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Structure of the Vangorda Pb-Zn-Ag deposit, Anvil Range, Yukon Territory

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Abstract

The Vangorda Pb-Zn-Ag deposit is a small polydeformed, polymetamorphosed sedex-type massive sulphide deposit in the Anvil Mining District of the Selwyn Basin, Yukon Territory. The ore body consists of a number of banded, gently southwest-dipping lenses of sulphide lithofacies in the hinge and overturned limb of a southwest verging F_2 *fold. Banding in the sulphide lithofacies occurs on a scale of millimetres to centimetres interpreted to be* S_1*. The* S_1 *banding is folded by mesoscopic northwest- to southeast-plunging, tight to nearly isoclinal, class 2 similiar style* F_2 *folds. The deposit is cut by northwest- and northeast-dipping extensional faults with a final stage of strike-slip to oblique-slip movement.* F_2*-folded ductile shear zones occur in the sulphide lithofacies.*

Preliminary microstructural work indicates that pyrite in the Vangorda deposit deformed by both ductile and brittle mechanisms. Subsequent annealing textures are common.

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INTRODUCTION

The Vangorda Pb-Zn-Ag deposit is a small (6.9 million tons), sedex-type massive sulphide ore body in the Anvil Mining District of the Selwyn Basin, Yukon Territory (Fig. 1). The deposit is currently being developed as an open pit mine producing approximately 13 500 tonnes of ore per day. The ore body consists of several lenses of fine- to medium-grained pyrite-sphalerite-galena-barite-quartz within the Lower Paleozoic upper Mt. Mye phyllite of the Anvil District. The deposit is polydeformed and polymetamorphosed to mid-greenschist facies. During the 1990 and 1991 field seasons detailed mapping and drill core logging were undertaken to carry out a structural analysis of the Vangorda deposit. The aim of this research is to establish the 3D geometry of the deposit, to define the structural evolution of the orebody and host rocks, and to define the effects of deformation and metamorphism in the sulphides. This paper presents the preliminary results.

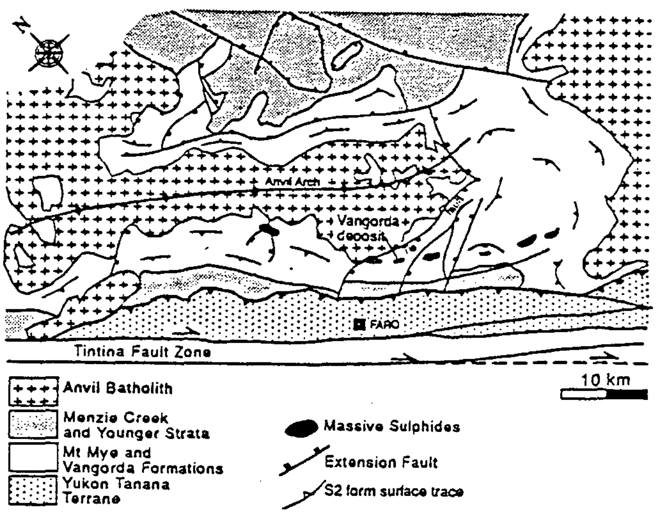

Figure 2. Schematic geological map of the Anvil District. Note the curvilinear distribution of the sulphide deposits. (Redrafted from Jennings and Jilson, 1986).

REGIONAL GEOLOGY

The Anvil Range lead-zinc-silver district is located within the Omineca Crystalline Belt of the northern Canadian Cordillera, approximately 200 km northeast of Whitehorse, Yukon (Fig. 1). The district lies immediately north of the Cretaceous-Tertiary Tintina fault, a major dextral strike-slip fault in the northern Cordillera (Fig. 2). Rocks in the Anvil District consist of a structurally thickened sequence of upper Proterozoic to lower Paleozoic polydeformed, polymetamorphosed, metasedimentary and metavolcanic schist and phyllite (Jennings and Jilson, 1986) interpreted as part of the ancient western North American margin. These rocks are intruded by Cretaceous granite (Pigage and Anderson, 1985) and granodiorite of the Anvil plutonic suite. The dominant structural feature in the district, the Anvil Arch, has a northwest-southeast structural grain outlined by foliation form-surface traces, and is related to uplift during intrusion of the Anvil plutonic suite. Late extensional faults such as the Tie fault (Fig. 2) are interpreted to be related to emplacement and unroofing of the Anvil Batholith (Jennings and Jilson, 1986).

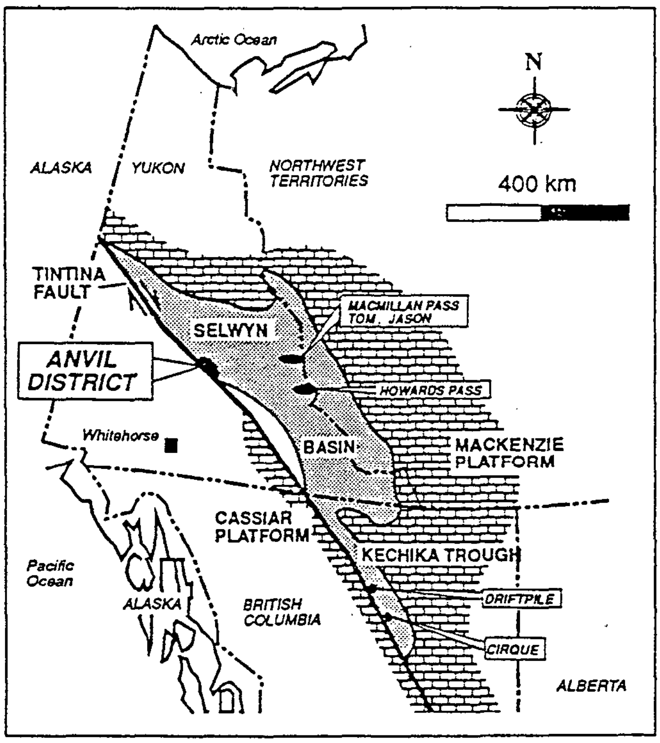

Figure 1. Generalized geological map showing the location of major mineral occurrences in the Selwyn Basin.

Five ductile deformation events have been recognized in the Anvil district (Jennings and Jilson, 1986). The first two are penetrative and form the dominant structural elements of the district. The first phase, D_1, is interpreted to be related to northeast-directed folding, thrusting, and nappe emplacement during the pre- to mid-Cretaceous docking of outboard terranes onto the ancient North American continent (Tempelman-Kluit, 1979; Mortensen and Jilson, 1985). D_1 resulted in the development of a penetrative regional foliation (S_1), and regional metamorphism reaching greenschist to amphibolite facies (Jennings and Jilson, 1986).

The second deformation event, D_2, is probably related to emplacement of the Anvil plutonic suite. D_2 resulted in southwest-directed folding, development of a penetrative foliation (S_2), greenschist to amphoblite facies contact metamorphism, and extensional faulting. The structural enviroment of D_2 is essentially that of a metamorphic core complex. The fold overprinting style between F_1 and F_2 is that of a type 3 hook structure (cf. Ramsay, 1967; Jennings and Jilson, 1986). D_3 to D_5 deformation events produced minor folds and steeply dipping crenulation foliations that overprint the D_1 and D_2 structural elements.

The Anvil district is host to five stratiform, massive sulphide deposits with an estimated geological reserve of 120 million tonnes (Jennings and Jilson, 1986) (Fig. 2). The five deposits lie along a northwest-southeast curvilinear trend, parallel to the regional structural grain of the district (Fig. 2). Ore rocks in the deposits are variably recrystallized metamorphic tectonites (Pigage, 1990) that display deformation textures that can be related to D_1 and D_2, and locally D_3 to D_5 (c.f. Jennings and Jilson, 1986).

LITHOSTRATIGRAPHY

The lithostratigraphy of the Anvil District consists of up to 5 km of polydeformed, late Precambrian to upper Paleozoic metasedimentry and metavolcanic rocks intruded by Cretaceous granites (Jennings and Jilson, 1986) (Fig. 3). Within it are two lithostratigraphic units important to this paper, the lower non-calcareous, carbonaceous Mt. Mye formation and the overlying calcareous, variably carbonaceous Vangorda formation. Near the Vangorda deposit these rocks are chlorite-muscovite phyllite that, in the case of the Vangorda formation, contain calcite and/or dolomite. The Anvil District deposits straddle the boundary between the Mt. Mye and the Vangorda formations, or occur up to 150 m below the stratigraphic contact between the two (Jennings and Jilson, 1986). Ore rocks in the Vangorda deposit are part of the synsedimentary, stratiform Anvil cycle (Fig. 3) as defined by Jennings et al. (1980) and Jennings and Jilson (1986). These authors envision the Anvil cycle to have formed from hot metalliferous brines discharged along a synsedimentary fault in a terraced fault system.

The Vangorda deposit occurs in the uppermost section of Mt. Mye phyllite directly below the Vangorda formation. The deposit appears to consist of lenses of varying thicknesses and bulk sulphide compositions and are typically accompanied by a footwall biased phyllitic, muscovite-chlorite alteration zone that grades into the ore lithofacies. The salient features of each ore lithofacies in the Vangorda deposit are outlined below.

Ribboned-banded, carbonaceous, pyritic quartzite: these are well banded, sulphide-bearing quartzite, with lesser sphalerite and galena. Bands are on a millimetre- to centimetre-scale and consist of quartz-sulphide and carbonaceous, phyllitic quartzite. Where F_2 folding occurs, S_1 is typically preserved in millimetre- to centimetre-scale lithons. Detailed mapping and drillcore logging shows that this lithofacies may occur alone or be absent from the previously defined Anvil cycle.

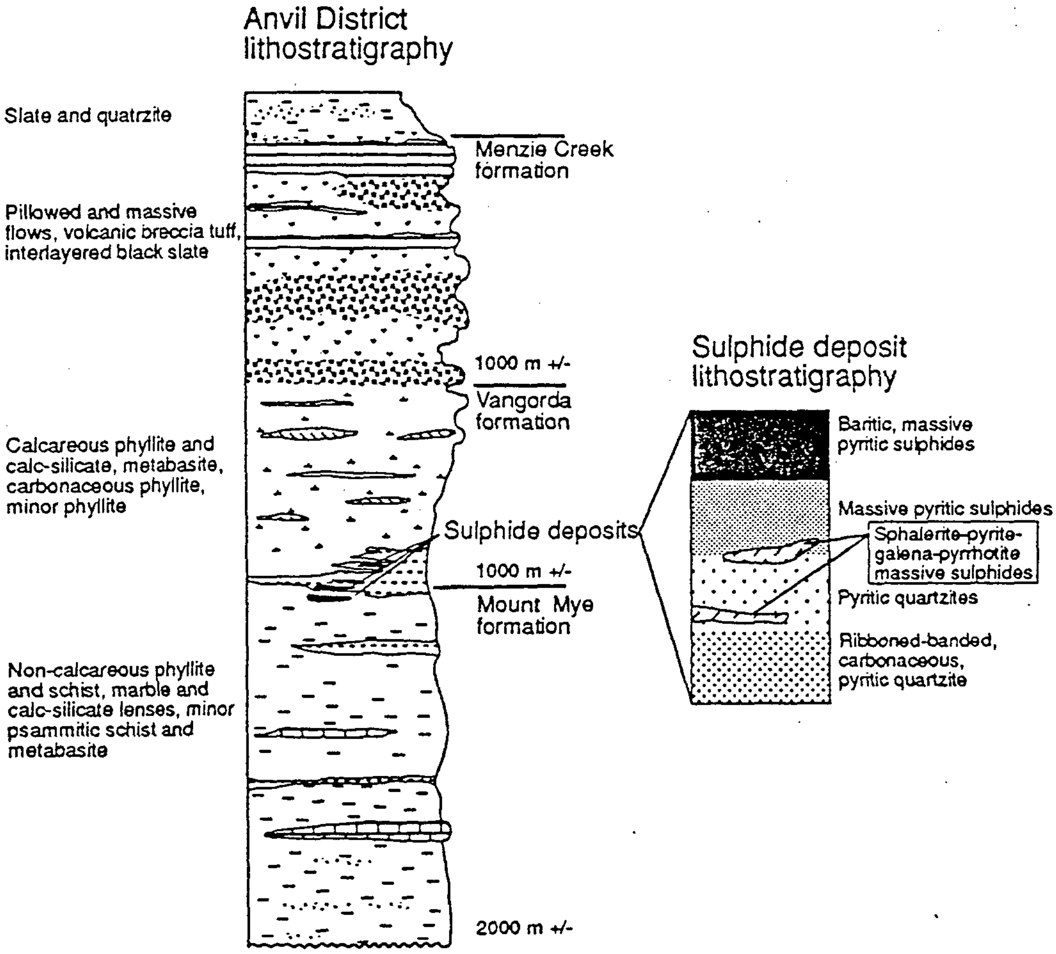

Figure 3. A schematic column of a portion of the Anvil District lithostratigraphy and the sulphide deposit lithostratigraphy. The sulphide deposits occur as lenses in the upper Mt. Mye formation, lower Vangorda formation. (Redrafted from Jennings and Jilson, 1986).

Pyritic quartzite: this consists predominantly of quartz with up to 40% pyrite and minor sphalerite and galena. These rocks are moderately to poorly banded with, locally, a well developed micaceous (muscovite) foliation. Sulphides are typically fine- to medium-grained (0.2 - 1 mm) , with local coarse-grained patches (1 - 2 mm). Galena, and less commonly sphalerite, may occur in coarse grained aggregates.

Massive pyritic sulphides: these are typically fine- to medium-grained (0.1 - 1 mm) massive pyrite with less sphalerite, galena, pyrrhotite, and minor magnetite. Quartz, barite, and carbonate are disseminated throughout or occur in aggregates. Total sulphide content ranges from 60% to 100%. Texturally the massive pyritic rocks are homogeneous to banded. Banding is developed on a scale of millimetres to centimetres as alternating thick bands of pyrite and thin bands of sphalerite + magnetite + galena. This lithofacies may be interbanded with the pyritic quartzites on a scale of centimentres to metres and commonly grades laterally into it. A foliation, defined by chlorite + carbon occurs locally.

Baritic, massive pyritic sulphides: these consist predominantly of barite with fine- to coarse-grained (0.1 - 2 mm) pyrite, sphalerite, galena, with minor magnetite. Quartz and carbonate are major matrix components. Clasts of pyrite and phyllite are common. Total barite content may be has high as 50%. Millimetre- to centimetre-scale interbanding of pyrite-rich and barite-rich layers is ubiquitous.

As well as the above lithofacies, whose distribution are believed to be relicts of primary depositional ore types, two lithofacies occur in areas of high strain and are interpreted as the result of metamorphic reactions and mobilization during deformation.

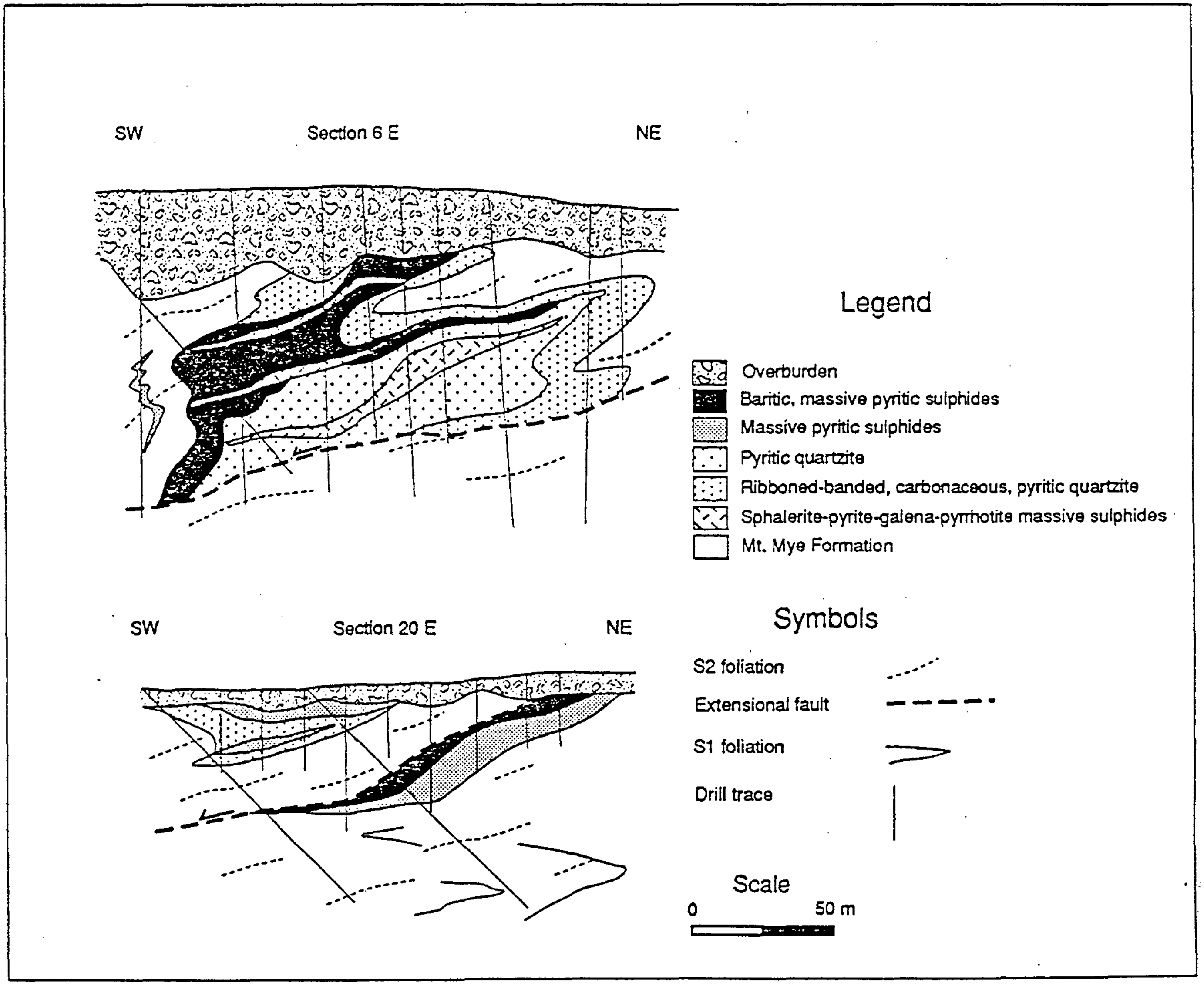

Figure 4. Cross-sections through the Vangorda deposit. Section 6 E contains the complete ore lithostratigraphy. Section 20 E consists of several lenses of sulphide lithofacies that are possibly separated by a fault. Sections were constructed using diamond drillhole data.

Pyrite-sphalerite-galena-pyrrhotite quartzite: this lithofacies is a variant of the pyritic quartzite in which the dominant sulphide is pyrite and sphalerite with lesser galena, and pyrrhotite. Grain sizes range from 0.01 to 2 mm and coarse (2 - 3 mm) patches of sphalerite or galena are common. Pyrite typically occurs as medium to coarse grained, submillimetre- to millimetre-sized porphyroblasts in an inhomogeneous, discontinuous foliation, or in isolated breccia clasts. These rocks are typically highly strained and commonly contain clasts of other rock types around which a well developed foliation anastomoses. Tailed clasts and rolling structures are common.

Pyrrhotitic massive sulphides: these contain predominantly fine-grained (0.05 -.1 mm) pyrrhotite with lesser pyrite, sphalerite, galena, and chalcopyrite. Pyrite is commonly porphyroblastic, reaching grain sizes of up to 1 mm. These rocks are typically highly strained and brecciated. Breccia clasts are rounded to angular, and generally have an internal foliation. Clasts may have symmetric or asymmetric tails and rolling structures are common.

THE VANGORDA DEPOSIT

The Vangorda deposit occurs 50 to 120 m beneath the carbonaceous base of the Vangorda formation. It consists of a number of gently northwest-plunging lenses and is elongated northwest-southeast. The deposit is interpreted to lie in the hinge and overturned limb of a macroscopic F_2 fold (Jennings and Jilson, 1986; Pigage, 1990). However, contrary to its structural position the overall lithostragraphy in this part of the deposit appears to consist of a single, right way up, idealized Anvil cycle (Fig. 4). An extensional fault of unknown offset truncates the orebody to the northwest, and in the southeast the deposit also appears to be truncated by extensional faulting. The deposit is cut approximately in half by a northwest-dipping extensional fault of unknown throw which juxtaposes two fault blocks of contrasting structural and lithostratigraphic styles. Northwest of this fault (Fig. 4, section 6 E) the deposit consists of a thick body of sulphide displaying one complete lithostratigraphic sequence, whereas southeast of the fault (Fig. 4, section 20 E) the orebody consists of thin lenses of individual lithofacies or group of lithofacies.

Regional D_2 metamorphic grade in the area decreases outward from the Anvil Batholith and metamorphism in the Vangorda deposit is thought to be due to contact metamorphism related to intrusion of the batholith (Jennings and Jilson, 1986). Metamorphic grade, recorded by muscovite-chlorite assemblages in wall rock phyllite, is sub- to mid-greenschist facies. The D_1 metamorphic grade regionally reached greenschist to amphibolite facies and in the orebody likely did not exceed greenschist facies.

Rocks in the Vangorda deposit are penetratively deformed by the D_1 and D_2 deformation events, making definition of any primary depositional features on a scale other than microscopic (see below) ambiguous at best. In most lithofacies in the deposit, banding is well developed on a scale of millimetres to centimetres. This banding is commonly folded by south- to southwest-verging folds presently accepted to be F_2 and is therefore taken to define S_1. Throughout the deposit, S_1 is commonly preserved as lithons in the hinges of F_2 folds in phyllite and the ribbon banded, carbonaceous quartzite. In sulphide-rich lithofacies S_1 is typically transposed into the F_2 axial surface. S_1 is used throughout this paper as the datum for determining the relative ages of the structural elements of the Vangorda deposit.

F_1 folds have not been identified in the Vangorda deposit previously because of penetrative overprinting by F_2 and because exposure was poor before mine development. This study identifies several examples of refolded folds in drill core and in pit wall exposures, indicating that F_1 folding may be important in the present geometry of the deposit. The widespread presence of S_1 in the ore lithofacies, and the evidence for F_1 folding in rocks near the deposit (eg., Jennings and Jilson, 1986) also point to the relative importance of F_1 folding.

The dominant fold phase in the Vangorda deposit is F_2. F_2 folds are typically east-west- to northwest-southeast-plunging, tight to near isoclinal (interlimb angle is commonly 5 - 25°) similiar folds. F_2 fold morphology changes as a result of relative competency and ductility contrasts between the different lithofacies, but the similar fold style is maintained. Where competency contrast is high, F_2 folds become somewhat disharmonic.

In the surrounding phyllite, a penetrative shallowly southwest-dipping, wavy D_2 axial planar cleavage (S_2) is developed. In some sulphide lithofacies, such as the ribboned-banded, carbonaceous quartzite, a differentiated axial planar S_2 cleavage is well developed. However, S_2 appears to be non-penetrative in the sulphides and is only rarely found in fold hinges. In general, the S_1 banding is transposed into the S_2 orientation, and is easily mistaken for S_2. In high strain zones, such as the overturned limbs of macroscopic folds, S_1 banding in the sulphide lithofacies is discontinuous as a result of shearing and a new, inhomogeneous S_2 foliation is developed.

There is little evidence for the relationship between F_1 and F_2 folds in the Vangorda deposit, but the rare occurrence of refolded folds indicates that the style of overprinting is the same as that recorded regionally, (i.e. type 3 of Ramsay, 1967) (cf. Jennings and Jilson, 1986, Fig. 21).

Locally, steeply south- to southwest-plunging to subvertical, open folds fold the S_2 cleavage and tighten F_2 folds. These folds are here termed F_3. F_3 folds are of minor importance and a local crenulation cleavage is associated with them.

The Vangorda deposit is strongly faulted by brittle extensional faults that, together with F_2 folding, provide the dominant control on the geometry of the orebody. Extensional faults examined truncate the S_2 cleavage and F_2 folds and postdate or are late D_2. Faults in the deposit are typically steeply northwest- to southeast-dipping gouge zones consisting of phyllosilicate and/or sulphide-quartz sand and/or breccia. Locally, these are cemented by a matrix of quartz and calcite and, in some instances, by pyrite. Breccias contain angular clasts of phyllite and sulphide ranging in size from several millimetres to several centimetres. Clasts are strongly broken and, in many cases, can be fitted back together. Pyrite slickensides on polished fault surfaces are typically subhorizontal or have a shallow pitch angle, indicating a late phase of stike-slip to oblique-slip movement. Faults have an offset of centimetres to several tens of metres. Paucity of marker horizons precludes measurement of exact offset on any fault.

Another type of fault common in the sulphide rocks is characterized by tectonic mixing of angular to rounded clasts of brecciated quartz, phyllite, and sulphide in a ductilely deformed, well foliated, and recrystallized pyrrothite-rich or sphalerite and galena-rich matrix (Fig. 5a). These faults range in size from several millimetres up to several tens of centimetres wide, generally with sharp boundaries. Clasts are tailed or rotated (5b), and internally folded, with the foliation flowing around them. Pyrite porphyroblasts are common in the matrix and in sulphide clasts. In several instances shear zones are folded by F_2 folds. These shear zones appear to be the extremely high strain end-member of a durchbewegung structure (see review by Marshall and Gilligan, 1989) and may represent discrete faults or zones of shearing. Thin breccias and ductile faults are common along boundaries between sulphide lithofacies indicating layer parallel shearing during deformation.

Several low-angle, post-D_2, northeast-directed thrusts occur within phyllite in the southeast end of the deposit. These cut the S_2 cleavage and have offsets ranging from centimetres up to several tens of metres.

MICROSTRUCTURE

Preliminary studies were carried out on several microstructural aspects of ore rocks from the Vangorda deposit. To date, deformation textures in pyrite have received the bulk of the attention. Selected polished sections were etched with warm, 30% nitric acid (HNO_3) to study growth features (e.g., grain boundaries and overgrowths), mineral phases, and deformation textures (e.g., dislocation structures).

Relict, primary colloform pyrite grains, although rare, occur in the massive pyrite and pyritic quartzite lithofacies within the Vangorda deposit. These are typically 0.05 - 0.5 mm-sized, equant to xenoblastic grains that occur alone or as cores with overgrowths of secondary, metamorphic pyrite.

Medium- to coarse-grained (0.25 - 2 mm), secondary, metamorphic pyrite, identifiable by its massive, typically inclusion-poor, equant to idioblastic nature, exhibits both brittle and ductile deformation textures. Zones of intense cataclasis have produced aggregates of angular comminuted grains. Within these zones a foliation, defined by micas and aligned quartz, anastomose around pyrite porphyroblasts. Indentation and axial cracking of large porphyroblasts is common (Fig. 5c).

One sample from the massive pyrite lithofacies shows an excellent example of grain shape preferred orientation of pyrite (Fig. 5d). These elongate grains typically show little or no evidence of brittle deformation, and only minor dislocation microstructure. Grain boundaries are straight to slightly curved, mildly sutured, and lightly indented. No overgrowths are apparent but pressure solution is the likely mechanism responsible for the preferred shape orientation.

Pyrite porphyroblasts commonly have overgrowths, either on relict colloform grains or on secondary metamorphic grains. In some cases numerous phases of grain growth can be recognized in one porphyroblast. These multiple phases of grain growth are evidence of a complex pyrite formation history.

Pyrite also shows annealing textures from metamorphism. In the massive pyritic lithofacies, grains are commonly submillimetre- to millimetre-sized, equant grains with straight to mildly sutured boundaries with 120° triple junctions. In quartz-rich areas and in the pyritic quartzite lithofacies, pyrite commonly forms larger (up to 3 mm locally), equant to idioblastic porphyroblasts.

Etched pyrite grains show dislocation microstructures which are characterized by straight to slightly curved, stepped, or branching dislocation walls and tangles.The dislocation walls and tangles commonly form grid-like arrays denoting the onset of polygonization and subgrain formation and incipient dynamic recrystallization (Fig. 5e).

Subgrain formation is common throughout the samples examined in this study. Subgrains are typically 5mm - 50mm, equant grains with straight to slightly curved grain boundaries that meet at 120° triple junctions. Subgrain formation commonly occurs along the boundaries of parent grains (Fig. 5f) resulting in a core-mantle texture.

Pyrite textures such as preferred grain shape orientation, subgrain formation, pressure solution, and dislocation structures indicate pyrite was deformed both by ductile and brittle mechanisms. Many ductile features outlined above have been studied experimentally (cf. Cox et al., 1981) and occur at temperatures of 500 to 650 °C and pressures of ~300 MPa.

CONCLUSIONS

This paper illustrates characteristics of the deformational style in the ore rocks of the Vangorda deposit. The dominant fabric element in the deposit is a penetratively developed banding and/or foliation, S_1, which can be used as a datum for determining the relative age of structural elements.

S_1 is folded by tight to near isoclinal, east-west-plunging F_2 folds with a class 2 similar geometry. In host rocks and some sulphide lithofacies, S_1 is preserved as lithons in the hinge zones of F_2folds, whereas in fold limbs S_1 has been transposed into the F_2 axial surface. S_2 is typically poorly, or not developed in massive pyritic rocks. The widespread occurrence of S_1 and the relative rarity of S_2 suggests that D_1 played an important role in the deformation and remobilization of the orebody and may be responsible for the

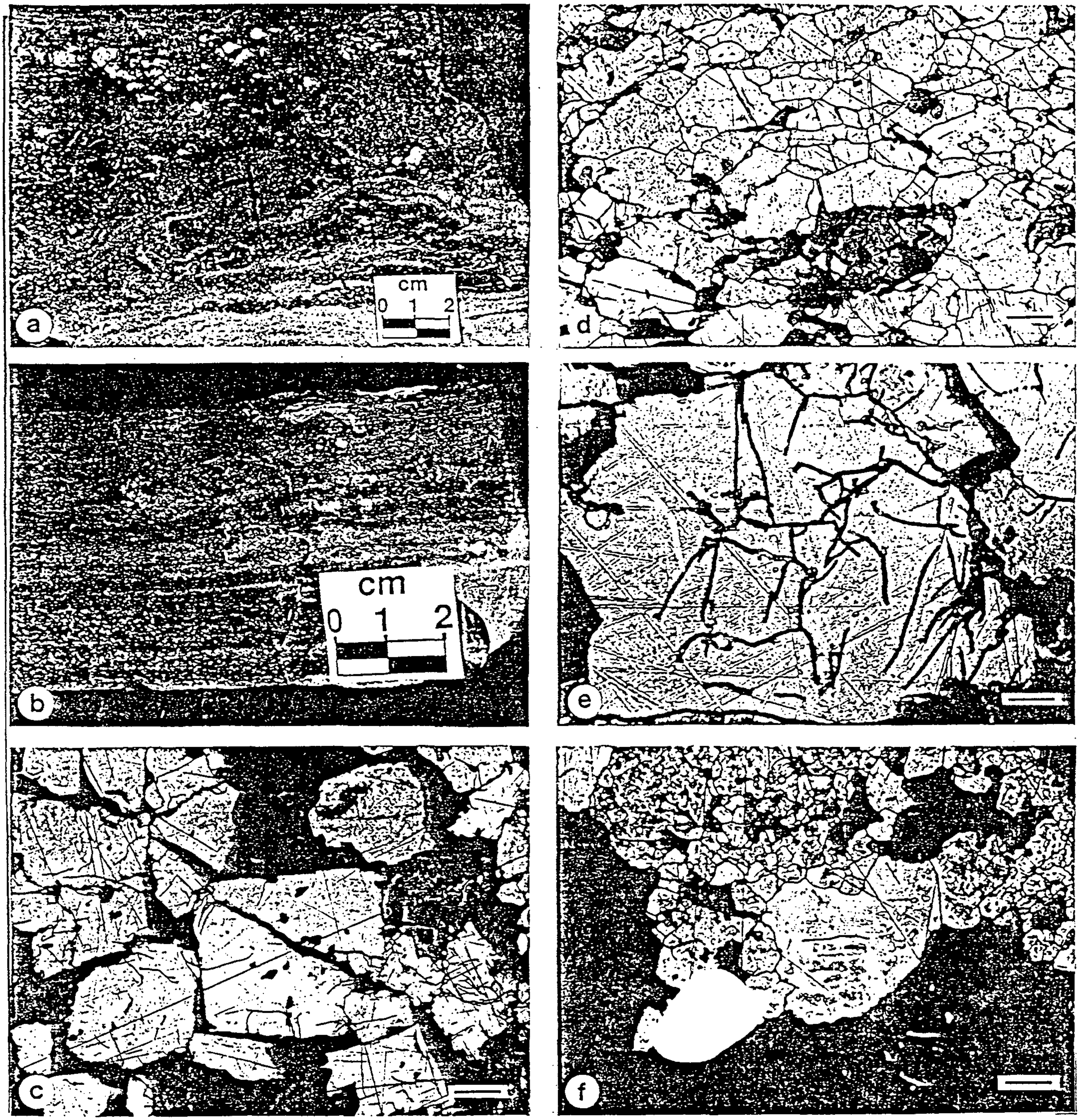

Figure 5(**a**) Ductile fault zone in massive sulphide. Matrix consists of sphalerite, pyrrhotite, and galena. (**b**) Sulphide mylonite with tailed, a-type porphyroclasts of quartz. (**c**) Pyrite porphyroblasts displaying indentation and marked axial cracking. Scale bar is 1.0 mm. (**d**) Preferred grain-shape orientation in pyrite. Grain boundaries are straight to moderately serate and meet at 120° triple junctions. Scale bar is 1.0 mm. (**e**) Dislocation walls and tangles marking the onset of polygonization in pyrite. Scale bar is 0.25 mm. (**f**) Grain boundary recrystallization and subgrain formation in pyrite. Scale bar is 0.5 mm.

bulk of deformation textures in the sulphides. Strong evidence for this is the occurence of F_2 folded sulphide shear zones. The D_1 distribution of sulphide lithofacies is tightly folded by F_2 folds.

The geometric relationship between F_1 and F_2 folds remains to be defined. The examples discussed above indicate that the refolding pattern is likely to be a type 3 (or hook structure), similiar to that recorded regionally.

Shear zones in the sulphides are complex and may result from D_1. Some appear to be geometrically related to F_2 folds.

Extensional faults in the Vangorda deposit appear to postdate or are late D_2 and clearly offset earlier D_2 features such as S_2 and F_2 folds. The amount of throw on these faults is generally not known. Determination of offset is further complicated by a late strike-slip to oblique-slip component of movement.

Pyrite in the Vangorda deposit ranges in grain size from 0.1 mm to 3 mm. Pyrite grains are deformed by ductile and brittle mechanisms. Ductile features include formation of dislocation walls and tangles, polygonization and subgrain formation. A preferred grain-shape orientation is developed locally. Annealing features such as grain-boundary bulging are common. Pyrite grains are also indented, cracked, and strongly disaggregated. Primary colloform pyrite still occurs locally.

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REFERENCES

Cox, S.F., Etheridge, M.A., and Hobbs, B.E.
1981: The experimental ductile deformation of polycrystalline and single crystal pyrite; Economic Geology, v. 76, p. 2105 - 2117.

Jennings, D.S. and Jilson, G.A.
1986: Geology and sulphide deposits of the Anvil Range, Yukon; in Mineral Deposits of Nothern Cordillera, (ed.) J.A. Morin; Canadian Institute of Mining and Metallurgy, Special Paper 37, p. 319-361.

Jennings, D.S., Jilson, G.A., and Pigage, L.C.
1980: Anvil Range stratigraphy, south-central Yukon Territory (abstract); Geological Association of Canada, Cordilleran Section, Programme and Abstracts, p. 16 - 17.

Marshall, B. and Gilligan, L.B.
1989: Durchbewegund structure, piercement cusps, and piercement veins in massive sulphide deposits: formation and interpretation; Economic Geology, v. 84, p. 2311-2319.

Mortensen, J.K. and Jilson, G.A.
1985: Evolution of the Yukon-Tanana terrane: evidence from southeastern Yukon Territory; Geology, v. 13, p. 806-810.

Pigage, L.C.
1990: Field guide Anvil Pb-Zn-Ag district, Yukon Territory, Canada; in Mineral Deposits of the Northern Canadian Cordillera, Yukon-Northeastern British Columbia; (ed.) J.G. Abbott and R.J.W. Turner; Geological Survey of Canada, Open File 2169, p. 283-308.

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

Ramsay, J.G.
1967: Folding and Fracturing of Rocks; New York, McGraw-Hill, 568 p.

Tempelman-Kluit, D.J.
1979: Transported cataclasite, ophiolite and granodiorite in Yukon Territory: evidence of arc-continent collision; Geological Survey of Canada, Paper 79-14.

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