004928

GEOLOGY, EXPLORATION POTENTIAL and MINERAL RESOURCES of ANVIL DISTRICT - Yukon

Curragh Inc.

May 1993

Report WH9306

TABLE of CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The orebodies of Curragh Inc.'s Faro Division occur in the Anvil Range, central Yukon. The five known deposits comprise one of the major lead-zinc-silver districts of the world. Pre-mining in-situ mineral inventory has been estimated at over 150 million tonnes. Production to date has totalled 62 million tonnes mainly from the Faro deposit.

This report summarizes the geology and exploration of the district, its mineral inventory and the potential for further discoveries. The geology of the Anvil District is described in detail by Jennings and Jilson (1986) and Pigage (1989). Exploration methods are described by Chisholm (1957), Aho (1966), Brock (1973) and an unpublished manuscript by Jennings and Simpson (1984).

LOCATION AND ACCESS

The Anvil District is located 200 air kilometres northeast of Whitehorse (Figure 1). Access is by all weather highway, approximately half of which is paved. The route runs north from Whitehorse to Carmacks on the Alaska and north Klondike highways and then east from Carmacks on the Campbell Highway. The Total highway distance from Whitehorse is 360 km.. Concentrates are hauled from the Faro concentrator to tidewater by B-train tractor trailer units a one way distance of 550 km. along the above route, plus the south Klondike Highway to Skagway, Alaska.

HISTORY

Lead-zinc-silver ore was first discovered in the Anvil Range in 1953. The Vangorda deposit was delineated by drilling between 1955 and 1956 but the reserves defined did not warrant development. Exploration resumed in the early 1960's leading to the discovery of the Swim deposit in 1964 and Faro in June of 1965. Drilling and underground work from 1964 to 1967 defined a large deposit at Faro. A feasibility study was completed in 1967 and a production decision was made in August of that year. The concentrator began production in September 1969 at 5,000 tonnes per day; the mill was expanded to 6,000 tonnes per day the following year and again to 9,000 tonnes per day in 1974. The Faro discovery lead to a major staking rush and considerable further exploration in the ensuing few years but no new finds. After considerable detailed exploration work, discoveries resumed when the Grum deposit was discovered in 1973 followed by the Dy deposit in 1976. In 1979 the operator of the Faro mine, Cyprus Anvil Mining Corporation, purchased the mineral rights to all the other deposits and began to plan for development of Grum to supplement the Faro operation.

Mining at Faro continued until 1982 when low metal prices and high operating costs compounded by the debt load of Cyprus Anvil's rapid expansion caused a mine closure

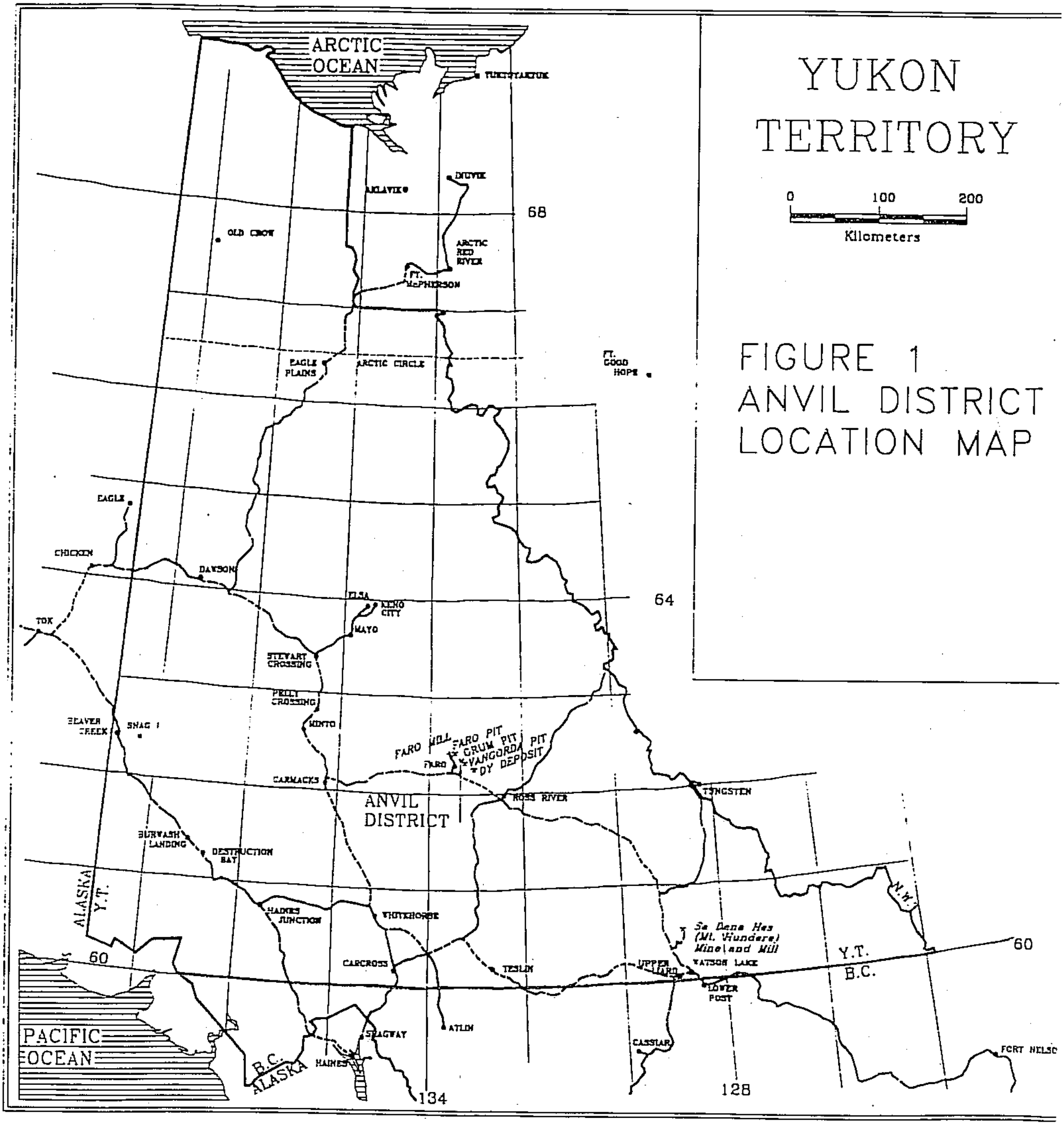

Figure 1. Location of Curragh Inc. Yukon Operations at Faro and Watson Lake. Concentrate is hauled to tidewater at Skagway, Alaska

and the failure of Cyprus Anvil. The Faro mine was re-opened in 1986 after being purchased by Curragh Resources Corporation, a predecessor to Curragh Inc., in 1985.

On re-opening mill tonnage throughput was increased to 11,600 tonnes per day and has gradually been further increased to it's current 13,500 tonne per day average. Curragh operated Faro as an open pit until mid-1992 when it was depleted. Salvage of small tonnages of high grade ore in the original pit walls continued into 1993. At the time of writing approximately 30,000 tonnes of ore remained at Faro below the main haulage ramp. An underground mine was developed in the southwest pit wall in 1990, it closed in 1992 also due to depletion of reserves. The Faro pit has now been converted into a tailings pond.

To provide further ore feed for the Faro concentrator the Vangorda and Grum deposits 14 km. to the southeast were developed as satellite pits in 1989. Mining was carried out in the Vangorda pit from 1990 to early 1993, approximately one million tonnes of ore remain. Pre production stripping has been carried out at Grum from 1990 to 1993 but only a small amount of ore has been released. Curragh's operations are currently in temporary closure due to poor market conditions.

Table 1 provides details of millfeed by year since the start of operations in 1969. Table 2 reconciles mill feed to mined quantities and Table 3 summarizes the quantities mined to date from each deposit. Production from, the Zone 3 Faro pit compares remarkably well to the reserve that formed the basis of the 1985 feasibility study for reopening the Faro mine (Table 2). To some extent this excellent comparison is an illusion since the reserve was calculated at a 4% Pb+Zn cutoff grade but Faro has mined to a 3% cutoff for several years. The extra tonnage from the change in cutoff presumably has compensated for tonnage lost when the northeast pit wall was moved to provide a greater safety berm. This reconciliation may change somewhat as various target areas in the Zone 1 pit are incorporated.

Curragh controls 2,355 claims and 67 mineral leases which form a contiguous land package encompassing 41,500 hectares. There are no other companies actively exploring in the district however several companies have various minority interests in some of the claims. A separate report (WH9301A) details the land holdings in the district at the time of writing.

REGIONAL GEOLOGY

The Anvil district is underlain by early Palaeozoic thru early Triassic sedimentary strata which, in a general sense, are part of the Selwyn Basin. The strata belong to the Cordilleran miogeocline and all but the Pennsylvanian and younger have strong affinities to ancestral North America. Chert and basalt of Pennsylvanian and Permian age may be allocthonous oceanic rocks. More certainly exotic terranes, including the arc related Yukon Tannana and oceanic Slide Mountain Terranes, both mainly Palaeozoic, abut the

TABLE 1
HISTORIC MILL PRODUCTION STATISTICS

Year		Millfeed Tonnes	%Pb+Zn	%Zn	%Pb
CYPRUS ANVIL'S OPERATING YEARS					
	1969	394,629	9.10	5.60	3.50
	1970	1,779,008	10.80	6.40	4.40
	1971	2,424,930	11.71	6.79	4.92
	1972	2,635,399	10.88	6.24	4.64
	1973	2,629,956	11.25	6.37	4.88
	1974	2,653,543	10.11	5.60	4.51
	1975	2,925,701	9.44	5.41	4.03
	1976	1,519,550	8.14	5.48	2.66
	1977	3,116,212	7.62	4.88	2.74
	1978	3,280,414	8.31	5.14	3.17
	1979	2,823,000	8.54	5.28	3.26
	1980	2,825,000	7.80	4.68	3.12
	1981	2,758,603	7.70	4.80	2.90
	1982	1,635,241	7.60	4.80	2.80
CURRAGH'S OPERATING YEARS					
	1986	1,639,000	7.62	4.62	3.00
	1987	4,539,000	8.24	4.93	3.31
	1988	4,126,000	8.49	4.87	3.62
	1989	4,379,084	7.62	4.69	2.93
	1990	4,714,035	7.88	4.88	3.00
	1991	4,126,588	7.56	4.53	3.03
	1992	4,548,744	7.78	4.58	3.20
	1993	1,030,483	7.62	4.54	3.08
CYPRUS ANVIL	(1969−1982)	33,401,184	9.19	5.50	3.70
CURRAGH	(1986−1993)	29,102,934	7.90	4.73	3.16
TOTAL MILLED	(1969−1983)	62,504,118	8.59	5.14	3.45

TABLE 2
PRODUCTION RECONCILIATION, FARO OPERATION

	Tonnes	Pb+Zn %	Zn %	Pb %
TOTAL MILLLED 1969 to 1993	62,504,118	8.59	5.14	3.45
MILLED FROM VANGORDA OREBODY	4,857,650	8.51	4.66	3.85
MILLED FROM FARO OREBODY	57,646,468	8.60	5.18	3.42
REMAINING IN FARO STOCKPILES	1,762,159	4.45	2.77	1.68
TOTAL MINED FROM FARO OREBODY	59,408,627	8.47	5.11	3.36
MINED FROM FARO UNDERGROUND	1,780,241	11.47	7.01	4.46
MINED FROM FARO PIT	57,628,386	8.38	5.05	3.33
MINED BY CAMC FROM FARO PIT	34,201,184	9.08	5.43	3.65
MINED BY CI FROM FARO PIT	23,427,202	7.36	4.50	2.86
1985 FEASIBILITY STUDY RESERVE	23,763,000	7.30	4.40	2.90

TABLE 3
SUMMARY OF ORE MINED TO DATE, ANVIL DISTRICT

AREA OR DEPOSIT	Tonnes	Pb+Zn %	Zn %	Pb %
MINED BY CAMC FROM FARO PIT	34,201,184	9.08	5.43	3.65
MINED BY CI FROM FARO PIT	23,427,202	7.36	4.50	2.86
MINED FROM FARO UNDERGROUND	1,780,241	11.47	7.01	4.46
SUBTOTAL MINED FROM FARO TO DATE	59,408,627	8.47	5.11	3.36
MINED FROM VANGORDA PIT	5,662,712	8.11	4.44	3.67
MINED FROM GRUM PIT	52,000	5.48	3.65	1.83
GRAND TOTAL MINED TO DATE	65,123,339	8.44	5.05	3.39

southwest boundary of the district along a major suture, the Vangorda Creek Fault. The district is part of the Omenica Belt and shows the early Mesozoic regional metamorphic overprint, complex polyphase fold deformation and mid-Cretaceous granitic plutonism that marks the ancestral North American part of that belt in Yukon. A major northwest trending Cretaceous granitic body, the Anvil Batholith, is the central feature of the district (Figure 2). Palaeozoic metamorphic rocks dip northeast and southwest away from the batholith. The five ore bodies occur in Cambrian phyllites or schists along the southwest flank of the batholith. The deeper strata, near the batholith, are more intensely metamorphosed than those less buried or more remote from the batholith. The polyphase deformation of the district is thought to be related to collision of the exotic terranes with the North American block in early Jurassic, causing northeast verging folding, nappe emplacement (including thrust sheets of the exotic sequences), depression of the crust, partial melting of the lower crust, and uprise of granitic magmas by middle of the Cretaceous. Granite emplacement was accompanied by high heat flow, metamorphism and southeast verging folding along shallowly dipping axial planes. The final emplacement of the batholith resulted in large scale extensional displacements as the batholith and its high grade metamorphic carapace forced its way upward through the lower grade strata. The district is located just northeast of a major Cordilleran lineament which marks the locus of the Tintina Fault a transcurrent fault with 500 km. of right lateral displacement.

DISTRICT GEOGRAPHY

The are three major geographic subdivisions of the Anvil Range: the Faro Block, the Vangorda Plateau, and the Swim Basin (Figure 3). These subdivisions correspond to important geologic domains in the district.

The **Faro Block** includes that portion of the district extending from the Tie Fault trace to the northwest of the Faro minesite. The favourable stratigraphic units here have been metamorphosed to amphibolite facies in large part. Rock unit boundaries and layering are largely transposed into the second phase metamorphic foliation which is pervasive in the area and generally dips gently southwest or west. Deep drilling in this area has concentrated on the area down dip of the Faro Deposit also extending along strike a few km to the northwest; one deep hole and a number of shallow holes have been put down between Faro and Grum northwest of the Ski Hill.

The **Vangorda Plateau** is an incised plateau or bench on the south flank of the granitic highlands of Mt. Mye. There are local patches of thick glaciofluvial deposits but fair exposure can be found over much of the area. The area lies between the Tie and Blind Creek faults southwest of the granitic rocks of Anvil Batholith and northeast of Vangorda Creek Fault Zone. In general the second phase metamorphic foliation (S_2) dips shallowly southwest away from the granite as do most rock units on a large scale. In the Grum vicinity first and second phase folds (F_1 and F_2) plunge shallowly northwest; fold plunge

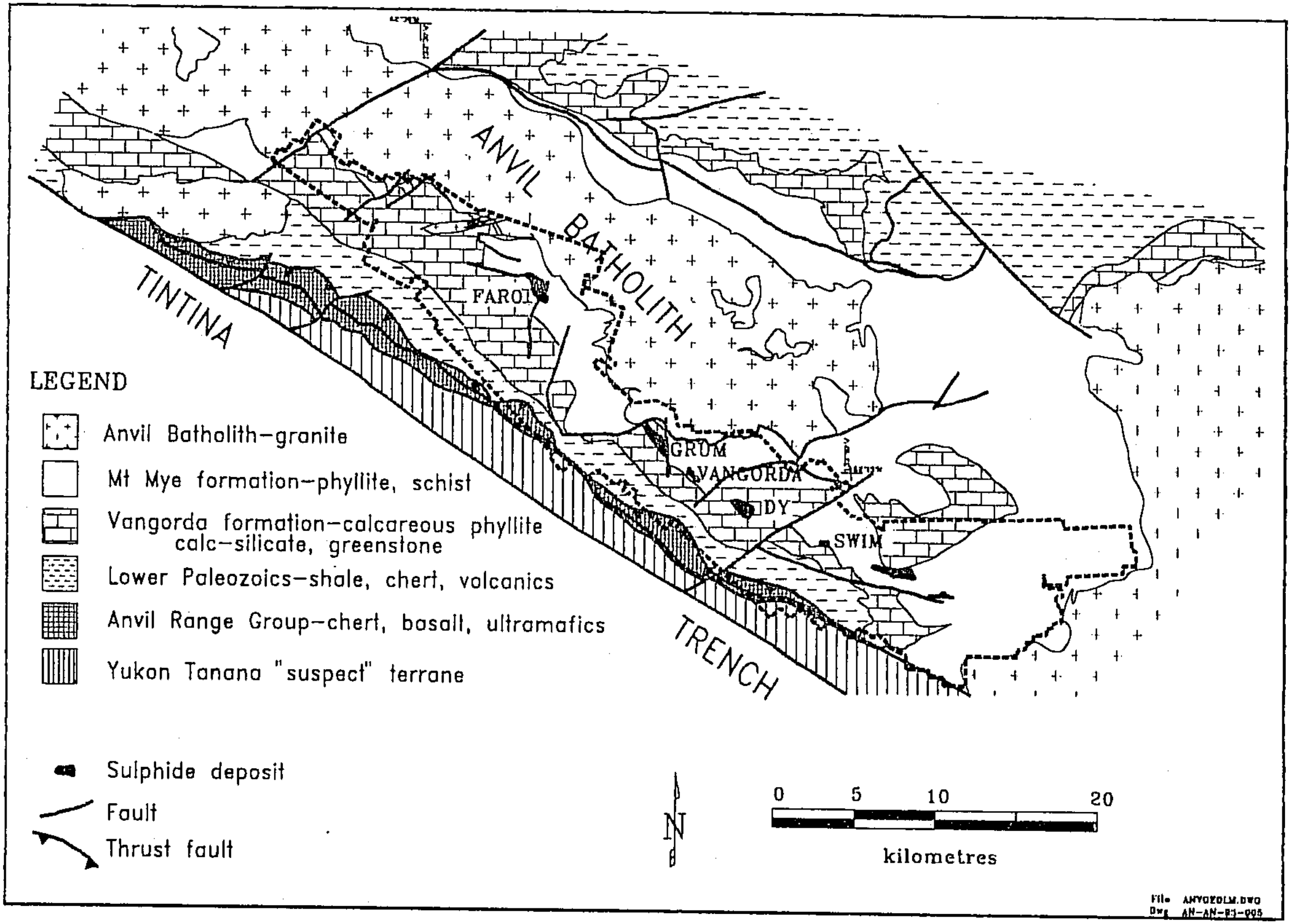

Figure 2. Geological Map of the Anvil District showing the location of known sulphide deposits. Only the named deposits are Zn-Pb-Ag bearing. The dashed-outline is the Curragh claim block.

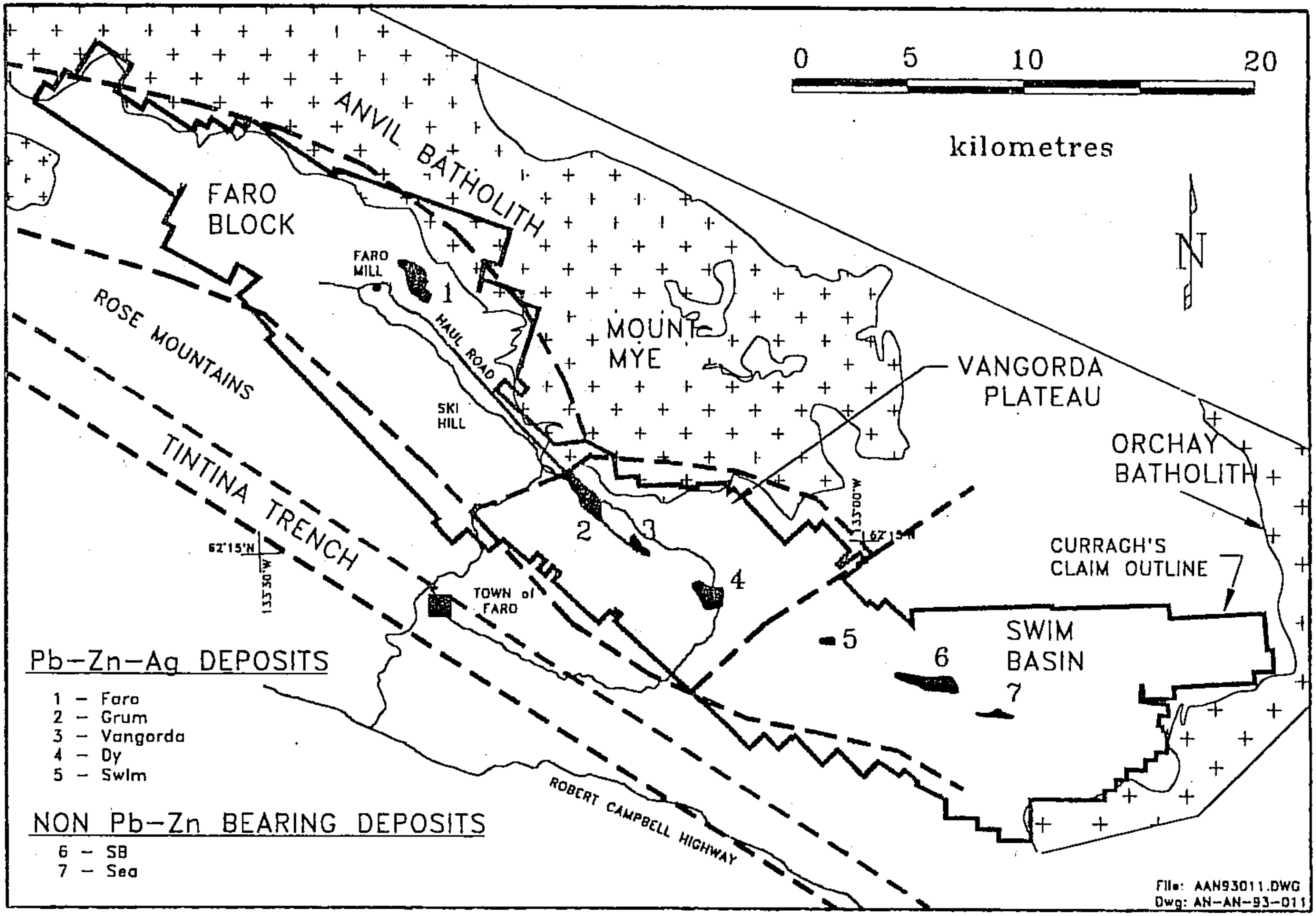

Figure 3. Geographic Regions of the Anvil District

elsewhere is probably also northwest but a reversal may occur between Vangorda and Dy. Greenschist facies metamorphism predominates and second phase transposition is less extensive than in the Faro Block.

The **Swim Basin** is a lowland between the granitic highlands of Mt. Mye on the northwest and Orchay Batholith on the southeast. To the southwest is a ridge of resistant late Palaeozoic volcanics bounded by splays of the Vangorda Creek Fault Zone. The area has few bedrock exposures and is heavily covered by thick, laterally extensive, glacial till. There are many small to moderate sized lakes and large swampy areas. Geophysical surveying and drilling are best done in much of this area in winter. The basin is essentially a structural basin whose periphery is underlain mainly by phyllites of the Mt. Mye formation. There is a large patch of Vangorda formation preserved in the centre of the basin. The basal member of the Vangorda formation is widespread as indicated by geophysical surveys. The area is mainly at greenschist facies and shows similar structural style to the Vangorda Plateau.

SURFICIAL GEOLOGY

All but the highest peaks in the area were ice covered in the last glaciation. Ice flow and transport direction was from southeast to northwest or east to west as evidenced by glacial striae and elongate land forms as well as transport of distinctive rock types such as the serpentinized pyroxenites in the upper Dixon Creek area.

Discontinuous deposits of glacial till and glacio-fluvial deposits are common in the area, however with local exceptions the deposits are not thick. Important exceptions are a buried valley filled with up to 70m of overburden over the subcrop of the Grum deposit and a ridge of highly compacted till up to 40m thick overlying the Vangorda deposit. Thick fluvial deposits also occur in the Rose Creek, the west fork of Vangorda Creek and in the Blind Creek valleys. In Swim Basin there is a widespread, thick, blanket of glacial deposits which significantly inhibits exploration.

Glaciers stripped off most of the weathered mantle, thus most geochemical anomalies are transported either hydromorphically or physically by downhill movements or ice transport.

STRATIGRAPHY

The stratigraphic sequence of Anvil District ranges in age from latest Precambrian to Permian. The lower part of the sequence (Silurian and/or earlier) is divisible into three major mappable units (Figure 4). From the base these are non-calcareous metapelite of the Mt. Mye formation, calcareous meta-pelite of the Vangorda formation, and meta-basalt of the Menzie Creek formation (Jennings and Jilson, 1986). All formational names in this sequence are informal. The aggregate thickness for this pre-Silurian sequence is approximately 5km.

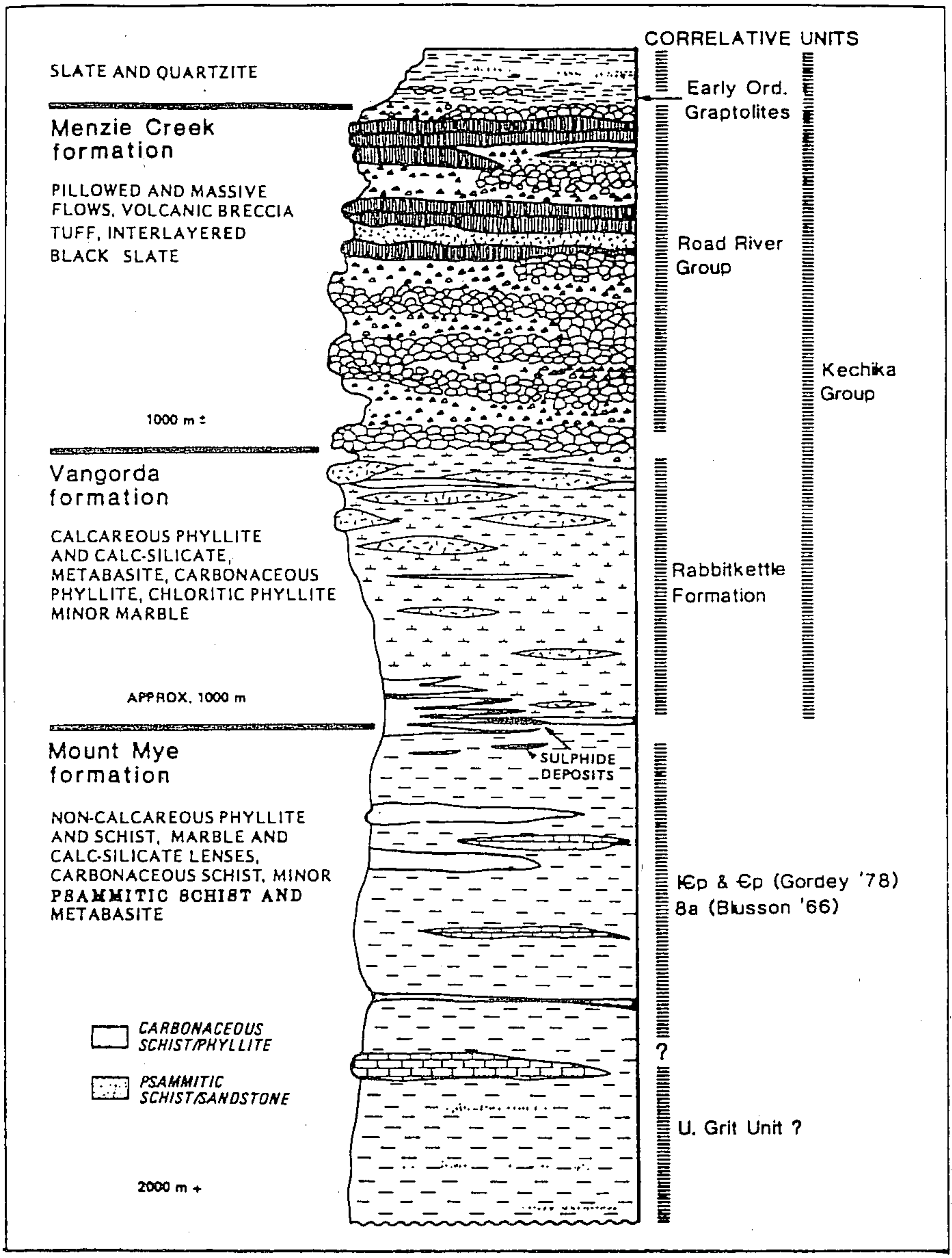

Figure 4. Stratigraphic Column of the older part of the Anvil District section

The strata overlying the above sequence are characterized by shale, chert, coarse clastics rich in chert fragments, minor limestone, and an uppermost basalt unit. Strata of the Devonian-Mississippian Earn Group (Gordey et al., 1982) and Pennsylvanian-Permian Anvil Range Group (Tempelman-Kluit, 1972) are present. All or part of this upper sequence may be allochthonous with respect to the underlying units. The boundary between allochthonous and parautochthonous strata is drawn at the base of the Anvil Range group where red cherts first become prominent in the section. The Earn group locally contains stratiform barite deposits.

The Devonian and younger rocks are not related to the ore deposits in the district and consequently are not discussed further (details can be found in Templeman-Kluit, 1972, and Jennings and Jilson, 1986). The three older units either host the ore deposits or are the environment of exploration thus are considered in more detail below.

Mt. Mye formation consists dominantly of non-calcareous, biotite-muscovite +/- andalusite +/- staurolite +/- garnet schist in areas of amphibolite facies metamorphism and non-calcareous, weakly carbonaceous, light to medium grey muscovite-chlorite phyllite in areas of greenschist facies metamorphism. It contains lesser, interlayered black carbonaceous phyllite or schist, calcitic marble, calc-silicate phyllite or schist, greenstone or amphibolite, and psammitic schist. The formation has a structural thickness of at least 2 km, the base is not exposed. The reddish brown weathering colour of the formation is characteristic and helps distinguish it from non-calcareous portions of the overlying Vangorda formation.

Dark grey to black carbonaceous phyllite or schist members comprise about 10 per cent of the formation. They are more abundant in the upper 400m of the formation. A distinctive assemblage of carbonaceous siliceous phyllite, and black carbonaceous limestone, appears to underlie, or be laterally equivalent to the lowest sulphide horizons.

Coarse-grained, white, calcite marble and calc-silicate also constitute about 10% of the Mt. Mye formation. The marble is light grey, medium crystalline calcite marble with boudins of pelite, amphibolite, and calc-silicate. Marble bodies may be up to 75m thick but are generally only a few tens of meters thick; they can be traced laterally for several kilometres. The calc-silicate lithology is a thinly interbanded sequence of purplish brown biotite pelite and pale green actinolite-epidote calc-silicates. Typically the calc-silicates are spatially associated with the marbles. The calc-silicates are identical to Vangorda formation calc-silicates, but a protolith for the associated clean marbles is not common in the Vangorda formation. The most persistent horizon of lenticular marble and calc-silicate bodies occurs about 500 to 700m below the top of the Mt. Mye formation. The marble plus calc-silicate assemblage appears to underlie the carbonaceous phyllite plus black limestone assemblage noted above. This is thought to be a lower Cambrian stratigraphic unit but alternative concepts such as a recumbent, isoclinal, synclinal infold of Vangorda formation, or thrust interleaved Vangorda and Mount Mye are possibilities which have not yet been ruled out. This problem is of great exploration significance and must be resolved to allow structural modelling of the district to advance.

Metabasite bodies in the Mt. Mye formation are generally only a few meters thick and have small lateral dimensions. Volumetrically they constitute less than 1% of the Mt. Mye formation. They are generally strongly foliated, dark green amphibolites lacking relict igneous texture. Compositions are similar to basalts of the Menzie Creek formation (Jennings and Jilson, 1986). They are interpreted as subvolcanic feeder dykes and sills of the Menzie Creek basalts.

The upper portion of the Mt. Mye formation is very similar to the buff weathering mudstone and blue-grey mudstone units, described by Gordey (1978), to the east near Howards Pass, and unit 8A of Blusson (1966). Correlation with these units would imply the top of the formation is lower Cambrian or possibly middle Cambrian. Jennings and Jilson (1986) suggested that the persistent marble and calc-silicate package may correlate with the widespread early Cambrian limestone conglomerate of Selwyn Basin. Parts of the Mt. Mye formation also resemble rocks underlying those presumed correlative units, implying that the Mt. Mye may include rocks as old as Hadrynian.

The **Vangorda formation** is characterized by light to medium-grey to greenish-grey, calcareous, phyllitic rocks made up of very thin (0.1-2cm) interlayers of medium grey, non-calcareous, weakly carbonaceous, muscovite-chlorite pelite and light grey, generally calcareous quartz-calcite +/- dolomite siltstone. At the higher metamorphic grade of amphibolite facies, the Vangorda formation phyllites are transformed to a thinly banded, pervasively foliated, green, cream, and purplish brown, calc-silicate. Major interbanded units include greenstone and carbonaceous pelite. Minor phyllitic limestone occurs locally. The Vangorda formation varies between 0.5 and 2 km. in apparent thickness. The formation becomes more calcareous up section. The light grey to tan coloured, drusy weathering of the formation is characteristic both within the district and elsewhere.

The greenstone bodies range from 1m to 100m in thickness and are up to several kilometres in length. They comprise approximately 15% of the Vangorda formation and are more prevalent near the top of the formation. Whole rock analyses show that the greenstones are compositionally similar to the overlying Menzie Creek basalts (Jennings and Jilson, 1986). Locally the greenstones contain coarsely crystalline serpentinized pyroxenite subunits, which may be pyroxene cumulates. Most greenstone bodies have medium-grained, equigranular centres with strongly foliated margins. Although marginal contacts of the bodies are superficially conformable, detailed inspection indicates the units are locally slightly crosscutting. The greenstones are thus interpreted as subvolcanic dykes and sills feeders to the Menzie Creek formation. Where the mafic units are thin, the entire body may be a foliated chloritic phyllite, commonly calcereous, with thin white bands of quartz and calcite. Some of these chloritic phyllites contain relict pyroxenes or feldspars, and develop a fine augen texture, while others have flat oviod dark chloritic spots on the foliation after vesicles or pyroxenes.

Typically the Vangorda formation adjacent to the greenstones is a thinly banded, hard, pale green, calcareous, chloritic phyllite. This lithology has been interpreted as a marginal tuff adjacent to basaltic flows (as noted in Jennings and Jilson, 1986). More extensive drill core inspection and additional outcrop exposures indicate that instead it represents a slight contact metamorphic aureole caused by intrusion of the greenstone bodies; further evidence that the greenstone bodies are intrusive. Where the mafic bodies are thin these altered phyllites can be difficult to distinguish from the sill and if the alteration is intense the mafic rock may not be noticeable at all. The greenstones are resistant and dominate outcrop in the district. Since the altered phyllites are always near the greenstones, outcrop examination gives a misleading impression of the chlorite content of Vangorda formation phyllites, compared to drill core examination. The overwhelming bulk of the formation is grey to greenish-grey, but that lithology does not crop out well.

Black, slightly calcareous to dolomitic, carbonaceous pelite members occur throughout the Vangorda formation. Dimensions and lateral continuity of these members are poorly known. The thickest and most extensive of these occurs at the base of the formation; it ranges from only a few tens of meters to 100m in thickness. This basal member becomes thicker in the immediate vicinity of the ore deposits and appears to be laterally equivalent to black, sulphide-bearing, ribbon-banded, carbonaceous, quartzite ores within some of the mineral deposits. Southwest of the Grum and Vangorda deposits the basal member is very siliceous and slightly pyritic enhancing the impression of equivalence to the carbonaceous quartzite ores.

The Vangorda formation is lithologically similar to, though more argillaceous than the Rabbitkettle Formation seen to the east (Gordey, 1978; Gabrielse et al., 1973). Based on this correlation the Vangorda formation may range in age from middle or late Cambrian through early Ordovician.

The Menzie Creek formation is a unit of basaltic metavolcanic rocks consisting of pillowed and massive flows with comparable amounts of massive, coarse, monolithic breccias and lesser, thin-bedded, tuff and/or volcanic sandstone and siltstone. The formation reaches a maximum structural thickness of 1.5km in the district. Whole rock major element and trace element data (Jennings and Jilson, 1986) imply that the flows of the Menzie Creek volcanic unit are dominantly alkali basalt erupted in a within-plate setting. Similar major and minor element compositions for the metabasites in the Mt. Mye and Vangorda formations suggest the metabasites are subvolcanic feeders for the Menzie Creek formation.

Carbonaceous phyllite and brown siltstone immediately overlying and interbedded with the uppermost Menzie Creek formation northeast of the Anvil Batholith contain graptolites of lower Ordovician to early Silurian age (Tempelman-Kluit, 1972; Gordey, 1983) suggesting correlation of the Menzie Creek volcanics with the widespread Road River Formation black shale and chert to the northeast. The Menzie Creek formation has been traced for 100km along strike and 30km across strike, showing that it is one of the largest of several basaltic units of its age in and around the Selwyn Basin.

FOLD DEFORMATION

The structural and metamorphic history of the Anvil District is complex and of considerable significance to present form and nature of the ore deposits, and hence exploration for them, since all of the deposits have experienced the full deformation history. Five phases of deformation have been recognized in the district. The first two are periods of intense fold deformation and concurrent metamorphism which determined the gross structure of the mineral deposits. The remaining deformations are only locally developed and do not generally form large or significant structures.

The first deformation (D_1) produced a regional metamorphic foliation (S_1) axial planar to tight to isoclinal mesoscopic folds (F_1) in bedding (S_0). Mesoscopic D_1 early folds are rarely preserved in the district; they are ubiquitously north-easterly inclined to upright, northeasterly verging (shaped like a 'Z' looking northwest) structures with shallow northwesterly or southeasterly plunging axes.

During the second deformation event (D_2), S_1 was strongly crenulated and ubiquitous close to tight mesoscopic folds (F_2) in S_1 were produced. Primary bedding (S_0) transposed into near parallelism with the S_2 foliation. Parallel to the axial planes of the D_2 folds is a crenulation cleavage (S_2) which imparts a well developed lithon structure to most rocks of the district, especially the strongly banded phyllites of the Vangorda formation. F_2 axial planes and S_2 axial plane foliations dip shallowly to the southwest or northeast, with fold axes subparallel to F_1 fold axes. Southwest of the Anvil Batholith the S_2 surfaces dip dominantly southwest, and F_2 minor folds have southwest vergence (shaped like a 'S' looking northwest). Northeast of the batholith S_2 surfaces dip dominantly northeast, and F_2 minor folds appear, on the basis of limited evidence, to have northeast vergence. The shallow dip of F_2 axial planes, the isoclinal nature of F_2 folds, and the transposition of bedding into foliation creates some of the more important exploration characteristics of the district. Rock units are flat lying or shallowly dipping on the average (Figure 5) although there are local exceptions (e.g. Grum). Electromagnetic methods must be able to couple well with and resolve multiple flat lying conductors. The shallow dip of the area also means exploration targets tend to present their largest dimension to a vertical drill hole.

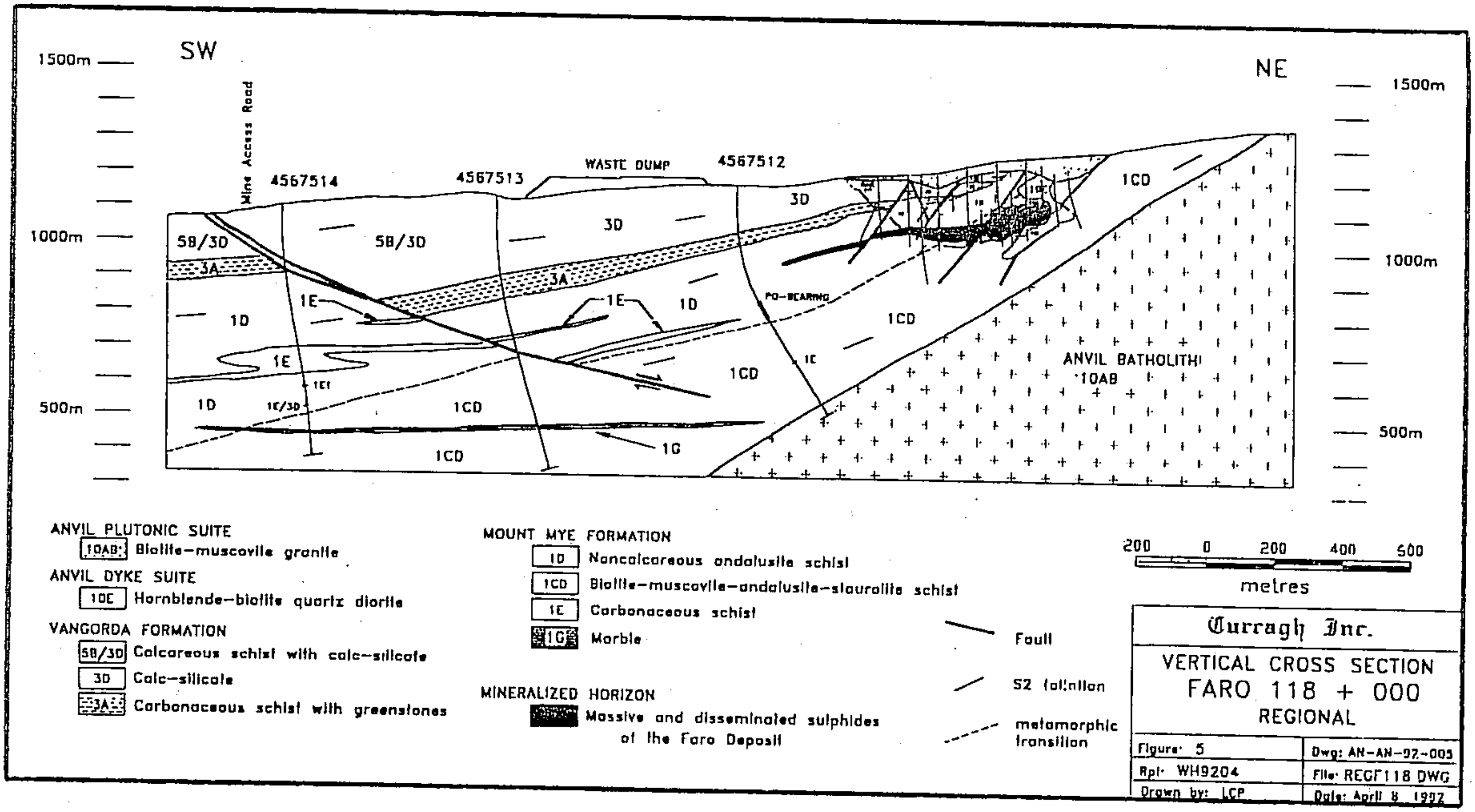

Figure 5. Cross Section through the centre of the Faro Deposit showing large scale transposition of layering into S_2 as is characteristic of the Faro Block

The largest megascopic folds known to have been formed during D_2 are those at the Grum Deposit (Figure 6 and 7) and comparable folds in the Swim Deposit (Figure 8). Three later, less intense periods of folding and associated faulting followed.

The later events (D_3 through D_5) generally produced open folds and weak crenulations in S_2 related to broad, regional structures. An important exception to this general rule is found in the vicinity of the Faro deposit where the fourth event (D_4) is intense with tight mesoscopic folds developed in nearly pervasive S_2. D_4 minor folds have appreciable mica growth along S_4 axial plane crenulation cleavages.

METAMORPHISM

Metamorphism was concurrent with deformation and was most intense during the major D_1 and D_2 folding deformations. D_1 metamorphism has been largely overprinted by the later D_2 metamorphism. Metamorphic grades during these two events appear to be comparable since mica mineral assemblages between microlithons (i.e. S_1 foliations) are similar to those defining the S_2 foliation surfaces. The rest of the discussion will focus on the D_2 metamorphism.

Metamorphic grade ranges from upper amphibolite facies (sillimanite-muscovite zone) to lower greenschist facies (muscovite-chlorite zone) in a low pressure Buchan type facies series. In pelites adjacent to the intrusions the typical assemblage is andalusite-staurolite-garnet-biotite-muscovite-quartz-plagioclase with local fibrolite and cordierite. Lower greenschist facies pelites contain the assemblage muscovite-chlorite-quartz-plagioclase.

Metamorphic isograds are roughly concentric about the Anvil Batholith. Locally isograds are truncated and juxtaposed by the late D_2 extensional faults. The Faro deposit (closer to the Batholith) is metamorphosed to amphibolite facies. All other deposits are metamorphosed to lower greenschist facies. This difference in intensity of metamorphism is reflected in decreased grain size and increased degree of mineral intergrowth in the less metamorphosed deposits (Tempelman-Kluit, 1970). This has a significant impact on metallurgical response of Anvil district ores.

IGNEOUS INTRUSIVES

During the later stages of the deformation history a large granitic body (Anvil Batholith) was intruded into the metamorphic sequence. Anvil Batholith ranges in composition from a biotite-muscovite peraluminous granite to a metaluminous to peraluminous hornblende-biotite granodiorite (Pigage and Anderson, 1985). Textures include equigranular massive, megacrystic massive, and various strongly to weakly foliated variants. Foliation within the intrusive rocks is concordant with S_2 surfaces in the surrounding metasediments. Several K-Ar ages on the granitic rocks yielded ages of 85-100 Ma (Tempelman-Kluit, 1972). Rb-Sr isochron ages of 99-100 Ma (Pigage and Anderson, 1985) and unpublished zircon model ages (Mortenson, pers comm.) are

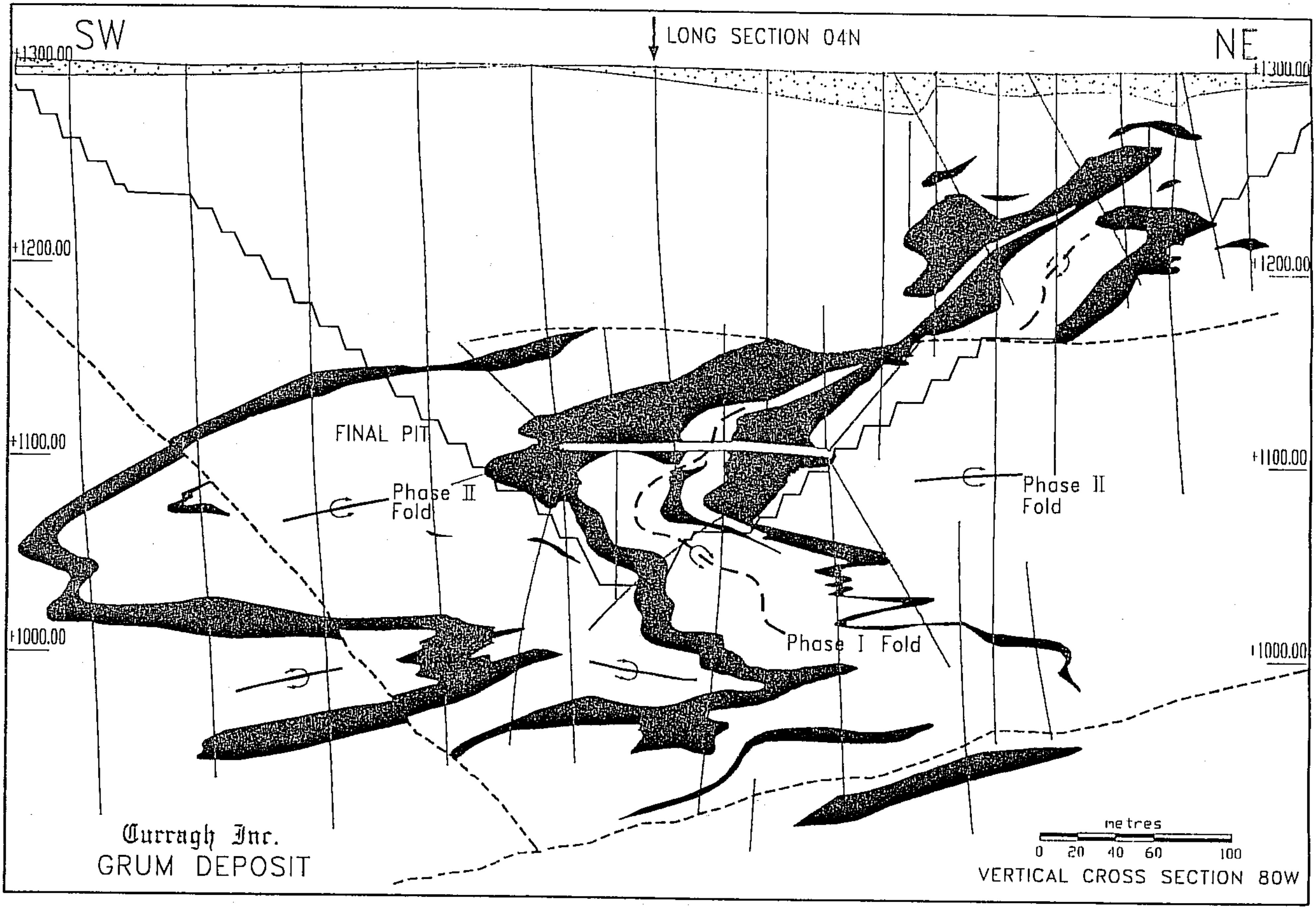

Figure 6. Cross Section through the Grum Deposit showing second phase S-shaped folds superimposed on a first phase Z-shaped fold

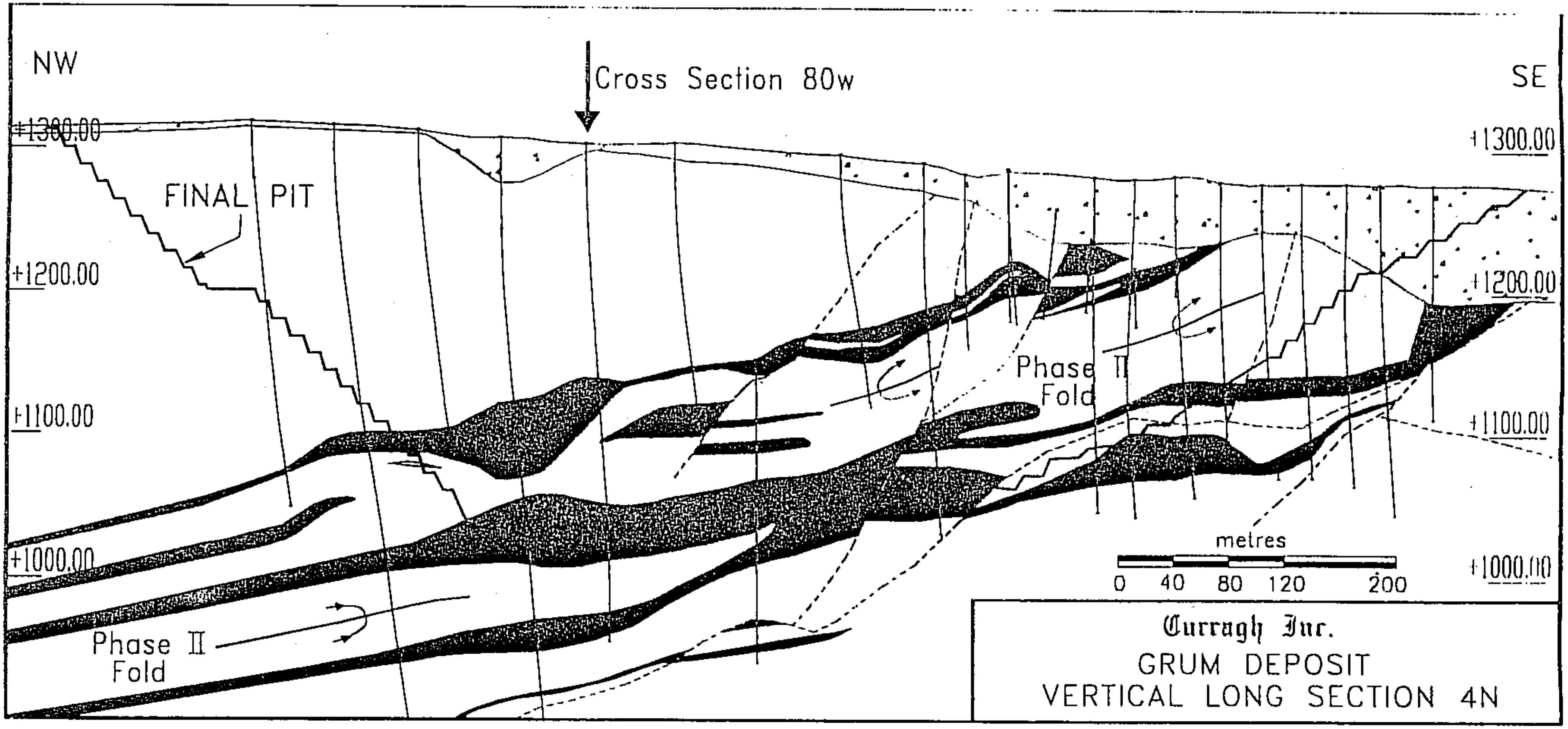

Figure 7. Longitudinal Section parallel to the second phase fold hinge at Grum, showing the 11° northwest plunge

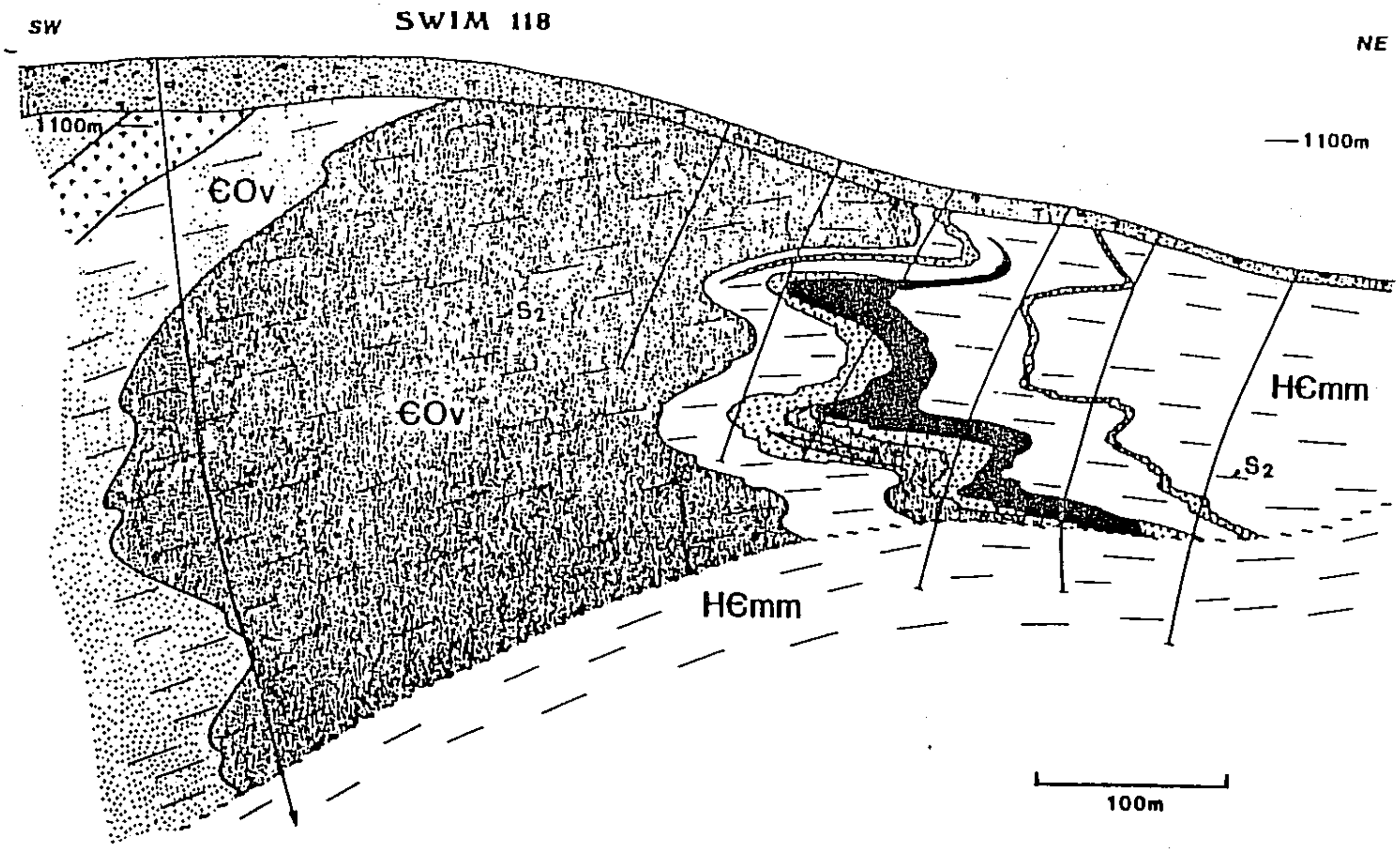

Figure 8. Cross-section 118 through the centre of the Swim Deposit

concordant with the K-Ar ages and indicate rapid cooling after high-level emplacement.

Anvil Batholith and surrounding metasedimentary rocks are crosscut by two families of post-tectonic dykes. The majority of the dykes are northeast-trending, medium to dark green, porphyritic, unfoliated, hornblende-biotite quartz diorite. These quartz diorite dykes appear to be associated with late extensional faults. Unfoliated, pale tan, smoky quartz-feldspar porphyry also occurs as late crosscutting dykes. The dyke suites have not been extensively isotopically dated; their absolute ages are thus uncertain. One important date has been obtained on a unsheared quartz-feldspar porphyry intruding the Tie fault zone (see below). This zircon age indicates that the dyke cooled at 100ma, (Mortenson, pers. comm., 1991) essentially the same age as the Batholith. This leaves little doubt that the Tie Fault is coeval with late stage high level emplacement and rapid cooling of the Batholith.

FAULTING

During the first and second phases of deformation low angle faulting appears to have occurred but the details are as yet poorly understood. Thrust faulting during the first phase of folding is likely and several candidates have been found. The most obvious of these are along the north flank of the district (Gordey, 1983) but additional, smaller, thrusts may occur in the vicinity of the ore deposits. Gordey and Irwin (1987) have indicated a major thrust northwest of the Faro mine (the Faro Thrust). It is not likely that such a structure crops out in that area but a similar thrust fault could exist if it is below the level of exposure in the core of the district. Brown and McClay (1992 and in preparation) have hypothesized the existence of such a thrust which would reach the surface along the north flank of the district and presumably would correspond to the Two Pete Thrust recognized there by Gordey and Irwin (op.cit.).

During the second phase of deformation, S_2 parallel displacement occurred along a attenuated second phase fold limbs. These S_2 parallel faults (tectonic slides) have been recognized in the Grum deposit, and are thought to exist at Vangorda. The role of these S_2 parallel structures is not well understood but they are thought to have displacements of no more than few 100's of metres.

Post folding and post metamorphism faulting is widespread and of great significance for exploration in the district. Intrusion of the Anvil Batholith further deformed the metamorphic sequence so that the overall structure of the district is an elongate dome cored by the Batholith. In the later stages of emplacement large extensional fault displacement occurred along the margins of the Batholith (Pigage and Jilson, 1985). S-C mylonitic banding within these fault zones, and in the granitic footwall of some, is consistent with development of the faults during late D_2 deformation. These faults determine the present day limits of several of the deposits. The faults with known offset appear to result from extension along the trend of the District and the Tintina Fault. The Tie Fault is one of the best examples of such a structure. As noted above, its age is well constrained at 100 ma. and it is coeval with the final stage of emplacement of the Batholith. These relationships suggest that the Anvil Batholith may have been intruded during the strike slip regime of the Tintina. Figure 9 is a longitudinal section through Grum and the Tie Fault. The slip line of the fault is in the plane of the section. The section shows the relationship of Firth to Grum and the relatively large displacements of this family of faults. Other similar structures occur at the southeast end of Grum, between Dy and Vangorda, and below Swim. These structures typically juxtapose a less intensely metamorphosed hanging wall against a more metamorphosal footwall. The identification of these structures is significant for exploration as they have the potential to open up large gaps in the stratigraphy because of their extensional nature and large displacement.

The youngest faults of the district are steeply dipping and diversely oriented. One of the most prominent sets strikes northeast. A second important set strikes approximately north-south. The northeast striking set is subvertical and commonly shows left lateral strike slip offset. This set may be second order structures to the Tintina Fault. The best example of such a fault is the Blind Creek Fault which offsets the favourable trend of deposits by 1.3 km. A group of faults of this set, northwest of the Faro mine, may have similarly offset the favourable trend there, however, this concept has not yet been drill tested. Many late faults show subhorizontal slickenslides, suggesting the last displacements were strike slip This is true even of structures in the Faro Pit which are well constrained to have small horizontal displacement compared to the vertical component of movement. Jennings (personal comment 1972) and Brown and McClay, (1992, in preparation) have noted late stage northeast directed small displacement, post metamorphic, thrust faults in the Faro and Vangorda pits, respectively.

ORE DEPOSITS

The lead, zinc, silver deposits of the Anvil District belong to the sediment hosted, stratiform, massive pyritic sulphide class (Gustafson and Williams, 1981; Large, 1980) also referred to as sedimentary exhalative (sedex) deposits (Carne and Cathro, 1982). They occur either as a thick sulphide lens with little or no interbanded metasedimentary rocks (e.g. Faro) or as several thinner lenses stacked approximately one above the other with substantial metasedimentary interlayers (e.g. Grum and Dy). The deposits and their ore types are described in more detail in Jennings and Jilson (1986) and Pigage (1990).

All deposits are composed of a small number of different ore types. The ore types are broadly divisible into massive sulphides and disseminated sulphides in quartzite. There are pyritic, baritic, pyrrhotitic and carbonate bearing variants of the massive sulphide ore types and carbonaceous and non-carbonaceous variants of the disseminated ore types. Ore type zoning is pronounced in the deposits. Stratigraphically lower and distal ore types are disseminated carbonaceous quartzites, upper and proximal types are baritic massive sulphides. An idealized and vertically exaggerated section through a model ore horizon is shown in Figure 10.

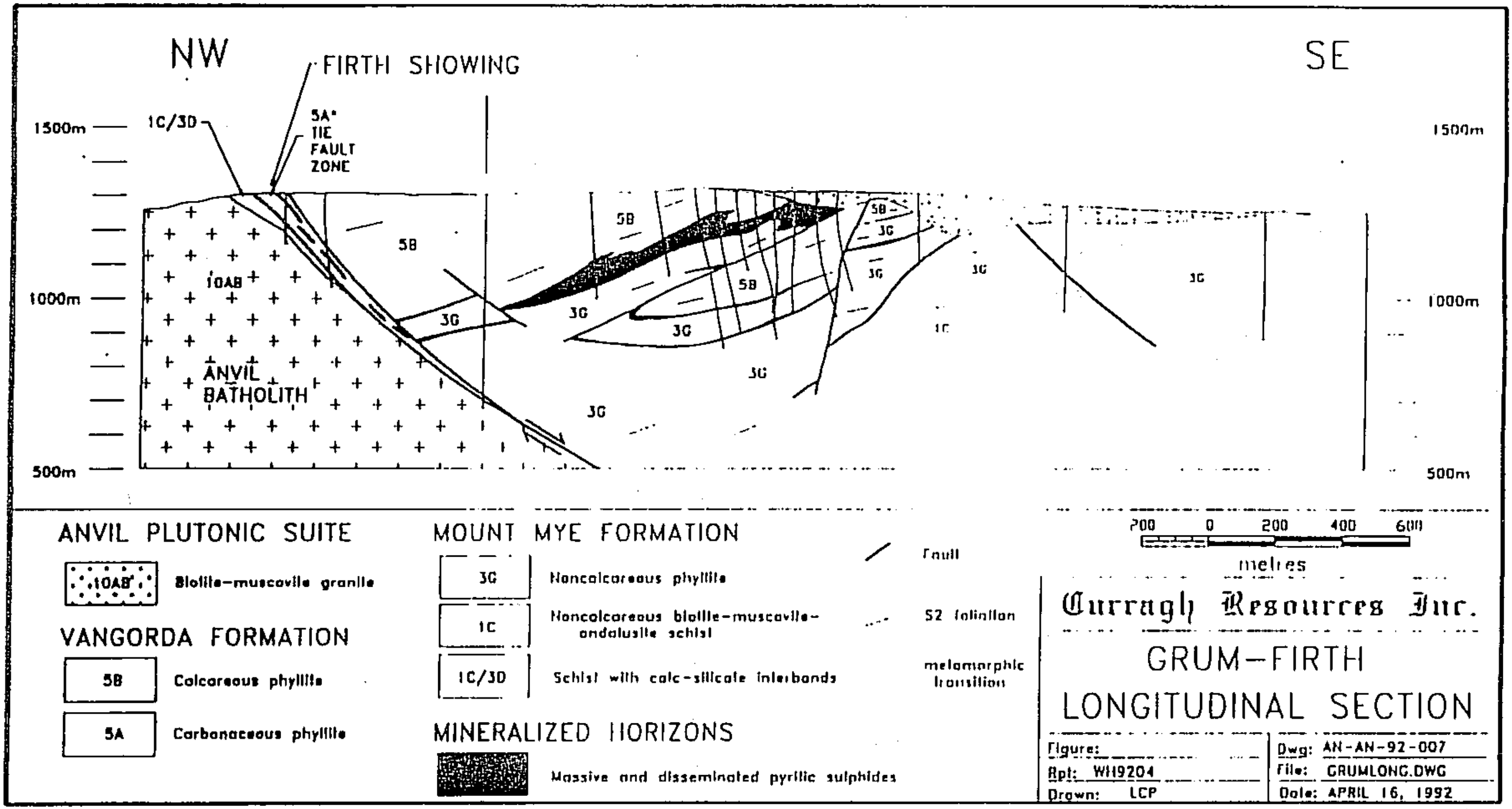

Figure 9. A longitudinal section along the plunge of the Grum fold structure. The section shows the interaction of the Grum fold with the extensional Tie fault. The Firth showing may represent mobilized or detached mineralization related to Grum. Such an interpretation implies the Tie fault slip line is directly down the dip. This direction is confirmed by S and C bands in the mylonitic margin of the Batholith.

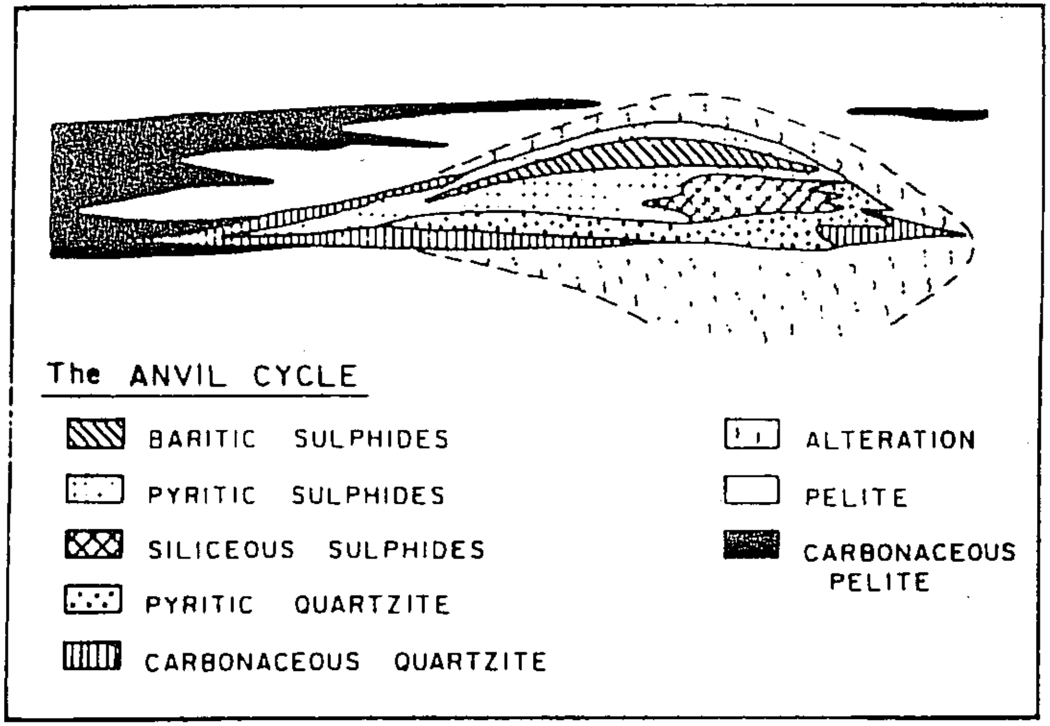

Figure 10. Idealized Anvil cycle of ore type facies variations based largely on the Faro and Vangorda deposit. The section is greatly vertically exaggerated.

The mineralization occurs in the thin, laterally extensive, sulphide sheets or horizons are deformed into complex fold structures. The deposits are elongate parallel to the D_2 fold axes and associated lineations in the host metasediments. The Faro deposit, which superficially does not appear to be complexly folded, actually showed great internal complexity in the geometry of high grade and waste layers.

Present deposit lengths are generally two to three times widths; unfolded, the deposits are interpreted to have had an amoeboid shape with diameters up to 4,000m. Individual sulphide horizons commonly are 10 to 40m in thickness. The upper contact and generally the lower contacts of sulphide horizons are sharp while lateral extensions grade into the enclosing host rocks. Parts of some deposits, particularly Vangorda (Figure 11), show a footwall rich in quartz and iron sulphides/oxides and enriched in copper and gold relative to zinc. This may be a footwall silicified and sulphide impregnated feeder zone.

All deposits show a variably developed, white mica-dominant, alteration overprint in the wall rocks. This results in the phyllites having a bleached appearance. Less intensely altered chlorite-muscovite ± pyrrhotite ± carbonate variants of the alteration are also found widely. At lower metamorphic grade this alteration tends to be found in the footwall of the ore horizons. At the Faro deposit, this bleaching/alteration halo is particulary intense and encloses the entire mineralized sulphide lens. The halo at Faro may be a fundamentally different sort of alteration related to the metamorphism of the deposit.

In general there is little signature in a drillhole that is a "near miss" to a deposit. Alteration is restricted to the vicinity of the ore bearing structure and is typically most pronounced below the sulphides, thus it provides little help. There has been little study of more cryptic chemical, mineralogical or isotopic signatures around the deposits or, for example, in the basal carbonaceous member of the Vangorda formation, thus no such guide to ore is currently available.

Relation of Stratigraphy to Ore Deposits

The ore deposits of Anvil District are stratiform and confined to an approximately 150m to 200m thick stratigraphic interval which includes the contact of the Mt. Mye and Vangorda formations. It is presumed that the deposits are syn-sedimentary, however, direct evidence of this is no longer preserved. This stratigraphic position and the nature of the deposits suggests the host rocks for the mineralization and the age of mineralization are Cambrian. The deposits consist of one to five layers of sulphide mineralization interbanded with barren metasedimentary rocks. For those deposits with more than one sulphide horizon, the mineralized horizons are generally stacked one above the other or

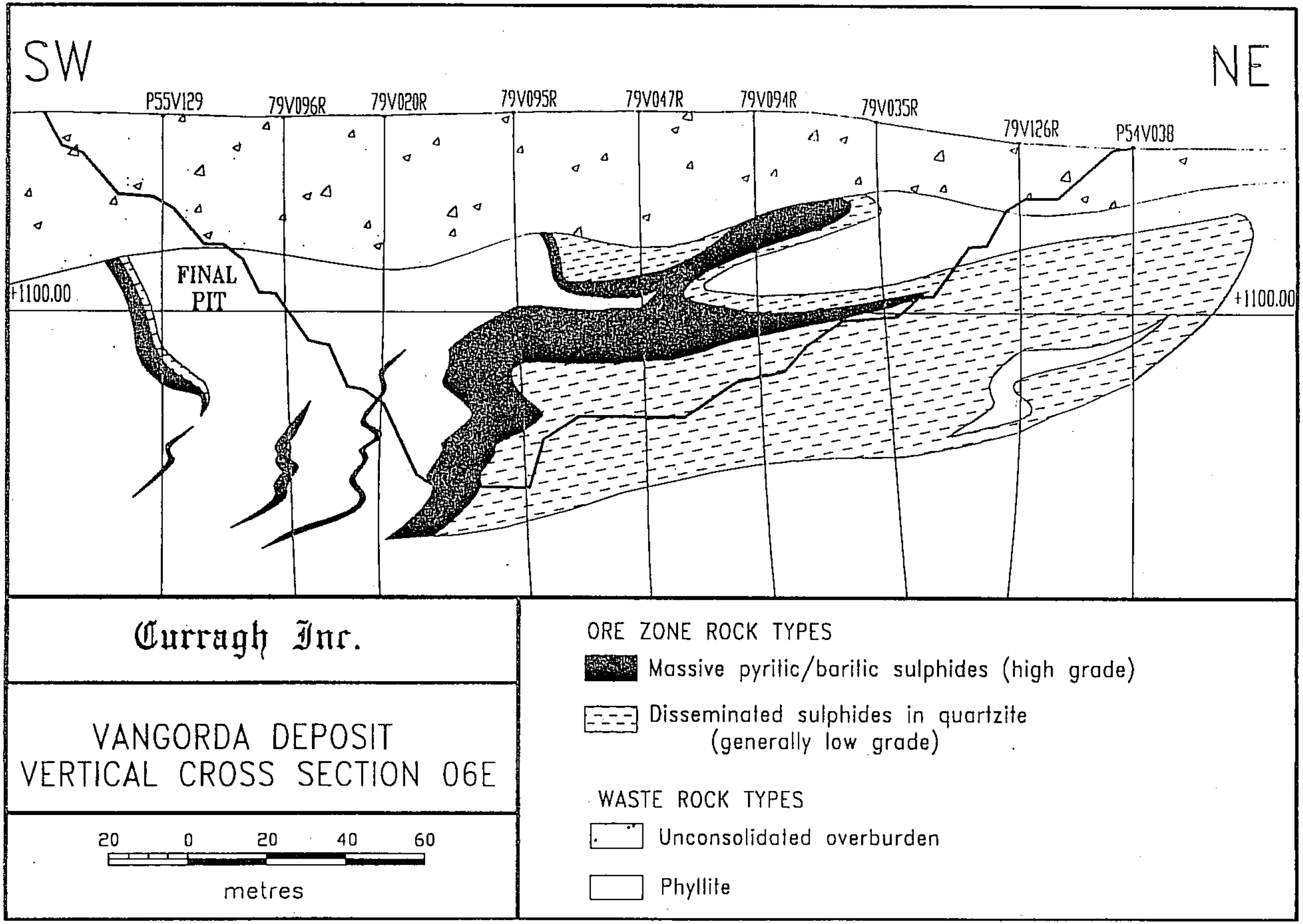

Figure 11. Cross Section through the Vangorda Deposit. The dashed unit lowest in holes 79V-095R-047R-094R and 035R is massive barren pyrite grinding down into pyrite + pyrrhotite + magnetite-bearing quartzites grinding further down into siliceous pyritic altered phyllite, and eventually altered phyllite. This unit has a higher Cu or/and Au ratio relative to Zn than the massive sulphides. It may represent a silicified feeder zone.

in en-echelon fashion. At least three of these mineralized horizons appear to be laterally equivalent to part of the basal carbonaceous member of the Vangorda formation.

The known deposits occur in a 25 km long curving trend following the prominent fold axial trends of the district. Southwest of this trend there is a tendency for the basal carbonaceous member of the Vangorda formation to thicken. The ore horizons tend to occur at the base of thick carbonaceous units suggesting the exhalative ore forming event was an initial stage in the formation of a anoxic sub-basin.

Unlike other sedimentary exhalative deposits of Selwyn Basin, the Anvil deposits are not characterized by a host stratigraphic section dominated by black carbonaceous rocks. Instead the carbonaceous rocks in the district are thin and subordinate or locally not even present near the sulphide deposits.

Mapping and drill results suggest the linearly distributed deposits lie close to a northeasterly "pinch out" of the basal carbonaceous member of Vangorda formation. To date, no sulphide deposit lithofacies have been encountered in a small number of drill holes through the ore-bearing horizon southwest or northeast of the deposit line. These observations and the relationships to carbonaceous rocks noted previously, suggest some genetic link between sulphide deposits and facies changes at a anoxic sub-basin margin. The linear trend suggests the possibility of fault controlled hinge lines of sub-basins. The faults may have channelled ore fluids leading to sea floor exhalation followed by sulphide deposition in the sub-basin where reduced sulphur was available.

EXPLORATION HISTORY AND EXPLORATION TECHNIQUES

The thirty-five year exploration history of the Anvil District has seen techniques evolve gradually through the following stages:

- conventional prospecting, resulting in the discovery of Vangorda in 1953,
- saturation geophysical and geochemical prospecting, resulting in the discovery of Swim in 1964 and Faro in 1965,
- geological extrapolation aided by detailed geophysics, resulting in the discovery of Grum in 1973,
- deep drilling guided by geological projections, which resulted in the discovery of Dy in 1976.

Each stage of exploration has detected deposits at greater depths of burial.

Successful techniques have included airborne magnetics, electromagnetic and gravity surveys, lead and zinc soil geochemistry, geology and prospecting. These techniques have been applied throughout the district from the late 1960's to early 1980's. Since the early 1980's there have been no substantive geophysical or geochemical surveys.

Conventional prospecting and local but highly effective use of geophysics and geochemistry (Chisholm, 1957) led to the discovery of the Vangorda as well as the shallow or outcropping Firth and Champ occurrences at either end of the Grum structure.

In the mid-sixties these methods were replaced with more widespread saturation airborne geophysical (magnetic and later EM) and less widely used geochemical methods (Aho, 1966; Brock, 1973). These rapid regional surveys were followed up by ground geophysics and rotary or diamond drilling. The second phase located two covered but near surface deposits with relatively strong but not always unambiguous geophysical and geochemical signatures: Swim in 1963 and Faro in 1964.

Followup of the second phase continued until the early seventies producing a patchwork of disconnected surveys, many of them conducted in haste and with poor control during the hectic years following the Anvil staking rush.

In the early seventies, a third phase started when a commitment was made by Cyprus Anvil (then Anvil Mining Corporation) and its parent corporations (Cyprus Mines Corporation and Dynasty Explorations) to initiate district-wide geologic mapping and more systematic ground surveys. A major rotary drilling program, designed to sample overburden, was also carried out in 1971.

Over the years a district wide Turam EM survey coverage was built up. By the mid to late 1970's EM took on a passive role than in the past, being intended not just to search directly for ore but more so to help trace units indicative of ore potential and to aid geologic mapping in areas of poor exposure. Many conductors were screened by gravity surveys and anomalous situations drill tested with generally unencouraging results.

By the mid-seventies geological, electromagnetic and drilling information were combined to produce a geological map of the district with common scaled compilations of other exploration information.This compilation and ongoing regional geologic mapping allowed the establishment of a tentative district stratigraphy which, in turn, led to a structural model for the main part of the belt. Figure 12 shows the outline of three of the most important sheets of this compilation, E6 (with Faro), F6 (the Vangorda Plateau) and G6 (the western Swim Basin).

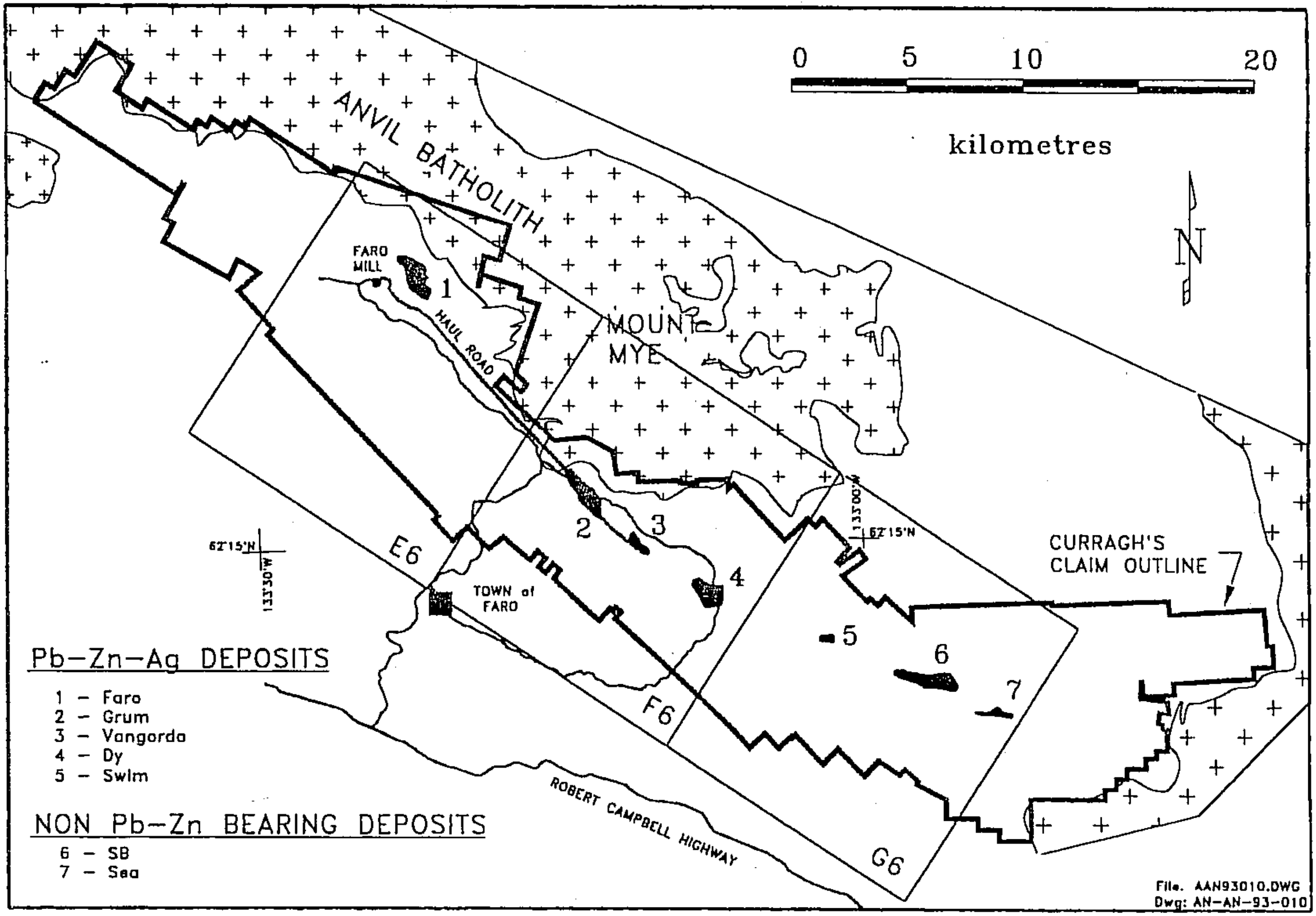

Figure 12. Location of three of the main sheets of the 1976-1981 Exploration Data compilation. Additional sheets in Row 6 are H6 to the southeast and C6 and D6 to the northwest.

The continuing negative results of anomaly testing and dwindling inventory of attractive targets began to indicate that the near surface, open pittable, potential of the district was becoming limited on C.A.M.C.'s ground. As target depths increased, gravity rapidly became in ineffective screen due to interference by bedrock relief, poor terrain corrections and instruments subject to high drift. Attention turned toward subtle anomalies supported by geology and to blind drilling beyond the limits of geophysical penetration following predictions based on geology.

A re-examination of Kerr Addison's land by A.E.X. Minerals led to the re-evaluation of gravity work following geological projections of favourable structure. The Grum discovery resulted in 1973.

The Dy discovery in 1976 was the result of drill testing the structural and stratigraphic model noted above. The Dy drilling was the beginning of a program of deep drilling laid out with spacing sufficient to make detection of various size targets and various depths likely (basically a Swim sized target to 330m (1,000 ft) and a Faro sized target at greater depths). The discovery hole was specifically drilled to test the favourable trend where the geologic model predicted favourable stratigraphy at 600m depth. This can be regarded as the fourth phase of exploration.

The deep drilling program was essentially suspended by the massive drilling requirements at Dy but resumed between 1979 and 1981 when several deep holes were put down particularly to test the down dip extensions of the Faro, Vangorda and Swim deposits with scattered holes elsewhere. Unfortunately since the stratigraphic model was incompletely developed at that time, some of these holes were not deep enough. The stratigraphic sequence, as now understood, provides a good "shut down unit", the marble and calc-silicate assemblage about 500 to 700m below the top of the Mt. Mye formation. Future drill holes should attempt to reach this unit if at all possible.

EXPLORATION MODEL

The geologic model of the deposits used to guide exploration is a variation of the sedex model. It is assumed that brine exhalation was fault controlled and that the favoured depositional setting was the edge of anoxic sub-basins (Shanks et. al., 1987) within which black shales were preserved. Empirical evidence shows that a broad stratigraphic interval, the 150 m. to 200 m. thick transition from Mt. Mye formation to Vangorda formation, is conducive to ore deposition. This interval will be termed the "Favourable Sequence". Secondly we observe that there is a "Favourable Trend", an alignment of the identified deposits. To date there are five known Pb-Zn bearing deposits along this 35 km. long trend and no important deposits off of it.

Exploration in the district is thus conceptually simple in that the Favourable Sequence must be traced through the area and extrapolated into the sub-surface where it can be tested by drilling with a priority on areas on the Favourable Trend. In practice exploration is more complex to do efficiently because of the structural complexity and the relatively poorly known detailed stratigraphy. The holes must be deep enough and avoid places where the Favourable Sequence is faulted out.

As noted previously at length, the structure of the district is highly complex involving isoclinal recumbent folds. In many areas the metamorphic foliation dips at a low angle and the stratigraphy is so strongly transposed that one can generalize that bedding has the same orientation on a large scale. On most of the claim block foliation dips to the southwest thus the Favourable Sequence southwest of the Favourable Trend is mostly buried but to the northeast it is mostly eroded and mineral potential is limited. Because of the low dips the target sequence is readily tested by vertical drill holes provided that they are deep enough. As the stratigraphy has been pieced together over the years it has become apparent that many holes were not.

Exploration has tended to focus on the Favourable Trend to date however there is no known reason that ore could not occur off this trend. The Favourable Trend heavily biases exploration thinking because of the simple empirical observation that success has occurred "on trend" but not yet "off trend" despite considerable effort. Areas on trend are thus considered to have significantly higher potential for ore discovery. It must be constantly realized that the off trend favourable stratigraphic horizon is only exposed at two places in the district and is fully tested by only a few drill holes thus there is considerable scope for new discoveries which could lead to revision of this restrictive exploration model.

There are currently no chemical mineralogic or isotopic zoning patterns recognised to provide a guide to ore. One feature that may be useful is a weak chloritic alteration associated with chloritic metamorphosed mafic igneous rocks. This has been recognized along the northeast edge of the Dy deposit and seems to also be present at Grum. The distribution of alteration suggests it may be a "hood" developed over the centre of exhalation and could be an important guide to deep ore. It is also important to begin carrying out analytical work on samples of the basal member of the Vangorda as they are collected. Unfortunately the existing sample set is very limited.

Exploration should focus on the edges of regional airborne EM conductors since these may indicate the margins of reduced sub-basins. One such area is thought to occur along the south edge of Swim Lake.

GEOPHYSICAL METHODS

The Faro deposit has generally been considered a geophysical discovery and geophysics played a part in the discovery of Swim and Grum, consequently geophysics has been widely used in the district. Vangorda, while not a geophysical discovery gives strong responses. Table 4 ranks anomalies associated with the various deposits and two minor

Table 4
Geophysical and Geochemical Response of Anvil District Deposits and Showings
(after Roth, 1990)

Year Discovered	Deposit Name	Zn–Pb–Ag Mineral Inventory (tonnes)	Tonnage of sulphide rock (tonnes)	Airborne EM	Ground EM	Airborne Magnetics	Ground Magnetics	Gravity	Induced Polarization/ Resistivity	Geochemistry
1953	Vangorda	7,000,000	22,000,000	3 Graphitic	3? Graphitic	3	(2)	3	3	2
1964	Swim	5,000,000	8,000,000	2? Graphitic	2? Graphitic	2	2	2	(2)	2
1965	Faro #2	4,500,000	Total 70,000,000	2	3	N	N	2	1	2
	Faro #1	29,000,000		?	1?	2 Mt & Po on Dyke contact	1 Mt & Po on Dyke contact	3	(2)	1
	Faro #3	24,000,000		N	1? Shallower Graphitic?	?	N	1+		N
1973	Grum	45,000,000	60,000,000 to 80,000,000	1? Graphitic	1? Graphitic	2	(1)	2	?	?
1976	Dy	20,000,000	80,000,000 to 100,000,000	N	??	?	(N?)	N	?? Shallower Graphitic ?	N
1964	S.B.	NA	NA	?	1?	1	1	?	(1)	N
1964	Sea	NA	NA	1?	2	1	1?	1?	(1)	1

3	Strong response
2	Moderate response
1	Weak but distinguishable
?	Weak uncertain
??	Very questionable
N	No response
( )	No survey, estimated response

Sulphide tonnages are from Cyprus Anvil "in–house" Tonnage and Grade Compilation by D.S. Jennings, Nov. 20, 1981 showings. This table shows that the deposits when close to surface, respond to a variety of methods. What is not so clear from the table is that there are significant sources of geologic noise that interfere with interpretation of survey results and that as the targets become deeper, and responses more subtle, the surveys are subject to severe limitations as signal is overcome by noise. This limitation of the existing data set will be dealt with further below.

A prerequisite of sound geophysical practice is a good understanding of the physical characteristics of the target and its host environment. Some quantitative work has been done over the years but it was not well documented and is now largely lost. The following discussion is thus in general and in qualitative terms.

Geophysical Characteristics of the Formations

The phyllites and schists of the Anvil District have a density of approximately 2.6 to 2.7 gm/cc. They are soft and easily eroded but have few other distinctive characteristics other than the schists have a high background chargeability due to their micaceous nature. The carbonaceous layers are black and highly conductive along carbon smeared S_2 folia. These rocks are the most conductive lithologies of the district and do cause strong electromagnetic anomalies. They form distinct layers which can be traced to help map the distribution of units in areas of poor exposure since the enclosing phyllites are non-conductive.

Greenstones and amphibolites are relatively dense (3.0 gm/cc), resistant, and commonly magnetic thus tend to form bedrock knobs which when buried by till create a positive residual gravity anomaly. Greenstones in the upper Vangorda formation are locally bounded by carbonaceous lithologies. This lithologic association can create coincident gravity, magnetic and electromagnetic anomalies which are of no economic interest. The combination of gravity and magnetic high is even more common and is often viewed with some scepticism in this district. In general, greenstones create difficult interference for gravity surveys.

Calc-silicates are also a dense rock type, approximating the density of greenstones, however the calc-silicates are more widespread and flaggy, thus less likely to form bedrock ridges. Where calc-silicates do form such ridges the high contrast between the rock and till densities can create a misleading positive residual gravity anomaly.

The Menzie Creek formation on the southwest side of Anvil Batholith is interlayered with carbonaceous phyllites. The Menzie Creek formation and overlying units thus have a very "active" EM signature on airborne and Turam EM surveys and make it easy to delineate the top of the Vangorda formation.

Granitic rocks are homogenous and restive, they create very flat EM response and have very low magnetic relief.

Geophysical Characteristics of the Ores

The sulphides have a number of physical characteristics which are important for geophysical exploration. The massive sulphides have densities in the range of 4.0 to 4.5 grams/cc thus form excellent density contrasts and against all rock types and strong positive gravity anomalies. Because of this density contrast gravity surveys have been an important and definitive exploration tool in the district. As the search depth increases however gravity surveys rapidly become ineffective because of the numerous corrections and spurious influences they are prone to. Disseminated sulphide bearing quartzites can be high grade but have densities only slightly greater than greenstones or calc-silicates (3.0 gm/cc), a further complicating factor; this surely limited the effectiveness of gravity over the F_t fold closure at Grum.

The massive sulphides are conductive but are actually less conductive than associated carbonaceous phyllites or graphitic quartzites and will not necessarily stand out compared to the carbonaceous rocks.

Several sulphide lithologies are pyrrhotitic and/or magnetite bearing and are strongly to weakly magnetic. Of particular interest is the low grade copper-gold footwall sequence at Vangorda which is rich in pyrrhotite with lesser magnetite. There is a less well developed footwall sequence at Swim. Similar magnetite ± pyrrhotite lithologies occur throughout the upper (Champ) horizon at Grum as well as in the footwall of one of the lower structural panels. At Faro, barren massive pyrite is commonly magnetite bearing and slightly magnetic. In all the greenschist facies deposits the baritic ores are slightly magnetic due to fine, disseminated magnetite. Adjacent to dykes the pyritic sulphides may be altered to pyrrhotitic assemblages or, in extreme cases, to massive pyrrhotite or even massive magnetite. This alteration is particularly pronounced adjacent to the large dyke at the northwest end of the Faro Pit and to a lesser extent along the dyke separating Zone I and Zone II (near section 118). Clearly while coincident positive magnetic and gravity anomalies may be the hallmark of greenstone they can be, and are, also caused by sulphides.

Airborne and Ground Electromagnetic Surveys

The entire area has been covered by reconnaissance airborne electromagnetic surveys which have proved to be very useful. The survey was flown in June 1965 (Brock, 1973) using a helicopter transported Lockwood AEM system operating at 4000 hz. Line spacing was 330 m. and mean terrain clearance was 50 m. (15 m. to 60 m.). The survey was not flown at the same time as the magnetic survey. The Lockwood survey has been of immense help in sorting out the geology of the district however the line spacing and uncertainty of location creates complications in some areas. There have been only a handful of additional conductors discovered that the Lockwood system failed to detect. There was a strong response over Vangorda and Swim although in both cases this may be mainly due to graphitic mete-sediments rather than the orebody. A weak and not very distinctive response was obtained over the Faro #2 but the response over the other zones was poor.

Much of the district has been covered by detailed Turam electromagnetic surveys and more limited Crone JEM and CEM surveys. These later surveys are useful but they are difficult to interpret in areas of overburden and only a small part of the area has been done in a systematic fashion. The JEM survey at Faro assisted in discovery as the airborne responses did not stand out well. The Turam survey was selected in the early 1970's as the method to be used for systematic district wide coverage as it was felt to give good depth penetration; anomaly resolution and interpretation was difficult with both systems except on areas of a few discrete conductors. The Turam surveys did not help discover any mineralization not already detected by the airborne system but locations were considerably refined and conductor correlation was improved.

Considering the value the old survey has been in unravelling the geology in the past even with its limitations, it is felt that a new district wide airborne EM survey would be beneficial to assist with geological interpretation prior to undertaking further deep drilling.

Further surveying is recommended (Roth, 1990) however state of the art time domain systems are preferred over further Turam work.

Airborne and Ground Magnetic Surveys

Airborne magnetic surveying was one of the first reconnaissance exploration tools used in the district and it was applied with some success. The Swim discovery is attributed to magnetics, Vangorda also has a strong response but the response over Faro is limited and local. Despite the local variations, every deposit but Dy has some known magnetic response. Even on the high level Geological Survey of Canada survey (1968) this is apparent. The older systems in use in the district may not have been sensitive enough to detect broad subtle anomalies from deep sources. In all cases it is not clear what causes the anomaly over known deposits. In retrospect it is clear that the strongest anomaly at Faro is due to magnetite and pyrrhotite derived from the massive sulphides where contact metamorphosed by a dyke at the northwest end of the Pit. Anomalies at Vangorda and Swim are likely due to low grade footwall lithologies rather than the ore. The anomaly at Grum may be due to the slight magnetite content of the Champ Horizon above the actual ore. These relationships show the importance of testing the anomaly setting thoroughly.

Ground magnetic surveys have been of more limited extent and were neither carried out with sensitive instruments nor were they well controlled. Some useful detail has been gleaned from these surveys (such as clarification of the Faro anomaly) but they are not helpful in attempting to outline subtle low magnitude features.

Gravity Surveys

Early in the history of the district both the utility and the limitations of the gravity method were realized. The method was attempted as a primary exploration tool but proved too slow and subject to drift and various interferences. Gravity surveys were then used as a follow-up tool to screen anomalies detected by other methods, particularly EM.

Many electromagnetic conductors near the Favourable Trend have been tested with gravity surveys but the coverage by detailed, well controlled surveys is far from complete. More work is needed in unsurveyed areas and while this is done the existing high quality and well documented surveys should be tied together better.

Other Methods

Induced polarization and resistivity surveys have been used locally in the district but these methods saw limited acceptance partly due to expense. Dynasty experimented with resistivity profiling to check bedrock relief at the site of gravity anomalies and found it accurate but not practical. Self potential surveys were tested by Kerr Addison (Chisholm, 1957) however this method also did not see widespread use. Hammer seismic was also tested to determine its use in conjunction with gravity to detect bedrock highs but concern over false bedrock indications from permafrost limited its use. Some engineering seismic investigation was also completed with without encouraging results. Borehole geophysics was tested in 1989 but this method proved to be difficult in Anvil District ground conditions; furthermore the abundance of carbonaceous phyllite suggests this technique will likely give misleading indications.

GEOCHEMICAL METHODS

Geochemistry has also been used widely in the district. Had greater emphasis been placed on geochemistry then some discoveries might be considered geochemical discoveries aided by geophysics rather than the reverse. The major media are soil and glacial sediments and these are discussed below in more detail.

Silt sampling has also been used as a reconnaissance tool with some success. Experimental heavy mineral sampling in Vangorda creek detected anomalous gold and barium in -60 mesh heavy, non-magnetic fraction of stream sediments 12 km. downstream from the deposit. Lead and zinc were not detected at that distance.

Bedrock geochemistry studies in the district are limited. Morton has shown that Pb and Zn are anomalous up to a hundred metres above and below the Faro deposit and further that these anomalous values have contributed to the metal content of surficial material where the orebody is buried. Barium is anomalous for a shorter distance into the hanging wall but not the footwall. Mo is anomalous in the white mica alteration that surrounds Faro.

Soil Geochemistry

Soil Geochemistry is an effective exploration tool for sub-cropping ore in areas of discontinuous till cover but is hampered by till in excess of 10 m. thick. This method is of limited value in areas with a thick relatively continuous till blanket such as the Swim Basin (Figure 3). Soil surveys have tended to exploit the poorly developed "B" horizon as sample media and analyses have generally been limited to Cu,Pb and Zn. Both total and cold extractable analyses have been used and there is no agreement on the optimum method. Much of the district was sampled in the early to mid 1970's on lines spaced 400 m. apart. The compilation of results shows clear dispersion trains extending down ice from Vangorda, Grum (Champ and Firth) and particularly Faro. In addition there are more local downhill anomalies, at several sites. Much of this more local dispersion was hydromorphic in the case of zinc.

Consideration was given to the use of mercury in soil for exploration as the ores are mercury bearing and the possibility of upward gaseous dispersion was appealing. In practice it was found that the strong coupling of organic carbon and mercury made the results too difficult to interpret thus be of little use. In 1988 test was done over Grum and Dy of Boliden's GEOGAS method; the results were uninterpretable apparently due to contamination of the proprietary collectors. This indicated the method to be impractical as the collectors were carefully placed.

Overburden Geochemistry

To help explore areas covered by thick glacial till a portion of the district was covered in 1971 by wide spaced overburden drilling with geochemical analysis of the recovered till. This work was coupled with coring of the first few feet of bedrock where it was reached. The bedrock data from this drilling has been of considerable use and there are very interesting anomalies that still have to be explained in Swim Basin but in general the overburden component was of limited effectiveness. Part of the reason for this may be that there was inadequate geologic support for the programme thus there was no surficial geological background within which to interpret the results. Sample descriptions were rudimentary and this may have added to the difficulties of interpretation as Morton (1973) showed that the background and anomaly threshold for the two types of overburden encountered at Faro, till and outwash, were very different. This method warrants further use as there is still no coverage for the bulk of the Swim Basin and methods have advanced considerably in the last 20 years.

DRILLING

The only diagnostic and reliable exploration tool in the district is the diamond drill guided by a reliable geologic model. Unfortunately there is limited drilling in the district away from the deposits and the narrow corridor they fall in. Much of the drilling that exists was done without a reliable stratigraphic model and it appears now that a considerable number of the deeper holes are too short; many are not diagnostic as they stopped short of the Favourable Sequence or did not completely test it. This is true of the holes down dip from Vangorda and particularly of the several holes down dip from Faro. It is an unfortunate fact of life that the poor exposure of the district means that little detail comes from surface mapping and only the drillholes allow significant advance in understanding of the district. In all there are approximately 40 deep holes in the district both on and off the favourable trend (but not near a known deposit) of which less than half are deep enough to be considered diagnostic tests.

Much more drilling needs to be done but the next phase of deep drilling should be preceded by a complete structural re-evaluation of the district using new information sources such as the proposed airborne MAG/EM survey. As noted above further overburden drilling in the Swim Basin is warranted.

EXPLORATION POTENTIAL

As indicated above the Anvil District has a long exploration history with many techniques having been applied. Most of the exploration data for the district up to 1980 has been compiled on a series of common scaled maps at 1:12,000. The three major sheets are indicated on figure 12. In the core areas of the district, such as the Vangorda Plateau, geology and drilling compilations have been updated on a new series of 1:5,000 scale maps although coverage is not yet complete. Geological mapping of most of the district still dates back to the early 1970's. About half the Vangorda Plateau and most of the claim block northwest of the Faro Mine have been re-mapped at 1:5,000 using the new stratigraphic concepts worked out in 1983.

Figure 13 shows the exploration potential of the district inferred from application of the above model in light of the known stratigraphy and structure. There has been very little diagnostic sampling of the area southwest of the "favourable trend" thus exploration off that trend should not be ignored.

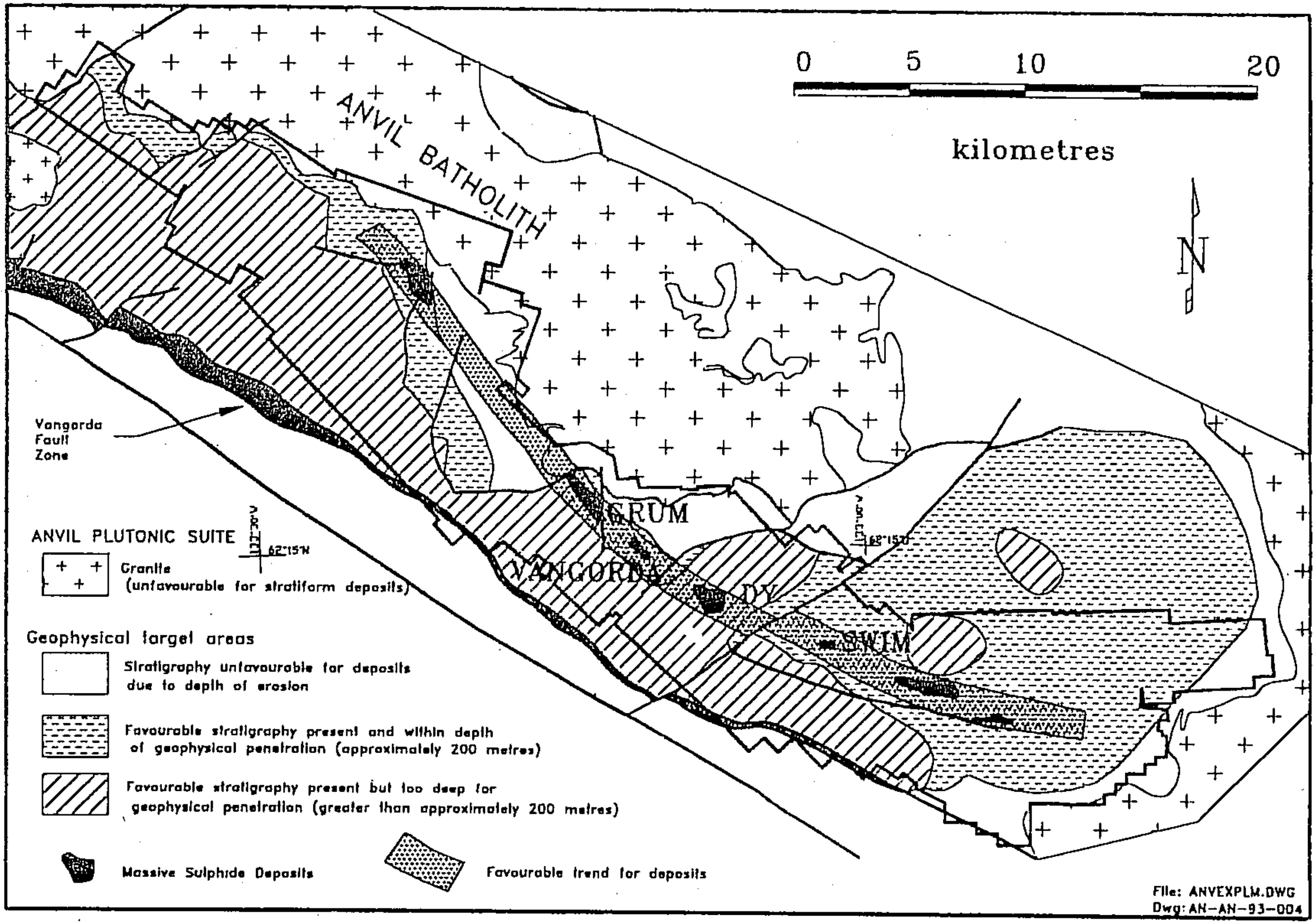

Figure 13. Exploration potential of the south flank of the Anvil Batholith, Anvil District, Yukon. Potential is highest along the favourable trend. It can be seen that there is little exposive in the favourable stratigraphy southeast of the trend; it is eroded to northeast.

Table 5

Geophysical Survey Coverage over the Favorable Phyllite Belt

Map Sheet	Airborne EM Coverage	Airborne Mag Coverage	Ground Mag Coverage	Turam Coverage	Gravity Coverage
D6	100 %	100 %	25 %	70 %	30 %
E6	100 %	100 %	70 %	70 %	50 %
F6	100 %	100 %	20 %	70 %	60%
G6	100 %	100 %	40 %	75 %	50 %

In essence there is little known of the district in the subsurface and practically nothing of the areas off the favourable trend. It is important that the district see a resurgence of exploration activity particularly deep drilling both on and off trend coupled with renewed surface geological mapping. Detailed, modern, airborne electromagnetic and magnetic surveys should also be completed to assist with the geology and to cover unsurveyed or inadequately surveyed areas as outlined in Table 5..

It is believed that this exploration effort will be rewarded with additional ore discoveries. Particular targets are the area northwest of Faro where there has been little deep drilling and possible left lateral, northeast trending faults may have offset the Favourable Trend away from the batholith. There are several areas requiring testing on Vangorda Plateau particularly in the vicinity of the Dy deposit. In general there is virtually nothing known of the deep potential of the area southwest of the Favourable Trend on Vangorda Plateau. The Swim Basin offers a number of targets, of special interest is the south shore of Swim Lake and an area at the east end of the Favourable Trend where overburden geochemistry suggests that there may be additional subcropping sulphides up ice flow direction from the last occurrence.

Closer to the deposits there is excellent potential to extend the Grum deposit down plunge to the northwest into an area where scattered high grade intersections have been encountered but most holes are too short to fully test the potential. Similarly the Dy deposit has not been closed off by drilling to the south, southwest or southeast and further deep drilling is likely to encounter additional mineralization. Both the Grum and Dy areas have been estimated to have the potential to host an additional 5 million tonnes each of mineralization with similar tenor to that already known.

In summary although the Anvil District has had a relatively long history of exploration, only the near surface has been well explored and the potential for additional discoveries at depth and in overburden covered areas remains good.

MINERAL RESOURCES AND MINERAL INVENTORY

There are five deposits with delineated zinc-lead-silver mineralization in the district, one of these, Faro, is now essentially depleted and, Vangorda is close to depletion as well. Despite this there is still a substantial inventory of mineralization in the district contained within the Grum, Dy and Swim deposits. As noted above there is excellent potential to increase this inventory further at the currently interpreted deposit periphery. Exploration is also likely to add to the inventory by the discovery of new deposits.

Table 6 presents the mineral inventory for the district at the end of May 1993 in terms of the tonnage and grade of defined in-situ mineralization at a variety of cutoff grades. Also presented in Table 6 is the potential mineralization speculated to be present near Grum And Dy. The tonnage at Dy is quite sensitive to cutoff grade emphasizing the

Table 6

Anvil District Geological Inventory as of start of Second Quarter 1993

Total in–situ mineralization, no adjustments for mining recovery or dilution

Deposit Name	Cutoff % Pb+Zn	Classification	Tonnage (tonnes)	Zn (%)	Pb (%)	Ag (g/t)	Au (g/t)
Faro	3	Prov.+ Prob.	30,000	5.60	3.30	35.0	0.10
Vangorda	3&4	Prov.+ Prob.	2,017,143	4.26	3.34	42.8	0.81
Grum 61W to 87W	3	Prov.+ Prob.	43,240,250	4.66	2.94	49.1	0.08
Grum 61W to 87W	8	Prov.+ Prob.	15,882,260	7.05	4.39	72.6	1.05
Grum northwest of 87W	NA	Potential	5,000,000	6.00	4.00	65.0	0.75
Dy AB and Extn., Above and Below AB	6	Prob. + Poss.	41,555,000	5.72	4.12	61.9	0.65
Dy AB and Extn., Above and Below AB	8	Prob. + Poss.	24,947,000	7.01	5.21	77.4	0.85
Dy AB and Extn., Above and Below AB	9	Prob. + Poss.	21,356,000	7.33	5.54	81.1	0.87
South, SW and SE of AB Zone	NA	Potential	5,000,000	7.33	5.54	81.1	0.87
Swim	4	Possible	5,130,000	4.40	3.50	47.0	0.65
Stockpiles	3	Proven	2,598,456	2.89	1.96	17.9	0.19
Total (Grum @3%, Dy at 9%)			84,371,849	5.49	3.83	58.8	0.42

importance of reducing miningand transportation cost to not only improve profits but also to add tonnage to the reserve base in areas already delineated.

MINABLE RESERVES

Table 7a presents the minable reserve for the Anvil District as of the end of March 1993. The reserve is based only on mineralization classified as proven or probable and for which the economics of extraction has been established. This material is fully diluted and expressed as recoverable ore. The details of the derivation of dilution are explained in separate reports on the specific deposits.

The inventory of mineralization that can reasonably be expected to be mined is greater than the reserve base however this material requires further drilling or improved economics to be added to the reserve base. This material is expressed as diluted recoverable material as with the ore reserve in Table 7b. Included in this category is incremental mineralization within a larger pit design for Grum, mineralization below the Grum Pit but not the northwest extension. Also included is possible mineralization in the AB Zone and AB extension Zone at Dy and the Swim Deposit.

The current status of high and low grade stockpiles at the Faro and Vangorda Plateau sites is indicated in Table 7c.

Table 7a

Anvil District

Start of 2nd Quarter Minable Reserves

Remaining at End of First Quarter 1993, cutoff (c/o) as shown below

	Classification	(metric tonnes)	Zn (%)	Pb (%)	Ag (g/t)	Au (g/t)	total zinc (million lbs.)	total lead (million lbs.)	total silver (thousand oz.)	total gold (thousand oz.)
Faro Pit – Zone I Ramp area	Prov. + Prob.	30,000	5.60	3.30	35.0	0.10	3.704	2.183	33.756	0.096
Vangorda Pit (3% Pb + Zn c/o)	Proven	1,004,736	4.40	3.60	46.9	0.92	97.467	79.796	1,516.000	29.703
Grum Pit (IV Pit, 3% Pb+Zn c/o)	Prov. + Prob.	24,760,000	4.54	2.74	46.0	0.70	2,478.222	1,495.667	36,616.425	557.206
Dy (9% Pb+Zn C/o)	Prob.	9,390,095	6.62	5.50	80.3	0.82	1,370.445	1,138.588	24,241.138	247.543
Stockpile	Proven	2,598,456	2.89	1.96	17.9	0.19	165.366	112.061	1,492.916	15.543
Total Minable Reserve	Prov. + Prob.	37,783,287	4.94	3.40	52.6	0.70	4,115.204	2,828.294	63,900.235	850.092

Table 7b

Anvil District

Start of 2nd Quarter Minable Inventory

Remaining at End of First Quarter 1993, cutoff (c/o) as shown below

	Classification	(metric tonnes)	Zn (%)	Pb (%)	Ag (g/t)	Au (g/t)	total zinc (million lbs.)	total lead (million lbs.)	total silver (thousand oz.)	total gold (thousand oz.)
Increment from IV to AB Pit (incl.Champ, 3%c/o)	Possible	5,782,000	3.59	2.16	35.4	0.70	457.621	275.338	6,580.347	130.120
Grum below AB Pit (52W to 88W, 8% Pb+Zn c/o)	Possible	2,832,000	6.38	4.17	68.6	1.00	398.334	260.353	6,241.201	91.046
Dy (9% c/o)	Possible	5,879,683	7.70	5.10	75.6	0.83	998.110	661.086	14,297.921	156.892
Swim (4% c/o)	Possible	3,910,000	3.91	3.22	42.0	0.65	337.045	277.566	5,279.509	81.707
Total Minable Inventory	Prov. + Prob.	18,403,683	5.40	3.63	54.8	0.78	2,191.110	1,474.343	32,398.979	459.764
Total Defined Minable Mineralization	Prov.,Prob.&Poss	56,186,970	5.09	3.47	53.3	0.73	6,306.314	4,302.637	96,299.214	1,309.856

Table 7c

Anvil District

Status of Stockpiles at Start of 2nd Quarter

Stockpiles at end of First Quarter 1993

	Classification	(metric tonnes)	Zn (%)	Pb (%)	Ag (g/t)	Au (g/t)	total zinc (million lbs.)	total lead (million lbs.)	total silver (thousand oz.)	total gold (thousand oz.)
Grum HG +5%, Plateau		7,414	4.28	2.02	20.0	0.70	0.700	0.330	4.767	0.167
Grum LG 3–5%, Plateau		23,821	3.11	1.51	15.0	0.30	1.633	0.793	11.487	0.230
Faro HG +5%, Faro		4,000	5.46	3.19	30.0	0.10	0.481	0.281	3.858	0.013
Faro LG 3–5%= A.C,LL S/Ps, Faro		1,758,159	2.76	1.68	15.0	0.10	106.980	65.118	847.846	5.652
Vangorda HG +6% G1 baritic, Plateau		13,954	4.82	3.76	45.0	0.70	1.483	1.157	20.187	0.314
Vangorda HG +6% Oxide Cap, Plateau		57,197	4.93	4.09	45.0	0.70	6.217	5.157	82.747	1.287
Vangorda HG +6% G1 baritic, Faro		32,321	4.56	3.55	45.0	0.70	3.249	2.530	46.759	0.727
Vangorda HG +6% G2 carbon, Faro		30,055	4.29	3.23	45.0	0.70	2.843	2.140	43.481	0.676
Vangorda LG 3–5%, Plateau		510,154	2.75	2.31	20.0	0.30	30.929	25.980	328.019	4.920
Vangorda LG 3–5%, Faro		161,381	3.05	2.41	20.0	0.30	10.851	8.574	103.765	1.556
Total Stockpiles		2,598,456	2.89	1.96	17.9	0.19	165.366	112.061	1,492.916	15.543
Total HG Stockpiles		144,941	4.69	3.63	43.3	0.68	14.972	11.595	201.799	3.185
Total LG Stockpiles		2,453,515	2.78	1.86	16.4	0.16	150.393	100.466	1,291.117	12.359
Total HG Stockpiles at Faro Site		66,376	4.49	3.38	44.1	0.66	6.573	4.951	94.098	1.417
Total LG Stockpiles at Faro site		1,919,540	2.78	1.74	15.4	0.12	117.831	73.692	951.611	7.209
Total Stockpiles from Faro Deposit		1,762,159	2.77	1.68	15.0	0.10	107.461	65.399	851.704	5.665
Total Stockpiles from Grum Deposit		31,235	3.39	1.63	16.2	0.39	2.333	1.123	16.254	0.397
Total Stockpiles from Vangorda Deposit		805,062	3.13	2.57	24.1	0.37	55.572	45.539	624.958	9.482

REFERENCES

Aho, A.E., 1966, Exploration Methods in Yukon with Special Reference to Anvil District, Western Miner, 39, 127-148.

Blusson, S.L., 1966, Frances Lake, Yukon Territory and District of Mackenzie. Geological Survey Canada, Map 8-1967.

Brock, J.S., 1973, Geophysical Exploration Leading to the Discovery of the Faro Deposit. Canadian Institute Mining Metallurgy Bulletin, Vol. 66, No., 97-116.

Brown, D. and McClay, K. (1992) Structure of the Vangorda Pb-Zn-Ag deposit, Anvil Range, Yukon Territory; in Current Research, Part A; Geol. Surv. Can. Paper 92-1A; p 121-128

Brown, D. and McClay, K. (1993) Structural Geology of the Vangorda Pb-Zn-Ag deposit; in prep.

Brown, D. (1993) Low Pressure, Low Temperature Metamorphism of the Vangorda Massive Sulphide Orebody; in prep.

Campbell, F.A. and Ethier, V.G. (1974) Sulphur Isotopes, Iron Content of Sphalerites and Ore Textures in the Anvil Orebody, Canada: Econ. Geol., vol. 69,p. 482-493

Carne, R.C. and Cathro, R.J., 1982, Sedimentary Exhalative (sedex) Zinc-Lead-Silver Deposits, Northern Canadian Cordillera. Canadian Institute Mining Metallurgy Bulletin, Vol. 75, No. 840, 66-78.

Chisholm, E.O., 1957, Geophysical Exploration of a Lead-Zinc Deposit in Yukon Territory. In Methods and Case Histories in Mining Geophysics, Sixth Commonwealth Mining and Metallurgy Congress, 269-277.

Gabrielse, H., Blusson, S.L., and Roddick, J.A., 1973, Geology of Flat River, Glacier Lake and Wrigley Lake Map Areas. Geological Survey Canada, Memoir 366, 153 p.

Geological Survey Canada, 1968, Geophysics Paper 4353 Rose Mountain 105K5; Geophysics Paper 4362, Butte Creek 105K3; Geophysics Paper 4372, Swim Lake 105K2

Gondie, J. (1972) Geology of the Anvil Mine in D.J. Glass (ed.), Major Lead Zinc Deposits of Western Canada: Int. Geol. Cong., 14th Session Guidebook

Gordey, S.P., 1978, Stratigraphy and Structure of the Summit Lake area, Yukon and Northwest Territories. In Current Research, Part A, Geological Survey Canada, Paper 78-1A, 3-48.

Gordey, S.P., 1983, Thrust Faults in the Anvil Range and a New Look at the Anvil Range Group, South Central Yukon Territory. In Current Research, Part A, Geological Survey Canada, Paper 83-1A, 225-227.

Gordey, S.P., Abbott, J.G., and Orchard, M.J., 1982, Devono-Mississippian (Earn Group) and Younger Strata in Each, Central Yukon. In Current Research, Part B, Geological Survey Canada, Paper 82-1B, 93-100.

Gordey, S.P. and Irwin. S.E.B. (1987) Geology, Sheldon Lake and Tay River Map Areas, Yukon Territory; Geol. Surv. Can. Map 19-1987, (3 sheets), scale 1:250,000

Gustafson, L.B., and Williams, N., 1981, Sediment-hosted Stratiform Deposits of Copper, Lead and Zinc. Economic Geology, 75th Anniversary Volume. 139-178.

Jackson, L.E. (1986) Terrain Inventory, Tay River, Yukon Territory; Geol. Surv. Can. Open File 1380; scale 1:125,000

Jennings, D.S. and Jilson, G.A., 1986, Geology and Sulphide Deposits of Anvil Range, Yukon. In J.A. Morin (ed.), Mineral Deposits of Northern Cordillera. Canadian Institute Mining Metallurgy, Special Paper 37, 319-361.

Jennings, D.S. and Simpson, J.G., Exploration Methods and Discovery Histories, Anvil District, Yukon Territory. Unpublished manuscript prepared for Northern Dynasty Explorations Ltd.

Kuo, S.L. (1976) Geology and Geochemistry of Stratabound Ore Deposits in the South Central Yukon Territory and Southeastern District of Mackenzie, North West Territories; Ph.D dissert., Univ of Alberta, Edmonton

Kuo, S.L. and Folinsbee, R.E. (1974) Lead Isotope Geology of Mineral Deposits Spatially Related to the Tintina Trench, Yukon Territory; Econ. Geol. v. 69, p 806-813

Large, D., 1980, Geological Parameters Associated with Sediment-Hosted Submarine Exhalative Pb-Zn Deposits. Geologisch, J., Reike, D. Heft 40, 149-129.

LeCouter, P. (1973) A Lead Isotope Study of Ore Deposits from the East Kootenay District, B.C. and The Anvil District, Yukon Territory; unpub. Ph.D thesis, Univ. of British Columbia

Modene, J.S. (1982) Origin and Sulphur Isotope Geochemistry of the Grum Deposit, Yukon Territory, Canada; unpub. M.S. thesis; Univ. of Wisconsin, Madison; 158 p.

Morton, P. (1973) Geochemistry of Bedrock and Soils in the vicinity of the Anvil Mine, Yukon Territory: Msc. Thesis,, University of British Columbia, 207 p.

Pigage, L.C., 1990, Field Guide Anvil Pb-Zn-Ag District, Yukon Territory, Canada. Geological Survey of Canada, Open File 2169, Field Trip 14, 283-308.

Pigage, L.C. and Anderson, R.G., 1985, The Anvil Plutonic Suite, Faro, Yukon Territory. Canadian Journal Earth Sciences, 22, 1204-1216.

Pigage, L.C. and Jilson, G.A., 1985, Major Extensional Faults, Anvil Pb-Zn District, Yukon. Geological Society America, Abstracts with Programs-Cordilleran Section, 17, 400.

Roddick, J.A. and Green, L.H. (1961) Tay River, Yukon Territory; Geol. Surv. Can. Map 13-1961

Roth, J. (1990) Geophysical Review of the Anvil District, Y.T.; unpub. report for Curragh Resources Inc. by Stratagex Ltd., May 1990, 10 p.

Shanks, W.C, Woodruff, L.G., Jilson, G. A., Jennings, D.S., Modene, J.S., Ryan, B.D. (1987) Sulphur and Lead Isotope Studies of Stratiform Zn-Pb-Ag Deposits, Anvil Range, Yukon: Basinal Brine Exhalation and Anoxic Bottom Water Mixing; Econ. Geol.; vol. 82; p 600-634

Smith, J.M. and Eardmer, P. (1990) The Anvil Aureole, an Atypical mid- Cretaceous Culmination in the Northern Canadian Cordillera; Can. Jour. Earth Sci.; vol. 27, p. 344-356

Tempelman-Kluit, D.J., 1970, The Relationship Between Sulphide Grain Size and Metamorphic Grade of Host Rocks in Same Stratabound Pyritic Ores. Canadian Journal Earth Sciences, 7, 1339-1345.

Tempelman-Kluit, D.J., 1972, Geology and Origin of the Faro, Vangorda and Swim Concordant Zinc-Lead Deposits, Central Yukon Territory. Geological Survey Canada, Bulletin 208, 73 p.