SYN-HYDROTHERMAL DEVELOPMENT OF FRACTURES IN THE SILVER QUEEN MINE AREA, OWEN LAKE, CENTRAL BRITISH COLUMBIA*
(93L/2)

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INTRODUCTION

The site and character of precious and basemetal epithermal deposits is determined by several principal factors which include: structure, stratigraphy, lithology, pressure and temperature, hydrology, chemistry of the mineralizing fluid, and syn-hydrothermal development of permeability or changes in hydraulic gradient (White and Hedenquist, 1990). This study investigates the syn-hydrothermal development of permeability by documenting the attitude and style of fracturing in the immediate area of the Silver Queen mine (Figure 2-5-1). This work represents a portion of a more extensive study investigating the mineralizing processes at the Silver Queen mine (*see* Cheng *et al.* and Hood *et al.*, this volume).

DEPOSIT GEOLOGY

The Silver Queen (Nadina, Bradina) deposit is located 100 kilometres southeast of Smithers, 30 kilometres south of Houston and 30 kilometres southwest of the Equity Silver mine (Figure 2-5-1, *inset*). It is hosted by Upper Cretaceous (77 to 75 Ma; Church and Barakso, 1990) andesitic volcanic rocks, tentatively correlated with the Kasalka Group (Leitch *et al.*, 1990). Mineralization is bracketed in age by altered, and therefore older, amygdaloidal dikes (51.3 ± 1.8 Ma, K-Ar, whole-rock) which parallel the veins described below, and unaltered bladed-feldspar porphyry dikes (51.9 ± 1.8 Ma, K-Ar, whole-rock).

Mineralization occurs in veins varying in width from 1 centimetre to 2 metres and consisting of silver, copper, lead and zinc sulphides in a gangue of quartz, carbonate and barite (*see* Hood *et al.*, this volume). The No. 3 vein (Figure 2-5-1), the focus of previous mining activity and the largest discovered in the immediate area, has a known length of 1.5 kilometres, a depth of at least 200 metres and a width varying from 0.1 to 2.0 metres. Country rocks are Tip Top Hill feldspar porphyry at the north end, Mine Hill microdiorite in the central segment, and medium to coarse tuff-breccia to the south (Figure 2-5-1). A distinct alteration envelope, consisting of strongly to weakly altered rocks, extends tens of metres into both the footwall and hangingwall of the vein (Cheng *et al.*, this volume).

FIELD OBSERVATIONS

The Wrinch Creek canyon west of the No. 3 vein, and a section 30 metres east of the vein along the underground Bulkley cross-cut (Figure 2-5-1) were chosen as study areas to obtain structural orientation data. Complimenting these observations are regional determinations and measurements on several sequences of diamond-drill core through the No. 3 vein.

DEFINITIONS

Based on experimental deformation studies (reviews in Price, 1966; Hobbs *et al.*, 1976) two general classes of fractures can be related to three axes of compressive stress: principal (σ^1), intermediate (σ^2) and minor (σ^3). The resulting fractures are referred to as extension (E), and shear (S) fractures (Figure 2-5-2). The 2Θ angle for extension fractures is 0°, and for shear fractures it ranges from greater than 0° to 90°. The acute bisector of conjugate shear fractures is developed parallel to the principal compressive stress direction (σ^1).

As an aid to field interpretation of fracture patterns Hancock (1985) suggests classifying fractures by shapes of letters in the alphabet. Summarizing this work: I-shapes suggest unidirectional extension (E) fractures; K-shapes suggest extension fractures formed under conditions of near hydrostatic stress; T-shapes suggest two episodes of orthogonal extension fracturing; H-shapes suggest non-systematic overprinting of orthogonal extension; V, Y and X-shapes suggest conjugate shear (S) fractures and non-systematic crossfractures resulting in an A-shape.

In this study, joints are defined as fractures with no megascopic indications of relative motion or accumulation of secondary minerals (Plate 2-5-1a).

Veins are fractures filled with secondary minerals, with or without an envelope of alteration. Three groups of veins are distinguished by width: less than 1 millimetre, 1 millimetre to 1 centimetre and greater than 1 centimetre (Plate 2-5-1a, b, c).

Faults are defined as fractures with evidence of relative motion. The most common type recognized in this study is identified by slickensides on planar surfaces with the sense of last motion determined by hackle-marks, if present (Plate 2-5-1a). Strongly silicified breccia zones are restricted to the footwall and hangingwall of veins greater than 1 centimetre wide and the margins of amygdaloidal dikes (Plate

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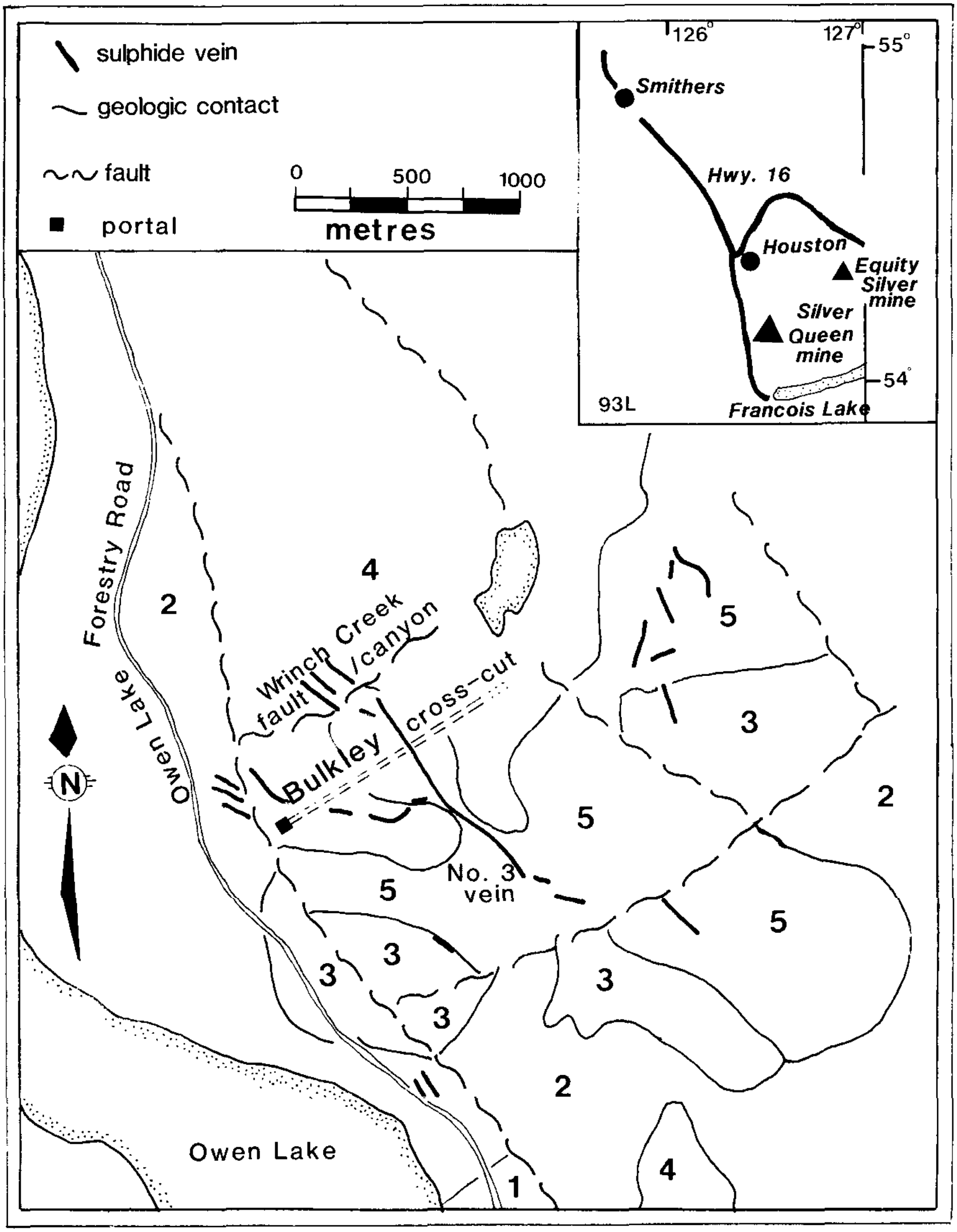


Figure 2-5-1. Simplified surface geologic map of the Silver Queen mine, highlighting the surface trace of the No. 3 vein and the other significant sulphide-bearing veins. Legend: 1=polymictic basal conglomerate; 2=crystal tuff; 3=medium to coarse tuff-breccia; 4=Tip Top Hill feldspar porphyry; 5=Mine Hill microdiorite (after Leitch *et al.*, 1990). Inset: location map of Silver Queen Mine.

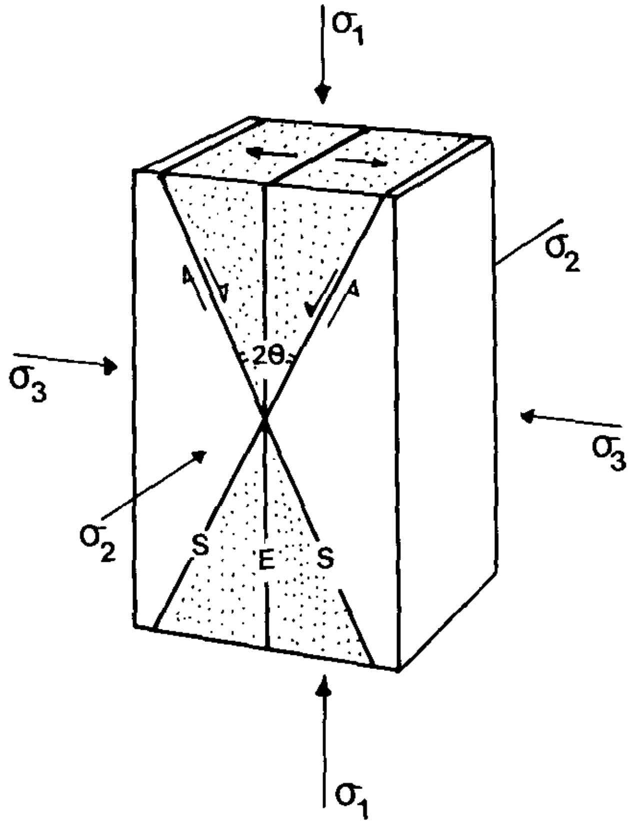
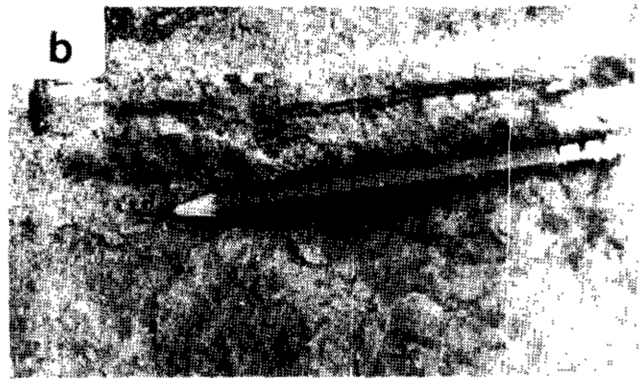


Figure 2-5-2. Block diagram showing the relationship of principal stress directions and extension fractures (E) and conjugate shear fractures (S) developed in a mechanically isotropic brittle rock.



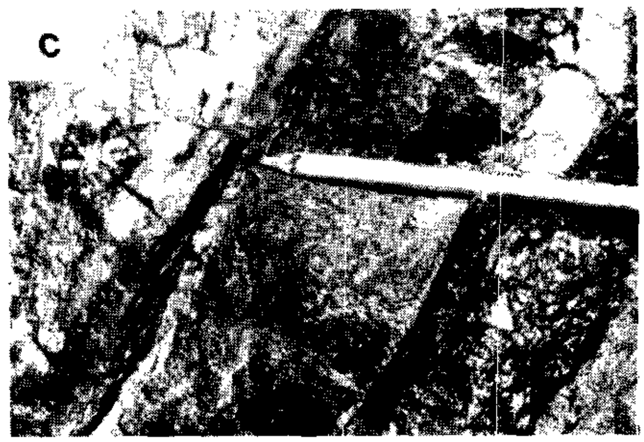


Plate 2-5-1. *(a) Joint fractures (J) in fresh feldspar porphyry. Gently plunging slickensides (SS) on a plane parallel* to Wrinch Creek canyon. (b) I-shaped, 1 millimetre to 1 centimetre wide veins cutting weakly altered microdiorite. (c) *Sulphide-rich vein greater than 1 centimetre wide with footwall (left) and hangingwall (right) brecciation. (d) Pencil-tip* sticking into clay-rich fault gouge in the footwall of a vein greater than 1 centimetre wide. Note the internal chaotic *nature of the vein.*

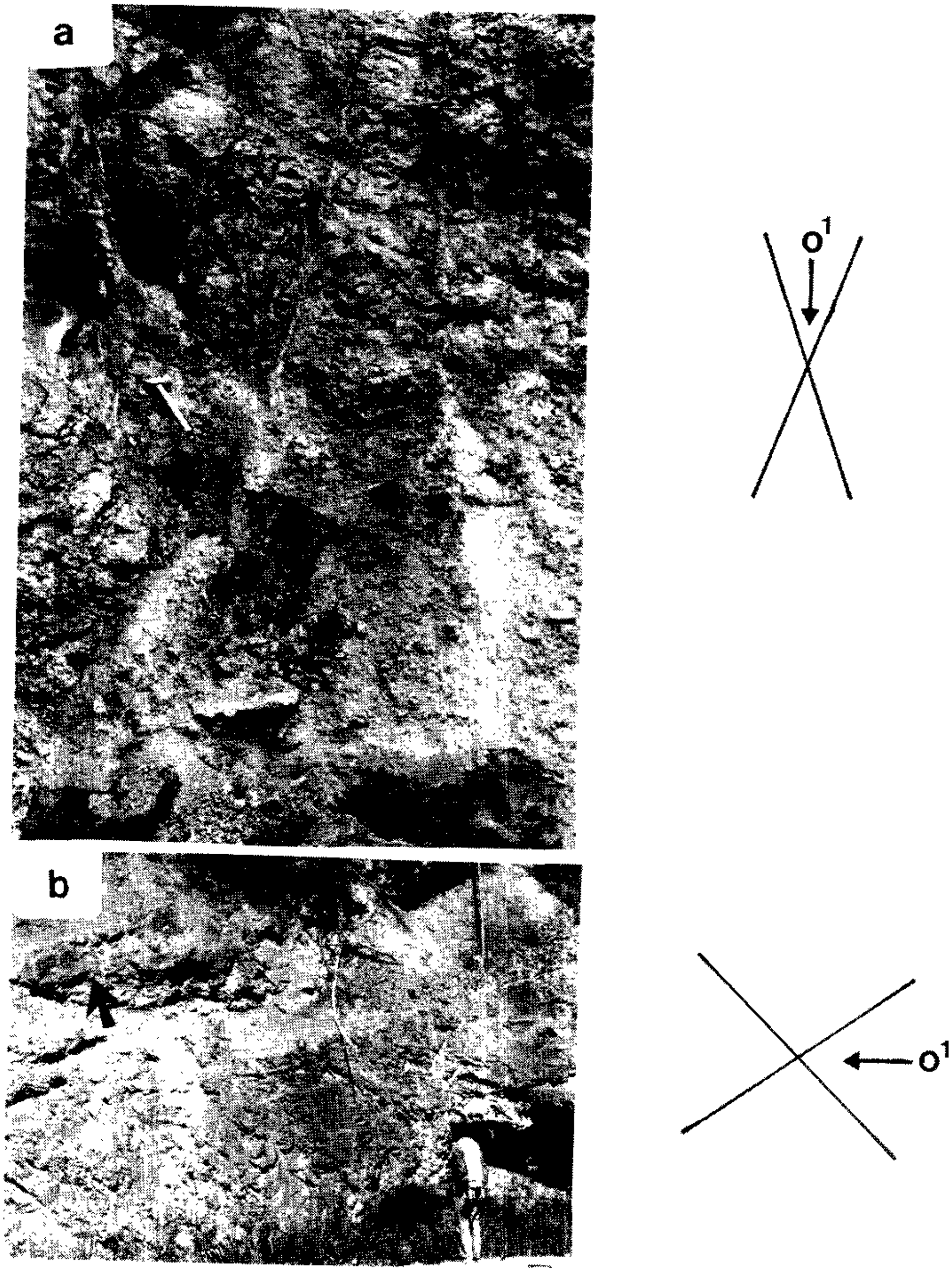


Plate 2-5-2. (a) Steeply dipping, conjugate shear fractures developed 20 metres away from the No. 3 vein. Acute bisector (σ^1) is vertical. (b) Gently dipping conjugate shear fractures 10 metres from the No. 3 vein. Acute bisector (σ^1) is horizontal. Arrow points to sulphide-bearing vein.

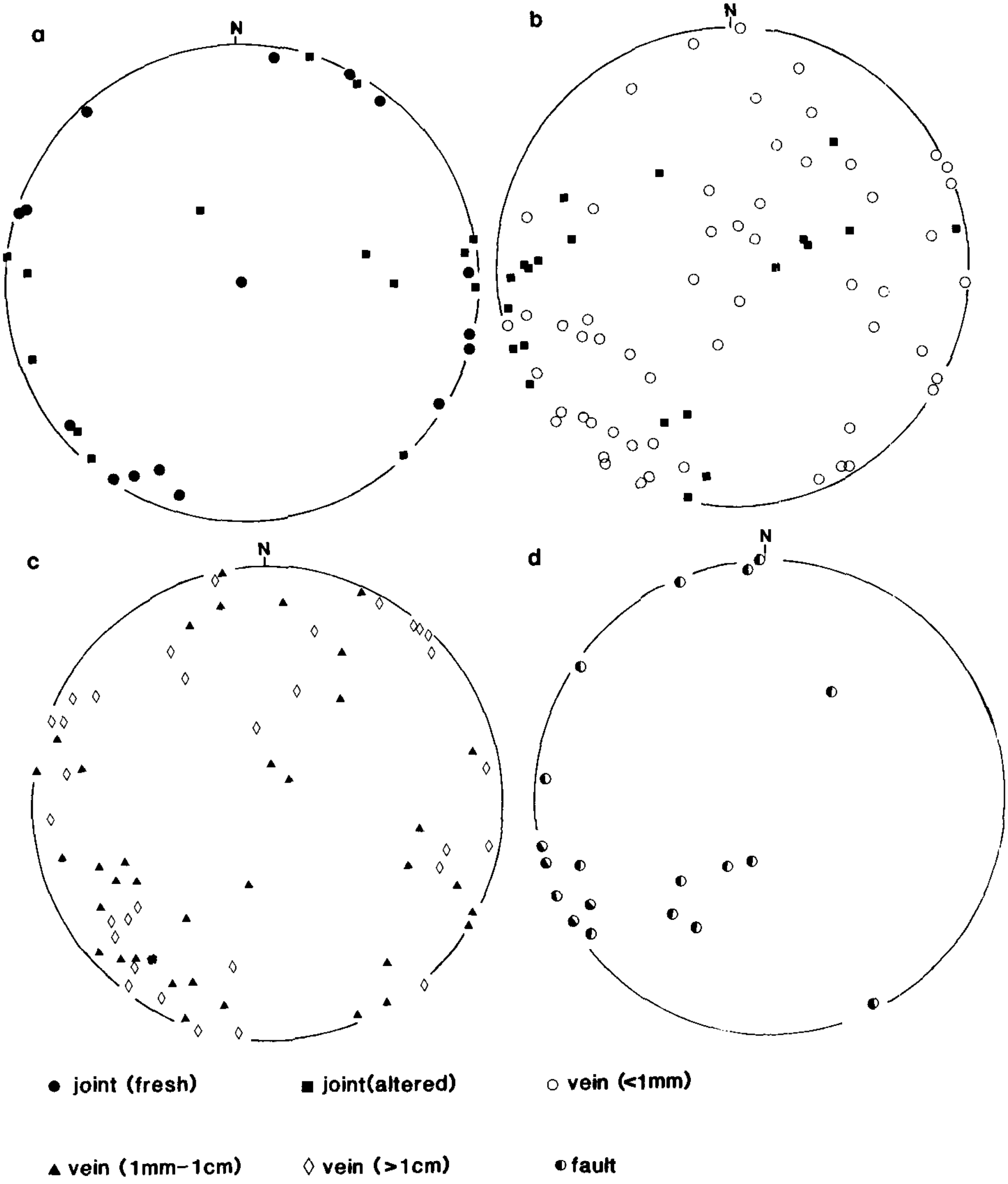


Figure 2-5-3. Lower hemisphere equal-area projection of fracture orientation data. (a) Joints and veins in unaltered to weakly altered rock 30 metres away from No. 3 vein, (b) Joints and veins in altered rock 20 metres away from No. 3 vein, (c) Veins 0 to 10 metres away from No. 3 vein, star is average orientation of No. 3 vein, (d) faults 0 to 10 metres away from No. 3 vein.

2-5-1c). Clay-rich gouge on faults is noted underground and in diamond-drill core (Plate 2-5-1d).

STRUCTURAL ORIENTATION DATA

Fractures in fresh feldspar porphyry and microdiorite, at a distance approximately 30 metres from the No. 3 vein, are orthogonally oriented, I-shaped joints (Plate 2-5-1a). They are regularly spaced at 20 to 50-centimetre intervals, and are both steeply dipping and flat lying (Figure 2-5-3a).

Close to the No. 3 vein (~20 m), narrow (less than 1 millimetre wide) vertical to steeply dipping quartz veins are characterized by buff-coloured envelopes of alteration 1 to 5 millimetres wide (Plate 2-5-1b). The veins are I-shaped, suggesting extension. They show a similar density and orientation to joints within the fresh rock (Figure 2-5-3a).

Within 10 to 20 metres of the No. 3 vein the fracture density increases to a 5 to 10-centimetre spacing, and veins less than 1 millimetre wide become more abundant. The veins are X and A-shaped conjugate shear fractures, with a vertical acute bisector (Figure 2-5-3a, Plate 2-5-2a).

At approximately 10 metres from the No. 3 vein, steeply and gently dipping X and A-shaped joints and 1-millimetre, and 1-millimetre to 1-centimetre-wide X and A-shaped veins are more abundant than I-shaped joints and veins (Figure 2-5-3b, Plate 2-5-2b). The acute bisectors of the steeply and gently dipping conjugate joints and veins are vertical and horizontal, respectively.

The No. 3 vein and most adjacent veins greater than 1 centimetre wide are commonly I-shaped and steeply dipping (Plate 2-5-1c, d, Figure 2-5-3c). However, a second population of gently dipping conjugate shear veins (1 millimetre to greater than 1 centimetre wide) are cut by the I-shaped veins, more than 1 centimetre wide.

Clay-rich fault planes are commonly developed marginal to veins greater than 1 centimetre wide (Plate 2-5-1d). The plunge of slickenside lineations is at a high angle and where hackle-marks are preserved, normal faulting is interpreted. A second set of fault planes has a shallow dip (Figure 2-5-3d), similar in attitude to the low-angle shear planes illustrated in Figures 2-5-3b and c.

The silicified breccias in the footwall of the No. 3 vein predate the vein, as the vein boundary is sharp against the breccia (Plate 2-5-1c, d) and postdate the amygdaloidal dike, as it is brecciated. Brecciation, however, was not a single event, but rather episodic, with evidence of internal brecciation within the No. 3 vein.

INTERPRETATION

Hubbert and Rubey (1959) and Secor (1965) have shown that the total effective stress (σ') across any plane can be resolved into a normal stress (σ^n) less the fluid pressure (p). This relationship has dramatic consequences with regard to the brittle failure of a rock. Figure 2-5-4 illustrates that an increase in fluid pressure will result in a shift to the left (A-A',B-B') of the Mohr stress circle, without changing the differential stress value (σ^1-σ^3). If the diameter of the stress circle (differential stress) is large (A), increases in fluid pressure will shift the stress circle tangent to the failure envelope, right of the ordinate (A'), the rock will fail through shear fracturing and conjugate shear planes will develop. If, however, the diameter of the stress circle is small (B), increases in fluid pressure will result in the circle becoming tangent to the failure envelope on the abscissa, in the tensile quadrant (B'), and the rock will fail through the development of extension planes. Simply stated, if σ^3 equals the tensile strength of the rock, extension will result.

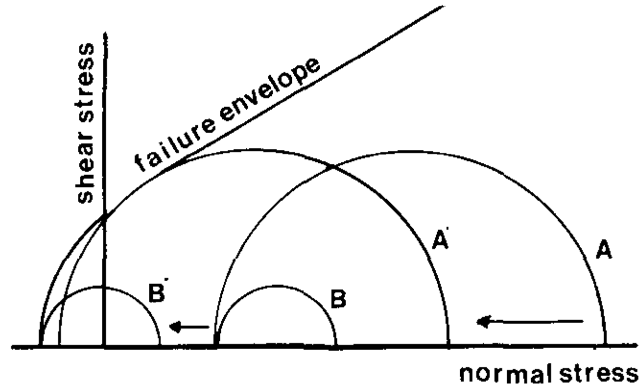


Figure 2-5-4. Mohr diagram with modified Griffith failure envelope and stress circles representing the influence of fluid pressure on the effective stress states. In the case A-A', increasing fluid pressure results in shear failure. In the case B-B', the increasing fluid pressure results in extension failure.

The joint and fracture system within the unaltered feldspar porphyry and microdiorite (greater than 30 metres from the No. 3 vein) is assumed to reflect the regional stress field. The vertical and horizontal orientation of joint sets suggests that the orientation of σ^1 and σ^3 have shifted from horizontal to vertical. This type of variation may be a product of unloading of the crust under near hydrostatic conditions (Price, 1966).

Approaching the No. 3 vein, the first indication of overprinting of the regional stress field comes with the development of conjugate shear veins with a vertical acute bisector (σ^1-vertical). The presence of an alteration assemblage marginal to the conjugate shear veins suggests that an increase in fluid pressure in the rock may have resulted in shear failure as illustrated in Figure 2-5-4.

With increased proximity to the No. 3 vein, steeply and gently dipping conjugate shear planes are both developed, indicating that σ^1 was both vertical and horizontal (Plate 2-5-2a, b). One possible explanation for this is the intrusion of a magma at depth, causing the inflation and extension of overlying rocks (Shaw, 1980). Evidence for a contemporaneous magma at depth comes from the occurrence of the amygdaloidal dikes parallel to the joint and vein attitudes.

Brecciation within the footwall and hangingwall of the No. 3 vein may be explained by a model of seismic pumping (Sibson *et al.*, 1975). This model suggests that prior to seismic shear failure, the region around the focus of the subsequent earthquake dilates in response to rising tectonic shear stress. Extension cracks and fractures open normal to the least compressive stress. The development of fracture porosity causes the fluid pressure in the dilatant zone to decrease, inducing a slow inward migration of fluids from the surrounding rock mass. At the onset of dilatancy, the drop in the fluid pressure causes a rise in the frictional resistance to shear along the fault. The migrating fluids fill the cracks, the fluid pressure rises again and frictional resistance decreases. Seismic failure eventually occurs when the rising shear stress equals the frictional resistance. The fluids in the dilatant zone are expelled upward through the fault and adjacent fractures. Cooling of silica and metal-saturated fluids, near the surface, will result in the deposition of quartz and sulphide-rich veins in the fault plane and adjacent fractures above the seismic epicentre. The No. 3 vein is therefore interpreted as a fault plane, which acted as a conduit for metal-bearing fluids, with the smaller veins of variable attitude hydraulically connected to the "seismic pump".

A model of an intruding magma at depth, with associated increased fluid pressure and seismicity, unifies most structural elements described above into a single process. There are, however, several observations which have not been discussed. For instance, as Church and Barakso (1990) point out, strike-slip and normal faulting are noted in the area, however, the relationship between normal and strike-slip faulting is unclear. Future work will have to accommodate these observations into the broader Eocene geologic history of the area.

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