SCIENTIFIC AND TECHNICAL REPORTS
RAPPORTS SCIENTIFIQUES ET TECHNIQUES

1. THREE POTENTIAL SITES FOR THE OCCURRENCE OF STRATIFORM, SHALE-HOSTED LEAD-ZINC DEPOSITS IN THE CANADIAN ARCTIC

Project 650056

D.F. Sangster
Economic Geology Division

Sangster, D.F., Three potential sites for the occurrence of stratiform, shale-hosted lead-zinc deposits in the Canadian Arctic; in Current Research, Part A, Geological Survey of Canada, Paper 81-1A, p. 1-8, 1981.

Abstract

Published literature describing the geology of the Canadian Arctic was examined relative to known attributes of shale-hosted lead-zinc deposits. Particular emphasis was placed on the search for evidence of depocentres, synsedimentary growth faults, and local geothermal anomalies. In this manner, Franklinian Basin, Baffin Basin, and Foxe Fold Belt were recognized to contain particular sedimentary formations favourable for the occurrence of shale-hosted lead-zinc deposits.

In a previous note (Sangster, 1970) the author listed ten areas in Canada regarded by him as favourable for the occurrence of undiscovered carbonate-hosted lead-zinc deposits. To date, all but two or three of these areas have been prospected to some degree and appear to be devoid of mineralization of any kind.

Having thus established his credibility as a prognosticator of potential lead-zinc bearing areas, the author now suggests three areas in Canada which he considers to be favourable for shale-hosted lead-zinc deposits. These areas were recognized as a result of the author's participation in a resource evaluation study of the Canadian Arctic Islands (Geological Survey of Canada, 1980).

Briefly, shale-hosted lead-zinc deposits are stratiform bodies consisting of layers of massive galena, sphalerite, pyrite and/or pyrrhotite occurring in shaly sedimentary rocks. Because "shales" are recognized more by their mechanical properties (i.e. they break along bedding and may possess a slaty cleavage) than by their mineralogical/chemical composition, deposits of this type are found in "shales" which may be argillaceous (Meggen, Rammelsberg in West Germany), extremely siliceous (i.e. cherty) (Howard's Pass, Yukon), silty or fine grained quartzite (Sullivan, B.C.), or dolomitic (Mt. Isa, HYC in Australia). In view of this wide range in host rock lithologies, the sedimentary environments in which these deposits are found also exhibit a wide range. Indeed, they range from starved basins with little or no detrital sedimentation (e.g. Howard's Pass), to those continuously, or periodically, receiving detrital material in abundance (e.g. Sullivan, Broken Hill) and from deep-water environments (e.g. Howard's Pass) to those in which shallow water features are abundant (e.g. HYC).

The deposits themselves are regarded as being of exhalative origin, albeit in essentially nonvolcanic terranes. The metalliferous solutions are considered to have debouched from unknown sources, through fractures, onto the ocean floor. Most deposits can be shown to occur in topographic lows on the seafloor and, in some cases, the metalliferous solutions (or a fluidic slurry of fine grained sulphide particles constituting essentially a "sulphide turbidite") appear to have migrated <u>away</u> from the exhalative centre before coming to rest in the ore-forming "depocentre".

Table 1.1

Basin classification and characteristics
(modified slightly from Krebs (1979))

<u>First Order Basins</u>

Lateral dimensions in hundreds of kilometres
Epicontinental re-entrant
On continental crust basement
Thick sedimentary sequence

<u>Second Order Basins</u>

Lateral dimensions in tens of kilometres
Local basins, troughs, and highs
Abrupt changes in sedimentary thickness
Local igneous activity

<u>Third Order Basins</u>

Lateral dimensions up to 5-6 km
"Black Shale" environment
Local synsedimentary faults

The depocentres in any one region are commonly arranged in a linear pattern which, in some instances, can be shown to lie within a graben or half-graben. Thus both the depocentres and the exhalative vents may be genetically related by virtue of the mutual relationship to synsedimentary growth faults.

The concept of relating "basins-within-basins" (i.e. depocentres in sedimentary basins), growth faults, and shale-hosted lead-zinc deposits has been portrayed by Krebs (1979) with reference to the Meggen and Rammelsberg deposits, West Germany, in Middle Devonian shales. The geological characteristics of Krebs' first, second and third order basins, summarized in Table 1.1, were considered to be of sufficiently large scale to be potentially recognizable from existing geological literature of the Canadian Arctic region. In this manner three basins were recognized to contain several of the geological features listed in Table 1.1 and hence regarded as favourable for the occurrence of stratiform lead-zinc deposits.

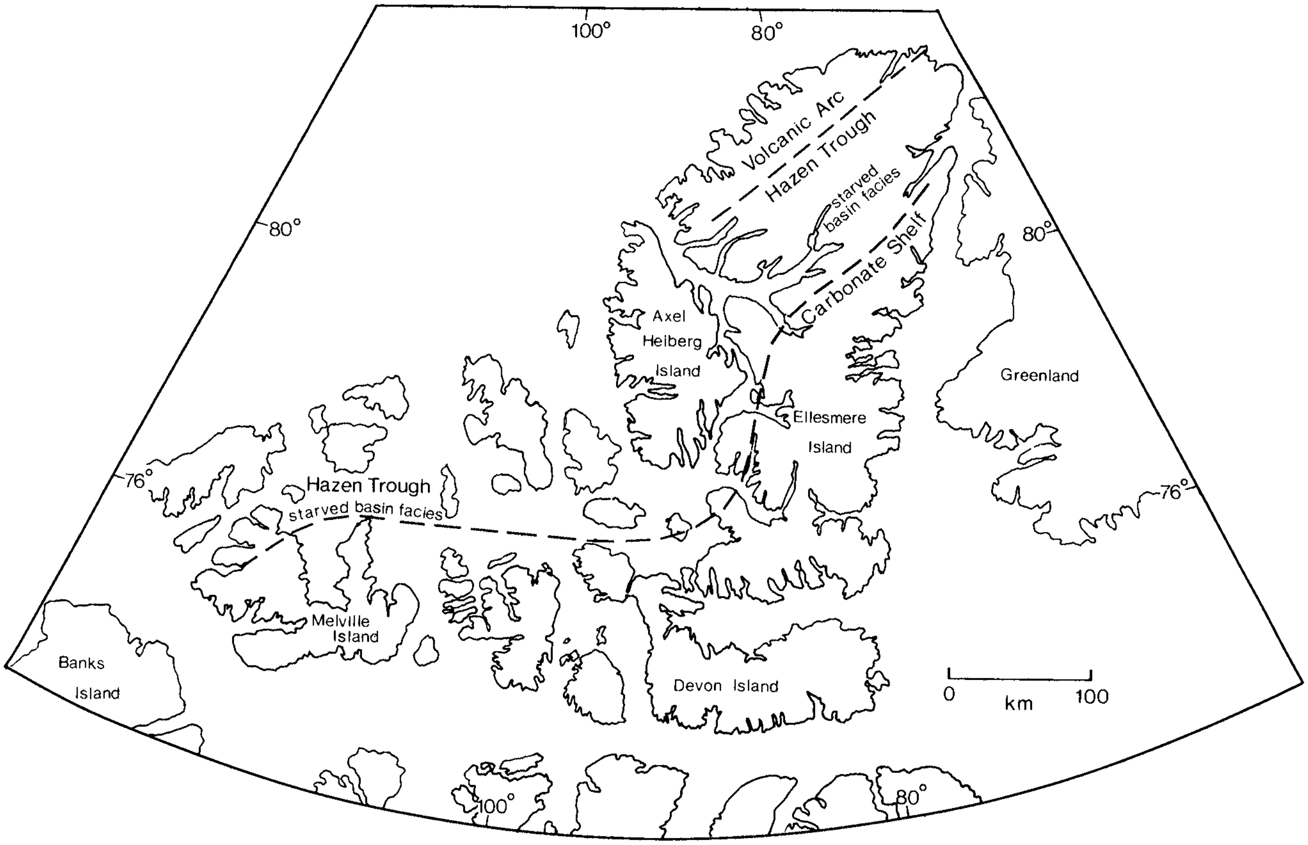

Figure 1.1. *Facies relationships and paleogeography, Franklinian Basin, during late middle Devonian (from Trettin and Balkwill, 1979).*

At this point it must be stressed that the evaluation process involved a literature search only; no field checks were possible under the assigned time constraints of the study which took place in January and February, 1980. The three basins, and specific formations within them regarded to be the most likely to contain shale-hosted lead-zinc deposits, are described in turn below.

Franklinian Basin (Fig. 1.1)

Occupying a major portion of the Queen Elizabeth Islands, the lower Paleozoic Franklinian Basin (Trettin and Balkwill, 1979, p. 752) stretches more than 1200 km southwesterly from northeastern Ellesmere Island to Banks Island. It evidently lies on continental crust as Trettin and Balkwill (1979, p. 750) stated "Precambrian crystalline terrains are exposed both north and southeast of the lower Paleozoic basin and probably underlie it in its entirety". On Ellesmere Island, the only region where a cross-section of the entire basin is exposed, the lower Paleozoic sedimentary sequence is more than 2500 m thick (Trettin, 1971). The Franklinian Basin, therefore, appears to fulfill the major requirements of Krebs' first-order basins.

Situated roughly along the axial line of the Franklinian Basin, the Hazen Trough, where exposed, is roughly 175 km wide (Fig. 1.1), bounded on the northwest by contemporaneous volcanic rocks and on the southeast by a carbonate platform. Table 1.2 shows the sedimentary sequence in northern Ellesmere Island.

The Grant Land Formation, consisting of nonmarine and marine sandstones and shales, was largely deposited under alluvial conditions (Trettin, 1971, p. 36). The assemblage represents a normal continental to shallow marine transgression onto the Precambrian craton.

The lithologies and depositional conditions of the Grant Land Formation contrast markedly with those of the overlying Hazen Formation which represents a "starved basin" facies, consisting as it does of a condensed succession of radiolarian cherts, shales, and resedimented carbonates. The overlying "flysch facies" of the Imina Formation effectively brought to a close deep-water sedimentation in the Hazen Trough.

Of these three formations, the Hazen on Ellesmere Island (including equivalent Canrobert and Ibbet Bay formations on Melville Island) is considered to have the most potential for stratiform lead-zinc deposits. The slow sedimentation rate, synchronous volcanism, and the possibility of coeval growth faulting make it the most attractive unit in Hazen Trough.

Filling of the Hazen Trough was a process of progradation along strike from northeast to southwest. Consequently, starved basin conditions prevailed much longer in the southwest. For example, the Canrobert-Ibbet Bay Formations starved basin facies on Melville Island range from late Cambrian to late Early Devonian (Trettin, personal communication, 1980).

Features considered to be particularly relevant to the occurrence of stratiform lead-zinc deposits are as follows:

1. The sudden and abrupt transition from continental and shallow marine conditions (Grant Land Formation) to a deep-water, starved basin environment (Hazen Formation). Such a dramatic deepening could most readily be achieved by synsedimentary faulting along the margins of the Hazen Trough. Growth faults such as these are extremely important because they serve not only as trans-strata channelways along which potential

Table 1.2

Table of formations, northern Ellesmere Island*

	Age	Formation	Thickness (m)	Lithologies
Hazen Trough	E Sil. to E Dev.	Imina	more than 2800	Calcareous greywacke, mudstone
Hazen Trough	E Camb. to E Sil.	Hazen	390	Chert, graptolitic shale, limestone, minor breccia
	E Cambrian	Grant Land	more than 1100	Quartzitic sandstone, phyllite, conglomerate

*From Trettin, 1971; Trettin and Balkwill, 1979; Trettin et al., 1979

metal-bearing solutions may rise but they also produce local depocentres in which the exhalative metalliferous brines collect. Synsedimentary faulting during Hazen time may also be recorded in the abrupt appearance of local sedimentary breccias in the Hazen Formation (Trettin, 1971).

2. The presence of contemporaneous volcanic activity to the northwest is important for establishing higher-than-normal thermal gradients in the Hazen Trough sedimentary basin. Anomalous thermal gradients would be capable of heating connate water in the Trough sediments; the heated water could then leach metals from the surrounding sediments, and then be driven up along synsedimentary faults to debouch onto the floor of the deep-water Hazen Trough.
3. The extremely slow sedimentation rate of the Hazen Formation is ideal for the accumulation of sulphides; the lack of detrital material would allow even slow rates of exhalation of metalliferous brines to produce strata of significant metal content.
4. The overall stratigraphic succession in northern Ellesmere Island is comparable in age, lithology, and depositional environments to those in Selwyn Basin where numerous stratiform lead-zinc deposits have been discovered (e.g. Wheeler and Gabrielse, 1972; Blusson, 1976; Gabrielse, 1976; Morganti, 1979). The analogy is further strengthened by the fact that the carbonate platforms of both basins contain important lead-zinc deposits (Brock, 1976; Kerr, 1977b).

In addition to the Hazen Formation of northern Ellesmere Island (and the correlative Canrobert and Ibbett Bay formations on Melville Island), the Cape Phillips Formation elsewhere in the Franklinian Basin possesses certain features which render it somewhat attractive for stratiform lead-zinc deposits. The largely Silurian shales of the latter formation have been interpreted by Trettin and Balkwill (1979, p. 756) as having been deposited in a backreef basin on the southeast rim of Hazen Trough (see Trettin and Balkwill, 1979, Fig. 5). Within this basin, possibly formed by faulting, sedimentation was slow (Trettin and Balkwill, 1979, p. 756). Kerr (1977a, p. 1383) described the Cape Phillips Formation as comprising "dark grey graptolitic shaly limestone, shale, and some chert" and as having been deposited in an euxinic basin. Again, the coincidence in time and space of slow sedimentation rates, euxinic conditions, and synsedimentary faulting make the Cape Phillips Formation a potential host to stratiform lead-zinc deposits in Franklinian Basin.

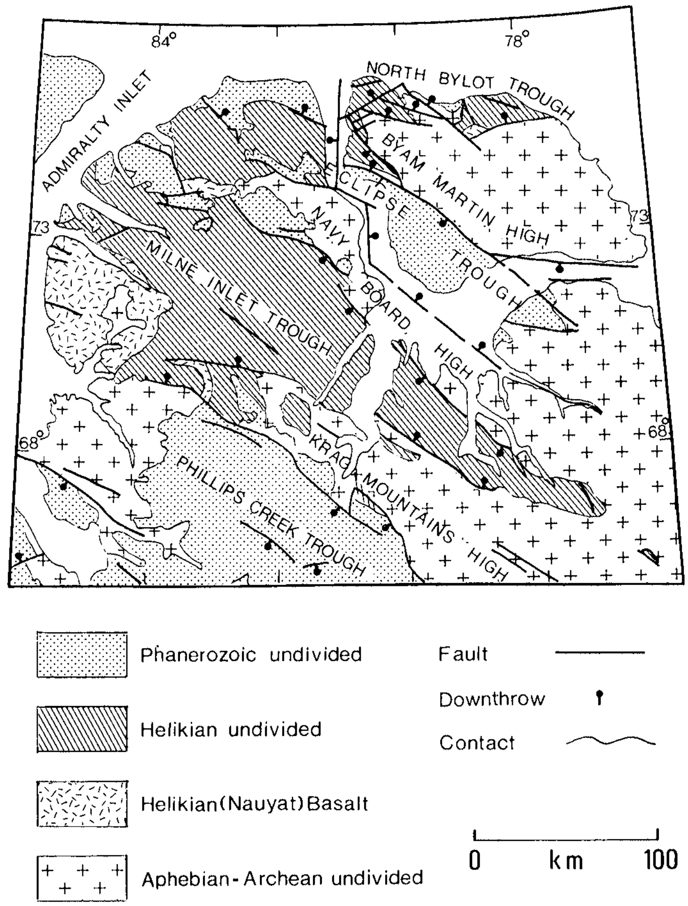

Figure 1.2. Borden Basin within the North Baffin Rift Zone. Borden Basin is shown as Milne Inlet Trough on this diagram (Jackson et al., 1975).

Borden Basin (Fig. 1.2)

One of a series of parallel northwest-trending horsts and grabens in the North Baffin Rift Zone (Jackson et al., 1975), Borden Basin extends southeasterly 325 km from Admiralty Inlet in northern Baffin Island (Fig. 1.2). Within the basin, up to 6000 m of Upper Proterozoic strata lie either in fault contact with, or unconformably on, older crystalline rocks.

Table 1.3

Table of formations, Eclipse Sound area, Borden Basin*

Age	Group	Formation	Thickness (m)	Lithology
Hadrynian		Franklinian Intrusions		Diabase
Neohelikian	Uluksan	Elwin	700+	Siltstone, quartzarenite
		Strathcona Sound/ Athole Point	870+/585	Arkose, conglomerate, shale/limestone, sandstone, shale
		Victor Bay	724	Limestone, dolostone, shale, siltstone
		Society Cliffs	825+	Dolostone, shale, sandstone, gypsum
		Fabricius Fiord/ Arctic Bay	1500+/600	Conglomerate, sandstone/calcareous shale, siltstone
	Eqalulik	Adams Sound	340	Quartzarenite
		Nauyat	90	Basalt, quartzarenite
Archean-Aphebian				Granitic gneiss complex

*From Jackson et al., 1980

Near the centre of the Borden Basin, the generalized upper Proterozoic stratigraphy is as shown in Table 1.3. A characteristic feature of the Rift Zone, however, is the effect syndepositional faulting has had on sedimentation, resulting in numerous facies changes and wide ranges in thicknesses of all formations. Jackson et al. (1978, p. 14) summarized the structural/sedimentological association as follows: "Abrupt vertical and lateral changes in lithologies and depositional environments, the cyclic nature of many of the formations, changes in transportation directions, and the presence of interformational unconformities, all indicate that syndepositional faulting played an important role in the sedimentation patterns within the basin...However, most of the faulting...seems to have occurred after deposition of the Eqalulik and Uluksan groups...". Significant to the possible occurrence of stratiform lead-zinc mineralization, however, is that some faulting did occur during deposition of the Uluksan Group, specifically during Fabricius Fiord/Arctic Bay time. Iannelli (1979) has described in some detail the relationship between these two formations. The former is largely conglomerate and coarse sandstone deposited in large delta fan complexes emanating from the southern margin of Borden Basin as a result of block faulting. The Fabricius Fiord Formation changes facies laterally, northward toward the centre of the basin, into the Arctic Bay Formation consisting predominantly of shale (locally pyritic) with minor dolostone and siltstone (Iannelli, 1979, Fig. 11.6, 11.7). The Arctic Bay Formation ranges in thickness from about 100 m in the type area near the western end of the Rift Zone (Lemon and Blackadar, 1963) to more than 1200 m near the eastern end (Jackson et al., 1975).

Features within Borden Basin, and in particular the Arctic Bay Formation, considered to be relevant to the possible occurrence of shale-hosted stratiform lead-zinc deposits, are the following:

1. The abundant evidence of synsedimentary faulting during deposition of the Arctic Bay Formation sediments.

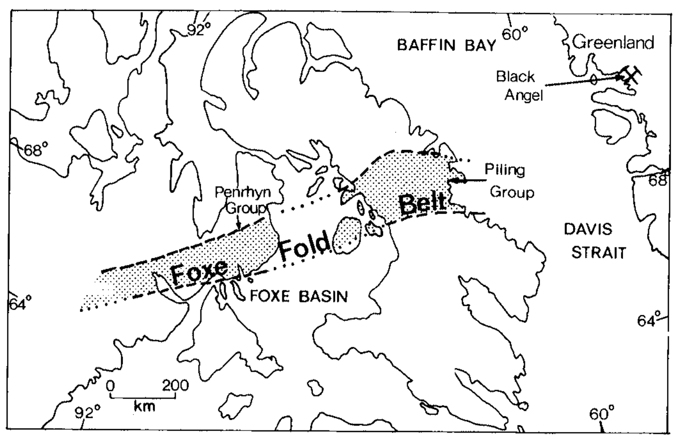

Figure 1.3. Position of Foxe Fold Belt, northeastern Canadian Shield (from Jackson and Taylor, 1972).

2. The series of horsts and grabens identified as "highs" and "troughs" in Figure 1.2 (equivalent to the submarine "Schwellen" and "Becken" of Krebs (1979)), produce second-order basins. These, in turn, suggest the possibility of third-order basins, of the size of individual lead-zinc deposits, occurring in the area. The wide range in thickness of the Arctic Bay Formation, for example, might be an indication of these smaller basins.
3. An early geothermal anomaly in the area is suggested by the presence of alkalic basalts at the west end of the basin which were extruded in the early stages of rifting.
4. The presence of the Nanisivik lead-zinc deposit in Society Cliffs dolomite (Olson, 1977) suggests that the region lies within at least a local lead-zinc metallogenic province. Olson (1977), in fact, concluded that the source of the metals in the Nanisivik deposit was the underlying Arctic Bay Formation.

Table 1.4

Comparison of lithologies and stratigraphic successions in three areas of the Foxe Fold Belt (see Fig. 3).*

Penrhyn Group		Piling Group	Marmorilik Formation
Psammites, pelitic metaturbidites (more than 1000 m)		Metagreywacke, psammite, slate minor amphibolite (more than 3000 m)	Semi-pelite (more than 200 m)
(possible unconformity)			
Marble, calc-silicate gneiss	1000 m		
Paragneiss (in part rusty, graphitic)		Graphitic sulphide schist (up to 200 m)	
Marble, calc-silicate gneiss		Marble, quartzite, calc-silicate (up to 200 m)	Marbles (1600 m)
Quartzite, minor amphibolite (up to 100 m)		Quartzite, minor amphibolite (up to 200 m)	Quartzite, conglomerate (60 m)
unconformity		unconformity	unconformity
Basement Complex		Basement Complex	Basement Complex

* Penrhyn Group stratigraphy from Okulitch et al. (1977) and J.R. Henderson (personal communication, 1980); Piling Group as in Table 1.5, and Marmorilik area from Garde (1978).

Table 1.5

Comparison of Aphebian Piling Group, Baffin Island and Lower Paleozoic formations, northern Ellesmere Island.*

Piling Group, Baffin Island		Northern Ellesmere Island	
Unit/Lithology	Thickness (m)	Unit/Lithology	Thickness (m)
Metagreywacke, psammite, slate, minor amphibolite	>3000	Imina Fm.: subgreywacke, greywacke, argillaceous greywacke	more than 2800
Graphitic sulphide schist, metachert	up to 200	Hazen Fm.: chert, shale	400
Marble, quartzite, calc-silicates	up to 200	limestone, chert, shale	
Quartzite, minor amphibolite	up to 200	Grant Land Fm.: quartzite, sandstone, shale	more than 1100
unconformity		unconformity	
Basement Complex		Basement Complex	

* Piling Group information from Morgan et al. (1975, 1976); Tippett (1978, 1979); Henderson et al. (1979); Henderson and Tippett (1980); Jackson and Taylor (1972); W.C. Morgan and J.R. Henderson (personal communication, 1980). Ellesmere Island information from Trettin (1971), Trettin and Balkwill (1979), and Trettin et al. (1979).

Foxe Fold Belt (Fig. 1.3)

"The Foxe Fold Belt is a continuous zone composed mainly of folded Aphebian rocks that extends on the mainland from west of Repulse Bay to the east coast of Melville Peninsula, and extends east across Baffin Island... The Aphebian strata comprising the fold belt were named the Penrhyn Group on the mainland by Heywood (1967), and the Piling Group on Baffin Island by Jackson (1971)" (Jackson and Taylor, 1972, p. 1657).

Most of the discussion that follows refers to the Piling Group on Baffin Island but many comments may apply also to the Penrhyn Group if for no other reason than the lithologies and stratigraphic successions of the two groups are so similar (Table 1.4).

Because of the regional upper greenschist to granulite facies metamorphism and attendant complex structure, favourable features for lead-zinc mineralization such as those discussed in the previous two basins (growth faults, variations in stratigraphic thickness, sedimentary breccias, etc.) cannot be evaluated in the Foxe Fold Belt.

Table 1.6

Geological attributes of three Canadian Arctic sedimentary basins compared to Krebs' (1979) basin classification

Basin Classification and Characteristics (Krebs, 1979)	Canadian Arctic Sedimentary Basins		
	Franklinian Basin	Borden Basin	Foxe Fold Belt
First Order Basins			
Lateral dimensions in hundreds of kilometres	1200 x 200 km	North Baffin Rift Zone; full extent unknown	1300 x 160 km
Epicontinental re-entrant	yes	yes	yes
On continental crust basement	yes	yes	yes
Thick sedimentary sequence	more than 2300 m	up to 6100 m	more than 3600 m
Second Order Basins			
Lateral dimensions in tens of kilometres	Hazen Trough; ca 175 km wide, min. length 600 km	Borden Basin; 330 x 80 km	"Piling Basin" 250 x 160 km
Local basins, troughs, and highs	not identified	yes	not identified
Abrupt changes in sediment thickness	not documented	Arctic Bay Fm., 75 to 1200 m	obscured by metamorphism
Local igneous activity	contemporaneous volcanics	alkalic basalts	contemporaneous mafic volcanics
Third Order Basins			
Lateral dimensions up to 5-6 km	not identified	not identified	not identified
"Black shale" environment	Hazen Fm., pyritic, cherty, carbonaceous	Arctic Bay Fm., black, pyritic calcareous shale	Graphitic sulphide schist
Local synsedimentary faults	inferred	well documented	inferred

In spite of this, however, the Piling Group, in particular the graphitic sulphide schist, is regarded as a potential host for stratiform, shale-hosted lead-zinc mineraliation for the following reasons:

1. The Piling Group sequence quartzite-marble-graphitic pyritic schist-metagreywacke is remarkably similar to that in Hazen Trough (Table 1.2). There, the abrupt transition from the continental to shallow marine conditions of Grant Land Formation sedimentation to the euxinic, starved basin facies of the Hazen Formation was attributed to possible rifting along synsedimentary faults. Much the same argument could apply to the Piling Group and, to a lesser extent, the Penrhyn Group. In both groups, the quartzite and marble would represent the shallow marine environment, the graphitic sulphide schist (Jackson and Taylor (1972) reported "metachert" in the unit as well) a possible starved basin facies of pyritic, carbonaceous, siliceous shale. In Penrhyn Group (Okulitch et al., 1977), the basal quartzite and marble units are present but the position of the graphitic sulphide schist of Piling Group is taken by paragneiss, in part rusty and graphitic.
2. From the evidence of minor volcanic lithologies in both groups, an elevated geothermal gradient may be inferred throughout Foxe Fold Belt. Tippett (1978, 1979) referred to metavolcanic rocks possibly overlying the quartzite in the central part of Piling basin. Elsewhere Morgan et al. (1975) reported basic volcanics with amygdules and pillows occur ring in the upper metagreywacke unit. In Penrhyn Group, Okulitch et al. (1977) recorded minor amphibolites, of probable volcanic origin, associated with the basal quartzite unit there.
3. As with the previous two basins (Franklinian and Borden), the Foxe Fold Belt is, or lies within, a probable lead-zinc metallogenic province. This is suggested by the presence of a major lead-zinc deposit (Black Angel) in carbonates of the Marmorilik Formation on the coast of Greenland (Fig. 1.3). The Marmorilik area is not only along strike with the Foxe Fold Belt, but its lithologies and stratigraphic succession (Table 1.5) are so similar to Piling Group that direct correlation seems unavoidable. If this correlation is correct and allowing for the relatively recent opening of Davis Strait, the Black Angel deposit must be regarded, geologically, as part of the Foxe Fold Belt.

The graphitic sulphide schist unit in both Piling and Penrhyn groups contains scattered occurrences of more massive sulphide lenses, some of which contain minor amounts of sphalerite. This suggests that the Piling and Penrhyn basins, in particular the sulphidic schist unit, could be part of a zinc metallogenic province. This was also suggested earlier by Cameron (1979) on the basis of a strong correlation between zinc anomalies in lake sediments and waters and sulphidic paragneiss in Penrhyn Basin.

Discussion

Various attributes of the three sedimentary basins (probably better described as "troughs") referred to in the previous pages are summarized and compared with Krebs' basin classification in Table 1.6. The 'degree of fit' depends almost entirely on the level of published geological detail and the metamorphic history of the basin. These two factors have largely determined whether critical geological features such as synsedimentary faults and protoliths were directly observable, as in some basins, or merely inferred, as in others.

It must be stressed here that none of the features discussed in the previous pages nor summarized in Table 1.1 are necessarily unique to basins containing lead-zinc deposits. Anomalous features leading to, or a result of, lead-zinc mineralization occur only on the scale of third-order basins or less and are not likely to be recorded in reconnaissance-scale mapping, the scale of the data base used in this report. A review of the world literature, together with personal experience, has revealed to this author that, although stratiform lead-zinc deposits rather consistently occur in sedimentary basins with the attributes summarized in Table 1.1, direct evidence of their presence seldom extends much beyond the ore basin (third-order basin) itself.

An illustration of this point would be pyrite content of the host rock shale. Unlike volcanogenic massive sulphide deposits, individual shale-hosted lead-zinc deposits may be pyrite-poor (e.g. Howard's Pass and Broken Hill) and, in these deposits, the surrounding host rock sediments are not noticeably pyrite-rich. The same is true for the base-metal content of the host rock. Only 22 km from the HYC deposit (190 million tonnes, 9.5% Zn, 4.1% Pb, 40 g/t Ag), but still within a second-order basin, the host dolomitic shale averages about 28 ppm Zn (Corbett et al., 1975). This should be compared with averages of 90 ppm for shale in general, 200 ppm for carbonaceous shales, and 20 ppm for carbonates (Wedepohl, 1972).

These examples serve to illustrate, once again, the well-known fact that regional geological mapping programs, and the resource evaluation studies based on them, serve mainly to identify only large-scale permissive evidence for mineralization. Direct evidence of the mineralizing process must be sought in follow-up studies on a much smaller scale. In the context of shale-hosted stratiform lead-zinc deposits, the scale of the target sought (metal-bearing third-order basins) would be of the order of a few hundred metres to a few kilometres.

Acknowledgments

Information and ideas from the author's colleagues at the Geological Survey of Canada have made significant contributions to this study. In particular the author wishes to acknowledge discussions with H.P. Trettin, G.D. Jackson, W.C. Morgan, J.R. Henderson, and A. Okulitch. Diagrams were competently drafted by S.B. Green.

References

Blusson, S.L.
1976: Selwyn Basin, Yukon and District of Mackenzie; in Report of Activities, Part A, Geological Survey of Canada, Paper 76-1A, p. 131-132.

Brock, J.S.
1976: Selwyn-Mackenzie lead-zinc province, Yukon and Northwest Territories; Western Miner, v. 49, no. 3, p. 9-16.

Cameron, E.M.
1979: Investigation of base metal mineralization in Proterozoic metasediments, Melville Peninsula, District of Franklin; in Current Research, Part A, Geological Survey of Canada, Paper 79-1A, p. 187-196.

Corbett, J.A., Lambert, I.B., and Scott, K.M.
1975: Results of analyses of rocks from the McArthur area, Northern Territory; Commonwealth Scientific and Industrial Research Organization (C.S.I.R.O.), Minerals Research Laboratories, Technical Communication 57.

Gabrielse, H.
1976: Environments of Canadian Cordillera depositional basins; in Circum-Pacific Energy and Mineral Resources; American Association of Petroleum Geologists, Memoir 25, p. 492-502.

Garde, A.A.
1978: The Lower Proterozoic Marmorilik Formation, East of Marmorilik, West Greenland; Meddelelser Om Grønland, Bd. 200, Nr. 3.

Geological Survey of Canada
1980: Non-hydrocarbon mineral resources of parts of northern Canada; Geological Survey of Canada Open File 716.

Henderson, J.R. and Tippett, C.R.
1980: Foxe Fold Belt in eastern Baffin Island, District of Franklin; in Current Research, Part A, Geological Survey of Canada, Paper 80-1A, p. 147-152.

Henderson, J.R., Shaw, D., Mazuraki, M., Henderson, M., Green, R., and Brisbin, D.
1979: Geology of part of the Foxe Fold Belt, central Baffin Island, District of Franklin; in Current Research, Part A, Geological Survey of Canada, Paper 79-1A, p. 95-99.

Heywood, W.W.
1967: Geological notes, northeastern District of Keewatin and southern Melville Peninsula, District of Franklin, Northwest Territories; Geological Survey of Canada, Paper 66-40.

Iannelli, T.R.
1979: Stratigraphy and depositional history of some Upper Proterozoic sedimentary rocks on northwestern Baffin Island, District of Franklin; in Current Research, Part A, Geological Survey of Canada, Paper 79-1A, p. 45-56.

Jackson, G.D.
1971: Operation Penny Highlands, south-central Baffin Island; Geological Survey of Canada, Paper 71-1, Part A.

Jackson, G.D. and Taylor, F.C.
1972: Correlation of major Aphebian rock units in the northern Canadian Shield; Canadian Journal of Earth Sciences, v. 9, p. 1650-1669.

Jackson, G.D., Davidson, A., and Morgan, W.C.
1975: Geology of the Pond Inlet map-area, Baffin Island, District of Franklin; Geological Survey of Canada, Paper 74-25.

Jackson, G.D., Iannelli, T.R., Narbonne, G.M., and Wallace, P.J.
1978: Upper Proterozoic sedimentary and volcanic rocks of northwestern Baffin Island; Geological Survey of Canada, Paper 78-14.

Jackson, G.D., Iannelli, T.R., and Tilley, B.J.
1980: Rift-related Late Proterozoic sedimentation and volcanism on northern Baffin Island and Bylot Islands, District of Franklin; in Current Research, Part A, Geological Survey of Canada, Paper 80-1A, p. 319-328.

Kerr, J.Wm.
1977a: Cornwallis Fold Belt and the mechanism of basement uplift; Canadian Journal of Earth Sciences, v. 14, p. 1374-1401.

1977b: Cornwallis lead-zinc district; Mississippi Valley-type deposits controlled by stratigraphy and tectonics; Canadian Journal of Earth Sciences, v. 14, p. 1402-1426.

Krebs, W.
1979: Devonian basinal facies; in The Devonian System; The Paleontological Association, Special Papers in Paleontology 23, p. 125-139.

Lemon, R.R.H. and Blackadar, R.G.
1963: Admiralty Inlet area, Baffin Island, District of Franklin; Geological Survey of Canada, Memoir 328.

Morgan, W.C., Bourne, J., Herd, R.K., Pickett, J.W., and Tippett, C.R.
1975: Geology of the Foxe Fold Belt, Baffin Island, District of Franklin; in Report of Activities, Part A, Geological Survey of Canada, Paper 75-1A, p. 343-347.

Morgan, W.C., Okulitch, A.V., and Thompson, P.H.
1976: Stratigraphy, structure, and metamorphism of the west half of the Foxe Fold Belt, Baffin Island; Report of Activities, Part A, Geological Survey of Canada, Paper 76-1A, p. 387-391.

Morganti, J.M.
1979: The geology and ore deposits of the Howard's Pass area, Yukon and Northwest Territories: The origin of basinal sedimentary stratiform sulphide deposits; unpublished Ph.D. thesis, University of British Columbia, Vancouver.

Okulitch, A.V., Gordon, T., Henderson, J.R., Reesor, J.E., and Hutcheon, I.E.
1977: Geology of Barrow River map-area, Melville Peninsula, District of Franklin; in Report of Activities, Part A, Geological Survey of Canada, Paper 77-1A, p. 213-215.

Olson, R.A.
1977: Geology and genesis of zinc-lead deposits within a Late Proterozoic dolomite, northern Baffin Island, N.W.T.; unpublished Ph.D. thesis, University of British Columbia, Vancouver, 371 p.

Sangster, D.F.
1970: Geological exploration guides for Canadian lead-zinc deposits in carbonate rocks; Canadian Mining Journal, v. 91, no. 4, p. 49-51.

Tippett, C.R.
1978: A detailed cross-section through the southern margin of the Foxe Fold Belt in the vicinity of Dewar Lakes, Baffin Island, District of Franklin; in Current Research, Part A, Geological Survey of Canada, Paper 78-1A, p. 169-173.

Tippett, C.R. (cont.)
1979: Basement-supracrustal rock relationships on the southern margin of the Foxe Fold Belt, central Baffin Island, District of Franklin; in Current Research, Part A, Geological Survey of Canada, Paper 79-1A, p. 101-105.

Trettin, H.P.
1971: Geology of Lower Paleozoic formations, Hazen Plateau and southern Grant Land Mountains, Ellesmere Island, Arctic Archipelago; Geological Survey of Canada, Bulletin 203.

Trettin, H.P. and Balkwill, H.R.
1979: Contributions to the tectonic history of the Innuitian Province, Arctic Canada; Canadian Journal of Earth Sciences, v. 16, p. 748-769.

Trettin, H.P., Barnes, C.R., Kerr, J.W., Norford, B.S., Pedder, A.E.H., Riva, J., Tipnis, R.S., and Uyeno, T.T.
1979: Progress in lower Paleozoic stratigraphy, northern Ellesmere Island, District of Franklin; in Current Research, Part B, Geological Survey of Canada, Paper 79-1B, p. 269-279.

Wedepohl, K.H.
1972: Zinc-abundance in common sediments and sedimentary rocks; in Handbook of Chemistry, K.H. Wedepohl, editor, Volume II/3, Section 30-K, Springer-Verlag, Berlin.

Wheeler, J.O. and Gabrielse, H.
1972: The Cordilleran Structural Province; in Variations in Tectonics Styles in Canada, Geological Association of Canada, Special Paper 11.