

THE VANGORDA DEPOSIT

Dennis Brown and Ken McClay

*Department of Geology, Royal Holloway, University of London, Egham, Surrey, U.K.,
TW20 OEX*

NTS map sheet: 105 K/6

Coordinates:

Area: Anvil District

Access: Robert Campell Highway

MINFILE #:

Company: Curragh Inc.

Commodities: Zinc, Lead, (Silver, Gold)

INTRODUCTION

The Vangorda deposit is a small (7.1 million tonne), SEDEX-type, Pb-Zn-Ag (barite) massive sulphide ore body, in the Anvil district, Yukon, Canada (Figure 1). The deposit is currently being open pit mined at approximately 13,000 tonnes per day by Curragh Inc.. A project was begun at the start of mine development in 1990 in order to define the deformational style of the deposit and, by extrapolation, that of the other massive sulphide deposits in the Anvil District. In addition, the detailed understanding of the structural controls on the orebody are beneficial during development stages, for grade control, and for short-term planning during mining. The sulphide textures that result from deformation, metamorphism, and remobilisation are important metallurgical factors that have significant effects on the milling properties of sulphide ores.

REGIONAL GEOLOGY

The Anvil District (Figure 2) is part of the Omineca Crystalline Belt of the western Canadian Cordillera (Monger et al. 1982). The district is structurally overlain by the allochthonous Yukon-Tanana terrane (Coney et al. 1980) and is adjacent to a major orogen-scale dextral strike-slip fault, the Tintina Fault. Rocks in the Anvil District consist of late Precambrian to upper Paleozoic metasedimentary and metavolcanic rocks that are correlated with Selwyn Basin stratigraphy (Jennings and Jilson 1986) which formed part of the ancient North American miogeocline until the Early Cretaceous. These rocks have been intruded by mid-Cretaceous granitoid rocks of the Anvil Plutonic Suite (Pigage and Anderson 1985; Jennings and Jilson 1986).

Five deformation events have been recognised in the Anvil District, the first two of which (D_1 and D_2) are regionally significant (Jennings and Jilson 1986). D_1 is interpreted to be related to the pre- to mid-Cretaceous docking of the allochthonous Yukon-Tanana terrane onto the continental margin (Tempelman-Kluit 1979) causing inversion of the rift basin, northeast-directed nappe emplacement, folding, thrusting and metamorphism of the continental margin sediments. D_1 deformation resulted in the development of northeast-verging F_1 folds and a penetrative regional foliation (S_1), and regional metamorphism. D_2 deformation is related to emplacement, uplift, and unroofing of the Anvil Batholith (Jennings and Jilson 1986). D_2 resulted in southwest-directed folding, development of a wavy, shallowly southwest-dipping, penetrative foliation (S_2), and greenschist to amphibolite facies metamorphism (Jennings and Jilson 1986; Smith and Erdmer 1989). F_2 folds are nearly coaxial with F_1 and, where seen, the interference pattern is typically type 3 (Ramsay, 1967; see Jennings and Jilson 1986, figure 21). Northwest-southeast - dipping, brittle to ductile extensional faulting, related to unroofing of the Anvil Batholith, is late- to post- D_2 folding (Pigage and Jilson 1985; Brown and McClay 1992). However, many faults in the district have subhorizontal to shallowly-plunging slickensides indicating at least a late phase of strike-slip movement (Brown and

McClay, 1992, in press). The D₃ to D₅ deformation events produced minor folding and steeply dipping crenulation foliations that locally overprint the D₁ and D₂ structural elements.

The lithostratigraphy of the Anvil District consists of up to 5 km of polydeformed metasedimentary and metavolcanic rocks that have been intruded by Cretaceous granites (Figure 3). The massive sulphide deposits are hosted by, or straddle the boundary between two lithostratigraphic units of importance to this paper, the Mt. Mye formation and the overlying Vangorda formation. The Mount Mye formation consists of noncalcareous schists and phyllites and has an apparent structural thickness of at least 2 km, though its base is not exposed. The Vangorda formation consists of calcareous schists and phyllites and varies from between 0.5 to 2 km in structural thickness.

The Anvil mining district, is the largest Pb-Zn play in northern Canada with estimated geological reserves before mining of 120 million tonnes with a combined Pb + Zn grade of 9.3% (Jennings and Jilson 1986). The district contains five SEDEX-type Pb-Zn-Ag (barite) deposits (Carne and Cathro 1981) of economic significance that lie along a curvilinear trend on the southwest flank of the Anvil Batholith (Figure 2). The deposits are interpreted to have formed in second and third order extensional rift basins (Jennings and Jilson 1986; Shanks et al. 1987), similar to those described elsewhere in Sewlyn Basin and Kechika Trough by McClay (1991) and MacIntyre (1992). The massive sulphide deposits are variably affected by the deformation events, with D₁ and D₂ being dominant (Jennings and Jilson 1986). The Faro deposit is deformed by D₁ through to and D₄ and metamorphosed to amphibolite facies. Grum, Vangorda, and Dy are mostly affected by D₁ and D₂, with only minor F₃ crenulation folding, and reach greenschist facies metamorphism.

THE VANGORDA DEPOSIT

Lithostratigraphy

The Vangorda deposit is hosted by the Mount Mye formation which consists of greenschist facies, light to medium grey noncalcareous, weakly carbonaceous, muscovite-chlorite phyllite with lesser, interlayered, carbonaceous phyllite, calcareous phyllite, and metabasite. The overlying Vangorda formation, which is exposed in the northwest end of the open pit, consists of light to medium grey, calcareous, weakly carbonaceous muscovite-chlorite phyllite and light grey, calcareous quartz-calcite (\pm dolomite) phyllite with interbanded metabasite, carbonaceous phyllite, and phyllitic limestone.

Ore lithofacies

The Vangorda deposit consists of a number of stacked sulphide lenses of varying thickness and bulk sulphide composition. Ore lithofacies are interbanded on a scale of centimetres to metres and commonly display a complete gradation from one to another. These are accompanied by, and interbanded with, Mount Mye formation phyllites. A footwall biased muscovite alteration zone is also developed but is not continuous.

Ribboned-banded, carbonaceous, pyritic quartzite: these are well banded, fine grained, carbonaceous, phyllitic to siliceous quartzite and interbanded, sulphide-bearing (pyrite, sphalerite, and galena) coarsely crystalline quartzite. Banding ranges from 0.2 mm to 2.0 mm in thickness and typically contains 10% to 30% sulphides. This lithofacies is typically low grade ore.

Pyritic quartzite: consists predominantly of quartz with up to 40% pyrite with subordinate

sphalerite and galena. These rocks are moderately to poorly banded with, locally, a well developed micaceous (muscovite-chlorite) foliation. Chalcopyrite \pm pyrrhotite infills subvertical fractures. The pyritic quartzite is commonly gangue but may locally attain ore grades.

Massive pyritic sulphides: these are typically massive pyrite with subordinate sphalerite, galena, pyrrhotite, and minor magnetite and chalcopyrite. Quartz, barite, and carbonates are disseminated throughout or occur in aggregates. Total sulphide content varies from between 60% to nearly 100%. Banding is developed on a scale of centimetres to metres as alternating massive pyrite and of pyritic quartzite, often grading from one to the other. A muscovite-chlorite foliation is common. The massive pyrite lithofacies is gangue.

Baritic, massive pyritic sulphides: these consist of up to 50 % barite with pyrite, sphalerite, galena, together with minor pyrrhotite and magnetite. Quartz and carbonate are major gangue components. Clasts of pyrite and phyllite are common within the banded sulphide. Total barite content varies but may be as high as 50 %. Millimetre- to centimetre-scale interbanding of pyrite-rich and barite-rich layers is ubiquitous. Massive barite has not been observed. There is a complete gradation between the baritic massive sulphide ores and the massive pyritic ore. This lithofacies is the major ore type in the Vangorda deposit.

Pyrrhotite-sphalerite-pyrite-magnetite-galena (breccia): this lithofacies consists predominantly of pyrrhotite and sphalerite with subordinate pyrite, magnetite, and galena. This lithofacies is typically highly strained with a well developed foliation in both the sulphides and the micaceous sulphides. These rocks often contain breccia clasts of other rock types around which the foliation anastomoses. Tailed porphyroblasts, winged inclusions, foliation boudins, and rolling structures are common. This lithofacies, though relatively minor, is typically high grade ore.

Metamorphism

Both the regional D₁ and D₂ deformation events were accompanied by metamorphism in the Vangorda deposit. D₁ metamorphic mineral assemblages found in lithons in phyllites (see below) in the Vangorda deposit consist of chlorite + muscovite with, locally, biotite.-chlorite intergrowths. These assemblages broadly indicate that the D₁ metamorphic grade was low to mid-greenschist facies. D₂ regional metamorphic grade in the Anvil District decreases outward from the Anvil Batholith in a Buchan-type facies series (Jennings and Jilson 1986; Smith and Erdmer 1989). In the Vangorda deposit, D₂ silicate assemblages in phyllites consist of transposed and recrystallised muscovite and chlorite, suggesting there may not have been any significant new mineral growth during the D₂ event. The D₂ metamorphic grade is also interpreted to be lower greenschist facies.

Structure

All sulphide lithofacies and phyllites in the Vangorda deposit have been penetratively deformed by the D₁ and D₂ deformation events, making definition of any primary depositional features difficult on a scale other than microscopic (c.f. Brown and McClay 1992, in press). However, the Anvil District macro-scale sulphide lithostratigraphic sequence defined by Jennings and Jilson (1986) may be a relic primary feature. The hangingwall and footwall, phyllite and sulphide lithofacies contacts are locally faulted, but are generally gradational.

The Vangorda deposit has an overall elongate shape in a northwest-southeast orientation and plunges shallowly northwest, parallel to the regional F₂ fold axes. The orebody is approximately 900 m long by 200 m wide and varies in thickness from 20 m to 60 m. It consists of a number of complexly folded and faulted lenses of massive and disseminated sulphides and baritic massive sulphides in quartzitic and graphitic phyllites. In cross section the deposit is folded by a series of southwest-verging, northwest-plunging, tight, symmetric to

slightly asymmetric F_2 folds (Figure 4). These folds have a wavelength of 50 m to 75 m. The cross section shows a thickening and concentration of baritic massive sulphides in SW-verging synformal-antiform hinge zone of a fold. Relatively thin pyrrhotite, sphalerite, pyrite, and galena-rich zones occur along the limbs of the folds and in the baritic rocks in the hinge, parallel to the F_2 axial surface.

F_1 folds are rarely observed in the Vangorda deposit, possibly as a result of the penetrative overprinting by the F_2 folding. Lithons in the phyllites and the ribbon-banded, carbonaceous quartzite are interpreted to contain a S_1 foliation (Figure 5a). Banding in the sulphide lithofacies is locally at a moderate to high angle to the phyllite contacts and is generally pervasively folded by F_2 folds, suggesting that it is also S_1 .

The dominant fold phase in the Vangorda deposit is F_2 . F_2 folds are typically east-west- to northwest-southeast-plunging, tight to isoclinal (interlimb angle is commonly between 5° to 25°) similar style folds (Figure 5b). Within the different sulphide lithofacies the F_2 fold morphology is variable, but, in general, a similar style is maintained.

In the surrounding phyllites there is a penetrative, wavy, predominantly southwest-dipping F_2 axial planar crenulation foliation (S_2). S_2 is defined by transposed chlorite/muscovite porphyroblasts and remobilised carbon. In the ribboned-banded, carbonaceous quartzite, a differentiated axial planar S_2 foliation is also well developed. However, S_2 in other sulphide lithofacies is found only rarely in fold hinges and high strain zones. In high strain zones, shearing has disrupted the S_1 banding and a new, inhomogeneous foliation is developed, parallel to the F_2 axial surface.

Steeply south- to southwest-plunging to subvertical, open F_3 folds refold the S_2 foliation and tighten F_2 folds. There is only a minor crenulation foliation associated with the F_3 folding.

Within the ore lithofacies rocks there are zones characterised by well foliated pyrrhotite + sphalerite + magnetite \pm galena and pyrite with angular to rounded inclusions of brecciated quartz, phyllite, and sulphides. These zones display textures such as winged inclusions (Hanmer and Passchier 1991), tailed and rotated clasts, foliation boudins, and brecciation (Figure 5). These structures indicate very high strains and are interpreted to be the product of shearing within sulphide shear zones. The shear zones occur along the limbs of F_2 folds, and range in width from several millimetres up to several metres thick and clearly show an increase in pyrrhotite. A similar increase in pyrrhotite content in high strain zones was also noted in the Ducktown deposit of Tennessee by Brooker et al. (1987)

The present down-plunge extent of the ore body is controlled by faulting. All faults examined in open pit exposures truncate the S_2 foliation and the F_2 folds and the sulphide shear zones, and therefore clearly post-date or are late D_2 folding. The deposit is truncated in the northwest by the steeply southeast-dipping Northwest fault, and in the southeast by the moderately to steeply south-dipping Sump fault (Figure 6). The deposit is cut in half by the steeply to moderately north-northwest-dipping Cross fault. Smaller faults, with offsets up to 5 m, commonly form graben and half-graben structures. Slickensides on these fault surfaces are steeply-plunging indicating a final phase of extensional movement.

However, there are also subhorizontal to shallowly plunging slickensides on many fault surfaces, thus indicating a late stage of strike-slip to oblique-slip movement (Figure 6). In the northern end of the deposit the Creek fault offsets the Northwest fault by approximately 50 metres. Sets of variably oriented slickensides attest to a complicated kinematic history for many of these faults, and a strike-slip reactivation of previously formed extensional faults is possible. In open pit exposures there is clear evidence of strike-slip faults cutting extensional fault structures. In the northern end of the open pit, minor NE-directed thrusting appears related to the strike-slip faulting. Thrusting may be the result of a transpressional component

to the strike-slip movement.

At the southern end of the deposit, in the hangingwall of the Sump fault, low-angle, post-D₂, northeast-directed thrusts occur within phyllites, cutting the S₂ foliation. Displacement along these thrust may be up to 10 m.

DISCUSSION

This paper illustrates the macroscopic deformational style of the Vangorda deposit. The deposit is deformed by four significant and one minor phase of deformation. The first two phases, D₁ and D₂, resulted in ductile and brittle deformation (i.e. folding and development of sulphide shear zones, fracturing), metamorphism, and remobilisation. These were followed by brittle extensional faulting and brittle strike-slip faulting, respectively. Minor F₃ folding has also been observed but its relationship with post D₂ faulting is unclear.

Though there is a very good correlation in macroscopic structural style between the host phyllites and the sulphides, the Vangorda deposit has mesoscale textures that reflect extensive shearing of the orebody, especially in the baritic and pyrrhotitic massive sulphides. There are abundant shear indicators such as tailed and winged clasts and inclusions and pressure solution fabrics in these lithofacies. These, together with other common features such as piercement veins, rootless folds, limb thinning and hinge zone thickening of folds, point to extensive mechanical mobilisation of the sulphide in the Vangorda deposit. The location of the pyrrhotitic (breccia) in the large-scale folds indicate significant shearing along the limbs. These shear zones may provide a mechanism by which large-scale mobilisation occurs in massive sulphide deposits.

Faults in the Vangorda deposit clearly offset F₂ and S₂ and therefore post-date or are late D₂. Major faults (i.e. Northwest fault, Cross fault, and Sump fault) dip steeply towards the

northwest or southeast and have moderate to steeply-plunging slickensides. Slickensides indicate a final oblique- to dip-slip component of movement. The lack of marker horizons make it difficult to impossible to determine the exact amount of offset on many faults or to determine their kinematic history. A post-extensional phase of strike-slip faulting strikes NE-SW and N-S. The Creek fault offsets the Northwest fault sinistrally approximately 50 metres. It is not clear if strike-slip faults are reactivated extensional faults.

The tight to isoclinal, similar fold style and complex internal deformation indicates that the Vangorda deposit has undergone significantly high strains. Strain partitioning has produced breccia zones and shear zones in part controlled by the sulphide and matrix rheologies. Shear zones in particular are localised in the baritic massive sulphide facies or along lithofacies boundaries, commonly along the limbs of the large F_2 fold structure.

An understanding of the location, orientation, and expression of structures and structural elements within a deformed and metamorphosed deposit are of interest to the mine geologists and engineers in the day to day operations of the mine. For instance, the orientation and location of features such as faults, joints, and various foliations provide important information that can be used to help predict and assess pit wall stability, potential problems with water, location of road access to the active mining area, and to predict loading pattern and charge of blasts. Likewise, an enhanced understanding of the location and orientation of folds and faults, and which are major and which minor, are of importance in grade control during mining. By paying careful attention to these factors dilution of the ore can be significantly reduced and mine development factors can be more efficiently assessed and the costs of mine operations reduced. These and other aspects of a structural analysis of a developing mine are beyond the scope of this paper but point to the importance of continuous and detailed mapping during mine operation.

ACKNOWLEDGEMENTS

Fieldwork for this project was jointly supported by DIAND (Geology Section, Whitehorse) and by Curragh Inc. Successful completion of fieldwork could not have been achieved without the help of the people at the Faro minesite, especially those in the Geology and Engineering departments. The G.S.C. (Vancouver) is thanked for field support during the 1991 field season. The Industry Association, Royal Holloway College, is thanked for logistical support during the 1991/92 field seasons. Brown is funded in part by the Rothemere Foundation (University of London) and by a Newfoundland Provincial Government "Special scholarship for studies in the sciences related to resource development" issued through Memorial University of Newfoundland.

REFERENCES

- Brooker, D.D., Craig, J.R., Rimstidt. (1987) Ore metamorphism and pyrite porphyroblast development at the Cherokee mine, Ducktown, Tennessee. *Econ. Geol.* 82, p. 72-86
- Brown, D., McClay, K. (1992) Structure of the Vangorda Pb-Zn-Ag deposit, Anvil Range, Yukon Territory. *In* Current Research, Part A; Geol. Surv. of Can., Paper 92-1A, p. 121-128
- Brown, D., McClay, K. (in press) Deformation textures in pyrite from the Vangorda Pb-Zn-Ag deposit, Yukon, Canada. *Mineralogical Magazine*.
- Coney, P.J., Jones, D.L., Monger, J.W.H. (1980) Cordilleran suspect terranes. *Nature*. 288, p. 329-333
- Hanmer, S; Passchier, C. (1991) Shear sense indicators: a review. Geological Survey of Canada, Paper 90-17, 72 p.
- Jennings, D.S., Jilson, G.A. (1986) Geology and sulphide deposits of the Anvil Range, Yukon. *In* Mineral Deposits of Northern Cordillera (J.A. Morin, ed.). Canadian Institute of Mining and Metallurgy, Special Paper 37, p. 319-361
- Jennings, D.S., Jilson, G.A., Pigage, L.C. (1980) Anvil Range stratigraphy, south-central Yukon Territory (abstract). Geological Association of Canada, Cordilleran Section, Programme and Abstracts, p. 16-17

MacIntyre, D.G. (1992) Geological setting and genesis of sedimentary exhalative barite and barite-sulphide deposits, Gataga District, Northeastern British Columbia. *Exploration and Mining Geology*. 1, p. 1-20

McClay, K.R. (1991) Deformation of stratiform Zn-Pb (-barite) deposits in the northern Canadian Cordillera. *Ore Geology Reviews*, 6, p. 435-462

Monger, J.W.H., Price, R.A., Tempelman-Kluit, D.J. (1982) Tectonic accretion and the origin of the two major metamorphic and plutonic belts in the Canadian Cordillera. *Geology*. 10, p. 70-75.

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* (J.G. Abbott & R.J.W. Turner, eds.), Geological Survey of Canada, Open File 2169, p. 283-308

Pigage, L.C., Jilson, G.A. (1985) Major extensional faults, Anvil Pb-Zn district, Yukon (abstract). Geological Society of America, Cordilleran Section Annual Meeting, Abstracts with Programmes, 17, p. 400

Pigage, L.C., Anderson, R.G. (1985) The Anvil Plutonic suite, Faro, Yukon Territory. *Canadian Journal of Earth Sciences*, 22, p. 1204-1216

Ramsay, J.G. (1967) *Folding and Fracturing of Rocks*. New York, McGraw-Hill, 567 p.

Shanks, W.C. III, Woodruff, L.G., Jilson, G.A., Jennings, D.S., Modene, J.S., Ryan, B.D.. (1987) Sulphur and lead isotope studies of stratiform Zn-Pb-Ag deposits,

Anvil Range Yukon: Basinal brine exhalation and anoxic bottom-water mixing. *Economic Geology*, 82, p. 600-634.

Smith, J.M., Erdmer, P (1989) The Anvil aureole, an atypical mid-Cretaceous culmination in the northern Canadian Cordillera. *Canadian Journal of Earth Sciences*, 27, p. 344-356

Tempelman-Kluit, D.J. (1979) Transported cataclasite, ophiolite and granodiorite in Yukon Territory. *Geological Survey of Canada, Paper 79-14*, 27 p.

FIGURE CAPTIONS

Figure 1. Generalised map of the Selwyn Basin and Kechika Trough showing the location of the Anvil District.

Figure 2. Geological map of the Anvil District. The Vangorda deposit is located in the hangingwall of the Tie Fault, in greenschist facies rocks. Deposits to the northwest are Faro and Grum, respectively. The large deposit immediately southeast of Vangorda is Dy.

Figure 3. Lithostratigraphic column of the Anvil District with the generalised ore lithostratigraphic sequence of the Vangorda deposit (modified from Jennings and Jilson, 1986).

Figure 4. Detail of cross section 6 through the Vangorda deposit. The baritic lithofacies shows extensive mobilisation into the hinge zone of the F_2 structure. The major structure containing the ore deposit is a southwest-facing synformal-antiform. High strain zones denoted by the pyrrhotite-sphalerite-pyrite-galena lithofacies occur along the fold limbs and in the hinge zone.

Figure 5.(a) Lithon texture defined by S_1 and S_2 in Mt. Mye formation phyllites. Coin provides scale. (b) F_2 fold folding S_1 banding in ribbon-banded, carbonaceous quartzite. Hammer in bottom left corner provides scale (c) Winged quartz inclusion in massive pyritic sulphides. Arrows indicate a sinistral sense of shear (note, however, that this sample is not *in situ*.)

Figure 6. Generalised status map of the Vangorda open pit showing the locations of the major faults.

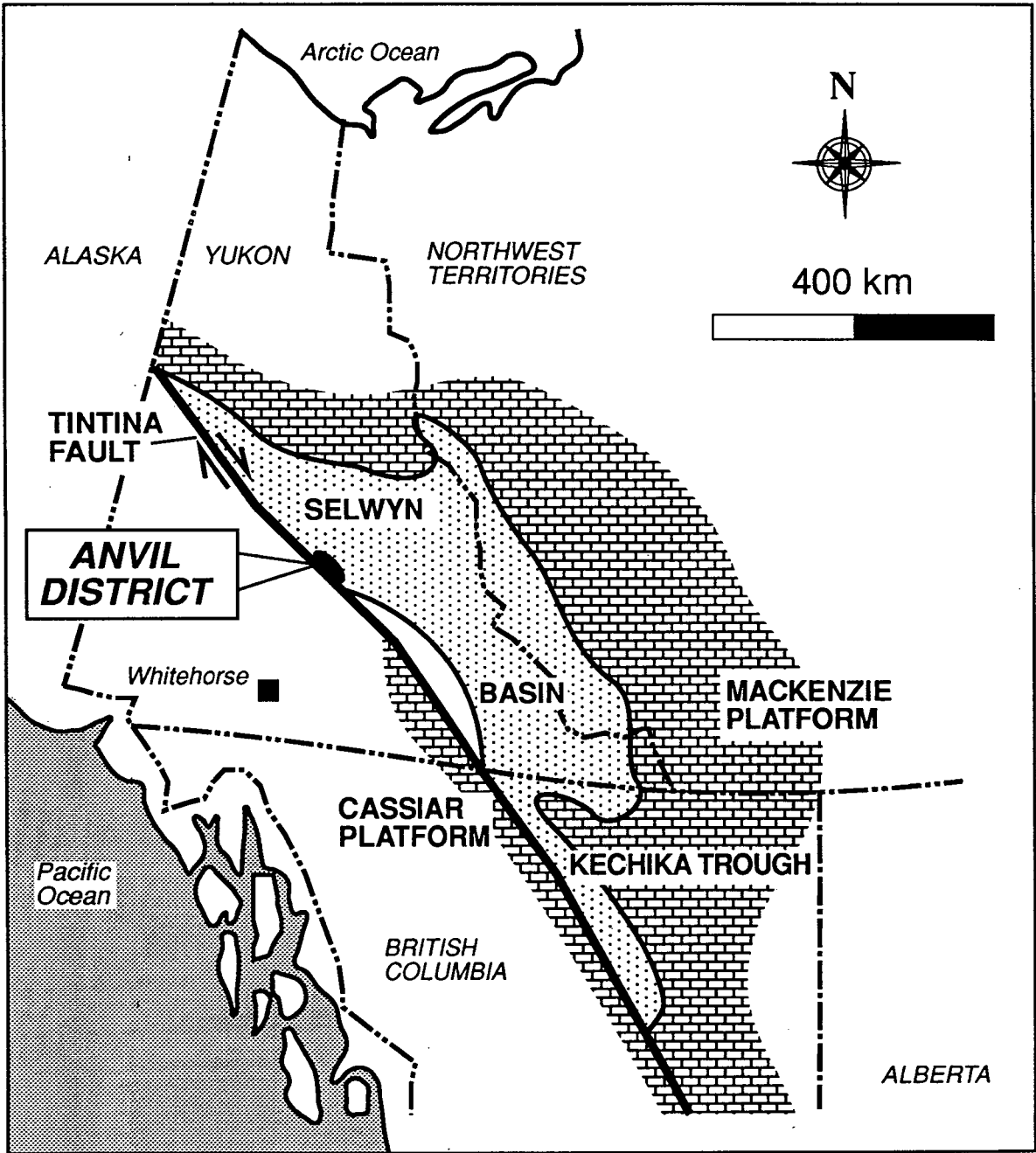


Fig 1

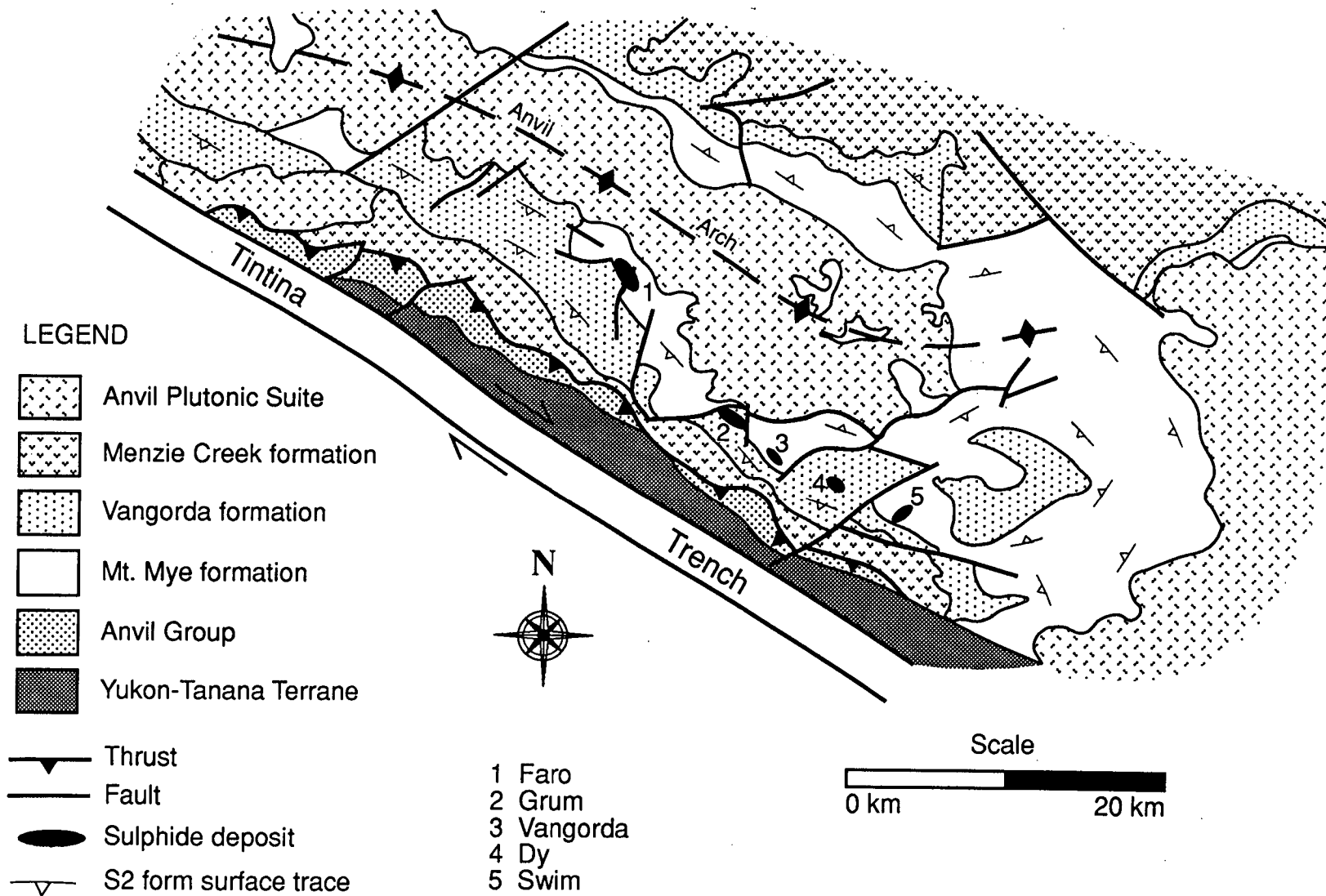


Fig. 2

Anvil District Lithostratigraphy

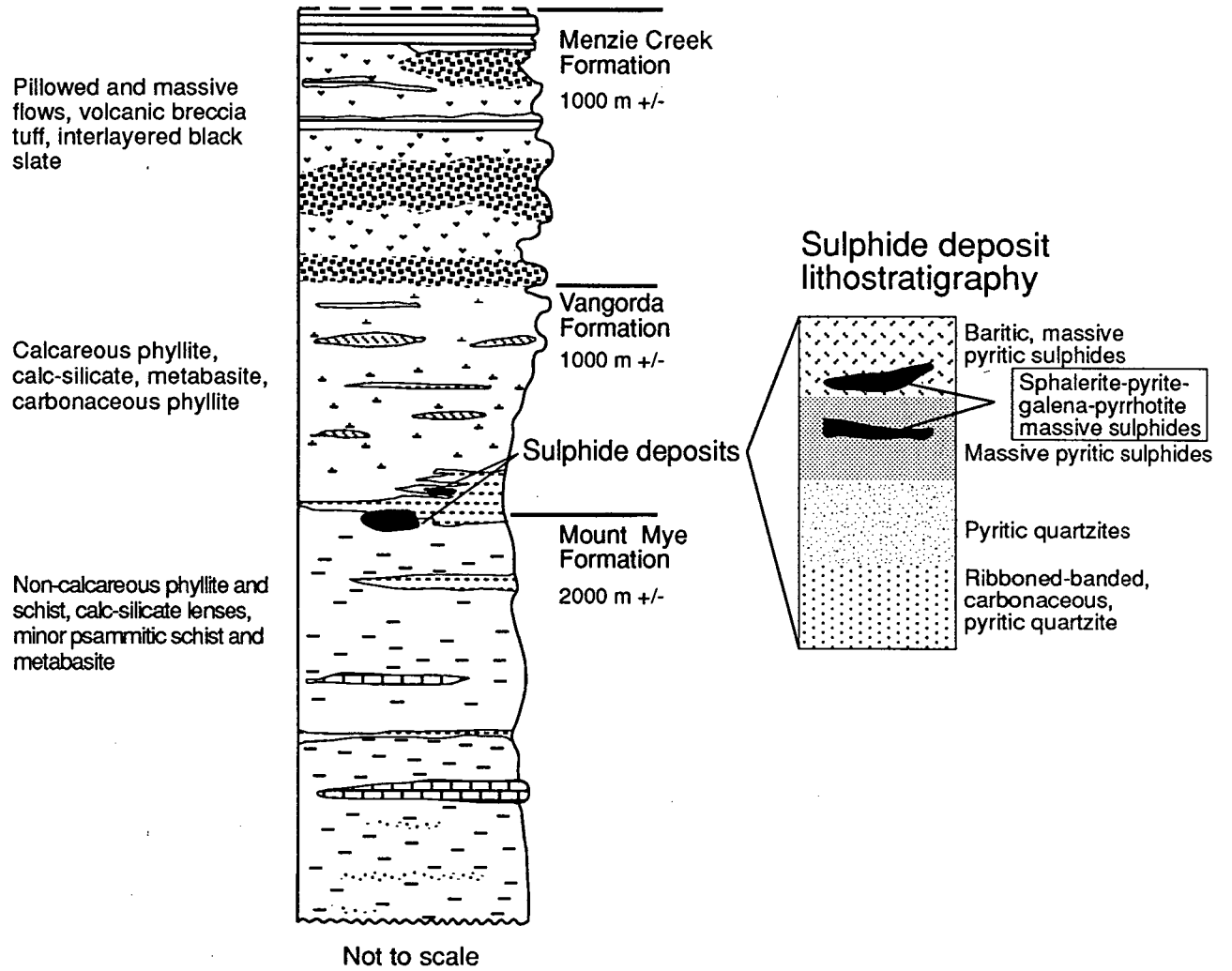


Fig. 3

Vangorda Deposit Section 6 E

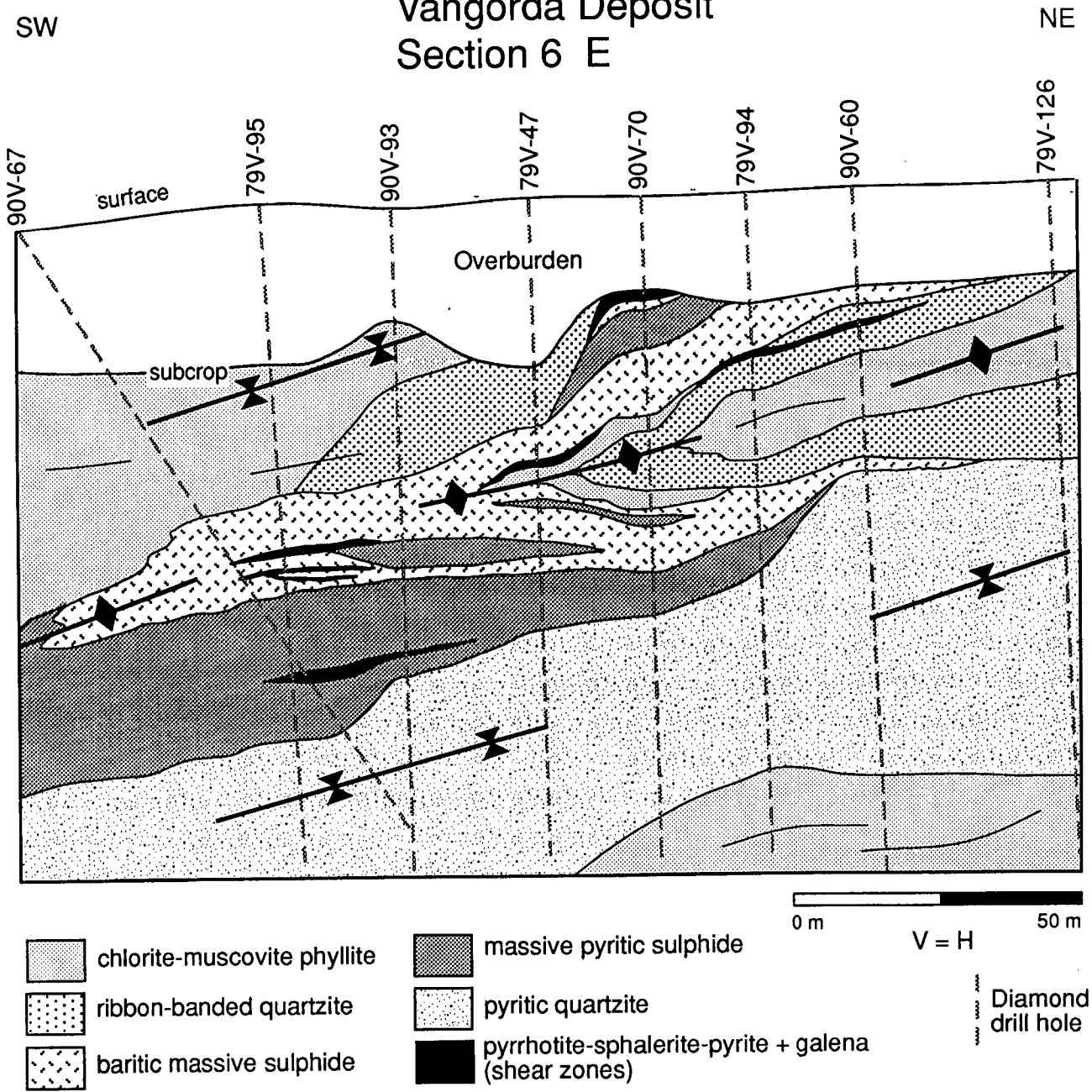


Fig. 4

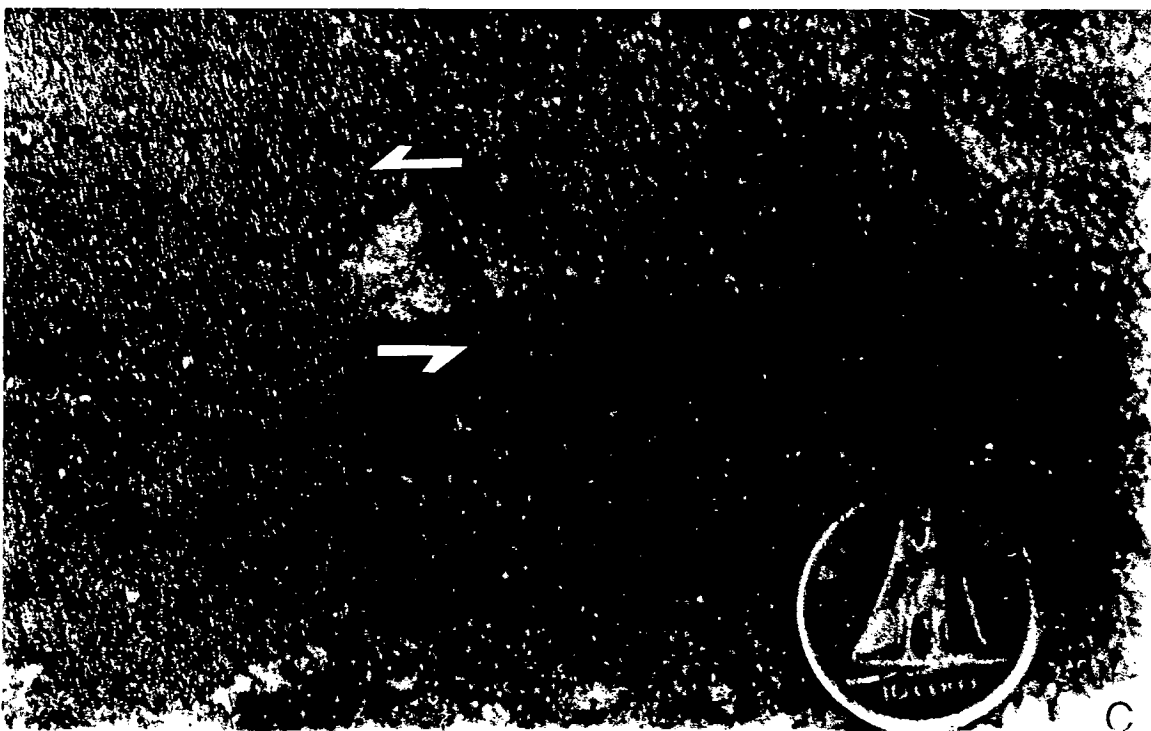


Fig. 5

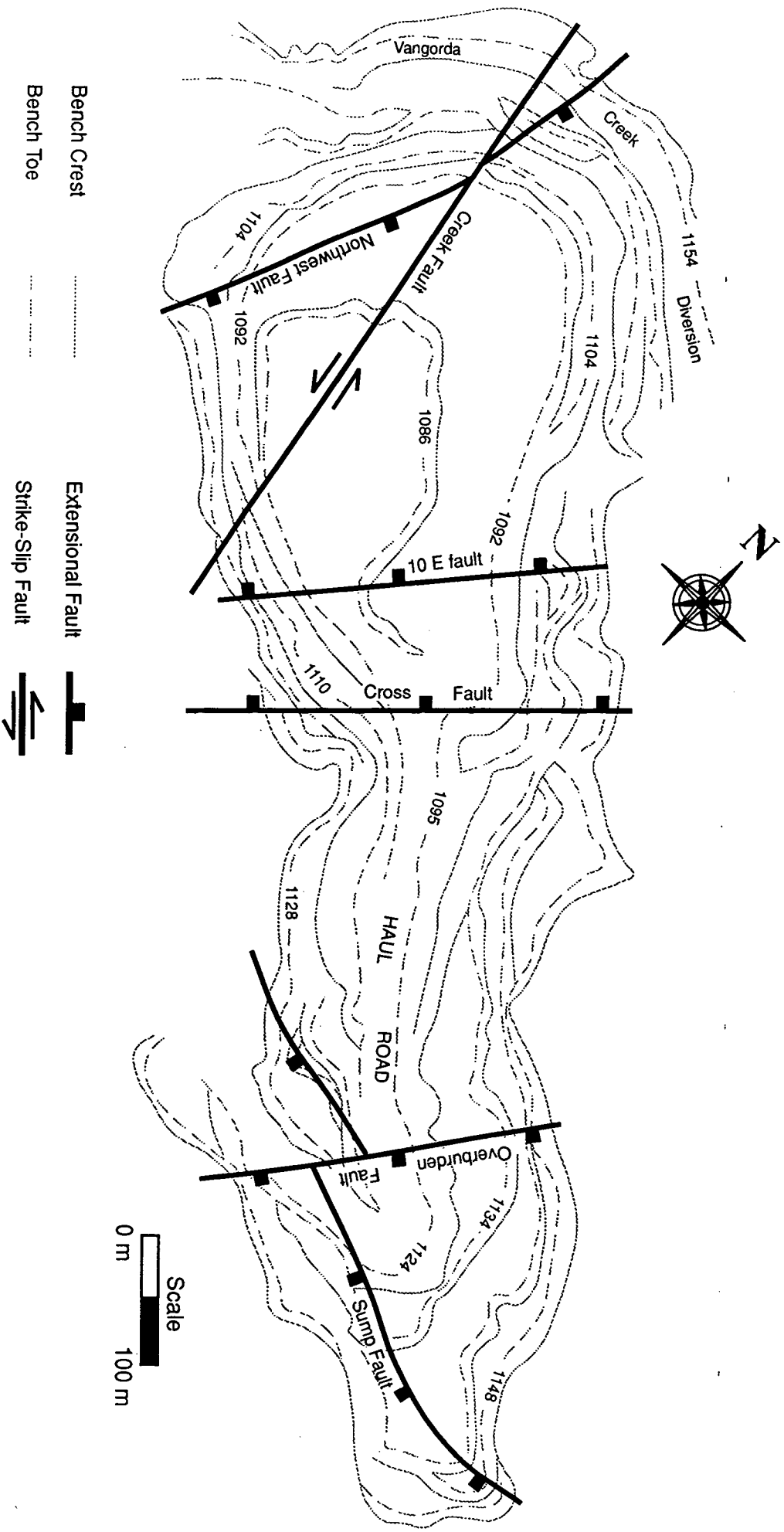


Fig. 6