Preliminary Structural Study of the Gold-bearing Shear Zone System at the Seabee Mine, Northern Saskatchewan

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Abstract

The Seabee gold deposit is a structurally controlled, mesothermal vein gold deposit developed in weakly deformed metagabbroic rocks of the Laonil Lake Intrusive Complex, northern Saskatchewan. The gold-bearing veins are hosted by narrow, steeply northwest-dipping to subvertical, northeast- and east-northeast-trending shear zones consisting of well-foliated L-S tectonites that are characterized by a steep mylonitic foliation and a steeply west-plunging mineral lineation. Auriferous veins occur as riedel 'R' and 'P' veins oriented 5° to 15° from the shear foliation, as fault-fill veins subparallel to the foliation, and as minor extension veins oriented at a high angle to the shear zone boundary. Coexisting strain and kinematic indicators reveal that the auriferous shear zones recorded a strong component of boundary-normal compression combined with subhorizontal dextral shear. The auriferous shear zones are either late reverse faults, reactivated as dextral strike-slip faults, or dextral transpression zones developed between converging rigid walls. Preliminary interpretation suggests that dextral transpression best explains the emplacement and deformation of the shear zones and associated gold-quartz veins.

Keywords: Seabee mine, Laonil Lake Intrusive Complex, gold mineralization, shear zone, C-S fabric, foliation, reverse faults, transpression, dextral shear, deformation partitioning.

1. Introduction

The Seabee Mine is about 120 km northeast of La Ronge in the northern part of the Glennie Domain, northern Saskatchewan. The property comprises two mineral leases totaling 326 hectares (~805 acres) and is 100% owned and operated by Claude Resources Inc. Since its opening in 1991, the mine has produced nearly 600,000 oz of gold at an average grade of approximately 9 g/t (0.263 oz/ton) Au.

The deposit is hosted by a complex anastomosing shear zone system transecting the Laonil Lake Intrusive Complex. Regional mapping in the Laonil Lake area (see Lewry, 1977 and Delaney, 1986) predated mining at Seabee, and hence did not treat the internal geometry of the gold occurrences in any detail. Although previous workers have recognized that brittle-ductile fractures are primary controls for mineralization (e.g. Gummer, 1986; Helmstaedt, 1986, 1987; Schultz, 1990, 1996; Basnett, 1999), none have described the nature of the gold-bearing veins in detail and determined the kinematic and structural evolution of the mineralized brittle-ductile shear zones. The present study is intended to address both in order to develop a geometric model for the evolution and emplacement of the Seabee deposit. The following observations are based on detailed surface mapping (1:1000) of outcrops and gold showings found in the immediate vicinity of the deposit combined with six days of underground mapping. Factual geometric information have also been extracted from a compilation of the first three mining levels (levels 60, 120 and 140). Initial results indicate that the gold-bearing shear zones are either reverse shear zones reactivated as dextral strike slip faults, or are zones of dextral transpression.

2. Regional Geology and Rock Types

The geological setting of the Seabee mine summarized below, is based mainly on work by Lewry (1977) and Delaney (1986). The Seabee gold deposit is hosted by the Laonil Lake Intrusive Complex, a triangular intrusion situated between the 1859 ±5 Ma, Eyahpaise granodiorite (U-Pb dating from Van Schmus *et al.*, 1987) to the south, the Pine Lake volcanic assemblage to the northeast, and the Porky Lake siliciclastic rocks to the north and east (Figure 1). All of these rocks in the northern part of the Glennie Domain have been metamorphosed to at least middle amphibolite facies (thus the prefix 'meta' has been omitted for simplicity).

The Pine Lake assemblage comprises a basal sequence of mafic to intermediate volcanic, and volcaniclastic rocks that is overlain by a package of felsic volcanic and volcaniclastic rocks, and associated sedimentary rocks (Delaney, 1986; Figure 1). A rhyolite from the upper package has yielded an 1838 ±2 Ma U-Pb age (McNicoll *et al.*, 1992).

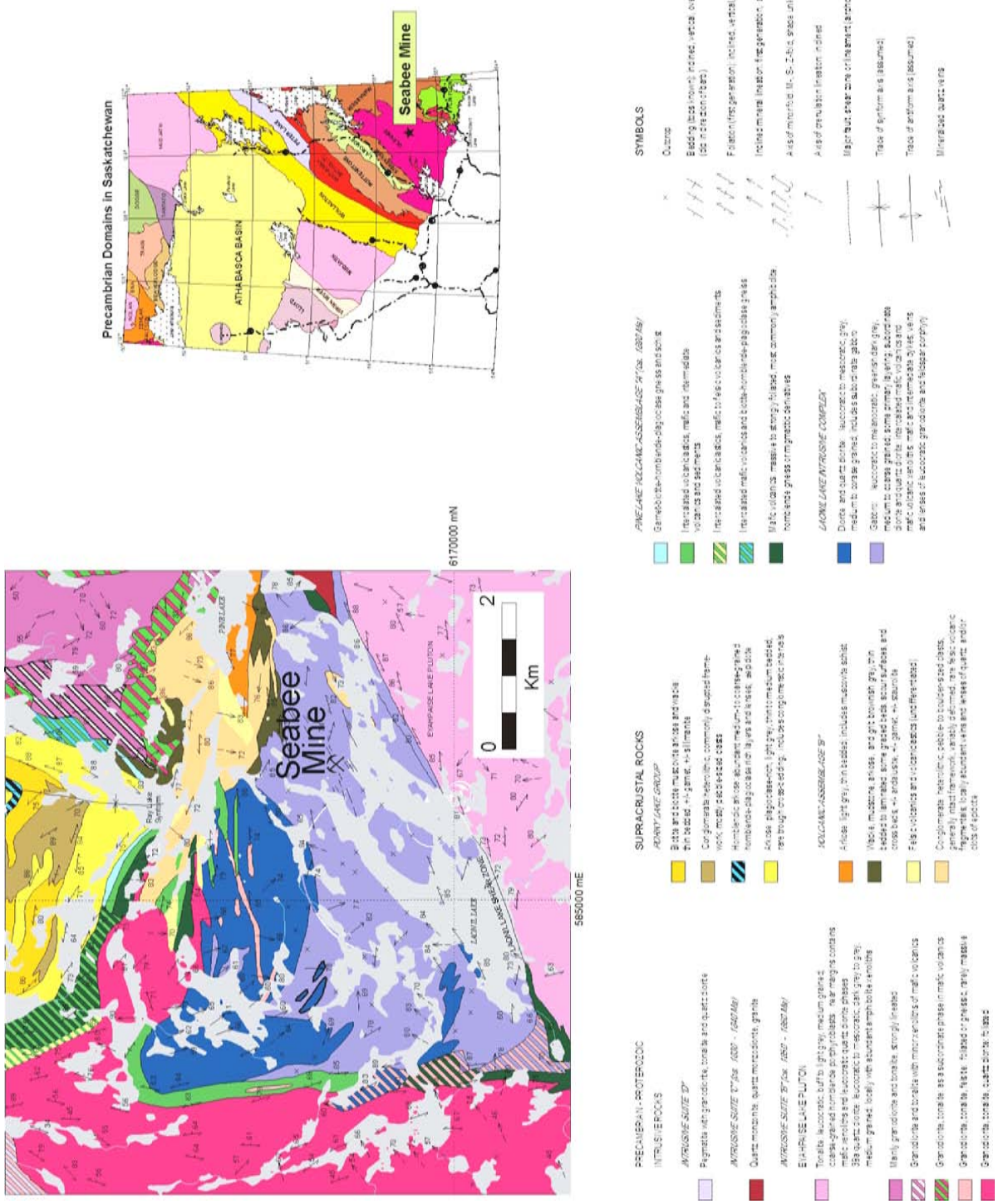

Figure 1 - Geologic setting of the Seabee deposit (after Delaney, 1986).

Original contact relationships between the Pine Lake Assemblage and the Laonil Lake Complex have been obscured by tight folding and related shearing.

The Porky Lake sedimentary assemblage unconformably overlies the Pine Lake assemblage and consists of layered arenites, wackes, conglomerates, and biotite schists (Delaney, 1986).

The Laonil Lake Intrusive Complex is a multiphase intrusion composed dominantly of gabbro, quartz diorite, and diorite which has yielded 1889 ±9 Ma crystallization age (Chiarenzelli, 1989), with minor granodiorite, feldspar porphyry, and mafic to intermediate dykes (Delaney, 1986). Metre- to decimetre-scale xenoliths of mafic volcanic, volcaniclastic, and sedimentary rocks are common. The main phase of the complex consists of a medium- to coarse-grained, equigranular hornblende gabbro.

The Laonil Lake gabbro is transected by small dykes striking northeasterly to easterly. These vary in width from a few centimetres to a few metres, and in composition from ultramafic to felsic (Figure 2). The felsic dykes are fine to medium grained and quartzo-feldspathic, consisting of up to 60% recrystallized quartz (<1 mm), 5 to 20% of altered feldspars (<2 mm) and subsidiary amounts of hornblende-actinolite, biotite, chlorite and sericite. All of the dykes are subvertical and generally subparallel, but locally the east-west mafic dykes crosscut their felsic counterparts. Most dykes have been deformed and display a weak to moderate foliation parallel to the regional foliation.

In the vicinity of the deposit, dykes of melanocratic gabbro and felsic intrusive rock are commonly associated with the auriferous brittle-ductile shear zones. A major (40 m thick) quartz-feldspar porphyry dyke occurs along the northern side of Lens 2 (Figure 2). It consists mainly of quartz, feldspar and biotite, locally with finely disseminated pyrite and pyrrhotite (Basnett, 1999).

A possibly related larger body of granodiorite has been mapped south of the Currie Rose vein (Figure 2). It is massive to weakly foliated, weathers white to light grey and is composed of quartz, feldspar and biotite with minor amounts of amphibole and pyrite (Helmstaedt, 1986).

As previously mentioned, xenoliths and rafts/screens of fine-grained mafic volcanic and sedimentary rocks are in the gabbro (Figure 2). The metamorphosed volcanic rocks consist almost entirely of fine-grained hornblende±actinolite and plagioclase. Although these rocks are intensely deformed and recrystallized, pillow selvages are locally preserved. Xenoliths of layered pelitic to psammitic sedimentary rocks within the main gabbro have been converted to quartz-feldspar-biotite schists. In metamorphosed hydrothermal alteration zones, sediments locally contain cordierite, garnet, staurolite, and anthophyllite.

Outstanding structural features include: (i) an early pervasive east-northeast striking regional S2 foliation and a variably oriented L2 mineral stretching lineation (D2 of Lewry *et al.*, 1990); (ii) late north-south-trending regional F3 folds represented by the Ray Lake Synform in the northern part of the area and by an antiform in the northwestern part of the Laonil Lake complex; and (iii) a high-strain zone (Laonil Lake Shear Zone) along the contact between the Eyahpaise Pluton and the Laonil Lake Intrusive Complex (Figure 1; Lewry, 1977; Delaney, 1986). Timing relationships between the Laonil Lake shear zone and the other major structures are still unknown.

3. Structural Geology

a) Regional Foliation and Lineation External to the Auriferous Shear Zones

Strain distribution in the Laonil Lake Intrusive Complex is heterogeneous and characterized by alternating panels of undeformed to weakly deformed rocks separated by narrow shear zones of penetrative ductile strain. External to the shear zones, the intrusive rocks have an isotropic mineral shape fabric or a weak foliation. This foliation and the associated lineation are ascribed to the regional D2 deformation (see Lewry *et al.*, 1990).

The S2 foliation in the gabbro is steeply dipping to vertical, and strikes northeastward to eastward. The fabric is defined by planar preferred orientation of hornblende, actinolite, and feldspar, and by flattening of mafic xenoliths. Within the foliation, the long axes of hornblende and actinolite, and of mafic xenoliths define a mineral and extension L2 lineation that plunges steeply to the west.

b) Mineralized Brittle-Ductile Shear Zones

Gold-quartz veins at the Seabee Mine are within an anastomosing brittle-ductile shear zone system crosscutting the Laonil Lake Complex (Figure 2). Several outcrops of the mineralized shear zone system have been mapped along the main mineralized structures, including lenses 2, 5, and 19 (Figure 2). The mineralized structures comprise several anastomosing shear zones delineated by relatively schistose L-S tectonites containing quartz-tourmaline-sulphide veins. They represent narrow bands of discontinuous deformation that are subparallel to or slightly

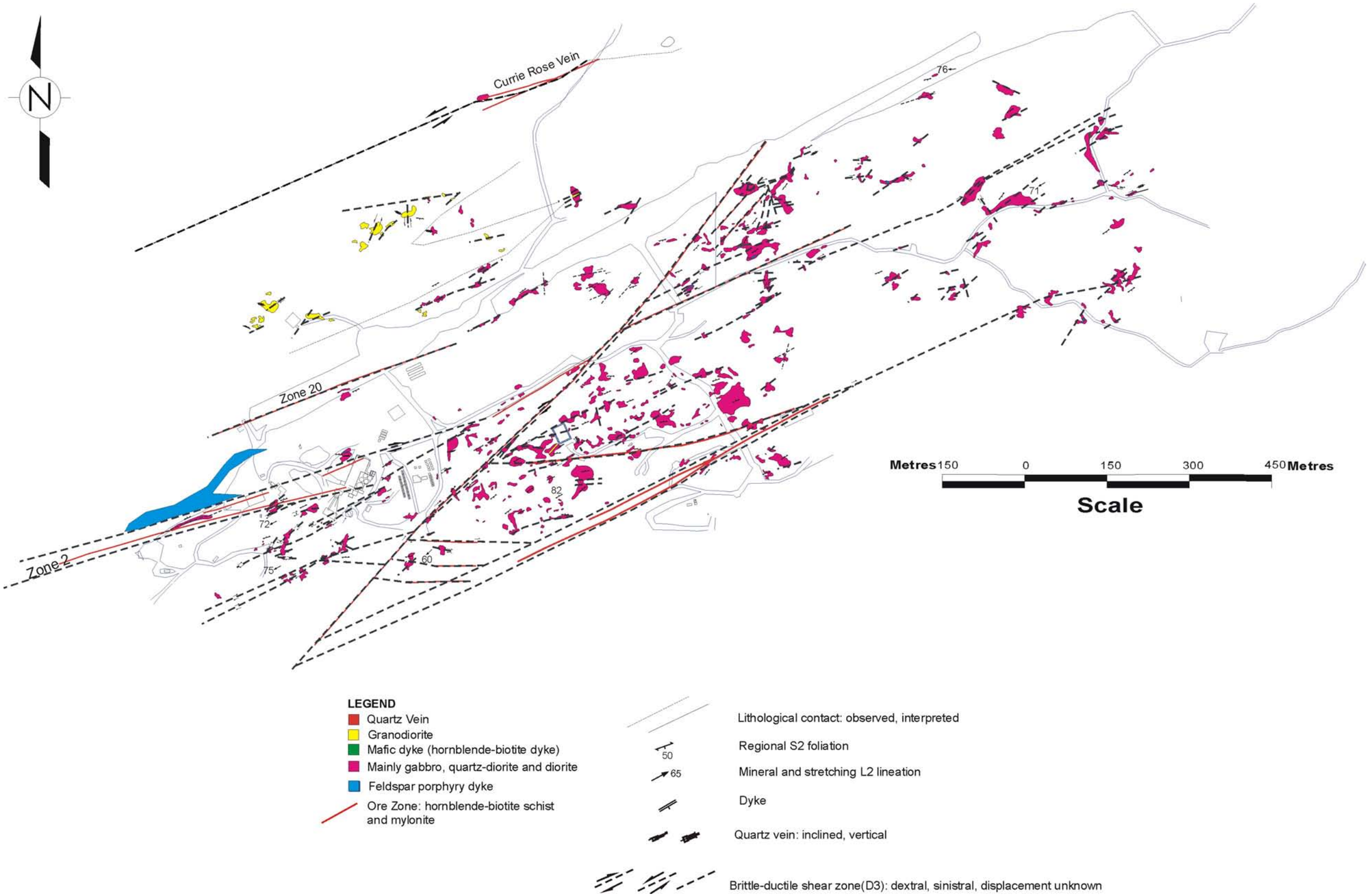

Figure 2 - Preliminary structural map of the Seabee Mine shear zone system (also see the map by Tourigny in the map package which accompanies this volume).

crosscut the S2 foliation and L2 lineation developed in the Laonil Lake gabbro. The shear zones clearly post-date the regional D2 deformation and probably developed synchronously with the regional D3 folds of Lewry *et al.* (1990).

The shear zones range from a few centimetres to 20 m thick, and include a northeast-trending set (Lens 19) and an east-northeast- to east-trending set (Lenses 2, 5, and 15) with several subsidiary minor mineralized structures. The average shear zone width in the mined zone is 3 m. All of these shear zones are subvertical to steeply (>80°) north-dipping and extend up to 2 km along strike. Some have been traced over 800 m in depth. Within the shear zones, the Laonil Lake gabbro has been transformed into a hornblende-actinolite-biotite-chlorite schist with a well-developed foliation defined by: 1) planar preferred orientation of platy minerals and 2) by alternating biotite-hornblende-chlorite and quartz-rich layers. Discontinuous mylonite layers within the high-strain zones are characterized by C-S fabrics and by grain-size reduction of quartz and feldspar. The shear zone alteration is manifested by pervasive replacement of the peak metamorphic hornblende and plagioclase into a biotite-actionolite-epidote-sericite±calcite assemblage. This retrograde assemblage is interpreted as being synchronous with D3 deformation.

Several shear zones are intimately associated with feldspar porphyry dykes and/or with mafic dykes that cut the host gabbro; this relationship suggests that the high-strain zones have nucleated and propagated along lithological contacts (Figure 3A).

In detail, shear zones overprint the dykes, which are preserved as boudins or as detached and transposed lenses within the shear zone foliation. Felsic dykes are more competent than the host gabbro and exhibit boudinage and pinch-and-swell structures. Less competent mafic dykes are more strongly foliated than the host rock and tend to be transposed along the shear zone. Along strike, shear zones locally depart from the lithological contacts and branch into narrow, anastomosing lenses of biotite-hornblende schist.

The shear zone boundaries commonly coincide with sharp biotitic slip planes; some simply grade into relatively undeformed gabbro. The internal penetrative foliation is generally subparallel to the shear zone boundaries (Figure 3B). A moderately to steeply west- to southwest-plunging mineral lineation is commonly defined by elongate actinolite-biotite aggregates. This foliation and lineation represent the accentuated L-S fabric inherited from the regional D2 deformation. Otherwise, some narrow shear zones with a newly created foliation and associated shear planes (i.e., C-S fabrics) are also in coarse-grained rocks with isotropic mineral shape fabrics.

Within continuous and discontinuous shear zones, the sense of displacement can be deduced unequivocally only where kinematic indicators (e.g. stretched objects and stretching lineations, asymptotic schistosity, rotated porphyroclasts, etc.) can be observed on sections perpendicular to the shear zone foliation and parallel to the stretching lineation (Berthe *et al.*, 1979). At the Seabee mine, the shear zone foliation is sub-parallel with the shear zone boundaries and no reliable kinematic indicators are developed in vertical cross-section in outcrops, underground or in thin sections. These relationships suggest that if there was a component of shearing during the development of the high-strain zones, it was at a high angle to the steeply plunging lineation, and consequently at a high angle to the extension axis of the strain ellipsoid. Such departure from the ideal simple shear zone model (i.e., reverse, oblique dip-slip or strike-slip faults) indicates a significant amount of coaxial flattening has taken place along the mineralized zones, consistent with a model of ductile transpression.

Kinematic indicators on sub-horizontal outcrops in the vicinity of Lens 2 yield an apparent dextral sense of displacement and are in good agreement with this interpretation. The foliation locally defines a sigmoidal C-S fabric (Berthe *et al.*, 1979) indicating an apparent dextral shear sense along the main mineralized east-northeast structure (Lens 2; Figure 3C). Dextral shearing is further confirmed by the asymptotic curvature of foliation near small-scale shear bands as well as by the "Z" asymmetry of folded mineralized quartz veins and rotated mafic xenoliths at the margin of the shear zones (see Figure 3 in Schultz, 1990).

Some sinistral shear-sense indicators have also been recognized in flat outcrops (Figure 2). For example, rotated quartz boudins indicate an apparent subhorizontal sinistral component of shear within the shear zone hosting the Currie Rose veins, a sub-economic gold occurrence (Figures 2 and 3D). Our mapping revealed, however, that subhorizontal dextral shear sense is dominant within the steeply dipping mineralized structures.

Conjugate north- and northwest-trending subvertical brittle faults and narrow mylonite zones overprint the northeast- and east-northeast-trending shear zones (Figure 2). North-trending mylonite bands are characterized by well-developed C-S fabrics revealing an apparent sinistral displacement in plane view (Figure 3E). Along the northwest-trending fractures, the apparent displacement is dextral. None of these late structures appear to have had any major influence on the geometry of the orebodies.

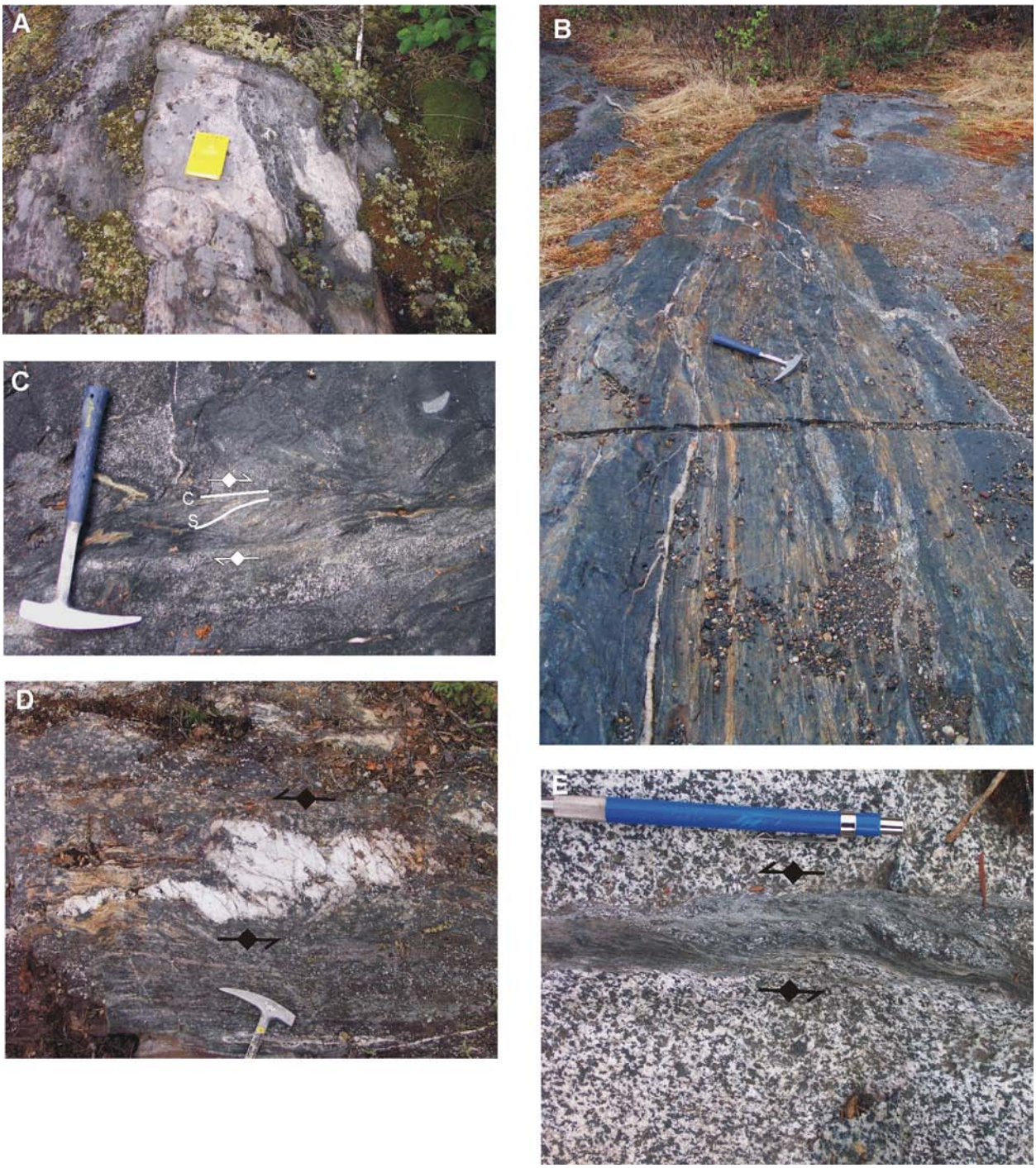

Figure 3 - (A) Deformed and transposed felsic (light grey) and mafic dykes (dark grey) within the shear zone hosting vein 2B. Notebook 12 x 19 cm. (B) Plan view of a major east-northeast-trending shear zone adjacent to Lens 2; hammer 32 cm long. (C) Plan view of C-S fabrics indicating dextral shearing along Lens 2. (D) Rotated quartz boudin indicating a sinistral sense of shear in the Currie Rose vein. (E) Plan view of a north-trending continuous sinistral shear zone with well-developed C-S fabric.

c) Mineralized Veins and Their Structural Setting

Economic gold mineralization at Seabee is in subvertical northeast- and east-northeast-trending quartz-tourmaline-sulphide veins in the cores of shear zones. Most of the ore comes from Lens 2, which is composed of numerous discontinuous quartz bodies, surrounded by zones of intense potassic alteration (biotite-rich schist). Individual veins may extend vertically and laterally for a few hundred metres; their thicknesses vary from a few centimetres to about 3 m. The veins are commonly laminated and contain slivers of foliated wall rocks, which indicates that they developed after the initial development of the shear zone foliation (Figure 4A). Quartz veins are commonly bounded by biotite-chlorite-rich slip planes oriented parallel to the veins. The slip planes contain down-dip to steeply northwest-plunging striations and/or mineral stretching lineations (biotite-chlorite-actinolite aggregates; Figure 4B), indicating that subvertical displacement occurred within the orebody during emplacement of the gold-quartz vein mineralization. The veins are mainly composed of quartz with subordinate amounts of tourmaline, pyrite, chalcopyrite, and pyrrhotite. Gold occurs as inclusions in sulphide, as fracture-fillings in the recrystallized quartz, and associated with complex tellurides.

Within Lenses 2 and 19, the main mineralized veins are commonly slightly discordant to the shear zone foliation. The overall strike of the vein system is approximately 80°E, whereas the average orientation of the shear zone foliation is between 60° and 75°E. In detail, the veins commonly cut the shear zone foliation at an 5º to 15° angle in a clockwise sense (Figure 4C). Combined with the evidence of dextral shearing within the host shear zones, this geometry suggests that the main veins may have formed in riedel shear fractures (see Mandl, 1988; Dresen, 1991) and rotated clockwise to develop Z folds during subsequent progressive dextral shearing (Figure 5A).

Some narrow veins also cut the shear foliation at low angle in a counterclockwise direction and may represent mineralized P shear fractures (Figure 5).

The hypothesis that R- and P-types veins represent rotated extension veins initially formed at 45° to the shear zone boundary is rejected as the shear zone foliation is not folded adjacent to the veins (see Hudleston, 1989).

Fault-fill veins oriented subparallel to the foliation were also observed in Lens 2 (Figures 4A and 5B). They are up to 1 m wide, strike ~70°E, and dip subvertically to steeply (>80°) to the north. These veins occur in the most ductile part of the shear and may connect laterally to the R-type veins (Figure 5B). They exhibit laminated textures defined by selvages of biotite-hornblende schist alternating with ribbons of quartz-tourmaline-sulphides (Figure 4A). Fault-fill veins central to the shear probably formed as D-type shear fractures mark-ing the zone of maximum shear strain and displacement.

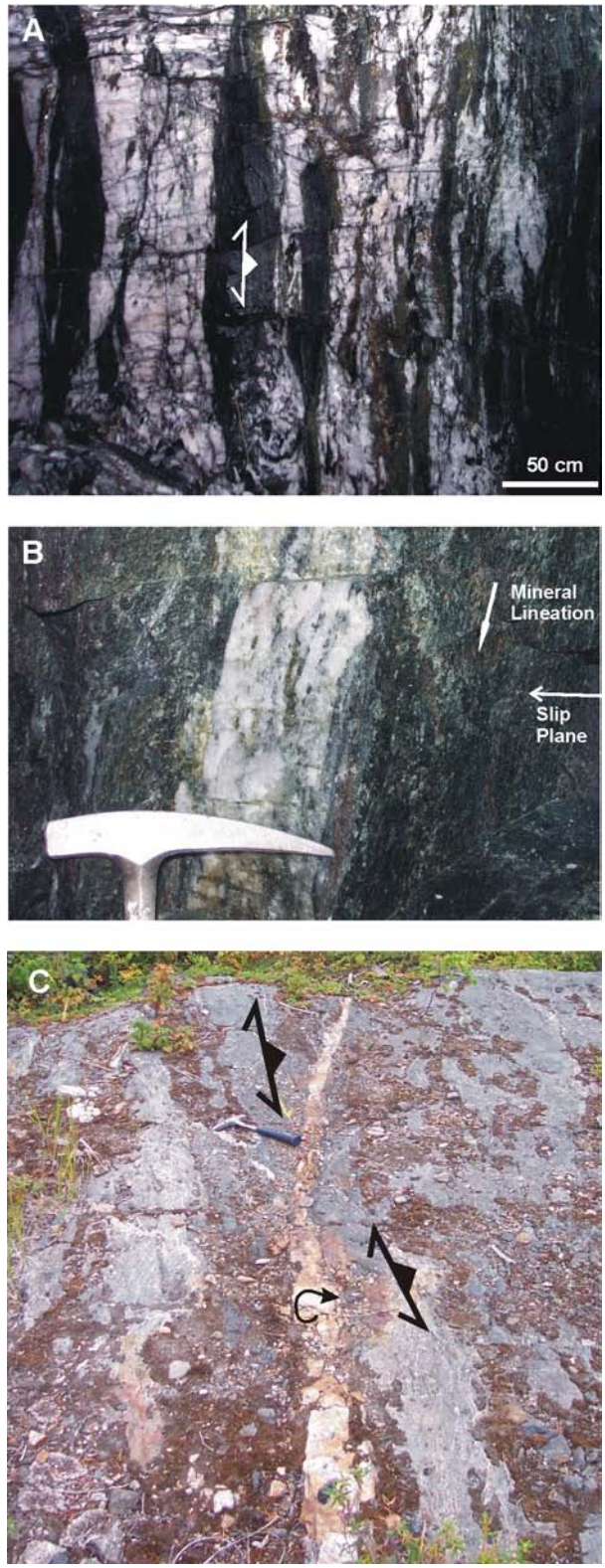

Figure 4 - (A) Vertical view of Lens 2 at the 140 mining level; note the flattened and foliated wall rock fragments within the vein. (B) Detailed view of a striated and lineated slip planes on a vein wall, 140 level. (C) Plan view of vein #19 which cuts the shear zone foliation in a clockwise direction.

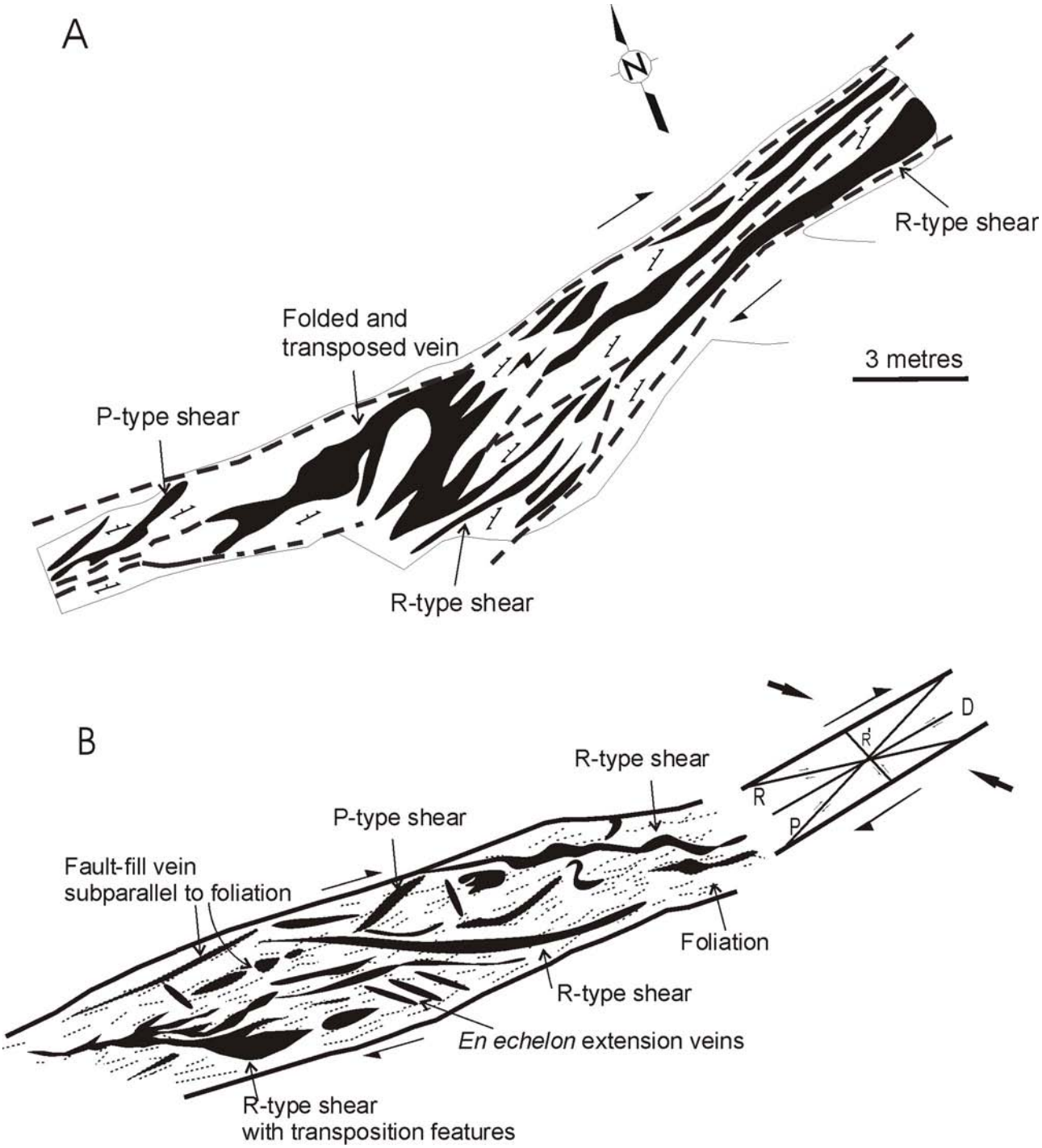

Figure 5 - A) Geologic map of the 140 mining level showing the complexity of the mineralized vein system. B) Composite sketch showing the structural features of the main vein system in Lens 2. The R-type and P-type veins (nomenclature of Mandl, 1988 and Dresen, 1991), cut the foliation at small clockwise and anticlockwise acute angles. In the central part of the shear, transposed veins and quartz boudins result from continuous shearing and deformation of R-type veins. The inset figure shows the pattern of Riedel fractures associated with a dextral shear. The scale is omitted because the sketch is a compilation of several features that were observed in outcrop and underground on levels 140, 280, 550, and 600.

R- and P-type veins and fault-fill veins record evidence of internal deformation. The most common mesoscopic structures are both vertical and lateral boudinage (i.e., "chocolate tablet structure"), transposition within the main foliation, and rare parasitic folds. These folds are mostly dextral and plunge steeply west to northwest.

Underground mine maps show that minor subvertical *en echelon* extension veins are common in Lens 2. These veins have short (<2 m) lateral and vertical extents and lie at high angles to the shear zone boundaries (Figure 5B). They are developed in the most isotropic part of the gabbro, either adjacent to the main mineralized shear zone or within the shear zone at the margins of the main ore-bearing veins. These veins are generally weakly deformed and disposed *en echelon* relative to adjacent slip planes. They probably reflect the original orientation of extension fractures formed in response to the dextral sense of shear along the orebody (Figure 5).

4. Discussion and Conclusions

Cross-cutting overprinting relationships at the Seabee mine show that the shear zones and associated gold-bearing veins and postdate the peak-metamorphism and regional D2 deformation of Lewry *et al.* (1990). The shear zone foliation and lineation occur partly as the inherited and intensified regional L-S fabric and as newly created surfaces (C-S fabrics) that are developed in the most isotropic parts of the host gabbro. The common spatial association of shear zones with narrow felsic and mafic dykes suggests that lithological contacts promoted development and propagations of shear zones.

The Seabee shear zones are dominated by dextral-transcurrent shear-sense indicators (e.g. C-S fabrics, *en echelon* extension veins, and Z-shaped drag folds in gold-quartz veins) on horizontal surfaces, and by steeply west-plunging mineral lineations in vertical cross-sections. Shear zones that have a steeply plunging lineation and horizontal shear indicators can be interpreted as: (i) transpressional shear zones or (ii) as zones of high-angle reverse faulting that were later reactivated as strike-slip faults.

In the transpressional model, strain partitioning is responsible for coexisting coaxial and non-coaxial domains of deformation within a single deformation zone (Sanderson and Marchini, 1984; Dewey *et al.*, 1998). In this model, shortening normal to the shear zone boundaries is accommodated by subvertical extension to produce a steeply plunging stretching lineation. At the same time, the rotational component of the strain is accommodated by subhorizontal transcurrent shearing resulting in structures such as C-S fabrics and a subhorizontal stretching lineation.

At Seabee, neither microscopic structures nor mesoscopic structures viewed on sections parallel to mineral lineation and perpendicular to foliation show any diagnostic features of non-coaxial, rotational strain. However, steeply plunging lineations and striations along the vein walls indicate localized subvertical dip-slip displacement. This suggests that the bulk deformation was partitioned into pure shear domains characterized by a steeply plunging stretching lineation and vertical dip-slip extrusion of the rocks, and simple shear domains characterized by transcurrent dextral shear. Coeval dip-slip and strike-slip movements in the shear zones seem to have been promoted by strain-softened zones such as the biotite-rich schist (see Mount and Suppe, 1987).

Alternatively, mineralized shear zones may have originated as north-dipping, high-angle reverse faults, which were reactivated as dextral strike-slip faults. With the exception of a few quartz veins with steeply-plunging lineations along their margins, however, all shear sense indicators are on subhorizontal surfaces, suggesting a prominent dextral subhorizontal component of shear.

Another alternative interpretation would be the possibility that the Seabee shear zones represent oblique, reverse-dextral shears. A common geometric feature of oblique dip-slip structures is the coexistence of asymmetric structures in both cross-sections and plan view (Lin and William, 1992). At Seabee, because asymmetric structures such as asymptotic schistosity (C-S fabrics) and other features of non-coaxial strain are only developed in plan view, it is unlikely that a simple oblique-slip faulting model was responsible for the finite geometry of the gold-bearing shear zones. Thus, the observed subhorizontal strike-slip displacement which took place at high angles to the steeply west-plunging lineations, combined with the absence of significant subvertical displacement is more consistent with the transpressive model of Sanderson and Marchini (1984).

In conclusion, the present preliminary study suggests that the main mineralized shear zones and associated quartz veins at Seabee are most likely zones of dextral transpression. In this model, the relatively undeformed gabbro lenses between the narrow shear zones acted as converging rigid blocks.

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