E seems to involve replacement of host sediment because Py crystals cut across laminae in the sediment.

Above Py types can be observed in shales as well as in coarse elastic beds. However, in shales Py generations A and B are most common, with Py-A being by far the most abundant one. Later diagenetic Py generations (Py-C through Py-E) are more abundant and better observed in sediments with relatively high initial porosity (siltstones, sandstones, conglomerates).

Base metal sulphides in shales

Sphalerite is the most common base metal sulphide and is scattered throughout the Newland shales without particular association to Py. It does not replace Py, and can be found included in Py-B through E. Sphalerite specs (1-200 ìm in size, average 10 ìm form xenomorphic grains of irregular outline (Fig. 4) that resemble micropores documented in microfabric studies of shales (Davies et al. 1988). In places these presumed micropores are filled with quartz, or contain both quartz and Shl. Sphalerite grains may in places contain inclusions of silicate minerals, indicating replacive growth or coprecipitation. Galena grains are similar in morphology to Shl but much less abundant. Chalcopyrite is the rarest base metal sulphide and is in most cases associated with Py (overgrowths on Py-C and Py-E, and replacement of preexisting Py).

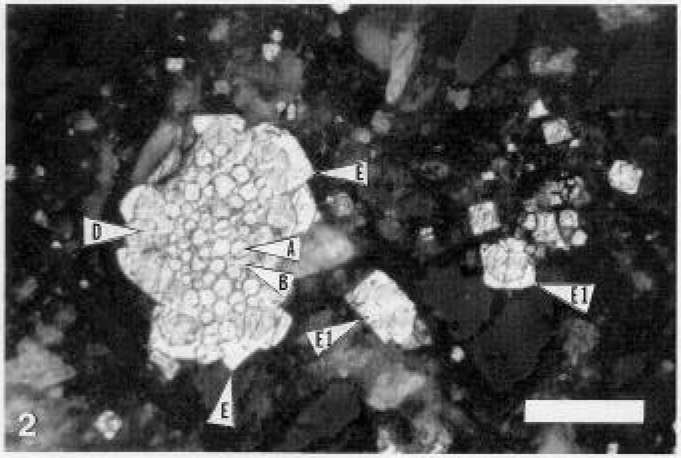
Base metal sulphides in sandstone and conglomerate layers

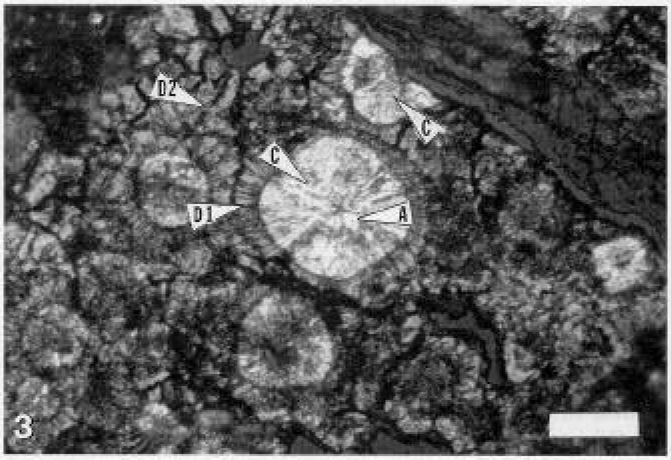
In coarse elastic beds only Shl and Gn were observed (Shl : Gn= 10 :1). Both minerals occur primarily as pore space fillings between detrital grains (Figs. 5 and 6). Sphalerite overgrowth crystals directly on the surface of detrital quartz grains (Fig. 7) indicate that it can occur quite early in diagenetic history, but most Shl grew after or towards the end of quartz deposition in pore spaces. Dolomite cement is found intergrown with and overgrowing Shl. In places replacement of dolomitic shale clasts by Shl was observed (Fig. 8). Galena has only been observed as a pore filling. It typically overgrows Shl cement (if present) and is in turn overgrown by dolomite.

Coarse elastic beds also contain the various Py generations mentioned above, with Py-A preceding diagenetic silica and Shl. Sphalerite occurs as inclusions in Py-B through Py-E, and is also observed as overgrowths on Py-B and Py-C.

Base metal sulphides in laminated pyrite beds

Overall abundance and appearance of base metal sulphides in laminated Py beds is the same as in "normal" striped shales. Sphalerite is most abundant, forms in places cement between Py-A grains, and may occur together with quartz in pore spaces.





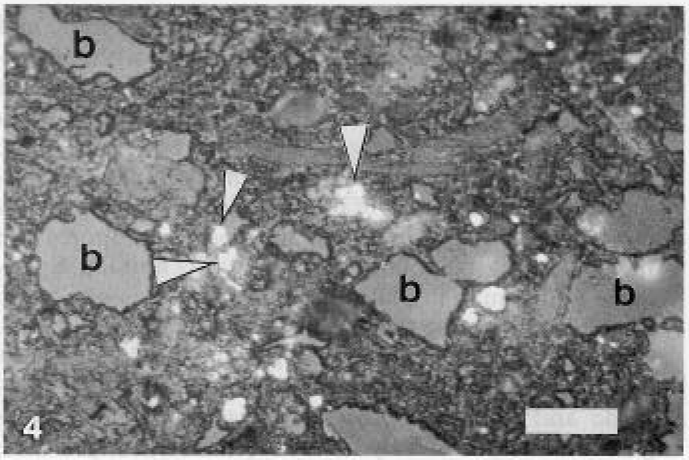


Fig. 2. Pyrite framboid in shale (reflected light), consisting of a cluster of Py-A grains (arrow A). Py-A grains cemented together by Py-B (arrow B). Framboid is overgrown by massive Py-D (gray colour, arrow D), which in turn is overgrown by Py-E (arrows E, euhedral cubic crystal habit). Smaller accumulations of earlier pyrite may be completely enclosed in overgrowing cubes of Py-E (arrows El). Scale bar is 50 ìm long

Fig. 3. Reflected light photomicrograph of spherules of Py-C (arrows C). Py-C is overgrown by Py-D (gray colour), that is of bladed-radial habit where it overgrows Py-C (arrow D1). and of blocky-massive habit further away (arrow D2). One of the spherules that are pointed out by arrows C contains a grain of Py-A in the centre (arrow A). Scale bar is 20 pin long

Fig. 4. Sphalerite in a shale sample from the Newland Formation (reflected light). Sphalerite specs (pointed out by arrows) have irregular outline. There are also several grains of Py-A in this photomicrograph (rounded, highly reflective grains). The shale matrix consists of quartz silt (marked as "q"), mica flakes, and clay. Scale bar is 20 ìm long

Controls on base metal sulphide mineralization

Sphalerite was observed in all shale and sandstone samples of the Newland Formation that were examined closely. Amounts of Shl in shales are typically below 0.01 vol.%, and as pointed out above, there is no noticeable difference between pyritic and normal shales.

Increased abundances of Shl were only observed in sandstone and lithoclast layers. Petrographic and analytical data show that sandstone beds throughout the Newland Formation contain elevated levels of zinc (Schieber 1985), regardless if they were associated with pyritic shales or not. Thus there is an association of Shl enrichment and sediment porosity, rather than a connection between pyritic shales and Shl mineralization (same reasoning applies to Gn). This conclusion is supported by the correlation of Pb-Zn contents and sandstone distribution shown in Fig. 9.

Nature and timing of mineralization

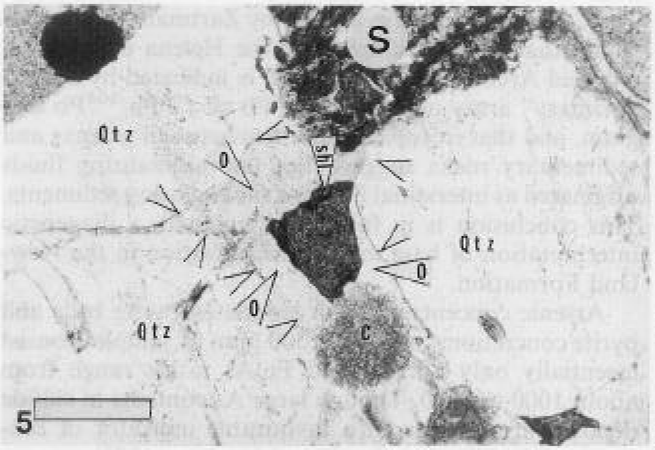
Sandstone hosted base metal deposits are known from sediments of all ages and have been studied in considerable detail (Samama 1976; Fleischer et al. 1976; Hayes and Einaudi 1986; Björlykke and Sangster 1981). Most investigators favour a diagenetic origin, although there is not complete agreement on that (Garlick 1981, 1988).

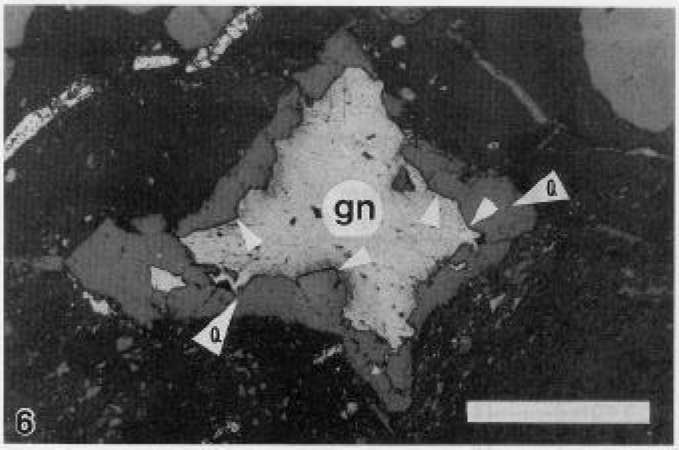
In the Newland Formation, shales between coarse elastic beds are the most likely source for mineralizing fluids, with the coarse elastic beds serving as a "dewatering aquifer" during compaction. Base metal sulphide cementation is an integral part of the diagenetic mineralization sequence of these beds (Fig. 10). At least a few meters of overburden are required to squeeze significant amounts of interstitial fluids out of the interbedded shales, and with an average sediment accumulation rate of 0.1 mm/year (Schieber 1985) it is obvious that noticeable diagenetic mineralization probably did not occur until several tenthousand years after deposition.

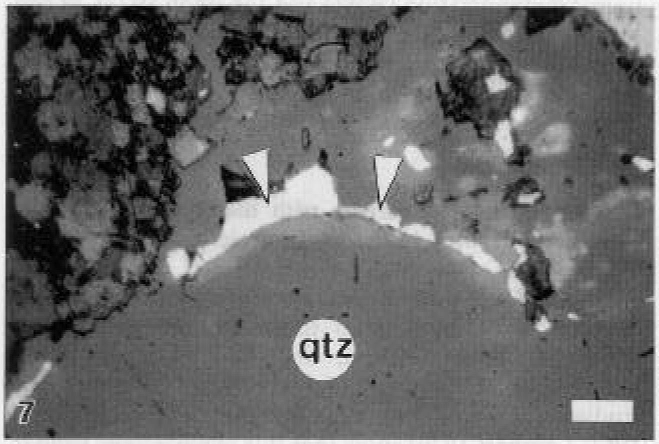
In a few places cross-cutting fractures were found (Fig. 11), filled with quartz, dolomite, Shl, and Gn, and the same mineralization sequence as observed in sandstone and conglomerate layers (Fig. 10). Deformation features indicate that fracture mineralization occurred before the sediment was completely solidified (Fig. 11), and that still 20-30% compaction occurred after mineralization. Application of mudrock compaction curves (Rieke and Chilingarian 1974; Perrier and Quibilier 1974) suggests fracture formation at a burial depth of about 200-500 m. Assuming 0.1 mm/year sediment accumulation and correcting for compaction, this implies that diagenetic base metal mineralization continued for at least 1.4 to 4 million years after deposition.

Geochemical data and their implications

Zn values from "normal" as well as pyritic shales (Fig. 12) of the Newland Formation are more or less grouped around the 95 ppm







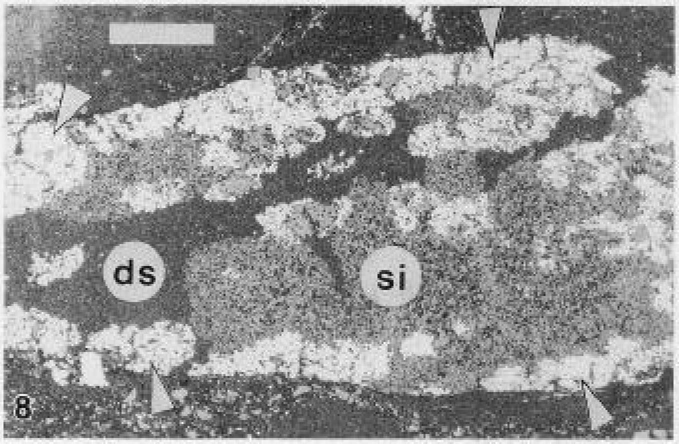


Fig. 5. Photomicrograph of sphalerite in pore space of sandstone (transmitted light). The Shl grain is pointed out by arrow "shl". The pore space is surrounded by quartz grains (qtz) and fragments of shale (marked as "s") and carbonate (marked as "c'"). Diagenetic quartz overgrowth cement (arrows O) was deposited on the surrounding grain surfaces. The boundaries between detrital grains and quartz overgrowth cement are pointed out by small arrows. Sphalerite was deposited in the centre of the pore space. Scale bar is 200 pin long

Fig. 6. Photomicrograph of galena in pore space of sandstone (reflected light). Pore space is surrounded by fragments of shale and carbonate. Pore walls are lined with quartz overgrowth cement (arrows Q) that in places shows well developed crystal faces (small arrows). The centre of the pore space is filled with Gn (marked as "gn"). Scale bar is 0.5 mm long

Fig. 7. Photomicrograph of sphalerite overgrowing quartz grain in sandstone (reflected light). The quartz grain is marked as "qtz". Sphalerite overgrowth indicated by arrows. Scale bar is 25 ìm long

Fig. 8. Photomicrograph of sphalerite and silica replacement of a clast of dolomitic shale (reflected light). Central portions of clast consist of dolomitic shale (dark gray, marked as "ds"). Areas replaced by silica arc light gray in colour and marked as "si". Areas of Shl replacement have the highest reflectance, are most conspicuous around the margins of the clast, and are pointed out by arrows. Scale bar is 200 ìm long

value reported by Turekian and Wedepohl (1961) for the average shale, and indicate that Zn contents in pyritic shales are by no means anomalous. The correlation between Pb-Zn contents and coarse elastics shown in Fig. 9 suggests porosity control of base metal mineralization, a concept that is supported by more recent analyses that show elevated base metal contents in sandstones throughout the Newland Formation.

Py-A of the New Formation has 8345 values of around -14%°. (Strauss and Schieber 1990), indicating bacterial sulfate reduction of contemporaneous seawater (open system conditions). Increasingly positive P'S values for later diagenetic Py generations indicate progressive reduction of sulfate availability in a closed pore water system. Lead isotopes were analysed for three Py and three Gn samples (Table 1). Similar Pb isotope ratios of late diagenetic Py and pore space Gn suggest formation from the same fluids and agree with petrographic observations on mineral paragenesis (Fig. 10). Py-A on the other hand shows distinctive enrichment in

Table 1. Galena samples from pore spaces of sandstones; 11-3-13 from pyrite concretion; 11-17-7A and 11-22-77A from laminated pyrite beds

Samp. #	Mineral	206Pb 204Pb	207Pb 204Pb	208Pb 204Pb
12-1-24	galena	16.739	15.590	36.495
12-1-30	galena	16.745	15.597	36.522
12-1-36	galena	16.700	15.573	36.467
11-3-13	Pv-D&E	16.666	15.500	36.241
11-17-7A	Py-A	17.223	15.611	36.836
11-22-77A	Py-A	17.224	15.605	36.639

radiogenic lead (large 206Pb/204Pb ratio). This lead isotopic difference between early and late diagenetic sulphides further confirms the conclusion that stratiform Py mineralization (laminated beds of Py-A) is unrelated to base metal mineralization in coarse clastic beds. The Gn samples in Table 1 were included in a study by Zartman (1990), who found that in the sediments of the Helena embayment recycled Archean crustal mineral is indicated by a steep "primary" array on a 207Pb/204Pb vs. 206Pb/204Pb diagram, and that isotopic similarities between galenas and sedimentary rocks suggest that the mineralizing fluids originated as interstitial fluids of the enclosing sediments. This conclusion is in full agreement with a diagenetic interpretation of base metal mineralization in the Newland Formation.

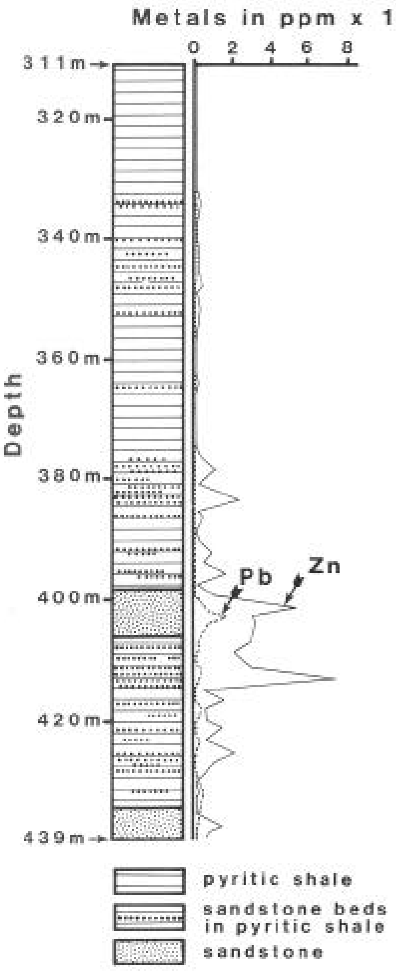


Fig. 9. Variation of zinc and lead contents in a drill core of pyritic shale from the southern Little Belt Mountains (Fig. 1). Sections of core of 1.52 m length (five feet) were split. homogenized, and analysed. Data are from an unpublished report of Anaconda Minerals Co. Increased amounts of zinc and lead coincide with increased abundance of sandstone in the sequence

Arsenic concentrations in laminated pyrite beds and pyrite concretions may reach 500 ppm (if samples consist essentially only of Py), and Fe/As ratios range from about 1000 to 2000. Though large As contents in sulfide deposits are considered a favourable indicator of economic mineralization (Boyle and Jonasson 1973), as concentrations in pyrites of the Newland Formation are within the same range as encountered within modern marine sediments (Belzile and Lebel 1986; Pilipchuk and Sevast'yanov 1968) and do not indicate anything unusual.

Discussion and comparison with major sediment-hosted base metal deposits in the Proterozoic

Pyritic shales of the Newland Formation closely resemble host rocks of base metal mineralization at Mt. Isa, McArthur River, Hilton, and Lady Loretta in the Proterozoic of Australia (Schieber 1990). Petrographic studies of some of these deposits (Love and Zimmerman 1961; Lambert 1976) show that this macroscopic similarity extends down to the microscopic scale. First generation Py and Py-A of the Newland Formation are identical, and successive Py generations compare closely to Py-B through Py-E. Pb-isotope data for the Australian deposits indicate that the ore metals were derived mainly from the underlying sediment piles (Lambert 1983).

Considering these similarities one wonders why Pb-Zn mineralization is so poorly developed in the Newland Formation, and what the differences might be with respect to above Australian deposits. A main difference is of course that in the Australian deposits Pb-Zn mineralization occurs predominantly as conformable sulphide laminae, suggesting a syngenetic exhalative

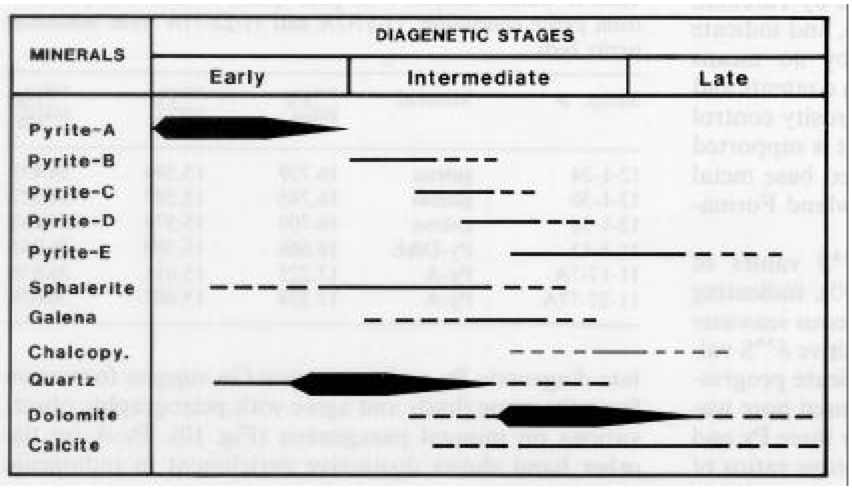


Fig. 10. Sequence of diagenetic minerals in sediments of the Newland Formation. Early diagenetic stage= soft sediment, Intermediate stage= sediment still plastic, Late stage= sediment consolidated. Relative line thickness indicates that Py-A, quartz, and dolomite are by far most abundant, that the various later Py generations, Shl, Gn, and calcite constitute a minor proportion of the diagenetic mineralization, and that chalcopyrite is very rare

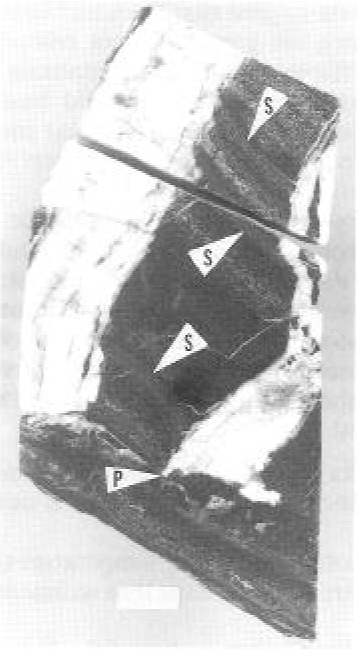


Fig. 11. Cross-cutting fractures in shales of the Newland Formation. These fractures formed before the surrounding sediments were fully compacted. as indicated by compactional deformation of sediment layers between the fractures (arrows S). The curvature of sediment laminae (convex at the bottom, concave at the top of the sample), as well as piercing of sediment layers by fracture fills (arrow P), suggests that fracture fills behaved rigidly in a still plastically behaving matrix. Scale bar is 10 mm long

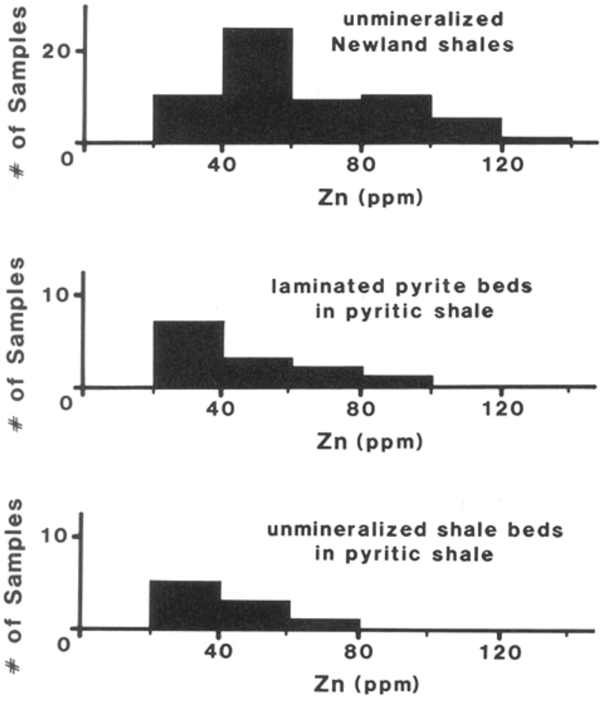


Fig. 12. Zinc distribution in "normal", unmineralized Newland shales, in laminated pyrite beds in pyritic shale horizons, and in non-pyritic interbeds of pyritic shale horizons

origin (Lambert 1983), whereas Pb-Zn mineralization in the Newland Formation is diagenetic.

Pb-Zn mineralization in the Newland Formation resembles disseminated interstitial sulphides in sandstone hosted lead deposits (Samama 1976; Björlykke and Sangster 1981), and disseminated Pb-Zn mineralization in the Revett Quartzite (Belt Supergroup) of the Coeur d'Alene district (Vulimiri and Cheney 1980; Crosby 1984). Actually, with exception of Sullivan (Höy et al. 1981), disseminated base metal mineralization in sandstones and siltstones is the most widespread mineralization type in the Belt Series (Hayes and Einaudi 1986; Harrison 1981; Reynolds and Harrison 1981; Lange and Eby 1978; Rye et al. 1981). Economic deposits of this type occur in the Revett Quartzite (Hayes and Einaudi 1986), and subeconomic deposits occur in the Bonner Quartzite and the Spokane Formation (Connor et al. 1981; Reynolds and Harrison 1981). In the Coeur d'Alene district economic Pb-Zn mineralization is also reported from Quartzites in the Prichard Formation (Crosby 1984).

Typically, disseminated economic base metal deposits in the Belt Series are underlain by at least 9 km's of sediment. Even the deposits in the Prichard Formation (Crosby 1984), are underlain by a minimum of 4 km of sediments (Cressman 1984). Sullivan, the only stratiform deposit, is underlain by >_2.3 km of Aldridge Formation (Lambert 1983) and 1.8 km of Fort Steele Formation (Price 1964), amounting to a total of at least 4.1 km. Sediment piles below the above mentioned stratiform PbZn deposits of Australia are in excess of 3 km thick, and these sediments were probably the main source of ore metals (Lambert 1983).

The thickness of the underlying sediment pile may well determine the total amount of metals available for formation of a deposit, and the relatively small sediment thickness (about 1.2 km; Schieber 1985) below Pb-Zn mineralization in the NTZ could be one of the decisive differences that sets it apart from above mentioned economic deposits. Thick basin fills also imply higher temperatures, metal release during smectite-illite transformation (Lydon 1986), increased solubility of base metals in basinal brines (Carpenter et al. 1974); and increased pore water pressures and potential for episodic fluid expulsion (Sawkins 1984). Assuming a sediment thickness of 1-2 km and a geothermal gradient of 3 °C/100 m, the base of the section below the NTZ would range in temperature from 30-60 'C, considerably too low for metal release by smectite-illite conversion that begins at about 90°C (Lydon 1986). This may be an additional cause for the lack of larger ore bodies in the Newland Formation.

Geometry and volume of a sandstone host are another factor worth considering. Whereas the Revett Quartzite comprises a thick (650 m) sandstone package of large regional extent (Harrison 1972), sandstones and conglomerates in the NTZ are commonly single beds (1150 cm) intercalated with shale (Schieber 1987). Thicker sandstone bodies (up to 50 m) occur locally, but are only of limited lateral extent (Schieber 1987). Thus, the Revett Quartzite could have been a major channelway of compaction-driven fluid expulsion for a large portion of the Belt Series, whereas sandstone bodies of the NTZ had only a small “catchment area” with respect to compaction fluids, further limiting potential Pb-Zn mineralization. An additional factor that might have prevented formation of larger sulphide ore bodies is the limited sulphate supply during later stages of diagenesis that is indicated by increasingly positive $\delta^{34}S$ values for diagenetically later sulphides (Strauss and Schieber 1990).

A final point to consider is the fact that low level base metal mineralization in sediments is not as unusual as one might think. A number of examples are illustrated by Ramdohr (1953), Mossler (1971) reports diagenetic Shl in carbonate rocks of Kansas, and Amstutz and Park (1971) describe the position of sulphides in sediment diagenesis from a variety of sediments and mineral deposits. Widespread diagenetic Shl and Gn has been described from the Triassic Muschelkalk of Europe (de Boorder et al. 1985), and in some horizons such mineralization can be shown to extend over wide areas (Schneiderhöhn 1955). Even the Belt basin itself contains numerous shows of small scale porosity controlled base metal mineralization (e.g. Reynolds and Harrison 1981; Lange and Eby 1978).

In one locality from the southern Little Belt Mountains subeconomic Cu-Co mineralization has been reported from pyritic shales in the Newland Formation (Engineering and Mining Journal, May 1989, p. 7, and April 1990, p. 7-8; Zieg and Rankin 1989). Examination of drill core material by the author indicates that chalcopyrite mineralization has replaced pre-existing Py in pyritic shales and that copper mineralization is associated with silicification. Precambrian rocks in the Little Belt Mountains were affected by Laramide (Late CretaceousEarly Tertiary) folding and faulting (Woodward 1981), and by Early Tertiary intrusions (Marvin et al. 1973). Copper mineralization associated with intrusive dikes and silicified fault breccias is common (Hruska 1967; McClernan 1969), and intrusive rocks can contain sulphide minerals (Py, pyrrhotite, chalcopyrite) in interstitial spaces (observations by the author). The Cu-Co mineralization occurs directly adjacent to a major Laramide fault along which igneous dikes were emplaced in various locations. These circumstances suggest strongly that Early Tertiary intrusive rocks were the source of copper and cobalt, as well as the heat source for hydrothermal circulation and metasomatism of pyritic shales along the fault.

Conclusions

Small scale Pb-Zn mineralization in pyritic shale horizons of the Newland Formation is found primarily in pore spaces of coarse elastic interbeds. There is clear spatial and temporal distinction between the strongly prevalent pyrite and the low level Pb-Zn mineralization. Geochemical and petrographic studies show that pyritic shales are not anomalous in base metals. Base metal mineralization is mainly related to initial sediment porosity, and identical Pb-Zn mineralization is found elsewhere in the Newland Formation wherever porous host rocks are present. Pb-Zn mineralization is diagenetic, postdates the bulk of Py mineralization (Py-A) in pyritic shales, and continued for several million years after deposition of the sediments. Lead isotope data suggest that Py-A and later diagenetic sulphide minerals are genetically not related and were derived from different fluids. The tantalizing, yet only superficial congruence between Py and base metal mineralization is simply due to the fact that the pyritic shale horizons occur in a sandstone-rich interval of the Newland Formation.

Although Pb-Zn mineralization in the Newland Formation differs from mineralization at e.g. Mt. Isa and McArthur River in that it does not occur as conformable sulphide laminae, elsewhere in the Belt basin sandstone hosted base metal mineralization has led to deposits of major economic importance. There are probably three main reasons for the absence of an economic deposit in sandstones of the Newland Formation:

1. relative to other deposits, the sediment pile below the Pb-Zn mineralization in the Newland Formation is not very thick.
2. decreased base metal solubility (lower temperatures) and pore water pressures are a result of the thin sediment pile.
3. the comparatively small sandstone bodies of the Newland Formation had only a small "catchment area" with respect to compaction fluids.

From the perspective that low level base metal mineralization is actually not uncommon in sediments of all kinds and all ages, the Pb-Zn mineralization in coarse clastics of the Newland Formation is more easily acceptable as a simple byproduct of the diagenesis of the Newland Formation. Given more favourable conditions, such as a thicker underlying sediment pile and larger sandstone bodies, the same processes that led to the observed low grade mineralization might very well have produced Pb-Zn deposits of economic size in the Newland Formation.

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