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District Geology

Introduction

The Anvil Range Pb-Zn-Ag District is located in the central Yukon Territory near the town of Faro (figure 1). The district contains one of the world's largest reserves of lead and zinc in several deposits (figure 2) including the ~~recently re-opened~~ Faro mine.

& Table I

Regional Geology

The Anvil District is part of the Selwyn Basin (figure 3), a large area of central Yukon where deep water shales accumulated along the ancient North American continental margin during the Paleozoic. The shales of the Selwyn Basin host most of Canada's large stratiform lead-zinc deposits, making it a metallogenic province of world wide significance. Unlike the remainder of the Selwyn Basin, the rocks and ores of the Anvil District are metamorphosed thus the shales are converted to phyllites and schists. The central part of the district is underlain by a large granitic body that cores an enlogate dome exposing the metamorphic sequence (Figure 4). The District contains several stratiform, lead-zinc-silver bearing, pyritic, massive sulphide deposits hosted by Cambrian metasediments on the southwest flank of the dome. The Tintina Fault, one of the major right lateral Cordilleran strike slip faults, passes just south of the district (Figures 3 and 4) but is not directly related to the ores.

figure 1 Yukon Location map
figure 2 Tonnage/Grade curves
Table I geological reserves
fig 3 Regional Geology
fig 4 district Geology

District Stratigraphy

Introduction

The stratigraphic sequence of Anvil District ranges in age from latest Precambrian to Permian. Two major divisions or assemblages of strata are present. They are separated by a poorly exposed interval of black shale of uncertain affinity which contains late middle Devonian limestone lenses (Tempelman-Kluit, 1972).

Lower Division

The lower division ranges in age from late Precambrian to perhaps Early Silurian. It is approximately 5 km thick and divisible into three major mappable units (figure 5). From the base these are non-calcareous metapelite of Mt. Mye formation, calcareous metapelite of Vangorda formation and basalt and black phyllite of Menzie Creek formation. Established formal stratigraphic nomenclature does not apply directly to this area but the rocks are very similar to those of Kechika Group (Gordey, 1981) south of the district in Pelly Mountains. The lead zinc deposits occur within a restricted portion of the lower division.

fig 5 Strat Col.

over 1 tab

→ over 1 Tab

Upper Division

The upper division includes rocks ranging in age from Devonian to Permian. In contrast to the lower division, the upper division is characteristically cherty and conspicuously coarsely clastic. All or part of the upper division may be allochthonous with respect to the lower. The upper division is host to stratiform barite deposits and to a number of interesting geologic problems beyond the scope of this summary. (See: Jennings and Jilson, 1986)

The Lower Division

Mt. Mye Formation

dominant and characteristic lithology of the (unit 3G) depending on metamorphic Grade

lithologies are:

The Mt. Mye formation varies from non-calcareous, biotite-muscovite schist to non-calcareous, weakly carbonaceous, light to medium gray muscovite-chlorite phyllites ~~with~~ lesser, interlayed, black graphitic phyllite, (unit 3E) marble, (unit 3F) calc-silicate phyllite or schist, metabasite (unit 3C) and psammitic schist. At the Faro minesite the formation is dominated by schistose variants of these rock types. On Vangorda Plateau the majority of the formation is phyllitic due to lower metamorhphic grade. The formation is at least 2 kilometers thick, its base is not exposed in the district.

(units 1D and 1C)

(unit 3D)

The upper portion of the formation is very similar to the buff weathering mudstone and blue-gray mudstone units described by Gordey (1978) to the east near Howards Pass and to unit 8A of Blusson (1966) near Cantung. Correlation with these units would imply the top of the formation is lower Cambrian or possibly middle Cambrian. Parts of the Mt. Mye also resemble rocks underlying those presumed correlative units, implying the Mt. Mye probably includes rocks as old as Hadrynian.

Vangorda Formation

(unit 5B)

The Vangorda formation is characterized by light to medium-gray, calcareous, phyllitic rocks made up of very thin (0.1-2 cm) interlayers of (a) medium gray, non-calcareous, weakly carbonaceous, muscovite-chlorite meta-pelite and (b) light gray, generally calcareous quartz calcite dolomite meta-siltstone. In areas of more intense metamorphism, such as near the Faro deposit, the calcareous phyllite is altered to a harder, banded, green, purplish brown and creme coloured calc-silicate. Other rock types interbedded with the calcareous phyllite include metabasite (unit 5C) and chloritic meta-tuffs, (units 5D and 5F) graphitic phyllite, and phyllitic limestone. (unit 5E)

(units 5A and 5G)

(unit 3D)

~~(unit 5G)~~

Most metabasite (greenstone) bodies are medium-grained and equigranular, thus they may have been sills; however, locally amygdaloidal margins and a common association with thin bedded, tuffaceous (?) rocks (unit 5D) suggests at least some were flows. Whole rock compositional data shows that the metabasites are all of basaltic composition. The bodies range from 1 to 100 meters in thickness and are up to several kilometers in length.

sp?

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. A major carbonaceous member occurs at the base of the formation. (Unit 5A)

The Vangorda formation is lithologically similar to, though more argillaceous than, 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 upper Cambrian through lower Ordovician. and represents the basinal equivalent of the Rabbitkettle Formation

Menzie Creek Formation

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. Carbonaceous phyllite and brown siltstone interbeds northeast of the Anvil Batholith contain graptolites of middle Ordovician or lower Silurian age (Tempelman-Kluit, 1972) suggesting correlation with the widespread Road River Formation black shale and chert to the northeast. The Menzie Creek formation varies from 0 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 and around the Selwyn Basin.

interbedded lithologies are:

at the top of the formation

Relation of Stratigraphy to Ore Deposits

The ore deposits of Anvil District are stratiform and stratabound to an approximately 150 m thick interval straddling the contact of the Mount Mye and Vangorda formations. The deposits consist of one to five horizons of sulphide mineralization stacked one above the other within this interval. They appear to be related to the northeastern pinch-out of the basal carbonaceous member of the Vangorda formation. (Unit 5A) A direct relationship to volcanism has not been established however it is clear that subordinate mafic volcanism occurred in the area during ore deposition. The development of metabasite in the Vangorda formation is far in excess of any other area of comparable stratigraphy in Selwyn Basin and the overlying Menzie Creek formation is best developed in Anvil Range. These igneous accumulations are, of course, younger than the ore bodies but may indicate a long lived thermal anomaly in the area that is related to ore genesis.

Deformation, Metamorphism and Plutonism

The structural and metamorphic history of the Anvil Range is complex and of considerable significance to the form and nature of the ore deposits. During mid-Mesozoic, the district suffered two periods of intense fold deformation and concurrent metamorphism which determined the gross structure of the mineral deposits.

The first deformation (D1) produced a regional metamorphic foliation (S1) axial planar to tight to isoclinal mesoscopic folds (F1) in bedding (S0). Mesoscopic early folds are rarely preserved in the district. Northeasterly inclined to upright, northeasterly verging megascopic folds with shallow northwesterly or southwesterly plunging axes appear to have formed at that time.

figure 6 V. Plat section

During the second event (D2), S1 was strongly crenulated and ubiquitous close to tight mesoscopic folds in S1 were produced (figure 6). Some of the largest megascopic folds known to have been formed during D2 are those at the Grum deposit (figure X) and comparable folds in the Swim Deposit (figure XX). Parallel to the axial planes of these D2 folds is a crenulation cleavage (S2) which imparts a well developed lithon structure and pronounced fissility to most rocks of the district, especially the strongly banded phyllites of the Vangorda formation. F2 axial planes and S2 dip shallowly, with axes subparallel F1 axes.

fig — Grum Deposit Section
fig — Swim Deposit Section

Three later, less intense periods of folding and associated faulting followed. The later events (D3 through D5) generally produced open folds and weak crenulations in S2 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 (D4) is quite intense. At Faro tight mesoscopic folds are developed in nearly pervasive S2 with appreciable mica growth along S4 (see figure XXX for examples of fourth phase affecting outline of the Faro deposit).

fig — Faro Deposit Section

During the later stages of the fold deformation history (probably D2 and later) a large granitic body (Anvil Batholith) was intruded into the metamorphic sequence. Anvil Batholith ranges in composition from granodiorite to quartz monzonite and textures include equigranular massive, megacrystic massive and various strongly to weakly foliated variants. Several K/Ar ages on the granitic rocks yield ages of 85-100 ma (Tempelman/Kluit, 1972). 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 (figure 4). In the later stages of batholith emplacement large extensional fault displacements occurred along its margins. These faults determine the present day limits of several of the deposits (figure~~s~~ X~~, XX and XX~~X).

fig — Grum long section

Metamorphism was concurrent with deformation and was most intense during the early deformations, especially D2. Metamorphic facies developed range from middle amphibolite facies to lower greenschist facies in a low pressure Buchan facies series. Metamorphic isograds are roughly concentric about the Anvil Batholith. Faro, close to the Batholith (figure 4) is strongly metamorphosed, while deposits such as Vangorda are less intensely metamorphosed. This difference in metamorphism is reflected in decreased grain size, increased degree of mineral intergrowth, and lesser iron content of sphalerite in the less metamorphosed deposits. This has a significant impact on metallurgical performance of Anvil district ores. The less metamorphosed deposits are richer in gold and its geochemically associated elements ~~probably~~ than is the Faro deposit. This is probably due to Faro having had this geochemical suite leached out by metamorphic fluids ~~and~~ with local concentration in dilatant zones.

Ore Deposits

General Description

The lead, zinc, silver deposits of Anvil Range are of the sediment hosted, stratiform, massive pyritic sulphide (Gustason & Williams, 1981; Large, 1980) or sedex type (Carne and Cathro, 1982). They occur as a single thick sulphide lens with little or no interbanded metasedimentary rocks (e.g. Faro) or as multilayered deposits with several thinner lenses stacked approximately one above the other with substantial metasedimentary or metavolcanic interlayers (e.g. Grum and Dy). An individual mineralized layer was deposited parallel to the bedding of the host sediments. It consisted of an upper, ~~often~~ commonly centrally positioned, lead-zinc rich, massive sulphide facies and a lower and peripheral, lower grade, quartzose, disseminated sulphide facies.

These sulphide sheets, or horizons, have since been deformed into complex fold structures. The deposits are thus elongate parallel to the fold axes and associated lineations in the host metasediments. The Faro deposit, which appears to be an exception to this generalization, actually shows great internal complexity in the geometry of high grade and waste layers.

Present day deposit lengths are generally two to three times widths; unfolded deposit dimensions range up to 4000 m across their ameboid shapes. Individual sulphide horizons commonly are 10 to 40 m in thickness. The upper and lower contacts of sulphide horizons are invariably sharp while laterally the sulphides grade into the enclosing host rocks.

All deposits are composed of a small number of different sulphide rock types. As noted above the sulphide rock types are broadly divisible into massive sulphides and quartzose, disseminated sulphides. There are pyritic, baritic, pyrrhotitic and carbonate bearing variants of massive sulphide types and carbonaceous and non-carbonaceous variants of the quartzose sulphide rock types. The typical spatial distribution of these different types is shown in figure 3.6 with great vertical exaggeration.

figure – Anvil Cycle

The simplified arrangement of the sulphide rock types in the horizons is important since lead-zinc grade and metallurgical performance varies by ore type. The baritic massive sulphides are always high grade, easily grindable and generally yield good grade concentrates with good recoveries. On the other hand the lower and distal graphitic quartzites are commonly low grade, hard and produce lower grade concentrates or low recoveries. Other ore types exhibit intermediate characteristics and performance.

All deposits show a variably developed, white mica-dominant, alteration overprint in the wallrocks.

There are presently five known lead zinc bearing mineral deposits along a prominent curvilinear tend on the south flank of Anvil Arch (figure 4~~[illegible]~~). From northwest to southeast they include Faro, Grum, Vangorda, Dy and Swim. Additionally two lead-zinc deficient sulphide occurances, the SB and Sea, are also known. Diagrammatic section through each of the major deposits are shown in Figures [illegible] through [illegible]2. Geological reserves are tabulated in table I.

Description of Sulphide Rock Types

Massive Pyritic Sulphides: (unit 2E/2F)

The massive sulphides consist of banded to homogeneous, usually weakly foliated and/or lineated, massive pyrite with lesser sphalerite and galena. Total sulphide content is at least 60%, generally greater than 80% and commonly nearly 100%. Gangue consists of quartz and/or barite and/or carbonates (calcite, dolmite, anderite). Accessory minerals include pyrrhotite, chalcopyrite, magnetite, arsenopyrite and marcasite. At amphibolite facies metamorphic grade, this rock type commonly develops a buckshot porphyroblastic texture of pyrite in a matrix of dark reddish brown to black lead-zinc sulphides. This texture usually is restricted to rocks with economic lead-zinc grades (Unit 2F). Hard, barren, massive pyrite, commonly with disseminated, black, magnetite prophyroblasts, is widespread at Faro particularly in the northeast part of the deposit.

~~and~~ the Footwall of Vangorda and between the two major ore lobes at DY.

Baritic, Massive Pyritic Sulphides

The baritic sulphides (Unit 2G) are strongly and thinly banded massive sulphide/sulphate rock consisting of pyrite, galena, sphalerite and commonly magnetite in a gangue of off-white barite and lesser carbonates (calcite, dolmite, anderite and probably barytocalcite). The amount of barite may be as high as ~~5~~70%; non-sulfidic, massive barite does not occur in the Anvil deposits. There is a complete gradation between this and the above facies with 10% visible barite by volume being the dividing line. This facies is usually quite high grade (10-15% combined lead-zinc). Sphalerite is characteristically honey coloured to reddish brown. Pyrrhotite is not commonly seen in the baritic facies except in the Faro deposit where generally overall pyrrhotite is more abundant.

and relatively higher than other ore types in lead and silver ~~as~~ as opposed to zinc. A ~~potentially~~ ~~high~~ lead, silver and gold enriched baritic ore layer occurs ~~in the upper par~~ at the top of the Faro deposit.

Carbonate-bearing, Massive Pyritic Sulphides:

The carbonate bearing sulphides (Unit 2K) are similar to massive pyritic sulphides but contain greater than 10% carbonate (calcite, dolomite, ankerite) either as interstitial gangue or as coarse patches and irregular blebs. This is a minor facies and is not known with certainty to always be an original composition variant. The most common occurance of coarse pinkish beige to tan, ankerite patches may represent recyrstallized original carbonate or re-worked pre/syn-metamorphic veins. This variant is generally lead-zinc poor. The variants with white interstitial gangue can be high grade and locally they texturally resemble the baritic sulphides.

should have the same left margin

Pyrrhotitic Massive Sulphides:

This rock type (Unit 2H) consists of massive, finely crystalline, usually well foliated pyrrhotite with less than 50% pyrite porphyroblasts and highly variable amounts of sphalerite and galena. Minor chalcopyrite is characteristic of this relatively copper-rich facies. Rounded to angular, rotated, foliated quartzite or quartz-vein clasts 2 cm or less in diameter are typical. This is a minor facies and is not known with certainty to be primary as some pyrite in the massive facies may invert to pyrrhotite during regional metamorphism. At Faro the pyrrhotitic facies is more volumetrically important than the other deposits. Pyrrhotite rich ores are generally much finer grained than non pyrrhotitic ores at Faro.

Ribbon Banded, "Graphitic", Pyritic Quartzite:

This unit (Unit 2A) is a dark gray to black, well banded, sulphide-bearing quartzite (metamorphic usage). Bands are: (a) dark gray, very fine grained carbonaceous phyllitic quartzite to siliceous phyllite (presumed metachert) and (b) light gray, quartz-sulphide (pyrite-sphalerite-galena) bands. These bands are usually 2 mm to 2 cm thick. Total sulphide content of unit 2A is usually between 10 to 30% but ranges from 2 to 60%. Pyrite is usually the dominant species but higher grade examples have sub-equal pyrite and lead-zinc sulphides. Lead-zinc dominant variants with little pyrite occur but are not common unless total sulphide content is low. Strong sulphide species differentiation between bands, such that barren pyrite bands are adjacent to or near sphalerite or galena rich bands, occurs but is not generally the case.

Pyritic Quartzite:

The pyritic quartzites (Units 2B, C, D) are light to medium gray, generally poorly banded, moderately to weakly foliated, micaceous quartzites with highly variable lead-zinc and pyrite contents. Pyrite contents are generally 10 to 40% ranging between 2 and 60%. Although there is a complete gradation from massive to quartzose ores there is usually little problem in separating this facies from the massive pyritic sulphides as the vast majority of examples have less than 40% total sulphides. A minor variant of this facies (unit 2B) shows low pyrite (< 5%) content with lead-zinc sulphides predominant. Barite in major amounts is uncommon in the quartzose facies; carbonate species are not typical but locally are abundant. Chalcopyrite, pyrrhotite and magnetite-bearing varieties are common. Sphalerite in the high grade examples is characteristically ~~a vibrant~~ reddish brown. At Faro the more sulphide rich variants of this facies are well developed along the northeast edge of zone 3. They are spectacularly barren but

where they grade into the ~~[illegible]~~ pyritic massive sulphides noted above.

no line (contain elevated copper contents and are rich in magnetite. A similar facies is developed at Vangorda and locally at Grum where the rocks are also ~~quite~~ Relatively gold rich (0.5 → 1.5 gm/tonne) and more clearly in the deposit footwall.

Alteration

Both wallrocks and certain ore facies of the Anvil deposits are overprinted by a prominent, easily recognized, light beige, white mica dominant alteration assemblage (Units 2L and 1D4). This overprint facies is not a depositional unit and may form as a reaction product between wallrocks and deposit forming hydrothermal fluids, or as a metamorphic reaction envelope unrelated to ore forming fluids or as a combination of these processes. In the multi-layered deposits, this alteration overprint appears discontinuous and often best developed in the footwall of a given lens or deposit as a whole. At Faro, a continuous envelope of this lithology encloses the entire deposit with local (especially Zone 1) best development in the hanging wall. The more intensely developed alteration assemblages can cause frothing problems in the mill since they contain talc or sericite that acts like talc.

Lithologic Terminology

A consistent alphanumeric code for lithology for all Anvil District deposits was introduced a number of years ago to facilitate storage of lithology data in a computerized database. Since occasional reference to these codes is made in the following sections a brief note of explanation is in order. The system works on the basis of a number followed by a letter and then a series of numbers and or symbols. The first number refers to metamorphic grade and hence structural level: 2 means amphibolite facies (Faro) and 4 means greenschist facies (all other deposits). The letter refers to the major lithology as shown in Table 3.1. The remaining letters and symbols are modifiers as outlined in Table 3.2. Thus 4A4 is a lead-zinc rich carbonaceous pyritic quartzite; 2A479 would be the same from Faro with pyrrhotite and chalcopyrite.

In some cases it is preferable to refer to a combination of sulphide rock types, particularly in a mining context. In such cases the letters are combined with the dominant component listed first. Thus 2EG would be mixed 2E and 2G; 2BCD refers to all non carbonaceous quartzites regardless of sulphide species. Another common combination is 2CE which can refer both to mixed 2C and 2E and semimassive sulphides between 2C and 2E in character. At Faro there are now three ore types mined: 2A, 2BG and 2H. In this case 2BG means all the detailed sulphide types from B through G.

The mine models generally require an integer lithologic codes and it has generally not been possible to use the same codes for all models; these codes are explained below for each model.

Grum Geology and Reserves

History

The Grum deposit was discovered in 1973 by AEX Minerals in joint venture with Kerr Addison Mines. Discovery was the result of drill testing a gravity anomaly in an area down fold plunge from the Vangorda deposit along what was then, as yet, a poorly defined favourable trend.

Surface drilling in 1973 and 1974 indicated a significant deposit; in 1975 and 1976 an underground sampling and drilling program, along with further surface diamond drilling, was carried out to further define it.

Kerr Addison sold the deposit, along with Vangorda and Swim, Cyprus Anvil Mining Corporation in 1979. From 1980 to 1982 Cyprus Anvil drilled additional holes in and around the deposit and re-logged all existing holes in it. All available sulphide intersections were re-sampled and re-assayed at that time.

Curragh drilled additional holes in 1987 and 1988 to further define shallow reserves.

General Geology

Stratigraphy and lithology

The Grum deposit consists of three to five highly contorted layers of massive and disseminated sulphide mineralization within a 150 m section of barren phyllite. The most important mineralized horizon occurs just beneath the basal carbonaceous member of the Vangorda formation. There are thin low grade horizons within the Vangorda formation and more important horizons in the upper part of the Mt. Mye formation.

At Grum, the Vangorda formation consists of soft, highly fissile, calcareous phyllites. Metabasites in the Grum area are minor and tend to be highly foliated chlorite phyllite rather than blocky, massive greenstones that typify the Vangorda formation elsewhere. The basal carbonaceous member of the formation (unit 5A) thickens across the deposit from about 10 m in the northeast to as much as 80 or 100 m southwest of the deposit. The sulphide horizons appear to be associated with the northeast pinchout of this unit. Immediately above the main ore horizon the carbonaceous rocks are soft, highly sheared and gouged but elsewhere they are moderately hard, highly fractured, black siliceous phyllites.
The Mt. Mye formation also consists of soft phyllites which are distinguished from those of Vangorda formation by being non-calcareous and less distinctly banded.

There are no significant post metamorphic dykes at Grum. The Anvil Batholith crops out 1.5 km northeast of the deposit but is separated from it by major faults. The batholith is unrelated to the deposit and does not appear to have significantly affected it.

Structure

The ore layers at Grum are contorted into a complex, shallowly northwest plunging, polyphase fold structure. The prominent S shaped folds (figure 3.8) are second phase structures. They are superimposed on a larger Z shaped first phase fold. The dominant plane of fissility (S2) in the phyllites at Grum is axial planar to the second phase folds and dips shallowly (10° to 30°) generally to the southwest. This fissility is a major factor in assessing slope stability for a Grum pit. The overall deposit elongation parallels the axial direction of the second phase folds (315° trend 11° plunge).

There are several important faults at Grum. The largest displacements occur on moderately (35°- 45°) dipping structures that truncate the deposit at both its northwest and southeast ends (figure 3.9). Neither of these structures would crop out in an open pit but smaller subparallel faults will be found in the pit. A steeply northwest dipping fault trending about 060°, passes between sections 70W and 72W and downdrops the deposit about 60 m to the northwest. A myriad of smaller faults were mapped underground by Kerr Addison trending on the average 080° and dipping steeply. Joints mapped underground and on surface tend to strike 060° and dip subvertically.

Surfical Geology

The subcrop of the ore deposit is covered by up to 100 m of tills and better sorted galciofluvial silts, sands and gravels. These unconsolidated sediments are water saturated and may contain pockets of permafrost especially where clay rich. The northeast wall of any pit designs at Grum must contend with thick sections of these sediments. Dewatering in advance of stripping may help increase stability substantially as well as simplify operations in the pit.

Ore Deposit Geology

As with other deposits in the Anvil Range a given ore horizon at Grum tends to have a massive sulphide upper and central portion and a quartzose, disseminated sulphide lower and perhiperal portion. The horizons can be up to 30 m thick but are mostly 15 m

no spce.

or less thick. Grade is strongly partitioned into massive, particularly baritic, sulphides thus the tops of horizons tend to be high grade and the bottoms low grade (except of course where the horizons are overturned). The sulphide horizons are separated by significant thicknesses of barren phyllite. Interfaces between ore and waste tend to be sharp at the stratigraphic hanging wall contact against barren phyllite and gradational both at the footwall and laterally against sulphide waste.

Grum, like Vangorda and Dy, has several characteristics that distinguish it from Faro. In large part this is due to the lower metamorphic grade the deposit has reached. The most outstanding difference between Grum, and all the other Vangorda Plateau deposits, as opposed to Faro is the form of the deposit. The Vangorda Plateau deposits consist of several distinct, highly contorted horizons separated by barren phyllite waste. Faro on the other hand is essentially one thick horizon in overall outline with lesser phyllitic waste but substantial barren sulphide waste banding. This implies that dilution by phyllite will be higher at Grum than at Faro. Faro however contains considerable internal sulphide waste thus its dilution is higher than might appear at first glance. It is none the less inescapable that Grum has more potential dilution and will have more complex mining problems than Faro. On the positive side, the dilutant at Grum will be more commonly easily identifiable phyllite rather than low grade sulphides as at Faro. Experience at Faro shows that phyllite dilution is much easier to control than low grade sulphides. ~~Grum's higher grade if diluted at 3 times the historical 5% dilution used at Faro still gives Grum a higher average grade.~~

The next most obvious difference is a finer grain size and more complex mineral intergrowth, necessitating finer grinding than Faro ores. Cyprus Anvil Mining Corporation had already made modifications to its mill to accommodate this fine grind prior to shutdown in 1982. When a large proportion of feed comes from Grum it will be necessary to utilize this grinding capability at the expense of tonnage throughput.

At a given Pb + Zn cutoff grade, ores at Grum are higher grade than those remaining at Faro, particularly in precious metals relative to base metals. The average gold content of Grum is several times higher than Faro. Similarly, other elements that tend to be geochemical associates of gold: mercury and arsenic, ~~tend~~ are reported to be higher at Grum. The sphalerite at Grum, and likely other Vangorda Plateau deposits, is richer in zinc due to lower metamorphic grade and resulting lesser iron content. This will help counteract higher pyrite-sphalerite middlings expected with Grum ores.

A feature unique to Grum among the Vangorda Plateau deposits is the relative abundance of quartzose ore types, particularly carbonaceous pyritic quartzites (4A) which comprise about 35% of the reserves above 4% Pb + Zn. It will undoubtedly create challenges for maintaining good lead concentrate grades, and probably necessitate stockpiling and planning campaigns of 4A during which depressants are used.
VANGORDA

GEOLOGY AND RESERVES

History

Vangorda was the initial discovery in the Anvil Range. The deposit was drill-tested from 1953 to 1955 by Prospector Airways, a predecessor to Kerr Addison Mines. This drilling showed a significant deposit existed but a production decision was not warranted at that time. Minor additional drilling was done by Kerr Addison, largely for metallurgical sampling, until the deposit was sold to Cyprus Anvil in 1979. Cyprus Anvil geologists examined the available drill core and concluded that it would be necessary to redrill the deposit to provide adequate material to re-evaluate it.

In 1979 the portion of the deposit from 2W to 12E was re-drilled with NQ core holes. Scattered core holes were put down in the southeast part of the deposit. Because of anticipated poor recoveries in this area it was judged advisable to drill this part of the deposit with rotary methods. This fill in drilling was done in 1981.

Selected fill in holes were drilled by Curragh in 1987. Also in 1987, test holes were put down in the southeast part of the deposit. These holes showed good recovery and the remainder of the deposit was redrilled in 1988 with NQ core holes.

General Geology

~~This section is an overview of the geology of the Vangorda deposit. For more detail consult Jennings and Jilson (1986). Rock types are summarized in Table xxx.~~

Stratigraphy and Lithology

The Vangorda deposit consists of one major sulphide horizon about 50 to 120 m beneath the basal carbonaceous member of the Vangorda formation. The host rocks for the deposit are dominantly non-calcareous phyllites (unit 3G), probably part of the Mt. Mye formation. However, formational assignments near this deposit are ambiguous, largely due to the strong wall rock alteration developed around the deposit. Most phyllites, especially in the deposit footwall, are bleached, locally silicified and/or chloritic and sulphide bearing (unit 4L).

A number of thin horizons occur above the main horizon. These horizons are too thin or too low grade to be mineable, with the exception of the southeast end of the deposit where they are shallow and the stripping ratio is low.

Structure

The Vangorda deposit occurs in the hinge of a large second phase fold. Overall the deposit has the shape of a "3" in cross section, however, there is considerable uncertainty in the details of fold morphology. The deposit is elongate in the northwest-southeast direction, parallel to the second phase fold axes, and has been traced over a 1300 m X 200 m area.

The northwest half of the deposit plunges about 10° towards the northwest but the southeast half is sub-horizontal (Figure ○). An axial planar foliation dips shallowly toward the southwest but is locally quite variable. in dip This foliation is the dominant plane of failure for the host rocks of the deposit and is a principal determinant of the slope stability of pit walls.

figure — Vangorda long section

The deposit is truncated by a steep normal fault at its northwest end. Steep normal or transcurrent faults offset the ore near 10E and 12E (Figure ○). Both these faults are late stage post-folding and post- metamorphism structures. Many gouge zones were observed in drill core but the orientation of the structures responsible for them is not known. A number of faults parallel to S_2 are predicted. These are "required" to make the structure and stratigraphy fit. These low angle structures are best thought of as sheared out fold limbs, they are not generally gouge zones and will pose no more serious a problem for slope stability than the S_2 foliation itself and the myriad of small gouge zones that parallel it.

Deposit Geology

The deposit is quite shallow, in most places subcropping beneath glacial till. The till blanket is up to about 30 m thick in the northwest part of the deposit, but thin in the southeast. Northwest of Vangorda Creek, till cover is also quite thin. Locally the basal overburden and uppermost broken bedrock are cemented by iron oxides into a tough breccia.

The deposit consists of the same sulphide rock types as the Grum and Faro deposits, but two types are particularly prominant. In the footwall of the main horizon of the deposit is a sulphide-rich quartzite (4C and 4EC). This quartzite grades downwards into siliceous phyllite and ultimately altered phyllite. Parallel to this downward decrease in silica is a downward decrease in the abundance of sulphides from quartz rich semi-massive sulphide (4EC) at the top to weakly pyritic altered phyllite at the base (4LO). Most of the sulphides in the quartzite are pyrite, however pyrrhotite is generally present and locally abundant or dominant. Magnetite is unusually well developed in the quartzite. The quatzite contains ony minor lead and zinc but is relatively rich in copper and unusually high in gold. The quartzite is similar to the semi-massive zone along the northeast edge of Zone 3 at Faro and one of the lower ore panels at Grum.

The main horizon massive sulphides that overlie the pyritic quartzite are commonly baritic and rich in lead and zinc. The unit is actually a mixture of about 50% 4E and 50% 4G ore types but separate treatment of pure types at Vangorda is not realistic from either the point of view of mining or the level of detail in the mine model. Of the mineralization exceeding 6% Pb+Zn, 90% is barite bearing massive sulphides (4EG). Most pyritic quartzite (4C and 4EC) is sulphide waste on the basis of lead-zinc content.

Of the other sulphide rock types, only 4A is of any importance. As is usual for these deposits, it tends to be low grade and peripheral to the deposit. Much of the 4A is actually part of the uppermost horizon associated with the carbonaceous phyllite at the base of the Vangorda formation.

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TABLE 3.1 THE ALPHA PART OF THE LITHOLOGIC CODE FOR SULPHIDE ROCK TYPES

A	thinly banded carbonaceous pyritic quartzite
B	weakly to non-pyritic quartzite
C	lead-zinc poor pyritic quartzite
D	lead-zinc rich pyritic quartzite
E	pyritic massive sulphide
F	buckshot textured pyritic massive sulphide
G	pyritic massive sulphide with >10% barite gangue
H	pyrrhotitic massive sulphide
J	non-pyritic or pyrrhotitic massive sulphide or massive magnitite
K	pyritic massive sulphide with >10% carbonate gangue
Q	foliated vein type quartz with sulphides

TABLE 3.2 LITHOLOGIC MODIFIERS FOR SULPHIDE ROCK TYPES

0	normal
1	siliceous
2	coarse porphyroblastic pyrite bearing
3	fine pyrite rich
4	lead-zinc rich
5	carbonaceous
6	barite bearing
7	pyrrhotitic
8	magnetite bearing
9	chalcopyrite bearing
*	undifferentiated carbonate bearing
#	calcite bearing
@	ankerite bearing
$	dolomite bearing

TABLE 3.1.5-1

FARO AREA

GEOLOGICAL RESERVES AND MINERAL INVENTORY

Source	Cut-off %Pb+Zn	Class	Tonnes	%Pb+Zn	%Pb	%Zn	Ag g/t	Au g/t
Faro								
Total Deposit	4.0	Proven	29,251,000	8.2	3.1	5.0	41	N.A
Grum								
Main Zone (61W-87W)	4.0	Proven	30,649,000	9.0	3.4	5.6	57	0.95
Champ Zone (51W-61W)	4.0	Probable	1,700,000	7.8	3.5	4.3	46	N.A
N.W. Extension (87W-100W)	N.A	Possible	8,000,000	10.0	N.A	N.A	N.A	N.A
Total Deposit	N.A	N.A.	40,349,000	9.1	N.A	N.A	N.A	N.A
Vangorda								
Total Deposit	4.0	Probable	7,457,000	8.7	3.8	4.9	54	0.69
Dy								
Total Deposit	9.0	Possible	21,059,000	12.2	5.5	6.7	84	0.95
Swim								
Total Deposit	6.0	Possible	4,309,000	8.5	3.8	4.7	51	N.A
TOTAL INVENTORY			102,425,000	9.4	N.A	N.A	N.A	N.A

NOTES: Two other deposits, SB and Sea, contain sulphide mineralization but have not been evaluated due to submarginal grades.

Effective Date January 1, 1986. During 1986, 1.8 million tonnes were mined from the Faro open pit.

3.3.3 **Drill Definition & Information Base**

The Grum deposit extends from section 52W in the southeast to section 112W in the northwest (figure ~~3.14~~). The deposit has been most densely drilled between 62W and 86W and it is this portion of the deposit for which proven geologic reserves are reported.

Fig drill map

Most of the deposit southeast of 88W has been drilled from the surface on at least a 61m X 30.5 m (200' X 100') pattern. Most surface holes are vertical.

Between sections 62W and 86W the deposit has also been explored by 15,000 m of underground drilling in fans from a pair of parallel inclines following the deposit trend. The strike length of the deposit examined from underground is 700 m, underground workings total 2900 m (the workings are now flooded). The fans are most complete on even numbered sections (ie: spaced 61 m apart); on odd numbered sections some fill in drilling has also been done from underground. The overall density of drilling is on the order of 15 m X 30 m with local areas being much in excess of that.

In the southeast part of the deposit additional fill in drilling was done by Cyprus Anvil in 1980-1982 from the surface to more closely define shallow ore for early production.

In 1987 and 1988 additional holes were drilled by Curragh to help resolve geometric problems to enhance reliability of the first years production from the proposed Grum pit. Samples from these holes were preserved for future metallurgical testing

Total drilling at Grum is 67,200 m of which 15,000 m is underground drilling and 52,200 m is surface drilling. Between 62W and 86W there is a total of 53,600 m of drilling in 372 drill holes (154 surface and 218 underground) of which 344 are used in the current model. The remainder not included in the model are underground holes that are at high angles to the geological sections and some short holes that did not intersect ore.

Without question Grum is the best drill defined deposit in the Anvil District.

There are 9000 samples in the Grum deposit assay database. Assay intervals generally average 1.5 m in length and are keyed as closely as possible to sulphide rock types. 90% of these were determined for Cyprus Anvil by Kamloops Research and Assay Labs between 1980 and 1983. For most of these samples Pb, Zn, Cu, and Ag assays are available. For 2/3 of these samples there is also insoluble Fe, soluble (in hot concentrated HCL) Fe, Au, and pulp SG. All assays were determined using a set of Anvil District ore type standards for control. Rejects and N_2 purged pulps (by now somewhat oxidized) have been retained for additional analytical work. There are no BaO or Mn assays available nor is there systematic data available for Hg, As, Cd or any other elements.

The remaining 10% of the assays are from Kerr Addison samples for which Pb, Zn and Ag only are available. Many of these samples are from the holes not used in the ore deposit model.

3.3.5.1 Geological Reserves

Table 3 Grum Geological Reserves

The geological reserves calculated for Grum are summarized in table 3.19 ~~for the two constituent models and for the entire deposit~~. Sectional reserves are summarized in table 3.20 for the entire deposit.

Southeast of section 62W the Champ zone is estimated to contain a additional 1.7 milliion tonnes averaging 3.5% Pb, 4.3% Zn and 46 g/t Ag. This figure is based on sectional calculation and quoted at a 4% Pb+Zn cutoff with no adjustment to reflect dilution. Northwest of 86W there may be an additional 5 to 10 million tonnes of deep mineralization not yet completely drilled off.

3.3.5.2 Model to Model Comparisons

Table 3.21. and 3.22 ~~A to D compare the newly calculated reserves (G8606 model) to~~ show the results of previous calculations on a whole deposit and sectional basis ~~respectively~~.

Unfortunately the calculations listed in table 3.21 are not exactly comparable. The first 3 (A-C) are all based on Kerr-Addisons geological interpretation. The Cyprus Anvil computer models differs in that some new assay data was used but the bulk of the data was the same as A and B.

The comparison shows that the total metal of all calculations is comparable. The oldest calculation, by Kerr Addison ~~is~~ gives a smaller tonnage but higher average grade. This is not suprising for a sectional calculation. Part of the tonnage difference is due to additional ore drilled off after 1977 when the calculation was done (2-3 million tonnes)

The last 2 (D & E on table 3.21) are based on the current geological interpretation and the current assay information which nearly completely replaces Kerr-Addisons data. These two calculations reflect some ore in the northwest part of the deposit that was drilled off in 1982, this amounts to about 3,000,000 tonnes largely of low grade material on sections 78W to 86W.

The early computer models did not use geologic control on interpolations which tends to average grade between disseminated and massive mineralization resulting in a larger tonnage of lower grade material than a comparable sectional calculation with sharp grade distinctions (compare A to B and C on table 3.21).

~~The current model has attempted to counter this averaging effect by restricting the choice of composites to the same rock type as the block being estimated. The result is a closer comparison in grade to the corresponding sectional calculation (compare D to E on table 3.21).~~ The current model however was not able to assign a grade to every block due to the stringent matching requirements and local paucity of assay information. Thus there 1023 uninterpolated blocks representing about 2,000,000 tonnes of sulphides distributed through the deposit. Only a portion of this is likely to be over 4% Pb + Zn in reality but for the purposes of the current model it is assigned a zero grade and included as sulphide waste. Much of this material (about 700,000 tonnes in 423 blocks) is in the lower part of section 86W partly accounting for the poor comparison to the hand calculation on that section (table 3.22D). The distribution of uninterpolated blocks by section in the two constituent models is given in table 3.23.

A further complication in comparing the current model to the hand calculated reserves obtained from the same geological interpretation is that two problems were encountered with the Cyprus Anvil/Dome calculation: a) there were some calculation errors involving volumes above cutoff and to a lesser extent tonnes on sections 78W to 86W and b) the SG used for sections 82W-86W was assumed to be 3.6 rather than the measured SG as used for the rest of the deposit, in retrospect this value was too high as much of the mineralization on those sections is considerably lighter. These points have been adjusted for in Table 3.22B. Table 3.22D shows the section by section variance between calculations. Between the Cyprus Anvil/Dome calculation and the current one the grade is almost always slightly down. In large part of this is probably due to the clipping of the extreme high end of the assay and composite population which was not done in the Cyprus Anvil/Dome calculation. The large variance in volume on sections 80W-86W is partly due to uninterpolated blocks but must be mainly due to differences in calculation method. The computer model interpolated grade into each block whereas the hand calculation averaged a large number of intersections to arrive at the grade for large panels of ore. In light of the relative paucity of drillhole information for some panels such large variances are not surprising. The interpolation method would be expected to give a more realistic picture of grade distribution.

A check on the volume of sulphides above 0% Pb+Zn grade shows that the volumes are essentially identical for the two calculations: 11,125,546 cu. m for the Cyprus Anvil/Dome versus 11,166,660 cu. m for the present model. The comparison for tonnage above cutoff for the two calculations with adjustment for a lower S.G. on sections 82W to 86W gives 37,415,941 tonnes for Cyprus Anvil/Dome versus 37,329,090 tonnes for the current model (the original Cyprus Anvil/Dome calculation using their S.G. gave 38,536,557 tonnes above 0%). Thus it is clear that the reserves only become inconsistent when a cutoff grade above 0% is used.

TABLE 3.20

GEOLOGICAL RESERVES BY CROSS SECTION FROM GB606 COMPUTER MODEL, 1986
~~TOTAL DEPOSIT~~, 4% Pb + Zn CUTOFF GRADE Sections 62W to 86W

SECTION	VOLUME (bcm)	SPECIFIC GRAVITY	TONNAGE (tonnes)	LEAD (%)	ZINC (%)	SILVER (g/t)	GOLD (g/t)	Pb+Zn (%)	TOTAL METAL (tonnes)
86 W	684,180	3.09	2,116,210	2.60	4.99	46.0	0.44	7.59	160,592
84 W	584,820	3.16	1,849,610	2.80	4.90	47.6	0.60	7.70	142,432
82 W	787,860	3.40	2,680,540	3.19	5.55	56.5	0.84	8.73	234,069
80 W	1,297,080	3.35	4,340,270	3.10	4.85	51.8	1.05	7.95	345,081
78 W	975,780	3.27	3,195,500	3.16	5.50	54.7	1.04	8.66	276,762
76 W	907,200	3.36	3,048,860	3.49	5.80	58.6	1.07	9.29	283,135
74 W	1,013,040	3.45	3,498,640	3.72	6.20	62.3	1.05	9.92	347,148
72 W	748,440	3.45	2,584,690	3.64	5.77	61.2	1.02	9.41	243,256
70 W	694,980	3.52	2,449,940	3.86	6.57	63.6	1.04	10.43	255,415
68 W	355,320	3.70	1,314,260	4.10	6.27	66.7	1.00	10.37	136,297
66 W	442,260	3.69	1,632,190	4.14	5.75	66.7	0.99	9.90	161,507
64 W	301,860	3.61	1,091,070	3.79	5.52	61.2	0.99	9.30	101,486
62 W	178,200	3.69	657,640	3.39	5.03	54.8	1.10	8.42	55,347
total	8,971,020	3.40	30,459,420	3.41	5.60	57.3	0.95	9.00	2,742,527

~~* The slight difference (0.1%) in tonnage between this figure and that on table 3.19 is due to a small amount of material outside the area limits set for the cross sections when computing these reserves.~~

TABLE 3.22 A

62W-86W

RESULTS OF KERR ADDISON SECTIONAL CALCULATION, 1977
~~TOTAL DEPOSIT~~ (both Vangorda Mines and AEX option) 4% Pb+Zn CUTOFF

SECTION	VOLUME (bcm)	SPECIFIC GRAVITY	TONNAGE (tonnes)	LEAD (%)	ZINC (%)	SILVER (g/t)	GOLD (g/t)	Pb+Zn (%)	TOTAL METAL (tonnes)
86 W	n/a	n/a	1,678,746	3.59	5.80	55.0	n/a	9.39	157,634
84 W	n/a	n/a	1,375,120	3.33	5.60	53.0	n/a	8.93	122,798
82 W	n/a	n/a	2,185,447	4.06	7.30	69.0	n/a	11.36	248,267
80 W	n/a	n/a	3,039,373	3.67	5.71	56.0	n/a	9.38	285,093
78 W	n/a	n/a	2,918,497	3.79	6.45	50.0	n/a	10.24	298,854
76 W	n/a	n/a	2,732,810	4.08	6.24	61.0	n/a	10.32	282,026
74 W	n/a	n/a	2,778,449	4.15	6.63	66.0	n/a	10.78	299,517
72 W	n/a	n/a	2,223,718	4.10	6.46	63.0	n/a	10.56	234,825
70 W	n/a	n/a	2,226,492	4.77	7.45	67.0	n/a	12.22	272,077
68 W	n/a	n/a	1,736,341	4.55	6.38	73.0	n/a	10.93	189,782
66 W	n/a	n/a	1,377,821	4.81	6.55	67.0	n/a	11.36	156,520
64 W	n/a	n/a	1,164,762	4.34	6.74	67.0	n/a	11.08	129,056
62 W	n/a	n/a	630,266	3.94	6.01	55.0	n/a	9.95	62,711
62W to 86W	n/a	n/a	26,067,842	4.07	6.43	61.50	n/a	10.51	2,739,161

TABLE 3.22 B

62W to 85W

RESULTS OF CYPRUS ANVIL/DOME SECTIONAL CALCULATION (SIMPSON-ADAMSON), 1983
~~TOTAL DEPOSIT~~, 4% Pb + Zn CUTOFF GRADE

SECTION	VOLUME (bcm)	SPECIFIC GRAVITY	TONNAGE (tonnes)	LEAD (%)	ZINC (%)	SILVER (g/t)	GOLD (g/t)	Pb+Zn (%)	TOTAL METAL (tonnes)
86 W	997,045 *	3.23	3,221,532	2.88	5.21	49.0	n/a	8.09	260,622
84 W	776,317 *	3.20	2,486,855	2.86	4.83	48.0	n/a	7.69	191,239
82 W #	989,573 *	3.29	3,256,446	3.00	5.10	52.0	n/a	8.10	263,772
80 W #	1,118,740	3.38	3,783,293	3.31	5.41	56.0	n/a	8.72	329,903
78 W #	994,148	3.11	3,093,642	3.37	5.96	59.0	n/a	9.33	288,637
76 W	886,940	3.39	3,006,734	3.61	6.06	62.0	n/a	9.67	290,751
74 W	934,978	3.46	3,237,299	3.66	5.97	61.0	n/a	9.63	311,752
72 W	659,715	3.62	2,389,111	3.80	6.11	65.0	n/a	9.91	236,761
70 W	656,848	3.69	2,425,119	4.06	6.62	68.0	n/a	10.68	259,003
68 W	386,618	3.73	1,440,349	4.54	6.88	73.0	n/a	11.42	164,488
66 W	446,215	3.62	1,613,702	4.41	5.95	71.0	n/a	10.36	167,180
64 W	282,918	3.64	1,028,545	3.84	5.75	62.0	n/a	9.59	98,637
62 W	170,190	3.72	632,340	3.32	5.66	63.0	n/a	8.98	56,784
62W to 86W	9,300,243	3.40	31,614,967	3.49	5.74	59.1	n/a	9.23	2,919,529

* An assumed value for S.G. of 3.6 was used on these sections.
This is too high and has been reduced by 10% for comparison purposes.

\# Volumes above cutoff have been recalculated due to an error
in the original calculation.