

## INTRODUCTION

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

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

## STRATIGRAPHY

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

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

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

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

similar to the fine-grained upper portion of the grit unit seen to the east (Gordey, 1980) and southeast (Gabrielse, 1974) with which it is presumed to correlate implying a late Proterozoic or lower Cambrian age. It should be emphasized that typical coarse, poorly sorted quartz and feldspar sandstones of the Grit Unit are not seen in the Mt. Mye formation.

The Vangorda formation is characterized by calcareous pelitic rocks made up of thinly interlayered, non-calcareous, weakly carbonaceous, muscovite chlorite phyllites and calcite + quartz metasilts. Major interbanded units include metabasite and meta-tuffs, graphitic phyllite, and phyllitic limestone.

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

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

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

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

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

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

## METAMORPHISM AND PLUTONISM

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

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

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

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

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

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

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

1971 PROGRAM

U. Jansons, D. Jennings

As in the case of the pit, the top direction for this section is arbitrarily defined and stratigraphic unit contacts are parallel to the main metamorphic foliation. Since the biotite-muscovite schist is exposed in the core of the Anvil Arch, it is considered the oldest stratigraphic unit on the grid.

The most plausible explanation for the graphitic schists and quartzites not being mappable units in the biotite-muscovite schist is their direct spatial and presumed genetic association with sulfides. In addition, exposure along the belt underlain by the schist unit is not particularly good.

Silicated marble horizons (2b) occur within the calc-silicate gneiss. These marbles may vary from moderately coarsely crystalline, white, essentially pure, carbonate rocks to finer grained, diopside-rich, light greenish gray calc-silicate bands. They vary in thickness from 50 to 150 feet and cannot be traced over distances greater than 1000 feet because of poor exposure.

The biotite-muscovite phyllite (unit 3a) cannot be subdivided on the Faro grid. Sporadic outcrops of an apparently more muscovite-rich phyllite are encountered which may occur as a unit in the phyllite elsewhere.

Fine grained, dark green amphibolites (10a) are the oldest intrusive rocks exposed on the grid. They show intrusive contacts with the enclosing calc-silicate gneisses and are the only intrusive rock type cut by the  $S_2$  foliation. On the basis of their outcrop pattern, these amphibolites are thought to be irregular gabbro plugs or dikes.

Rocks of the Anvil Batholith appear to be the next igneous suite to intrude the Eocambrian metamorphic section. The bulk of the batholithic rocks are coarsely crystalline biotite-quartz monzonites to biotite-granodiorites (11a) with large, characteristic, potassium feldspar megacrysts. The monzonitic and granodioritic rocks show a penetrative foliation defined by the preferred planar orientation of biotite flakes and long axes of the feldspar megacrysts. Within the plane of foliation, the long axes of these megacrysts are randomly oriented. This foliation in all likelihood is an igneous flow foliation since it bears no relation to any foliation in the country rocks. Leucocratic, unfoliated, medium crystalline, hornblende-biotite

Menzie Creek  
dykes

diorites (14c) occur as border phases of the batholith at two areas along its contact on the Faro grid (Figure 6). Their genetic relationship to the monzonitic phase of the batholith is unknown at present. Contact metamorphic effects attributable to the Anvil Batholith appear to be negligible, as there is minimal development of hornfels near its contact with the country rocks. Petrographic examination of contact zone rocks will shed further light on this matter.

Coarsely porphyritic, medium to dark green, hornblende diorite dikes (13a) cut the batholithic rocks at several places on the grid. These dikes follow a northeasterly trend and may be intruded along fracture sets produced by intrusion of the batholith. The diorite mass in the north end of the pit is the largest single body in this diorite clan. A narrow (up to 100 feet) zone of contact hornfelsing is developed in the pit rocks adjacent to it. Phase assemblages in the hornfels defining its grade (<sup>s</sup>) of metamorphism have not been worked out.

Intrusion of hornblende diorite in the country rocks around zone 3 produced extensive brecciation (Figure 6). Diorite, seen as the breccia matrix, appears to have exploded its superencumbent cap rocks as volatile pressures associated with the original diorite melt exceeded lithostatic pressures on the melt. Fragments in the breccia vary in size from 1/4 inch to approximately 10 feet on their long dimension. In general, there is very little diorite matrix in the breccia, which, as a result, has the appearance of randomly jumbled, welded blocks of rock. The limits of brecciation are difficult to define because of generally poor exposure. On the basis of surface exposures, brecciation occurs only between the center and north base lines and lines 24 W to 52 W (Figure 6). The age of brecciation is at least that of the D<sub>3</sub> deformation since fabric elements associated with that event are affected by brecciation. A more probable age is mid to late Cretaceous since quartz-monzonite of the Anvil Batholith gives potassium-argon ages of 90-95 m.y. and is cut by the diorites. Moderately large, angular blocks of banded, highly weathered, massive sulfides occur in the breccia near line 36 W between the center and north base lines. These sulfides represent the brecciated northeast extension of zone 3 and will be discussed in a later section.

hbl dykes

Another breccia is exposed near the intersection of line 8 W and the North Fork of Rose Creek. The preponderance of fragments in this breccia are calc-silicate gneiss averaging less than 2 feet along their maximum dimensions. Hornblende diorite, again the matrix of the breccia, shows moderate amounts of sphalerite and galena mineralization. A representative analysis of the breccia indicates the following metal values: (not available)

A relatively minor, medium grained, equigranular, dark pink monzonite intrudes the breccia. This phase seems to follow joint surfaces in the existing breccia and appears to be later than the main phase of brecciation. It is unmineralized. Source of the base metals in the diorite is possibly an eastern extension of the Number 2 zone intruded by the diorite. The presence of the calc-silicate gneiss fragments in the biotite-muscovite schist unit remains unexplained. An irregular, subsurface intrusive diorite body centered on line 16 W between the central and south base lines may be the parent of the diorite causing brecciation.

Intrusion of smokey quartz-feldspar porphyry (14b), minor muscovite granite (14a) and leucocratic, tourmaline-garnet monzonite dikes (11b) is the last recognizable intrusive event on the Faro grid. In the absence of definitive cross cutting relationships, intrusion of these granitic rocks is considered to be one event. Since the muscovite granite and monzonite dikes cut hornblende diorite dikes and the porphyry cuts a breccia most probably produced by diorite intrusion, these granitic rocks are considered to be younger than the diorite clan.

In summary, four intrusive rock sequences are recognized on the Faro grid. On the basis of cross cutting relationships, the amphibolites are the oldest recognizable intrusive unit since they are cut by the  $S_2$  foliation ( $D_2$  metamorphism is Ordovician according to Templeman-Kluit).<sup>2</sup> The next recognizable event is the intrusion of the Cretaceous Anvil Batholith. Hornblende diorites intrude the batholithic rocks and brecciate the Eocambrian metamorphic rocks near inferred centers of diorite intrusion. Late stage granitic and monzonitic dikes cut rocks of the diorite clan and breccia produced by it.

# ANVIL RANGE LITHOSTRATIGRAPHIC CODE

Eagle  
Prismacolor  
No.

938	11Q	BULL QUARTZ VEIN, POD				
932	11G	PYROXENITE AND SERPENTINIZED EQUIVALENTS				
937	11F	SMOKY QUARTZ - FELDSPAR PORPHYRY				
934	11E	PORPHYRITIC HB - BIO QUARTZ DIORITE				
956	11D	EQUIGRANULAR HB - BIO QUARTZ DIORITE				
939	11C	QUARTZ MONZONITE PEGMATITE DIKES				
929	11B	PORPHYRITIC, BIOTITE - QUARTZ MONZONITE				
928	11A	MUSCOVITE - BIOTITE GRANODIORITE				
942	10	UNDIFFERENTIATED POLYMICITIC CONGLOMERATE	Pelly Formation			
917	9H	GRAYWACKE, SHALE, MINOR CONGLOMERATE				
918	9G	THICKBEDDED SILTSTONE				
940	9F	FLYSCH FACIES GRAYWACKE AND SHALE				
914	9E	BASALTIC GRAYWACKES AND ARGILLACEOUS CHERTS				
909	9D	BASALT FLOWS				
968	9C	VARI-COLORED RIBBON CHERTS AND NON-CALCAREOUS PHYLLITE				
961	9B	INTERBEDDED CARBONACEOUS LIMESTONE AND GRAPHITIC PHYLLITE				
925	9A	RUSTY WEATHERING, FINE GRAINED, POLYMICITIC CONGLOMERATE				
907/950	8G	ECLOGITE				
907/931	8F	BASALT				
933	8E	HARZBURGITE				
965	8D	DIABASE				
907	8C	GABBRO				
924	8B	RODINGITE				
933	8A	SERPENTINITE				
931	7A	MASSIVE AND FRAGMENTAL BASALT FLOWS				
905	6I	CALC - SILICATE PHYLLITE / ARGILLITE				
912	6H	TUFF TO TUFFACEOUS CHERT	Rose Creek Formation			
930	6G	MAROON CHERT				
951	6F	VARI-COLOURED PHYLLITIC CHERT / QUARTZITE				
919	6E	MARBLE / PHYLLITIC MARBLE	Kalgoos Formation			
940	6D	BARITE - 2				
921	6C	CHERT GRANULE / PEBBLE CONGLOMERATE / QUARTZITE	Crystal Peak Formation			
942	6B	BARITE - 1				
962	6A	CARBONACEOUS TO GRAPHITIC, GREY SILICEOUS ARGILLITE / PHYLLITE	Pisswick Pond Formation			
962	5I	CARBONACEOUS TO GRAPHITIC, ARGILLITE / PHYLLITE				
911	5H	AMYGDALOIDAL CHLORITIC PHYLLITE				
949	5G	VARIABLY CALCAREOUS, GRAPHITIC PHYLLITE				
945	5F	CHLORITIC PHYLLITE				
904	5E	PHYLLITIC MARBLE AND SILICATED MARBLE				
910	5D	LAMINARLY BANDED, VARIABLY CALCAREOUS, CHLORITIC PHYLLITE				
908	5C	METABASITE				
920	5B	CALCAREOUS MUSCOVITE CHLORITE ± BIOTITE PHYLLITE				
936	5A	VARIABLY CALCAREOUS, GRAPHITIC PHYLLITE HOST TO UNIT 4				
923	4	GRUM, VANGORDA, DY, FIRTH, SWIM, SB, SEA SULPHIDE DEPOSITS UNDIFFERENTIATED				
916	3I	GRAPHITIC QUARTZITE IN NON-CALCAREOUS PHYLLITE / SCHIST				
913	3H	TUFFACEOUS CALC - SILICATE PHYLLITE / SCHIST (ASSOCIATED WITH 3D)				
941	3G	NON-CALCAREOUS, MUSCOVITE - CHLORITE ± BIOTITE PHYLLITE / SCHIST, UNDIFFERENTIATED				
906	3F	MARBLE AND SILICATED MARBLE				
963	3E	GRAPHITIC PHYLLITE / SCHIST				
913	3D	CALC - SILICATE PHYLLITE / SCHIST				
908	3C	METABASITE				
946	3B	CHLORITIC PHYLLITE / SCHIST				
912	3A	TRANSITION ZONE WITH UNIT 1				
923	2	FARO SULPHIDE DEPOSIT UNDIFFERENTIATED				
901	1G	MARBLE AND SILICATED MARBLE				
908	1F	METABASITE				
967	1E	GRAPHITIC SCHIST				
947	1D	CARBONACEOUS, BIOTITE - MUSCOVITE - ANDALUSITE SCHIST				
943	1C	QUARTZO - FELDSPATHIC, BIOTITE MUSCOVITE GNEISS / SCHIST				
902	1B	TACTITE AND SILICATED MARBLE				
943	1A	UNDIFFERENTIATED UNIT 1				
907/950	0G	ECLOGITE				
933	0F	SERPENTINIZED ULTRAMAFIC METABASITE				
908	0E	METABASITE				
966	0D	GRAPHITIC PHYLLITE / SCHIST				
948	0C	VARIABLY CALCAREOUS MUSCOVITE - CHLORITE ± BIOTITE PHYLLITE / SCHIST				
(	0B	VARIABLY CARBONACEOUS, CALCAREOUS QUARTZITES / GRITS				
915	0A	UNDIFFERENTIATED UNIT 0				

Intrusive Rocks  
 Pelly Formation  
 Vangorda Range Ultramafic Complex Arc Assemblage  
 Triassic Magmatic  
 Triassic Flysch  
 Assemblage  
 Vangorda Group  
 Earn Group  
 Kechika Group  
 Vangorda Formation  
 Mt Mye Formation  
 Faro Formation  
 Alan Group  
 Mt Pike Group  
 (Klondike Schist?)  
 (Englishman's Group?)

L U Cretaceous  
 M Triassic  
 U Triassic  
 U Pa  
 Permian  
 L  
 M Devonian  
 U Pa  
 Permian  
 M Devonian  
 M Devonian  
 M Cambrian  
 M Ordovician /  
 M Cambrian  
 Hadrynian?  
 Devano - Mississippian?