PROPERTY DESCRIPTIONS

The magmatic and structural setting of the Brewery Creek gold mine, central Yukon

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ABSTRACT

The Brewery Creek gold mine (13.3 Mt @ 1.44 g/t Au) is a bulk tonnage, heap leach operation located 57 km east of Dawson City, Yukon. The deposit lies on the northeastern side of the Tintina Fault and within Selwyn Basin.

Gold mineralization is hosted by intrusions of the mid-Cretaceous Tombstone Plutonic Suite (TPS), and Silurian to Carboniferous clastic metasedimentary rocks of the Steel Formation and Earn Group. The sedimentary rocks are faulted and variably folded, however they display poor cleavage development. The TPS intrusions are also faulted and contain rafts of argillaceous sedimentary rock. No regional ductile fabrics were observed to crosscut the intrusions. Five phases of intrusion have been recognized; these are 'raft' monzonite, feldspar porphyry (FP1), biotite monzonite, a second phase of feldspar porphyry (FP2), and a pyroxenite.

The most important feature at Brewery Creek is a linear zone of monzonite intrusions, faulting and mineralization termed the Reserve trend. This zone trends west-northwest and has a moderate dip to the south. A number of stages and orientations of faulting have been identified along the Reserve trend; lithological relationships suggest a substantial amount of vertical movement occurred post-TPS emplacement and pre- to syn-mineralization.

RÉSUMÉ

La mine d'or Brewery Creek (13,3 Mt titrant 1,44 g/t Au) est une exploitation de lixiviation en tas à fort tonnage qui est située à 57 km à l'est de la ville de Dawson (territoire du Yukon). Le gisement repose sur le côté nord-est de la faille de Tintina, dans le basin de Selwyn.

La minéralisation aurifère est présente dans les intrusions de la Suite plutonique de Tombstone (SPT) du Crétacé moyen ainsi que dans les roches métasédimentaires clastiques du Silurien au Carbonifère de la Formation de Steel et du Groupe d'Earn. Les roches sédimentaires sont déformées par des failles et des plis d'intensité variable, toutefois elles présentent une schistosité mal développée. Les intrusions de la SPT sont aussi affectées par des failles et contiennent des inclusions de roche sédimentaire argileuse. On n'a pas observé de fabrique ductile régionale recoupant les intrusions. On peut identifier cinq phases intrusives : monzonite «à inclusions», porphyre feldspathique (PFI), monzonite à biotite, une seconde phase de porphyre feldspathique (PFII) et une pyroxénite.

L'élément le plus important à Brewery Creek est une zone linéaire, connue sous le nom d'axe Reserve, qui semble contrôler l'emplacement d'intrusifs de monzonite, le dévelopment de failles et la minéralisation. Cette zone a une direction ouest-nord-ouest et un pendage modéré vers le sud. Les relations lithologiques de part et d'autre de cet axe indiquent qu'un déplacement vertical important a eu lieu après la mise en place de la SPT et avant ou en même temps que la minéralisation.

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INTRODUCTION

The Brewery Creek gold mine (13.3 Mt @ 1.44 g/t Au; Diment and Craig, 1999) is a bulk tonnage, heap leach operation located 57 km east of Dawson City, Yukon Territory, Canada (Fig. 1). The ownership and exploration history of the property has been documented by Diment and Craig (1999). The deposit lies on the northeastern side of the Tintina Fault, and within Selwyn Basin. To date, all mining has taken place along a linear structure known as the Reserve trend. This trend is a 500-700 m wide belt of monzonite intrusions and faults, along which 95% of the gold reserves at Brewery Creek are located. The Reserve trend extends for at least 12 km from west to east, contains a number of complex fault orientations and has an overall moderate southerly dip. Minor gold mineralization is found in skarn, sheeted veins and disseminated bodies outside the Reserve trend.

There are a number of open pits located along the Reserve trend. From west to east these include Blue, Canadian, Upper and Lower Fosters, Kokanee (K1 – K4), Golden (North and South), and Lucky. Access during this study was limited to Blue, Upper Fosters, K3, K4, Golden (North and South), and Lucky (Fig. 2).

The aims of this paper are to:

- document the intrusion emplacement history along the Reserve trend;
- describe the structural orientations which control the location of alteration and mineralization assemblages; and
- propose a preliminary geological history for the deposit.

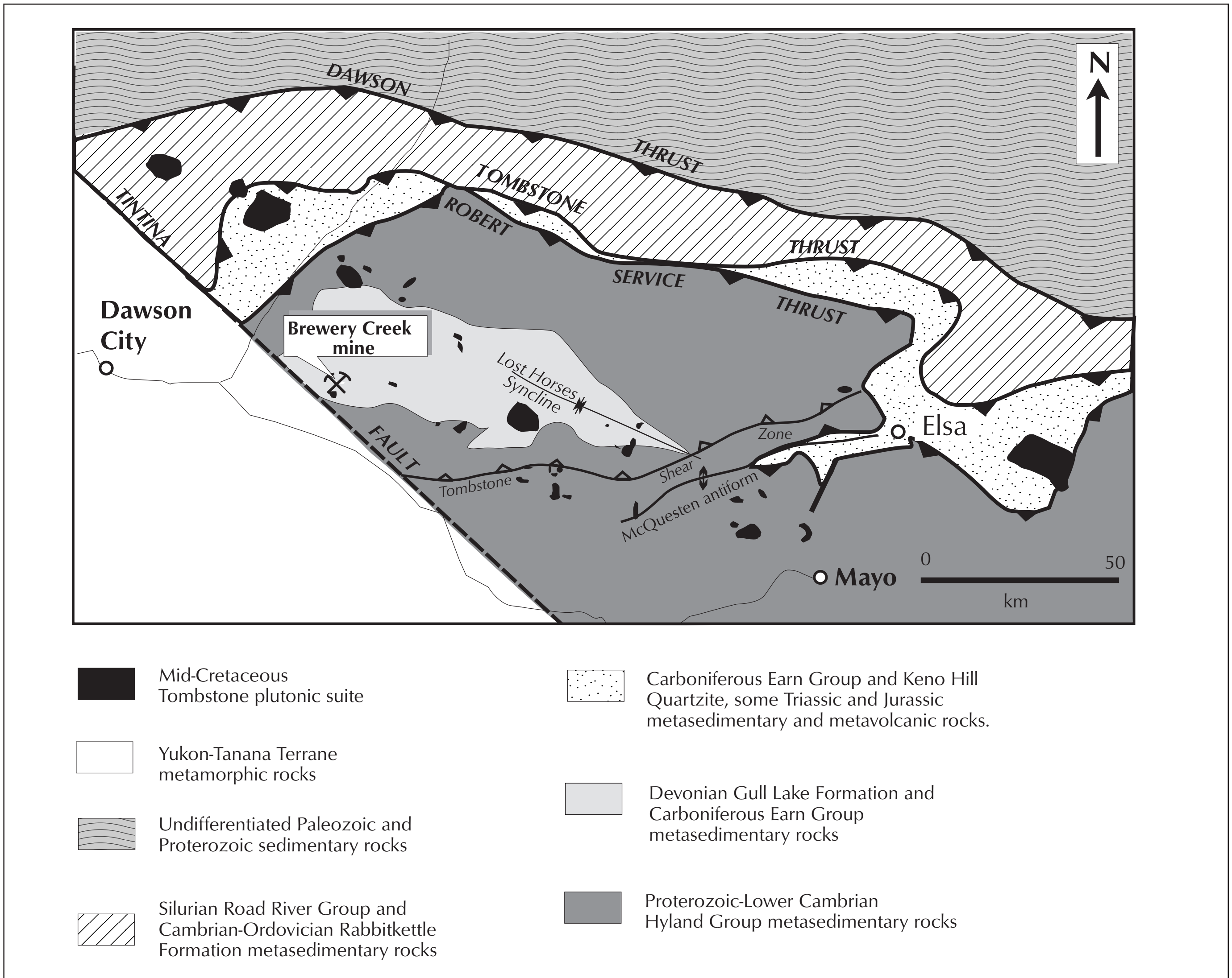


Figure 1. *A geological interpretation of the Selwyn Basin in the Dawson-Mayo area (modified from Murphy, 1997).*

REGIONAL GEOLOGY

The Brewery Creek deposit lies within Neoproterozoic to Carboniferous sedimentary rocks of the Selwyn Basin (Fig. 1). To the north and west this package is bound by the Dawson Thrust. To the south, the Tintina Fault juxtaposes sedimentary rocks of the Selwyn Basin against deformed and metamorphosed rocks of the Yukon-Tanana Terrane. Post-Cretaceous dextral movement along the Tintina Fault is interpreted to be as much as 450 km (Gabrielse and Yorath, 1991).

The structural history of the Selwyn Basin prior to the mid-Cretaceous in the McQuesten River region has been documented by Murphy (1997). A number of basin-scale features have been recognized (see Figure 1) including: (1) the Dawson Thrust, a major structure of uncertain age; (2) the Lost Horses syncline, which has been broadly bracketed between Devonian and mid-Cretaceous; (3) the Jura-Cretaceous Robert Service Thrust, which is crosscut by (4) the Tombstone high strain zone and the Tombstone Thrust, which are Jura-Cretaceous in age; and (5) the Jura-Cretaceous McQuesten antiform, which folds all of the structures listed above.

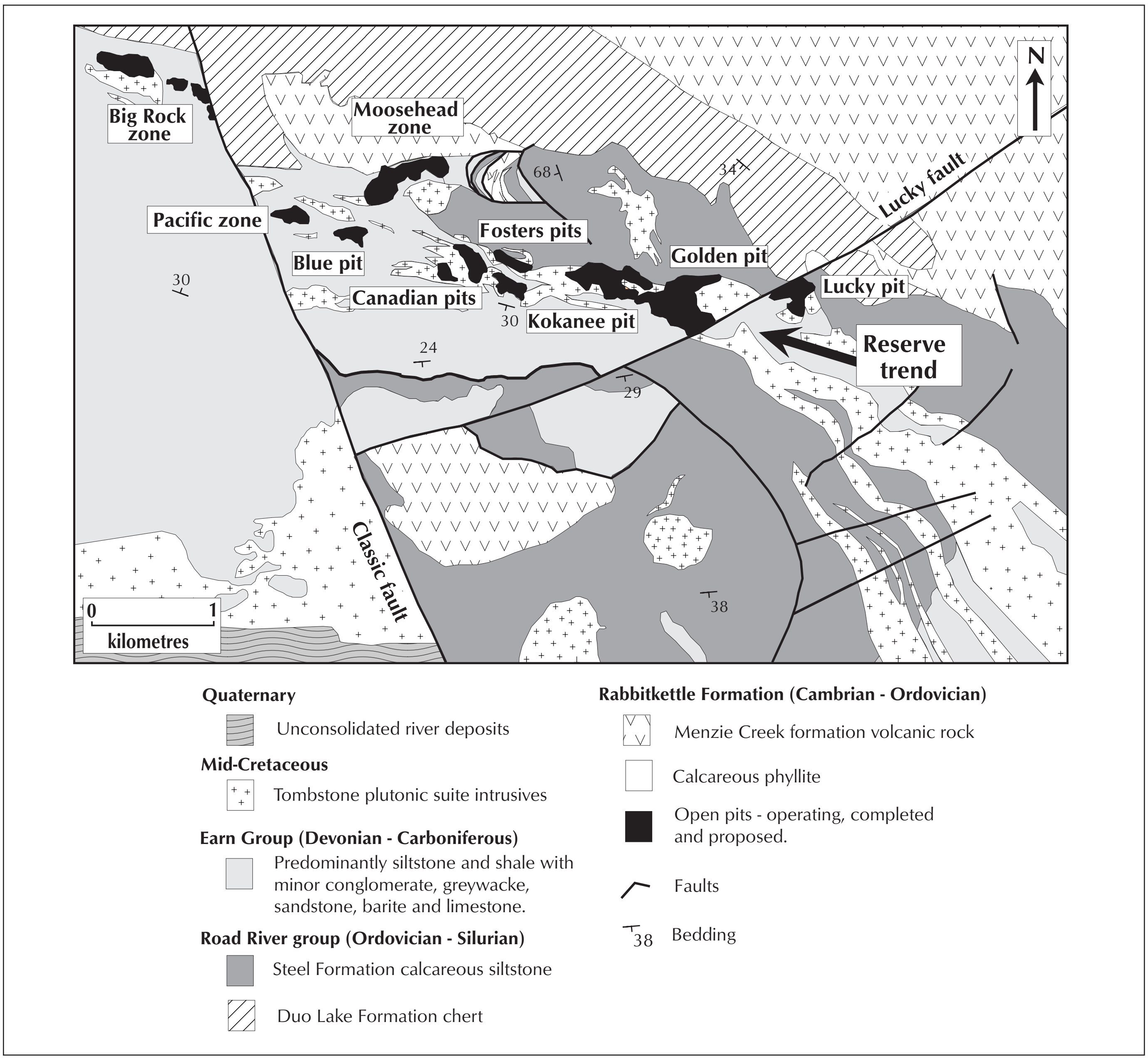


Figure 2. *A geological interpretation of the Brewery Creek property (adapted from an unpublished 1998 Viceroy Resources Ltd. company report). Note the orientation of the Reserve trend and the location of open pits along this trend.*

Mid-Cretaceous (90-95 Ma) magmatism produced a diverse suite of intrusions known as the Tombstone Plutonic Suite (TPS). TPS intrusions range from less abundant mafic phases (clinopyroxenite, gabbro, diorite) through to more common felsic end-members (granodiorite, granite; Mortensen et al., 1996).

The TPS is associated with a broad range of gold mineralization styles. These include quartz-sulphide veins, sheeted veins, stockwork, replacements and disseminated mineralization in felsic intrusive rocks, and in both carbonate and non-carbonate metasedimentary rock (Poulsen et al., 1997).

PROPERTY GEOLOGY

Previous workers (Diment and Craig, 1999; Diment, 1996; Bremner, 1993-1994) have recognized two major stratigraphic packages of sedimentary rocks at Brewery Creek. These have been correlated with the Silurian Steel Formation and the Carboniferous Earn Group of the Selwyn Basin (Fig. 2). Other comparatively minor stratigraphic units are the Carboniferous to Ordovician Rabbitkettle Formation, including the Menzie Creek formation, and the Ordovician to Silurian Duo Lake Formation.

A variety of distinct phases of intrusive rocks are present at Brewery Creek. These include quartz monzonite, monzonite, syenite and pyroxenite. A quartz monzonite sill has yielded a zircon age of 91.4 ± 0.2 Ma (Diment, 1996), indicating that the intrusions are part of the TPS. The most important intrusions are semi-conformable monzonite sills, which host approximately 80% of known mineralization. The monzonite sills have intruded along the broadly east-oriented Reserve trend.

The rocks at Brewery Creek have undergone a number of stages of deformation. Metre-scale folds are common, however cleavage development is poor. The axis of the regional-scale Lost Horses syncline trends toward Brewery Creek. To date, this structure has not been recognized on the property.

Brittle structures post-date all regional ductile deformation. Intrusive rocks were not observed to be affected by regional ductile fabrics, but they are crosscut by a number of stages of faulting. Notably, Brewery Creek is located close to the Tintina Fault. The orientation of the Reserve trend with respect to the Tintina Fault, combined with dextral offset along the fault, suggests that movement along the Tintina Fault would create a compressive regime at Brewery Creek. Some of the structures identified at Brewery Creek may be directly related to the Tintina Fault.

Gold mineralization is manifested in a wide variety of styles. These include, in order of abundance: (1) structurally controlled mineralization within intrusive rocks; (2) structurally controlled mineralization within non-carbonate sedimentary rocks; (3) decarbonization, brecciation and silicification of carbonate-rich sedimentary rocks; (4) sheeted veins within intrusions; and (5) tremolite skarn.

INTRUSIVE HOST ROCKS

The majority of known mineralization at Brewery Creek is hosted by monzonite sills, which have been emplaced along the Reserve trend and exposed in the Canadian, Fosters, Kokanee, Golden and Lucky pits. These sills occur as elongate intrusions and are only affected by the latest stages of faulting within this trend (see next section). The linear nature of the intrusions (Fig. 2) suggests that sill emplacement may have been partly controlled by structures comprising the Reserve trend. A variety of intrusive rocks have been recognized along this trend. These intrusions are described below and their relationships are summarized in Figure 3.

(1) Raft monzonite (RM). The RM is characterized by the presence of argillaceous metasedimentary (argillite) rafts as xenoliths within the intrusion (Fig. 4). The RM is variably fine- to medium-grained and locally equi-granular, porphyritic or mega-crystic. At outcrop-scale this intrusion is highly variable in composition and contains 5-30% biotite (with phenocrysts 1-3 mm long), 55-40% alkali feldspar, 40-30% plagioclase, minor quartz, and rare amphibole.

The contact between the RM and the host argillite is highly irregular. At the margins of the intrusion, the RM occurs as a number of bedding concordant sills, 2-5 m thick. Toward the centre of the Golden pit the intrusions thicken, are bedding discordant, and host rafts of argillite as xenoliths. The RM was observed to outcrop along the entire length of the Reserve trend. The absence of argillite rafts would hinder the distinction of the RM from the FP1 and BM described below.

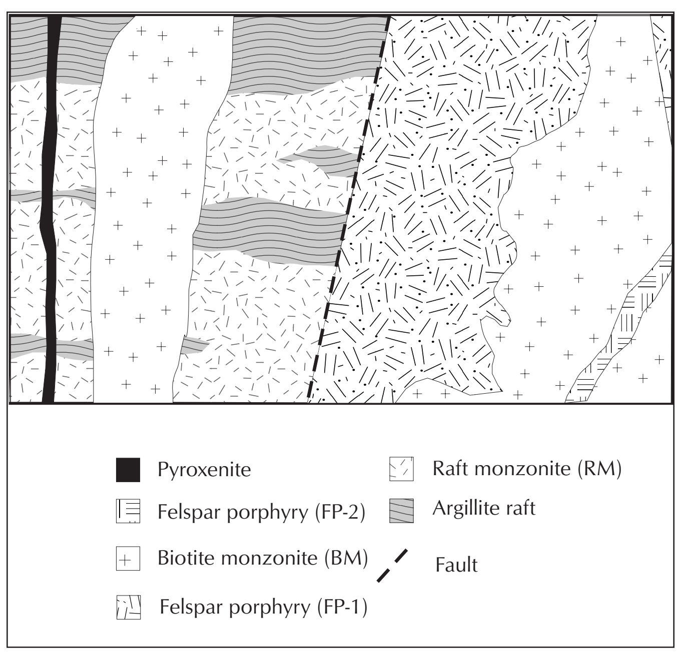


Figure 3. *A schematic cross-section illustrating the overprinting relationships of intrusive rocks identified along the Reserve trend.*

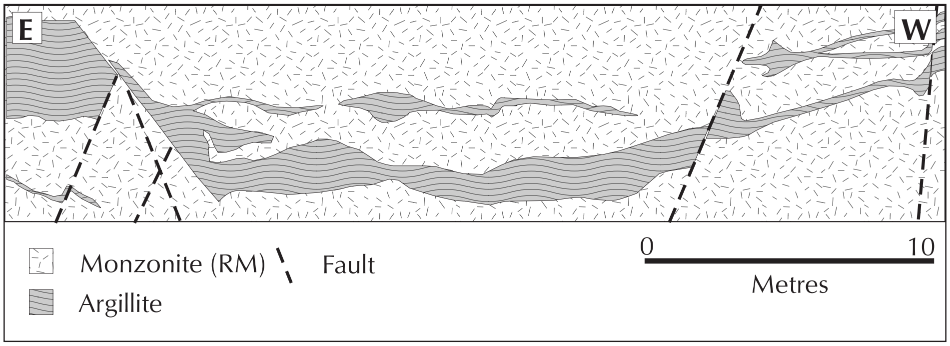


Figure 4. *A sketch of raft monzonite outcropping in the southern wall of south Golden pit (looking south). Note the highly irregular nature of the contacts between monzonite and argillite.*

(2) Feldspar porphyry (FP1). The FP1 intrusion is characterized by the absence of argillite rafts, similar amounts of alkali feldspar and plagioclase, and minor biotite. This fine-grained intrusion is generally porphyritic and is composed of 45% plagioclase, 45% alkali feldspar, 5-7% biotite, 2% quartz and rare hornblende. Feldspar phenocrysts vary between 1 and 5 mm in length. The relationship of FP1 to the RM is uncertain as the contacts between these two intrusions are faulted. This phase was observed to outcrop in the Golden and Kokanee (K3) pits.

(3) Biotite monzonite (BM). The BM is characterized by a high percentage of biotite relative to the other phases of intrusion and the absence of argillite rafts. The BM is a fine-grained and commonly porphyritic unit that contains 10-30% biotite (with phenocrysts 1-3 mm long), 40-50% plagioclase and 30-40% alkali feldspar (phenocrysts are generally 2-5 mm long, but may be up to 15 mm long). Minor quartz, rare hornblende and localized spherical, black xenoliths, containing up to 40% biotite were also noted. The BM intrudes FP1 in the Golden pit. The BM was also observed as a dyke that crosscuts the RM. This intrusion outcrops in Golden, Kokanee (K3, K4), and Blue pits.

(4) Feldspar porphyry dykes (FP2). The FP2 phase of intrusion is characterized by the presence of biotite and absence of quartz and hornblende. This unit is fine grained and porphyritic. The FP2 intrusion borders on a syenite/monzonite composition with 10-20% biotite (with phenocrysts 1-2 mm long), 55-60% alkali feldspar and 25-30% plagioclase (feldspar phenocrysts 1-4 mm long). FP2 is manifested as two dykes that crosscut the BM in the south Golden pit.

(5) Pyroxenite. One occurrence of pyroxenite dyke (30-50 cm wide) was observed in the Golden pit and crosscuts the RM. This intrusion is characterized by a composition of greater than 95% pyroxene. Minor biotite, plagioclase and rare quartz were also noted. The pyroxenite is generally fine grained with pyroxene crystals 1-3 mm long. Although younger than the RM, the relationship of this dyke to all other stages is uncertain. It is also uncertain if this intrusion can be correlated to the TPS or whether it represents an unrelated magmatic event.

DEFORMATION

The Brewery Creek property is dominated by the broadly east-oriented Reserve trend, which contains 95% of known mineralization. Diment (1996, 1999) suggested that this structure might represent a series of imbricate east to east-southeast-trending thrust faults. Analysis of brittle and ductile deformation along the Reserve trend has been undertaken. Shear zone asymmetries and lithological relationships in the Blue pit (Fig. 5) and in the Fosters pit (Fig. 6) suggest a

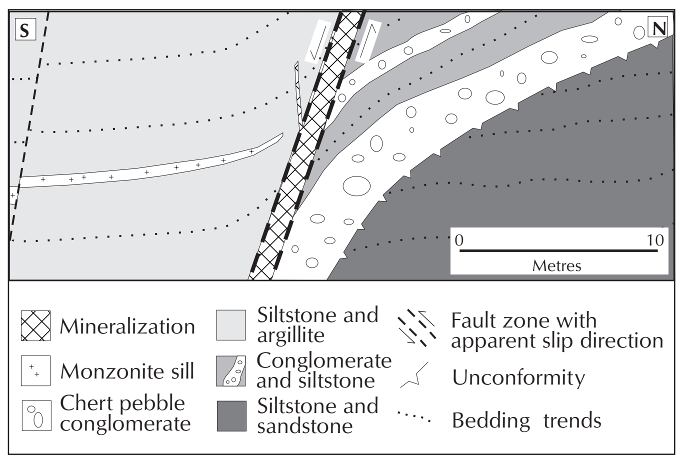


Figure 5. *A sketch of the western wall of Blue pit looking west. Three distinct packages of sedimentary rock were identified. The northern wall of Blue pit is comprised of siltstone interbedded with sandstone, which is unconformably overlain by chert pebble conglomerate interbedded with siltstone. These two units are faulted against siltstone interbedded with argillite and intruded by a number of monzonite sills; these units comprise the southern wall of the pit. Note that the sedimentary rocks, unconformity and intrusion are wrapped into the fault indicating an apparent normal movement. The siltstone, interbedded with argillite and monzonite sills, was not recognized in the northern wall of the pit indicating a minimum offset of 70 m (the height of the pit walls). Note also that a mineralized vein crosscuts this folding (vein not to scale).*

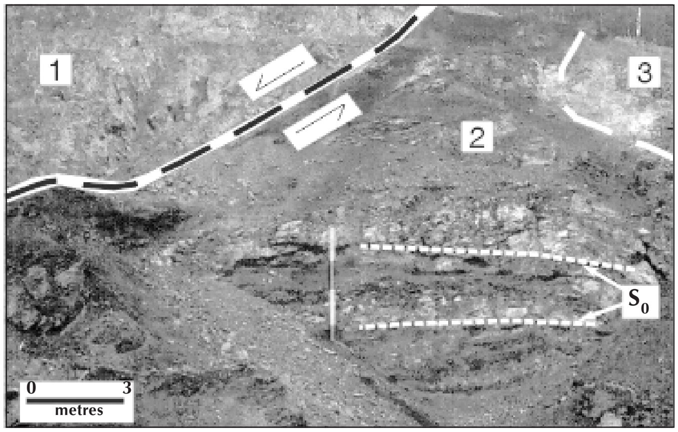


Figure 6. *A photo of a wall in Fosters pit (looking north). A monzonite (1) is faulted against Earn Group sedimentary rocks (2). Shear band asymmetries along the fault suggest normal movement. Drilling indicates that mineralization is restricted to the hanging wall intrusion (R. Diment, pers. comm., 1999). The intrusion (3) in the footwall of the fault is barren.*

substantial component of normal movement (minimum of 70 m). Horizontal slickensides on fault planes along the Reserve trend indicate a component of lateral movement, however the amount of offset is unknown.

To date, there has been no detailed description of the structural history of the Brewery Creek property. Initial fieldwork results indicate a number of phases of deformation, which are described below.

(1) Ductile deformation. Sedimentary rocks at the Brewery Creek property are variably folded, however, as a result of low metamorphic grade and low strain the rocks show poor cleavage development. Folds display wavelengths from centimetres to hundreds of metres and are commonly overturned. Complex geometries and tight folding are common, with the fold axial traces disrupted by late faulting and local refolding (Fig. 7). Intrusive rocks were not observed to be affected by any regional ductile fabrics.

(2) Early development of the Reserve trend. At Brewery Creek, the Reserve trend is typically developed along the contact between the Steel Formation and Earn Group (Fig. 2). The initial development of structures along the Reserve trend that strike west-northwest and dip moderately to the south is inferred as a mechanism for localizing TPS intrusions in a linear belt. The movement sense during the initial development of the Reserve trend is uncertain. The Reserve trend was not observed to be folded.

(3) Thrust faults. North- and west-vergent thrust faults explain observed relationships of Steel Formation overlying Earn Group, and Rabbitkettle Formation outcropping adjacent to Earn Group. The relationship of this thrusting to the early development of the Reserve trend is uncertain. Thrust faults crosscut regional ductile deformation fabrics and TPS intrusions truncate these thrust faults.

(4) Steep structures. Moderately dipping structures formed during the early development of the Reserve trend, and TPS intrusions trending parallel to these structures have been crosscut by steeply orientated, dominantly normal faults and shear zones (Fig. 8). The dominant orientations strike 110°, 150° and 260° with subordinate sets striking at 040-050° and 190°. There are a number of phases and orientations of faulting associated with this stage.

(5) Normal faults. The steep structures described above are truncated by normal faults (Fig. 6) that strike 095-105° and dip moderately to the south. Drilling indicates that the dip of these faults become shallow at depth (R. Diment, pers. comm., 1999).

(6) Lucky fault. The Lucky fault (Fig. 2) truncates alteration and mineralization assemblages that follow the orientation of the steep structures and the normal faults. The Lucky fault trends northeast and displays an apparent sinistral movement of one kilometre, however the dip is uncertain.

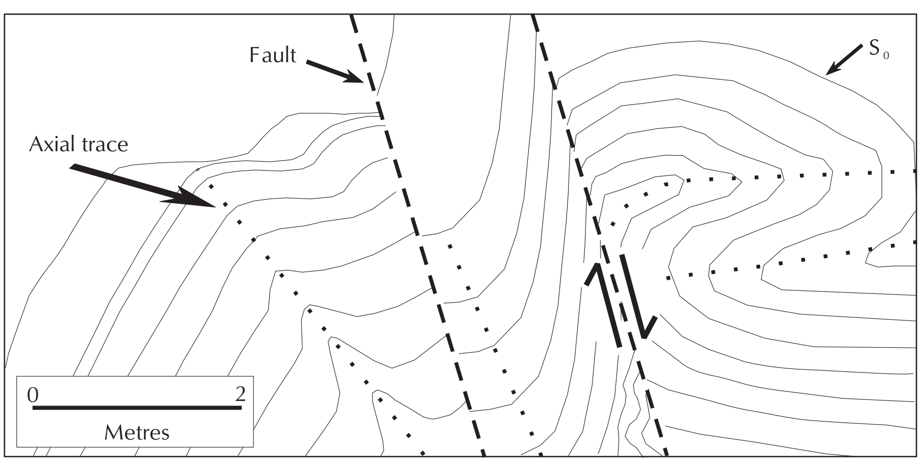


Figure 7. *A sketch of complex fold orientations in Earn Group sedimentary rocks in the northern wall of the Blue pit (looking north).*

(7) Classic fault. The Lucky fault and the Reserve trend are crosscut by the Classic fault (Fig. 2). The Classic fault strikes southeast and displays an apparent dextral movement of one and a half kilometres. Sub-vertical sheeted quartz-pyrite-gold veins trending parallel to this fault suggest a steep dip. Early movement on this structure may pre-date the thrust faulting and/or the steep structures.

STYLES OF GOLD MINERALIZATION ALONG THE RESERVE TREND

Gold mineralization along the Reserve trend is structurally controlled within intrusive and non-carbonate sedimentary rocks.

(1) STRUCTURALLY CONTROLLED MINERALIZATION WITHIN INTRUSIVE ROCKS

This style of mineralization occurs as: (1) pyrite-quartz-gold veins and associated disseminated pyrite and gold; (2) mineralized shear zones and faults; (3) breccia zones with a matrix of massive stibnite and minor quartz (± gold); and (4) sheeted stibnite-quartz (± gold) veins.

The stibnite-quartz (± gold) sheeted veins and the breccia zones may be contemporaneous, however their relationship with the pyrite-quartz-gold veins is uncertain.

At mine-scale, mineralization is hosted by monzonite sills that were emplaced along the Reserve trend. The mineralized zones stretch for more than 12 km along this trend. At outcrop-scale, mineralization is controlled by discrete fault zones that display

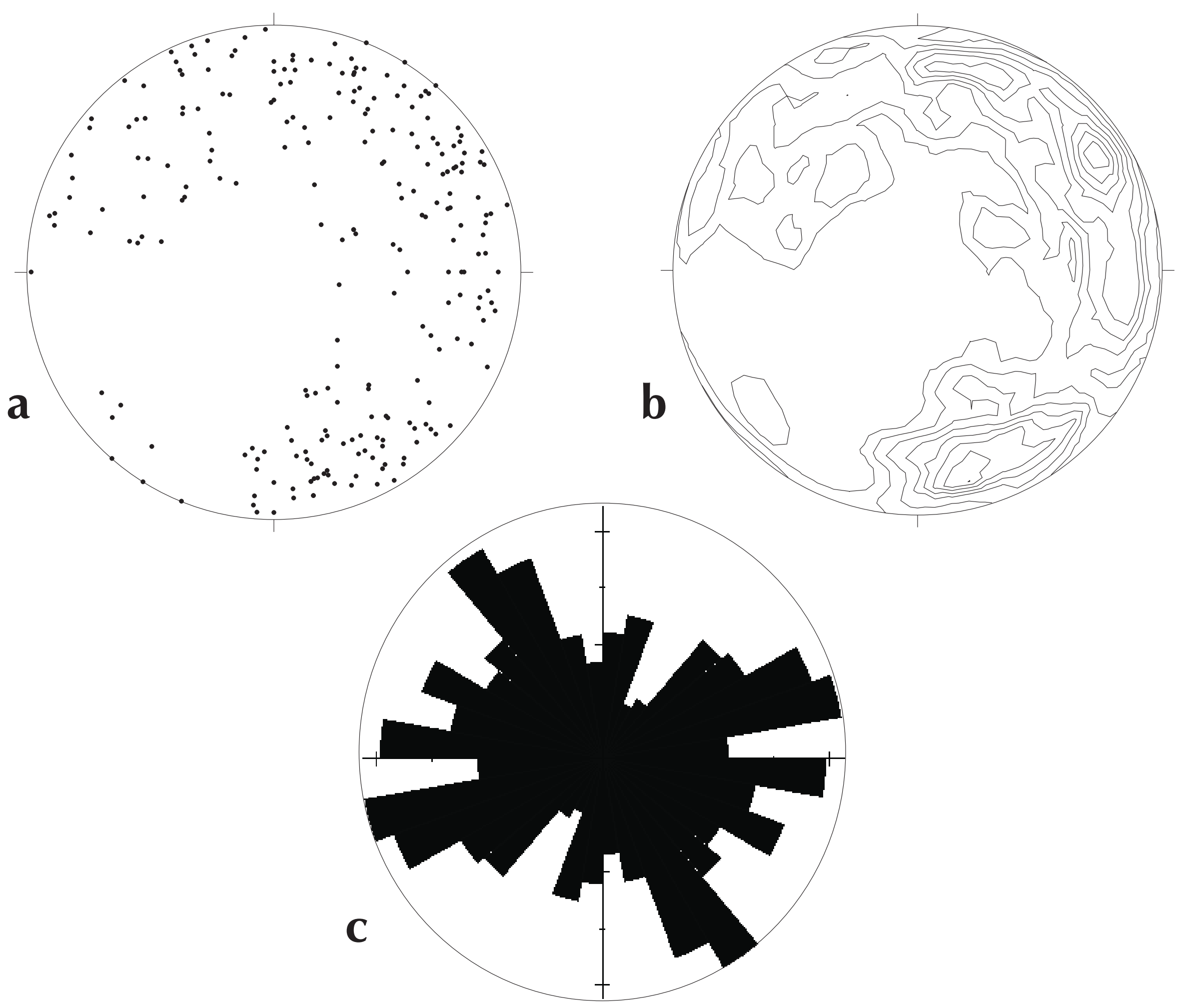


Figure 8. *Equal-area, lower hemisphere stereographic projections showing (a) poles of all fault planes measured along the Reserve trend, (b) a contour plot which illustrates three dominant poles to faults (oriented at 110°, 150° and 260°), and (c) a rose diagram of the strike of the measured fault planes.*

specific orientations (Fig. 8). The sheeted stibnite-quartz (± gold) veins and the individual pyrite-quartz-gold veins parallel these orientations.

In the Fosters pit, mineralization is restricted to the hanging wall of a normal fault. This fault juxtaposes a monzonite sill (hanging wall) against argillite (footwall; Fig. 6). A small monzonite intrusion, which is hosted by the footwall argillite, is barren (R. Diment, pers. comm., 1999). This relationship suggests that either the fault is directly related to mineralization (as a conduit), or that the fault postdates mineralization and potentially highlights a strong brittle structural control on mineralization.

(2) STRUCTURALLY CONTROLLED MINERALIZATION WITHIN NON-CARBONATE SEDIMENTARY ROCKS.

Mineralization within the Blue pit is manifested as disseminated gold in argillaceous sedimentary rocks. It is controlled by brittle structures and associated with strong argillic alteration, and breccias infilled with massive stibnite and sporadic gold. In the Blue pit, the main structural feature is the Reserve trend, which occurs as a discrete fault striking 060°, that dips moderately to the south. Bedding immediately adjacent to this structure has been folded into the fault and indicates normal movement. A vein displaying argillic alteration similar to the main ore zone was observed to crosscut this folding (Fig. 5).

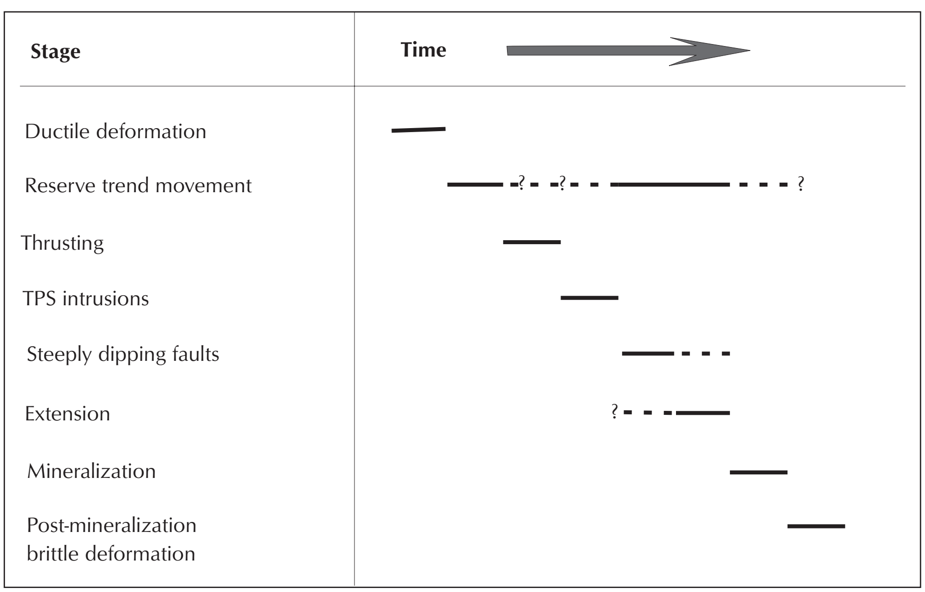
DISCUSSION

Initial fieldwork at Brewery Creek has revealed a number of important relationships from which a preliminary geological history has been established. A geological history for the Brewery Creek property is proposed below and summarized in Table 1.

Following Jura-Cretaceous regional ductile deformation, the first events recorded at Brewery Creek are the early development of structures that comprise the Reserve trend and major north- and west-vergent thrust faults. The relationship between the Reserve trend and thrusting is uncertain. It is possible that the initial development of the Reserve trend may have been triggered by the same compressive regime that generated the thrust faults. Subsequent movement along the Reserve trend may have continued through to the final stages of deformation, intrusion emplacement and gold mineralization (Table 1). Both the Reserve trend and the thrust faults truncate regional ductile fabrics.

The development of the Reserve trend provided a structural pathway for the emplacement of TPS intrusions. A variety of intrusive phases were identified along the Reserve trend and include (i) raft monzonite (RM), (ii) felspar porphyry (FP1), (iii) biotite monzonite (BM), (iv) feldspar porphyry (FP2), and (v)

Table 1. *A paragenetic chart displaying the interpreted geological history of the Reserve trend following Jura-Cretaceous deformation.*



pyroxenite. However, limited outcrop of the FP2 and pyroxenite makes their position in the geological history uncertain.

The RM, FP1 and BM are crosscut by a number of steep faults and shear zones. These steep structures appear to be bound at depth by normal (possibly extensional) 'flat bottomed' faults. It is unclear if the steep faults are truncated by normal faults or if the steep faults developed as a result of collapse during extension.

Gold mineralization is hosted by the steep structures and normal faults. A mineralized vein crosscuts bedding that has been rotated into the main structure in the Blue pit (Fig. 5). These relationships suggest that significant movement along the Reserve trend post-dates TPS emplacement and is pre- to syn-mineralization.

Post-mineralization brittle deformation resulted in the development of the sinistral Lucky fault (Fig. 2). Mineralization in Golden pit and Lucky pit is separated by this fault. The Lucky fault and the Reserve trend are crosscut by the Classic fault.

CONCLUSIONS

The following conclusions can be summarized from the geological history.

- The TPS intrusive history along the Reserve trend at Brewery Creek is complex. Five phases of intrusion have been recognized; these are raft monzonite, feldspar porphyry (FP1), biotite monzonite, a second phase of feldspar porphyry (FP2), and a pyroxenite.
- Mineralization at Brewery Creek is strongly controlled by brittle structures. The dominant structure is the Reserve trend, which has a long history of movement. This structure provided a pathway for the emplacement of TPS intrusions and for focussing gold-bearing fluids.
- Relationships in the Blue pit indicate that substantial movement along the Reserve trend has occurred post TPS emplacement, and pre- to syn-mineralization.

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