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GEOLOGY OF THE ANVIL RANGE AND
ITS ORE DEPOSITS:

A SYNOPSIS

with REVISIONS

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INTRODUCTION

The Anvil Range lead-zinc-silver district is located 200 kilometers northeast of Whitehorse, Yukon Territory, Canada. Open pit mining from the Faro deposit, at up to 10,000 tonnes per day since 1969, constitutes Yukon's largest mining operation. Present, proven, geological reserves total 92 million tonnes of 8.3% combined lead-zinc with 50 grams/tonne silver out of an estimated total sulfide tonnage of 225 million tonnes.

Seven stratiform, stratabound, pyritic massive sulfide deposits occur in one horizon in the lower Paleozoic section of the district. Detailed lead isotopic studies of the Anvil deposits were undertaken to define lateral and vertical isotopic variation in two of the deposits and shed further light on the age(s) of all deposits. Results of this study bear less on these topics and more on the source of lead in, and the origin of the Anvil deposits.

STRATIGRAPHY

The Anvil District lies on the southwest margin of the important lead-zinc-silver province known informally as Selwyn Basin¹ (Figure 1). The district is underlain by late Proterozoic and Paleozoic metasedimentary and lesser metavolcanic rocks that formed on the ancient North American continental margin. The southwest boundary of the district is the Vangorda Creek fault, part of a major early Mesozoic structure (the Finlayson Lake fault system) juxtaposing the radically different, allochthonous Yukon Cataclastic Complex (Tempelman-Kluit, 1979) against rocks of the district.

The district (Figure 2) is underlain by strata as young as Permian, but only those of Ordovician and older age will be summarized. The older rocks of the district are divided into three mappable compositional units for which provisional stratigraphic names are given. From oldest these are: Mt. Mye formation - dominated by non-calcareous metapelites, Vangorda formation - dominantly calcareous metapelites, and Menzie Creek formation - basaltic metavolcanic rocks and graphitic pelites (Figure 3).

The Mt. Mye formation varies from non-calcareous, biotite-muscovite schist to non-calcareous, weakly carbonaceous, sericite-chlorite phyllites with lesser, interlayered graphitic phyllite, marble, calc-silicate schist, metabasite and psammitic schist or fine metasandstone. The unit is at least 2 kilometers thick and shows little obvious vertical or lateral variation not attributable to metamorphism. The formation is lithologically

Handwritten scribbles:
The Mt. Mye formation is a sequence of pelites and graphitic schists.

¹ The term Selwyn Basin in its strict sense (Gabrielse, 1968) applies to Silurian to mid-Devonian rocks in the area to the northeast of Anvil District; however, it is used here in a loose sense for all relatively basinal late Proterozoic and Paleozoic rocks southwest of the carbonate/orthoquartzite Mackenzie Platform as is common practice among exploration geologists in the Northern Cordillera.

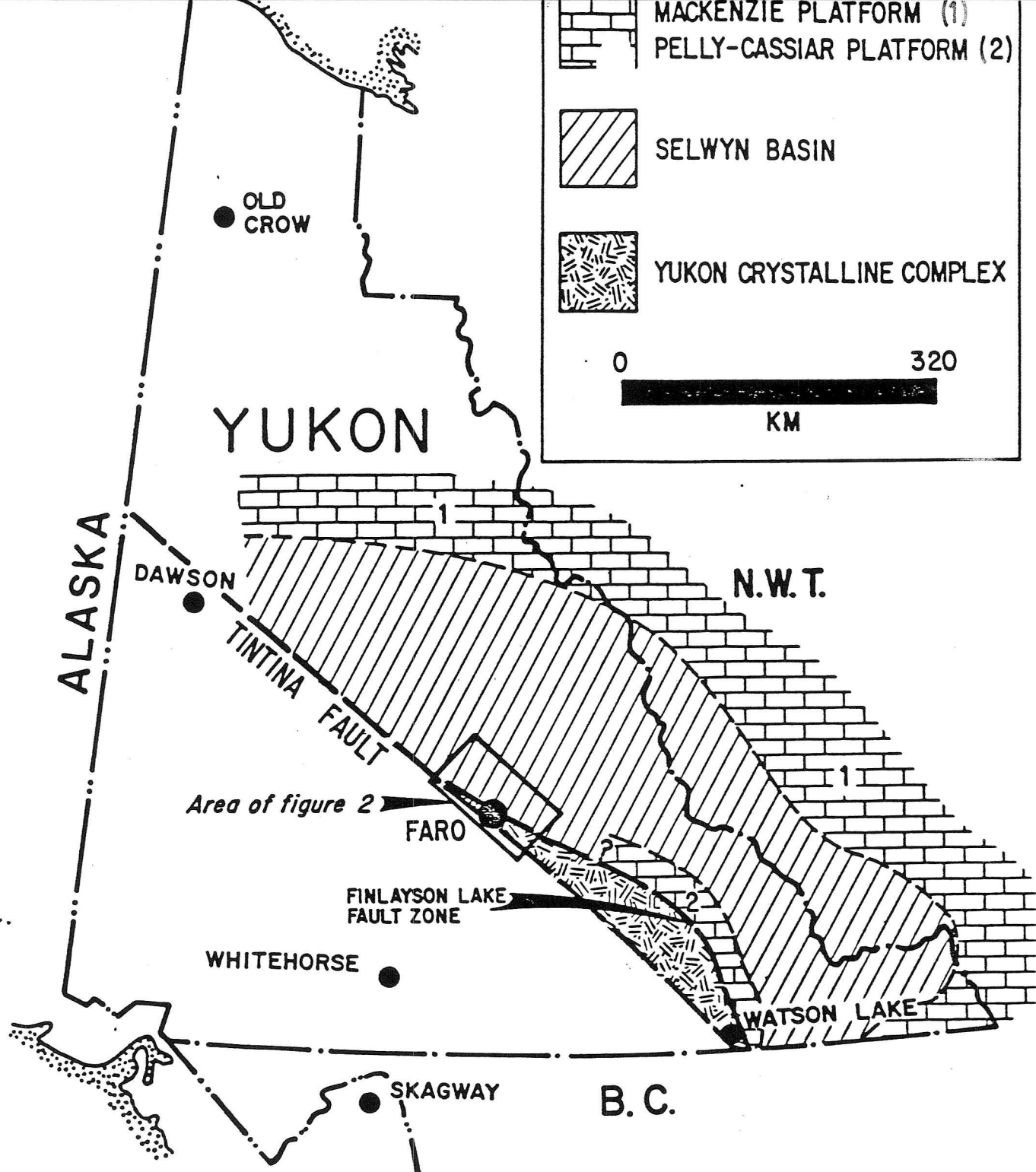


Figure 1

Location of the Anvil Pb-Zn-Ag district with respect to selected Paleozoic and Mesozoic tectonic elements northeast of Tintina fault. Tintina fault is an upper Cretaceous, right lateral strike slip fault with approximately 450 km displacement. Yukon Crystalline Complex (also known as Yukon Cataclastic Complex) is an imbricated sequence of mid Paleozoic magmatic arc related rocks and upper Paleozoic ophiolitic rocks; it is exotic with respect to the Yukon further northeast and was "accreted" in upper Jurassic - lower Cretaceous along the Finlayson Lake fault zone, a major transcurrent fault or an upturned thrust.

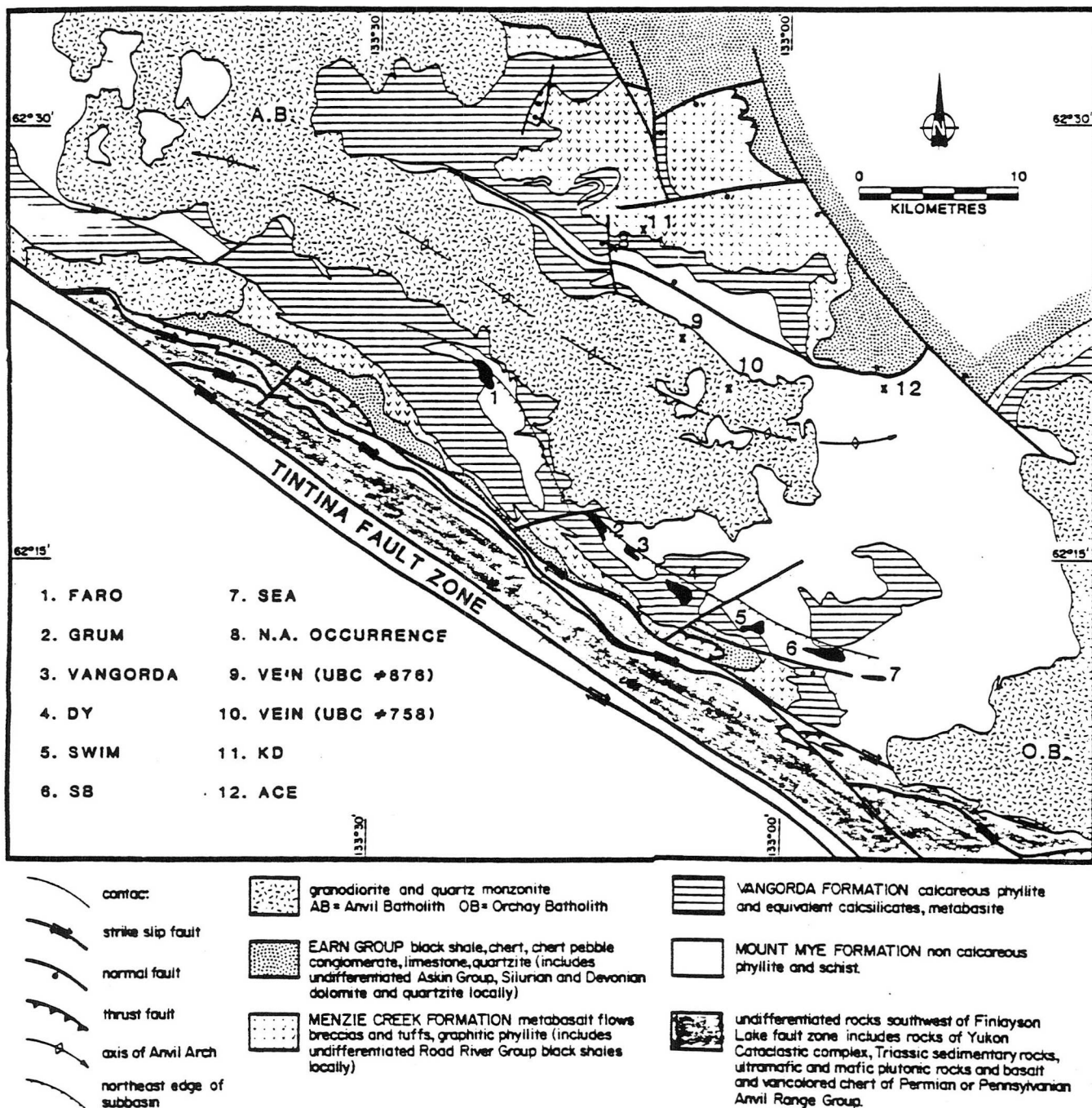


Figure 2

Geologic map of the Anvil Pb-Zn-Ag district showing location of ore deposits. Nos. 1-7 are the main stratiform deposits, of which only Nos. 1-5 contain significant Pb-Zn.

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similar to the fine-grained upper portion of the grit unit seen to the east (Gordey, 1980) and southeast (Gabrielse, 1974) with which it is presumed to correlate implying a late Proterozoic or lower Cambrian age.

It should be emphasized that typical coarse, poorly sorted quartz and feldspar sandstones of the Grit Unit are not seen in the Mt. Mye formation.

~~The upper portion resembles (Imp. Gordey unit of 1980) or small marble like siltstone unit. High in the formation may represent the metamorphic equivalent of the basal carbonate of these units.~~

The Vangorda formation is characterized by calcareous pelitic rocks made up of thinly interlayered, non-calcareous, weakly carbonaceous, muscovite chlorite phyllites and calcite ± quartz metasiltstones(?) Major interbanded

units include metabasite and meta-tuffs, graphitic phyllite, and phyllitic limestone. ~~The thin interlayering of pelitic and silt components results in development of the characteristic thin structure of the rocks of this formation. (Fig -)~~

Most metabasite bodies are medium-grained and equigranular leading to the suggestion that they may have been sills, however, apparently amygdaloidal margins and a common association with probable, thin bedded, tuffaceous rocks suggests at least some were flows. Whole rock compositional data shows that the metabasites are all of basaltic composition (Jennings et al 1980). The bodies range from 1 to 100 meters in thickness and are up to several kilometers in length.

The Vangorda formation varies between 0.5 and 2 kilometers in apparent thickness with basic igneous rocks comprising approximately 15% of the section. The formation becomes more calcareous up section, paralleling an increase in metabasaltic units. At the base of the formation, Vangorda and Mt. Mye lithologies are interbanded over an interval of tens to hundreds of meters. Within this transition zone is a widespread and laterally

variable graphitic phyllite unit which is, in part, a stratigraphic equivalent to the ore horizon.

The Vangorda formation is lithologically similar to, though more argillaceous than, the Rabbitkettle formation seen to the east (Gordey, 1979, Gabrielse et al, 1973), as well as some rocks beneath the Rabbitkettle formation (unit 1Cp of Gordey, 1979) and is correlated with these formations. It is important to note the apparent absence of the sub-Rabbitkettle unconformity at the base ^{of} or within Vangorda formation. The age of the Vangorda is thus thought to range from lower Cambrian through lower Ordovician.

The Menzie Creek formation consists dominantly of basaltic metavolcanic rocks, mainly pillowed and massive flows with comparable amounts of massive, coarse, monolithic breccias and lesser, thin bedded fine tuff and/or volcanic sandstone and siltstone. Whole rock major element and trace element data (Jennings et al, in prep.) imply that the flows of the Menzie Creek formation are dominantly alkali basalt erupted in a within-plate setting similar to metabasites of Vangorda formation. Graphitic phyllite interbeds are widespread northeast of Anvil Batholith. These interbeds contain graptolites of middle Ordovician or lower Silurian age (Tempelman-Kluit, 1972) suggesting correlation with the widespread Road River Group black shale and chert to the northeast (Cecile, 1980). The Menzie Creek formation varies from zero to about 1.5 kilometers in thickness in and near the district. It has been traced for 100 kilometers along strike and 30 kilometers across strike, showing that it is one of the largest of

several basaltic units of its age in Yukon. Similar and probably correlative units have been mapped by Cecile (1980) as Marmot Creek formation to the northeast and in an unnamed unit to the northwest by Tempelman-Kluit (1970).

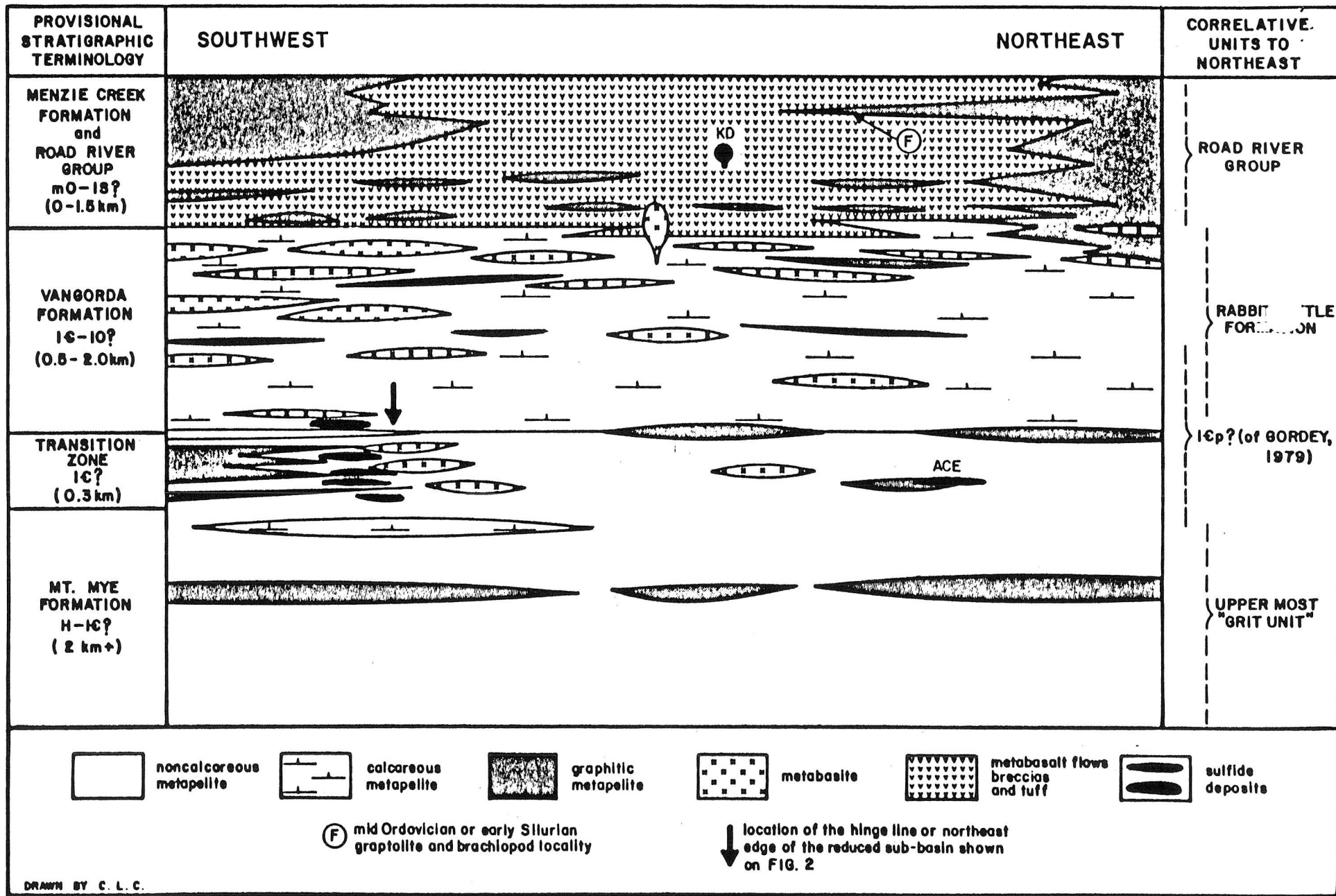


Figure 3

Older Paleozoic stratigraphy of the Anvil Pb-Zn-Ag district.

METAMORPHISM AND PLUTONISM

The Anvil District has suffered a complex history of intense deformation, metamorphism and granitic intrusion which places limits on the credibility of genetic speculation, especially that derived from geochemical data.

Rocks of the district show the effects of at least five periods of deformation. The first two periods are the most pronounced and were accompanied by metamorphism ranging from low greenschist facies to middle amphibolite facies in a low pressure, Abukuma-type facies series.

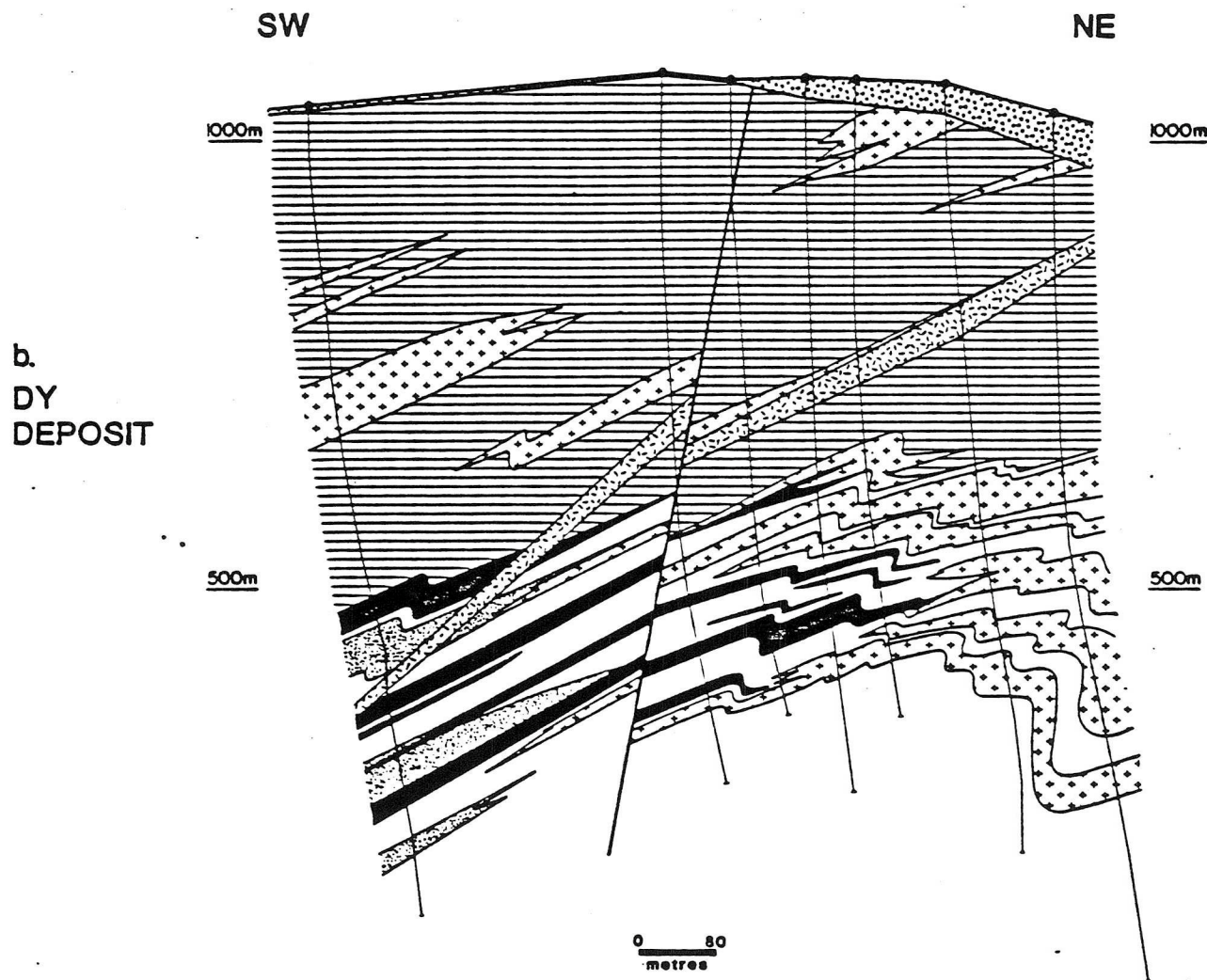
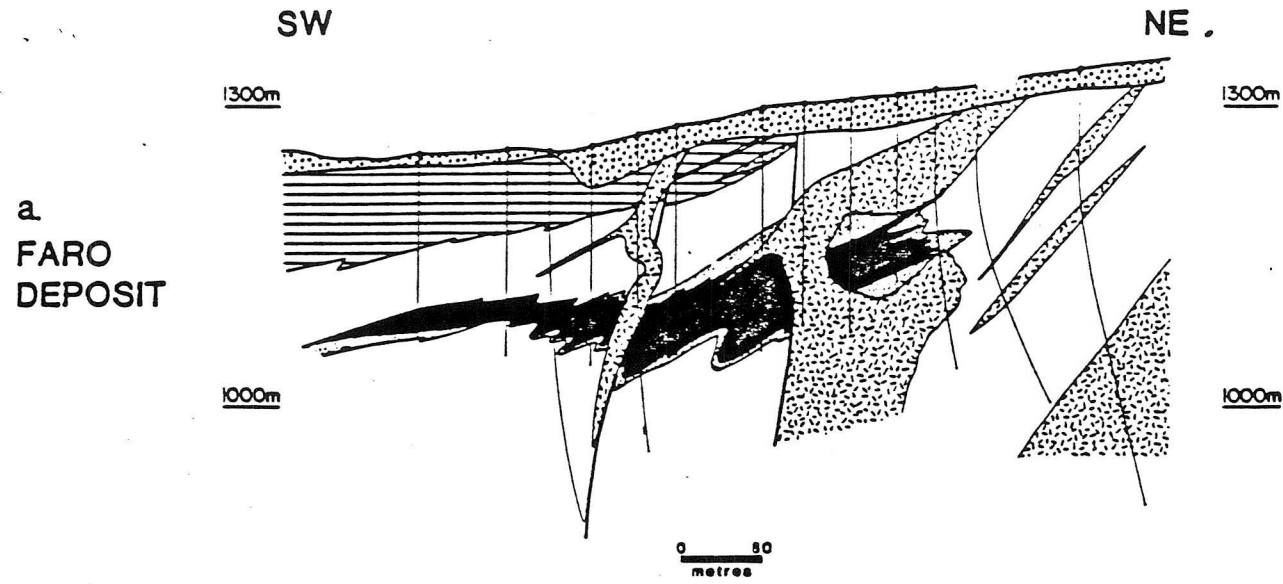
As has been shown previously (Tempelman-Kluit, 1969), metamorphic grade increases from the Swim deposit (low greenschist) to Faro deposit (amphibolite) with a parallel increase in grain size of the sulfides. It should be further emphasized that sulfides, sulfates and host silicates in all deposits are extensively recrystallized and the textures seen today are largely metamorphic.

The first deformation produced a regional metamorphic foliation (S_1) axial planar to tight to isoclinal, mesoscopic folds in bedding (S_0) which are rarely preserved in the district. ^(Figure -) Northeast vergent, megascopic folds appear to have formed at that time. ^(Figure -) During the second event, S_1 was strongly crenulated and ubiquitous tight mesoscopic folds in S_1 were produced. ^{Regional scale} ~~Important~~ megascopic structures apparently did not form during this event. ^{though orebody size folds are common (Fig 6B)} The S_2 regional, crenulation foliation produced during this event generally dips at low angles and, on a large scale, is sensibly parallel to lithologic layering. Layering and S_2 depart dramatically in

hinges and short limbs of the large asymmetric phase one folds (see Figure 4b for an example of this northeast of DY deposit).

The later events generally produce open folds and weak crenulations in S_2 related to broad, regional structures. The third event appears related to the formation of Anvil Arch (Tempelman-Kluit, 1972), a large, doubly plunging antiform which warps S_2 and is cored by Anvil Batholith. An important exception to this general rule is found in the vicinity of the Faro open pit where the fourth event is quite intense, with tight mesoscopic folds developed in nearly pervasive S_2 with appreciable mica growth along S_4 (see Figure 4a for an example of fourth phase folds affecting outline of the Faro deposit).

Anvil Batholith ranges in composition from granodiorite to quartz monzonite and texturally includes equigranular massive, megacrystic massive and various strongly to weakly foliated variants. The earliest foliation, perhaps an igneous flow foliation, is cut and crenulated by a later foliation that extends into country rocks as S_2 showing that at least the foliated phases of the pluton were in place during the second deformation and possibly the first. Elsewhere, less foliated phases of the batholith cut S_2 and retrograde second period metamorphic minerals. Several K/Ar ages on the granitic rocks yield ages of 85 - 100 my (Tempelman-Kluit, 1972) showing that the Anvil Batholith is part of the 100 my granitic suite common in the eastern Cordillera and Omineca Crystalline belt. These relations imply metamorphism in the district is late Mesozoic rather than pre-mid-Ordovician as previously reported (Tempelman-Kluit, 1972), a fact of potential importance in lead isotope systematics.









- | | | |
|-----------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
|  overburden |  VANGORDA FORMATION
calcareous phyllite |  alteration overprint |
|  diorite and quartz monzonite
porphyry |  mafic meta-igneous rocks and
chloritized pelite |  MT MYE FORMATION
non calcareous phyllite and schist |
- massive and disseminated sulphides

Figure 4: Generalized cross sections of Faro and Dy deposits.

ORE DEPOSITS

The presently known deposits of Anvil Range lie along the south flank of Anvil Arch (Figure 2). From northwest to southeast, they include the Faro, Grum, Vangorda, DY, Swim and SB deposits. Additionally, two sulfide occurrences, the Sea and Firth, are also known in the district. Current tonnage and grades for each of these deposits are summarized in Table 1.

All deposits are stratiform, crudely stratabound, pyritic, ZnS and PbS bearing, massive to disseminated sulfide lenses with lengths generally two to three times widths. Quartz and barite are the principal gangue minerals. Deposits occur as single lenses with little or no interbanded metasedimentary rocks, e.g. Faro, or as multi-layered lenses with substantial metasedimentary or metavolcanic interlayers, e.g. DY (Figure 4b). The upper and lower contacts of any given sulfide body are invariably sharp while lateral margins appear to grade into the enclosing host rocks. All deposits show a variably developed, white mica-dominant, alteration overprint in the immediately adjacent host rocks (Figure 5). This overprint ~~facies~~ is not a depositional unit and may form either as a reaction product between wallrocks and deposit forming hydrothermal fluids or as a metamorphic ~~sulphurization~~ reaction envelope or combination of these processes. In the multi-layered deposits, this alteration overprint seems best developed in the footwall of a given lens or deposit as a whole.

The Anvil deposits occur within the gradational contact zone of the Mt. Mye and overlying Vangorda formations. In the main deposit area, this transition occurs over an interval of approximately 300 meters. A regionally developed but discontinuous graphitic phyllite unit occurs in this zone with

TABLE 1

1981 Reserves for Anvil District Deposits

<u>Deposit</u>	<u>Proven Geological Reserves (tonnes)</u>	<u>Grade</u>			<u>Estimated Total Sulfide Tonnage (tonnes)</u>
		<u>Lead %</u>	<u>Zinc %</u>	<u>Silver (gm/tonne)</u>	
Faro	36.9 million	3.0	4.8	37	70 million*
Grum	27.8 million	3.1	4.9	48	50- 80 million
Vangorda	5.2 million	3.3	4.3	48	10- 15 million
DY	18.0 million	5.6	7.4	83	70-100 million
Swim	4.3 million	4.7	3.8	47	8- 10 million
Composite	92.2 million**	3.6	4.7	50	208-275 million

*(before mining)

**Includes 50.3 million tonnes minable open pit reserves at 3.0% lead, 4.7% zinc and 41 gm/tonne silver.

the sulfide deposits in, laterally equivalent to or slightly below the graphitic phyllite (Figure 3).

While the bulk of the basaltic metaigneous rocks occur up-section from the Anvil deposits, it is important to note that the first significant pulse of basaltic activity is regionally coincident with the Mt. Mye/Vangorda transition suggesting at least a temporal relationship between ore formation and basaltic magmatism (Jennings et al, 1976, 1980). It should be emphasized, however, that there is a generally poor spatial association of sulfide deposits and metabasaltic rocks. The DY deposit is the notable exception to this generalization. In this sense, the Anvil deposits are dominantly pelitic sediment hosted.

In map view, the deposits form a prominent curvilinear array along the Mt. Mye/Vangorda boundary (Figure 2). Detailed ^{geophysical} mapping and drilling suggest the deposits lie close to a northeasterly "pinch out" or "zero edge" of the associated graphitic phyllite. To date, no sulfide deposit lithofacies have been encountered in a moderate number of drill holes through the transition zone southwest of the deposit line. Taken together, these observations suggest some relationship between sulfide deposits, ^{linear} facies changes ^(fault controlled?) at reduced basinal margins and basaltic activity.

While deposits of the Anvil belt show distinct differences in terms of numbers of mineralized horizons per deposit, spatial relationship to metabasaltic rocks and grades of regional metamorphism, their overall similarity of sulfide lithofacies is overwhelming. The principal ore types include:

1. Ribbon-banded, sulfide-bearing graphitic quartzites: alternating laminae on a millimeter to centimeter scale of dark grey to black, siliceous, carbonaceous pelite and light grey, pyrite, sphalerite and galena-bearing quartzites; *Figure*
2. Muscovite, pyrite quartzites: disseminated (5%) to nearly massive (60%) pyrite and highly variable sphalerite and galena in a light grey, muscovite quartzite matrix; *usually 5-36%*
~~commonly banded.~~
3. Massive pyritic sulfides: massive pyritic sulfides (> 80% total sulfides by volume) generally enriched in sphalerite and galena relative to the previous unit with quartz as gangue; unit ~~may~~ grades into massive non-pyritic base metal sulfides or massive pyrrhotite.
4. Baritic and ferroan carbonate-bearing massive pyritic sulfides: massive sulfides, sulfates and carbonates commonly most enriched in sphalerite and galena with subsidiary magnetite and quartz gangue.

All lithofacies are commonly banded and show narrowly gradational, vertical contacts. The similarity of sulfide facies between deposits strongly suggests a consanguinous origin for the Anvil District deposits.

An arrangement of these facies in a vertical and lateral sense is so commonly seen within and between deposits it is referred to as the Anvil Cycle. Details of this cycle are best seen in an idealized model of an Anvil deposit (Figure 5). The base of the cycle is marked by ribbon-banded, sulfide-bearing graphitic quartzites succeeded upward by pyritic quartzites, massive pyritic sulfides and baritic massive sulfides. This vertical array is also seen laterally with ribbon-banded, sulfide-bearing graphitic quartzites forming the marginal or distal facies of a deposit inward to the baritic massive sulfide facies. *Anvil cycles are commonly capped by a poorly developed unit of ribbon banded graphitic quartzite*

Metal zoning compliments this facies distribution pattern in that the base of a cycle tends to be Zn-enriched with lead and silver enrichment toward the top in the baritic facies. Copper and gold seem to be preferentially

distributed in siliceous facies of the footwall-biased alteration overprint or in the pyritic quartzite facies of the stratiform sulfides.

This facies and metal zonation picture, though common and well defined, is somewhat idealized. It is important to note that the Anvil Cycle is developed on a variety of scales and to varying degrees of completeness. A series of complete and partial cycles may cumulatively form a mega-cycle on the scale of a deposit, e.g. Faro, or on the scale of a single sulfide horizon within a multi-layered deposit, e.g. DY, generating the concept of cycles within a cycle. Also, complete cycles are seen over a one meter stratigraphic interval (or less), emphasizing the scale at which facies ordering can occur.

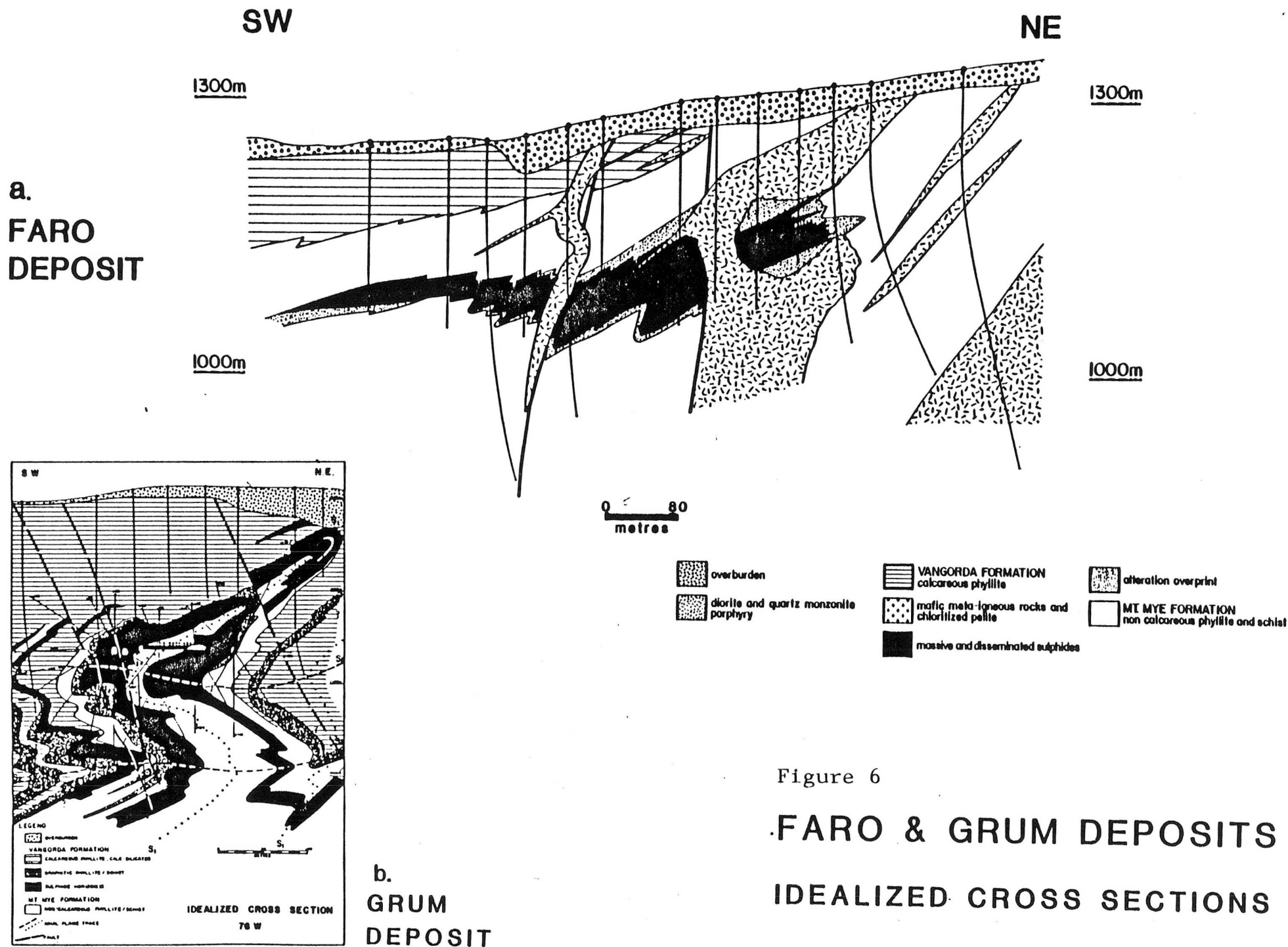


Figure 6
FARO & GRUM DEPOSITS
IDEALIZED CROSS SECTIONS

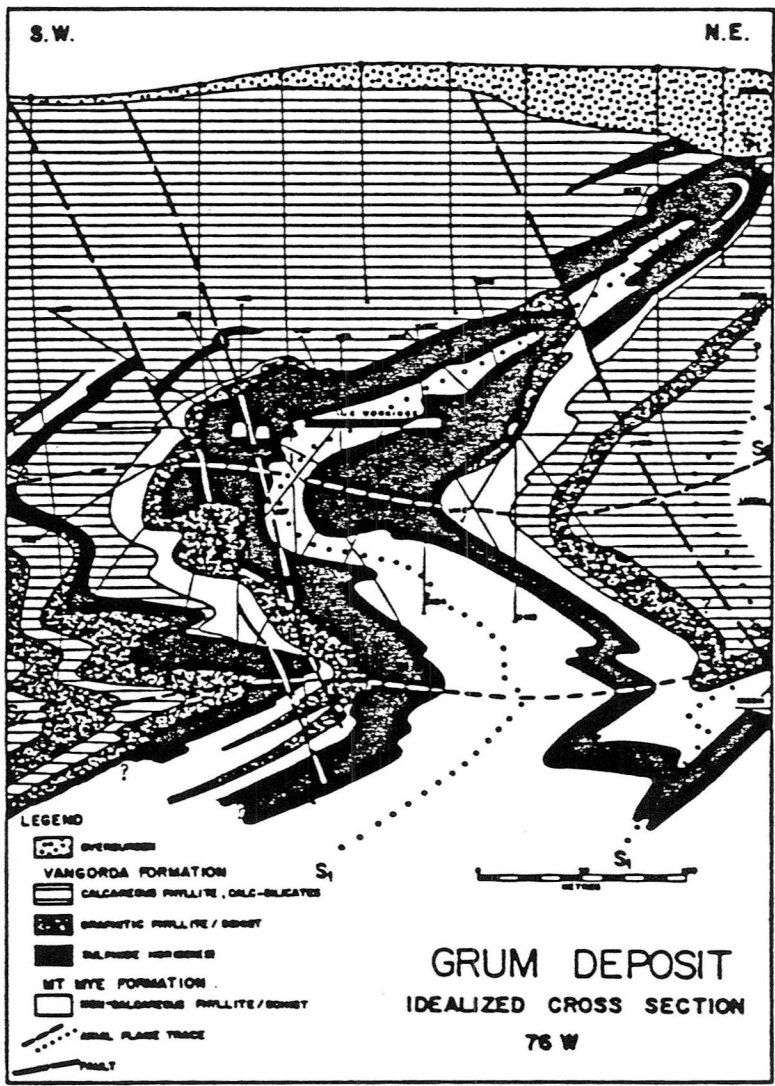


Figure 6b

More detailed version of the Grum deposit section shown on Figure 5.

GENETIC MODEL

The metamorphic overprints on the ores clearly show the ores are pre-metamorphic. Prevalent compositional banding, interlayering with metasedimentary rocks, and the occurrence of deposits at a relatively restricted stratigraphic horizon in a curvilinear array spatially associated with facies changes strongly suggest that the deposits are synsedimentary.

Reconnaissance fluid inclusion work by Kuo (1976) and wall rock alteration developed around some deposits ^{suggest} ~~show~~ a hot saline fluid was involved in ore transport. The curvilinear array of deposits may indicate a synsedimentary fault or fault zone controlling basinal topography, possibly providing a depression(s) for pooling of hydrothermal fluids as well as influencing sedimentary facies, particularly the zero edge of the deposit-associated graphitic phyllite. Additionally, this synsedimentary fault or hinge line may have provided a channel for fluid migration to the sea water-sediment interface.

In summary, the ore deposits are thought to have formed during a period of extensional tectonism and minor basaltic volcanism in a within-plate setting during the late Hadrynian or lower Cambrian. Hydrothermal fluids are envisioned to have migrated up fault zones, and were exhaled into a relatively deep marine basin which was receiving distal turbidite sedimentation. Lead-zinc bearing sulfides were deposited perhaps from a plume at the edge of a fault controlled, second-order, reduced basin or from brines ponded in such a sub basin. A recurrently evolving set of environmental parameters at the site of deposition of sulfides and/or in the area

of generation of the hydrothermal fluids must be responsible for the Anvil Cycle.

The source of hydrothermal fluids and metals is a subject for which there is even less hard, geologic data to guide speculation than used above. The following thoughts, which represent an attempt to place ore genesis into the overall evolutionary pattern of the sedimentary basin, are put forward here since they prove to be of interest in the interpretation of lead isotope data. We have previously suggested (Jennings et al, 1979) that since the northern Cordillera evolved following a Wilson-like cycle (see Monger and Price, 1979; Tempelman-Kluit, 1979 for recent models of Cordilleran evolution), the Anvil District may be underlain by red beds and evaporites deposited in rift basins on preCambrian, continental crust. This postulated shallow marine and continental sequence may have been overlain, as the rift basin deepened, by thick, relatively coarse turbidites which, if subsidence out paced, sedimentation could pass upwards through finer sediments ultimately to be capped by deep water shales. The Mt. Mye formation may represent the shale-rich upper member of this hypothesized stratigraphic cycle, while the grit unit, which is presumed to extend beneath the Mt. Mye rocks of the Anvil District, may be the upper part of the turbidite package (Figure 6). Candidates for the evaporite-red bed sequences can now be seen in the Proterozoic of the Mackenzie Mountains (Eisbacher, 1979) but they are not known to extend beneath the grit unit.

Such an arrangement would provide an attractive reservoir-seal situation within which connate waters could evolve into hot, metaliferous fluids.

It is hypothesized that connate waters in this reservoir leached evaporites to become highly saline, at the same time became gradually geothermally heated and interacted with the coarse clastic reservoir rocks to leach metals from such sources as feldspar grains, pigments of red beds (Carpenter, 1979), interbedded shales, grain surfaces or any other available source. The fluids may have gradually become geopressed as well. Such a reservoir might be stratified with respect to chemical and isotopic composition of the fluid, its temperature and salinity because of host rock stratification, and general downward temperature increase leading to a potential source of some of the variation seen in the Anvil Cycle.

During renewed extensional tectonism, this shale cap was breached and the evolved fluids escaped upwards to the sea floor. In such a model, volcanism may be entirely passive and simply reflect the tectonic environment. More active roles can be envisioned where basaltic magmas transfer large amounts of heat to the reservoir by sill emplacement (Figure 7) and/or sub volcanic feeders accomplish the breaching of the shale cap.