Alteration zonation, veining and mineralization associated with the Wernecke Breccias at Slab Creek, Yukon Territory, Canada

Melanie Brookes and Tim Baker[1]
James Cook University[1]

Julie Hunt[2]
Yukon Geology Program

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ABSTRACT

Detailed vertical-face mapping of 'Slab Creek' was carried out in the summer of 2001 to evaluate the relations of Wernecke Breccia bodies with alteration, veining and iron oxide-copper-gold mineralization. Slab Creek is situated near the 'Slab' mineral occurrence in the Bonnet Plume River district of the Wernecke Mountains. Meta-sedimentary rocks in the area consist of meta-siltstone, meta-silty dolomite and phyllite of the lower succession of the Early Proterozoic Wernecke Supergroup, known as the Fairchild Lake Group. These rocks were folded and metamorphosed to lower greenschist facies, and were subsequently intruded by the Wernecke Breccias during the Mid Proterozoic. Three alteration zones can be recognized within Slab Creek, an inner feldspar zone coinciding with the large breccia bodies, surrounded by a chlorite-quartz-carbonate zone, grading outward into a sericite-chlorite zone. Alteration, veining and mineralization is most intense within the albite alteration zone where iron oxide-copper-gold (cobalt-uranium) mineralization is disseminated and occurs as vein infill.

RÉSUMÉ

Au cours de l'été 2001, on a dressé une carte détaillée de la paroi verticale au « ruisseau Slab » afin d'établir les relations entre les corps de brèche de Wernecke et l'altération, la disposition des filons ainsi que la minéralisation en oxyde de fer-cuivre-or. Le ruisseau Slab est situé à proximité de l'occurrence minérale « Slab », dans la région de la rivière Bonnet Plume, des monts Wernecke. Les roches métasédimentaires dans la région sont du métasiltstone, de la dolomie silteuse métamorphisée et du phyllade de la succession inférieure du Supergroupe de Wernecke (Groupe de Fairchild Lake), qui date du Protérozoïque précoce. Ces roches ont été plissées et métamorphisées au faciès des schistes verts inférieur; elles ont été ultérieurement pénétrées par les brèches de Wernecke pendant le Protérozoïque moyen. On peut reconnaître trois zones d'altération au ruisseau Slab : une zone intérieure d'albite recouvrant les gros corps de brèche, qui est entourée par une zone de chlorite-quartz-carbonates passant vers l'extérieur à une zone de séricite-chlorite. L'altération, la disposition des filons et la minéralisation sont les plus marquées dans la zone d'altération en albite, où la minéralisation en oxyde de fer-cuivre-or (cobalte-uranium) est disséminée et se présente sous forme de matériaux de remplissage de filons.

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[1] *Economic Geology Research Unit, James Cook University, Townsville, Queensland, Australia, tim.baker@jcu.edu.au*

[2] *Yukon Geology Program, 300-345 Main Street, Whitehorse, Yukon, Canada Y1A 2B6. Current address: Economic Geology Research Unit, James Cook University, Townsville, Queensland, Australia, julie.hunt@jcu.edu.au*

INTRODUCTION

'Slab Creek' is located on NTS map sheet 106E/1 as a tributary of the Bonnet Plume River, adjacent to an area unofficially known as 'Slab Mountain' (Fig. 1; Fig. 2 of Hunt et al., this volume). Approximately 150 km northeast of the town of Mayo, the Slab Mountain area is isolated and mountainous, with elevations of 560 to 1500 m above sea level. The geomorphology and remoteness of the area permits only access by air during the summer months, and by vehicle along the Wind River Trail during the winter (Hunt et al., this volume).

The region is host to numerous sub-economic occurrences of iron oxide, copper, gold, uranium and cobalt. Mineral exploration programs carried out in the region since the 1960s recognized a correlation between mineralization and extensive breccia bodies (Archer and Schmidt, 1978). More recent work carried out by Newmont Exploration Ltd. from 1994 to 1997 resulted in a 1:5000-scale geological and lithological interpretation of the Slab Mountain area. This map formed the basis on which detailed mapping of Slab Creek was undertaken. Vertical exposure of up to 50 m in the 'Canyon Zone' of Slab Creek allowed 1:400-scale mapping of geology, alteration, veining and mineralization along horizontal intervals totalling 630 m in length (Figs. 2a and 2b). Intervals were measured in 10-m increments along base lines from which detailed mapping of each face was made.

The purpose of this study was to determine the association between alteration, veining and mineralization with respect to that of the Slab Creek breccia bodies. The orientation of veins, crosscutting relationships, relative timing of mineralization and alteration styles, and their distribution were mapped and sampled. This paper primarily covers field observations with petrographic and geochemical data to follow in April of 2002 in the form of a fourth year Honours thesis, currently being completed at James Cook University, Australia.

REGIONAL GEOLOGY

The Wernecke Mountains consist of meta-sedimentary rocks, meta-volcanic rocks, igneous intrusive rocks and breccias. Sedimentation took place throughout the Early Proterozoic to Palaeozoic and was punctuated by

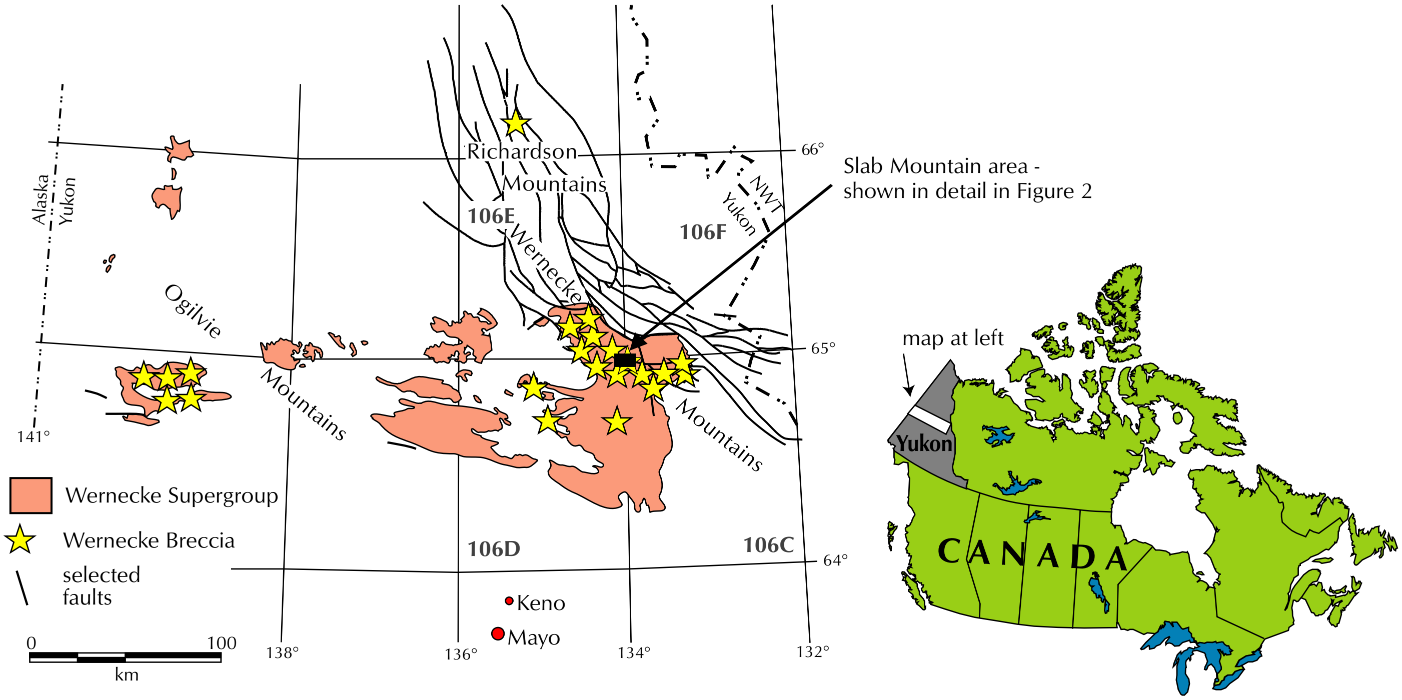


Figure 1. Location of the Slab Mountain map area and distribution of Wernecke Breccia occurrences and Wernecke Supergroup rocks in the Yukon (Hunt, this volume, modified from Thorkelson (2000)).

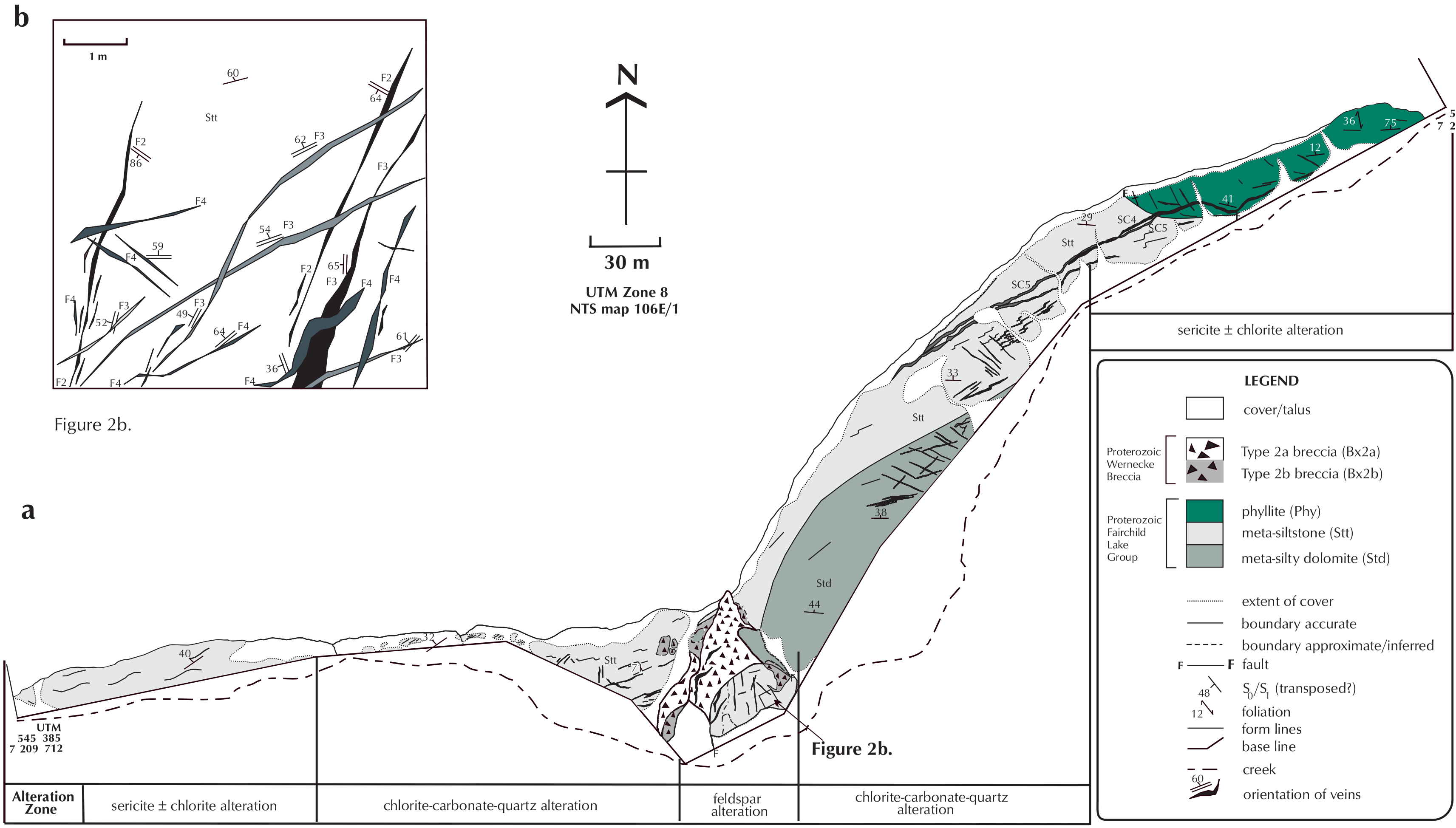


Figure 2. *(a) Near vertical face map of the Slab Creek showing 'Canyon zone' general geology and alteration zones (from Hunt et al., this volume). For explanation of vein stages SC4 and SC5 in the sericite-chlorite alteration zone see Figure 5. (b) Inset showing meta-siltstone of the feldspar alteration zone and crosscutting vein relationships typical of this alteration zone. Veins were mapped in the vertical plane and orientated in the horizontal plane. Feldspar alteration zone vein stages (see also Fig. 7): F2=feldspar ± quartz, F3=carbonate ± quartz, F4=chalcopyrite-magnetite-carbonate-quartz ± feldspar and F5=chlorite-carbonate-quartz.*

numerous phases of deformation, igneous activity, metasomatism and mineralization (see Fig. 3 of Hunt et al., this volume; Thorkelson et al., 2000).

The oldest rocks in the region are that of the Wernecke Supergroup. These rocks were deposited during the Early Proterozoic and are interpreted to unconformably overlie a crystalline basement of Archean or Early Proterozoic age (Thorkelson et al., 2000). The Wernecke Supergroup comprises the lowermost Fairchild Lake Group, middle Quartet Group and upper Gillespie Lake Group. The Wernecke Supergroup is ~14 km thick and as a whole, represents two carbonate-dominated cycles, of which the deposition of siltstone, shale, sandstone and dolostone represent initial basin development followed by subsidence and marine transgression (Delaney, 1981).

Intrusion of dioritic to syenitic dykes and stocks (the Bonnet Plume River Intrusions ~1.72 Ga), and undated biotite lamprophyre, possibly took place prior to the onset of a southeast-directed compression in the Racklan Orogeny (Thorkelson et al., 2001; Gabrielse, 1967). The 'Slab volcanics' (possibly a comagmatic extrusive component of the Bonnet Plume River Intrusions) is preserved as a single down-dropped block at the Slab Mountain mineral occurrence (Yukon MINFILE, 2001, 106D 070). The undated Slab volcanics exist as a megaclast (0.25 x 0.6 km) within an extensive brecciated zone of Slab Mountain. It is assumed that uplift and erosion associated with orogenesis left no in-situ remnants of the Slab volcanics (Thorkelson, 2000).

Individual breccia zones collectively form an extensive breccia system covering 3500 km^2 (Archer and Schmidt, 1978). Previous terminology of the breccias has included 'pre-breccia', 'slurry', 'homolithic', 'typical', 'Wernecke', 'colourful' and 'heterolithic' breccia (Archer and Schmidt, 1978; Laznicka and Edwards, 1979; Laznicka and Gaboury, 1988). Mapping carried out this summer by Hunt et al. (this volume) defined two breccia types, herein termed Type 1 and Type 2 breccias. In the Canyon zone of Slab Creek, Type 2 breccia was recognized and further divided into Type 2a and 2b breccias on the basis of crosscutting relationships (see Fig. 2). The breccias have been dated at ~1.6 Ga using U-Pb dating on titanite (Thorkelson et al., 2000). Clasts of folded, metamorphosed sedimentary rocks, dykes and sills, and the Slab volcanics further constrain the relative timing of brecciation.

The Pinguicula Group unconformably overlies the brecciated, sheared and faulted Wernecke Supergroup. Sedimentation within a basinal to platformal environment during the Middle Proterozoic resulted in the deposition of carbonate and siliciclastic rocks that were intruded by the Hart River sills at ~1.38 Ga and later by the Bear River dykes at ~1.27 Ga (Thorkelson et al., 2001). Unconformably overlying the Pinguicula Group is the Hematite Creek Group. The uncomformity represents a hiatus in which sedimentation ceased for some 300 million years, recommencing around 1033 Ma (Thorkelson, 2000). The Hematite Creek Group consists of shallow-water carbonates and clastics derived largely from rocks affected by the Grenvillian Orogeny (~1250-1000 Ma; Hoffman, 1989). The Hematite Creek Group, older Pinguicula Group and localized portions of the Wernecke Supergroup were later folded and thrust faulted during the Corn Orogeny, possibly a late phase of Grenvillian orogenesis (Thorkelson, 2000).

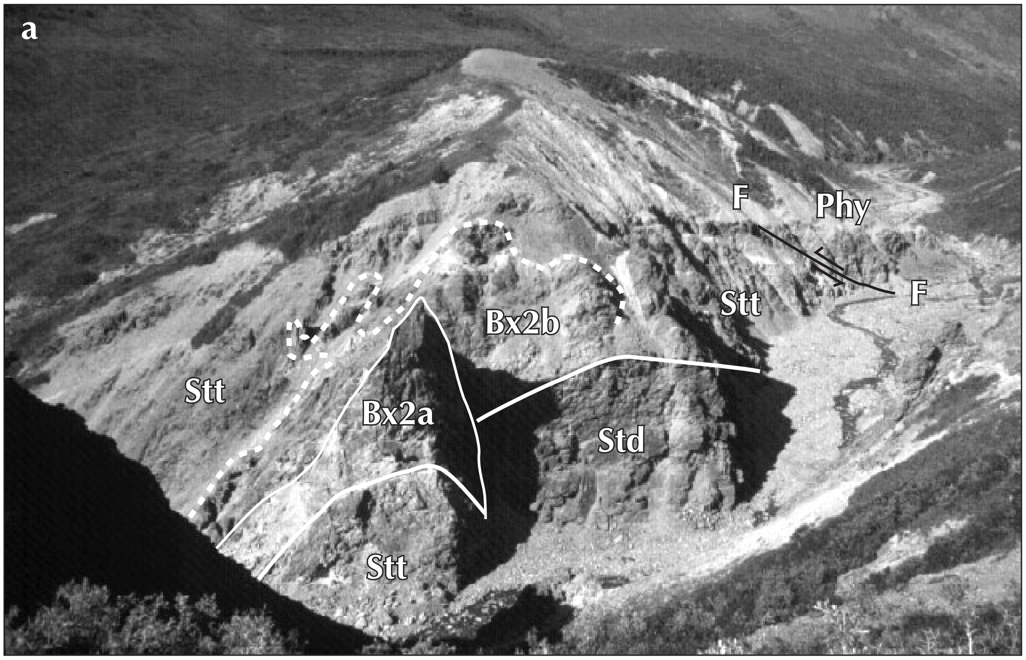
The Late Proterozoic (~755 Ma) saw the deposition of the Windemere Supergroup as two distinct sedimentary packages, the Lower and Upper Rapitan groups, both of which are divided into several formations. The Lower Rapitan Group consists of tillites, whilst the Upper Rapitan Group consists of three clastic carbonate cycles. The Windemere Supergroup is overlain by dolostone, arenite, conglomerate and siltstone of Upper Proterozoic to Lower Paleozoic age. In the western portion of the Wernecke Mountains, mostly shelf environment carbonates and clastics of Cambro-Devonian age overlie the Werenecke Supergroup. The Laramide Orogeny of the Mesozoic to Early Tertiary produced large-scale folding that affected all geological units, with more localized thrust faulting.

LOCAL GEOLOGY

The meta-sedimentary rocks of Slab Creek are part of the lowermost sedimentary succession of the Early Proterozoic Wernecke Supergroup, the Fairchild Lake Group (see Fig. 2 of Hunt et al., this volume). Outcrop in the study area extends over approximately 650 m and runs parallel to the canyon forming Slab Creek, in which the rocks are exposed to a height of up to 50 m (Fig. 3a). A thin cover, commonly less than 5 m, marks the boundary between strata of the Fairchild Lake Group and that of overlying, unconsolidated Quarternary glacial sediments.

STRUCTURE

Deformation, associated with Racklan orogenesis, accompanied lower greenschist facies metamorphism and



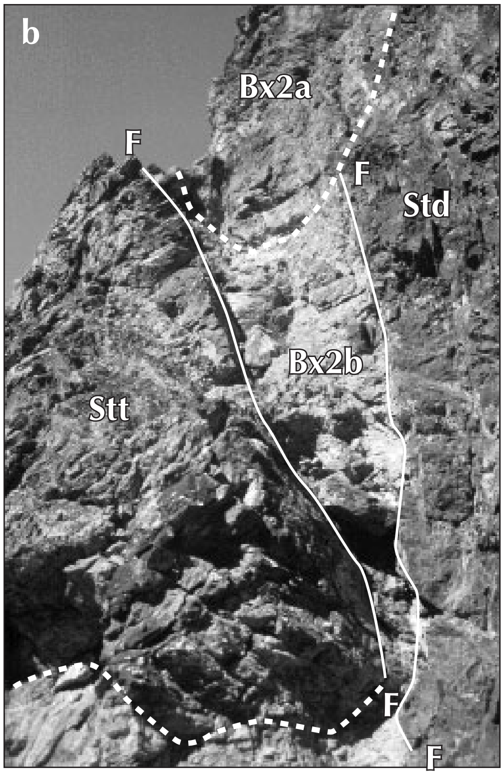


Figure 3. *(a) 'Canyon Zone' of Slab Creek, looking north. Scale east to west is approximately 600 m. Phy = phyllite; other abbreviations, see below. (b) Lithological contacts between Type 2a breccia (Bx2a), feldspathically altered meta-siltstone (Stt) and meta-silty dolomite (Std; dashed lines). Their faulted margins (F-F) are intruded by Type 2b breccia (Bx2b; full lines). Outcrop is approximately 7 m in height.*

resulted in schistosity, crenulations and kink banding of the more micaceous meta-sedimentary rocks of Slab Creek (Brideau et al., this volume). Compositional layering of the meta-sedimentary rocks has a northerly trend, dipping shallowly at the distal margins of the outcrop and gradually steepening toward the central brecciated zone (Fig. 2a). Both brittle faulting and ductile shearing postdate the layering. East-trending faults are evident as sharp contacts and fault gouge between the meta-siltstone and meta-silty dolomite, and meta-siltstone and Type 2a breccia sits within these faulted margins (Fig. 3b). At the far-eastern end of the outcrop, sinistral shearing has juxtaposed the fine, micaceous phyllite with meta-siltstone.

STRATIGRAPHY

Meta-siltstone of Slab Creek consists of finely to very finely laminated, compositional layering of micaceous quartz-rich silt and carbonate-quartz-rich layers that vary in colour from dark grey to off white, respectively. Relict graded bedding gives some direction of younging, however the compositional layering may have been transposed. The presence of chloritoid porphyroblasts (<3 mm) is indicative of the lower greenschist facies metamorphic grade of the area. Chlorite is also common, however it is unclear whether this relates to regional metamorphism or hydrothermal activity.

Porphyroblastic phyllite crops out for approximately 100 m toward the eastern end of the section (Fig. 2a). The contact is marked by an area of high strain associated with folding and shearing where the phyllite has been juxtaposed against the meta-siltstone. The light-green coloured phyllite consists of fine- to medium-grained micas and quartz, mineralogically differentiated to form intercalated chlorite-muscovite and muscovite-rich bands averaging 3 to 10 mm in width.

A sharp contact defines the boundary between the meta-siltstone and that of a lower dolomitic unit containing silt-dominated layers (meta-silty dolomite). The meta-silty dolomite is crudely layered with vague original laminations 10-30 mm in thickness. Along weathering surfaces, oxidation within the more dolomitic layers has produced a deep, earthy red colour, while the more silty layers remain dark to light grey.

BRECCIA BODIES

The lithological units of Slab Creek are host to two discordant breccia bodies that together cover a 50-m area. The breccias form the core of the Slab Creek exposure. Type 2a breccia is the most prominent feature of the study area, outcropping to a height of over 40 m and contacting sharply with that of the surrounding country rock. A later phase of breccia, termed Type 2b breccia, is observed to extensively finger into the earlier breccia body and meta-sedimentary rocks.

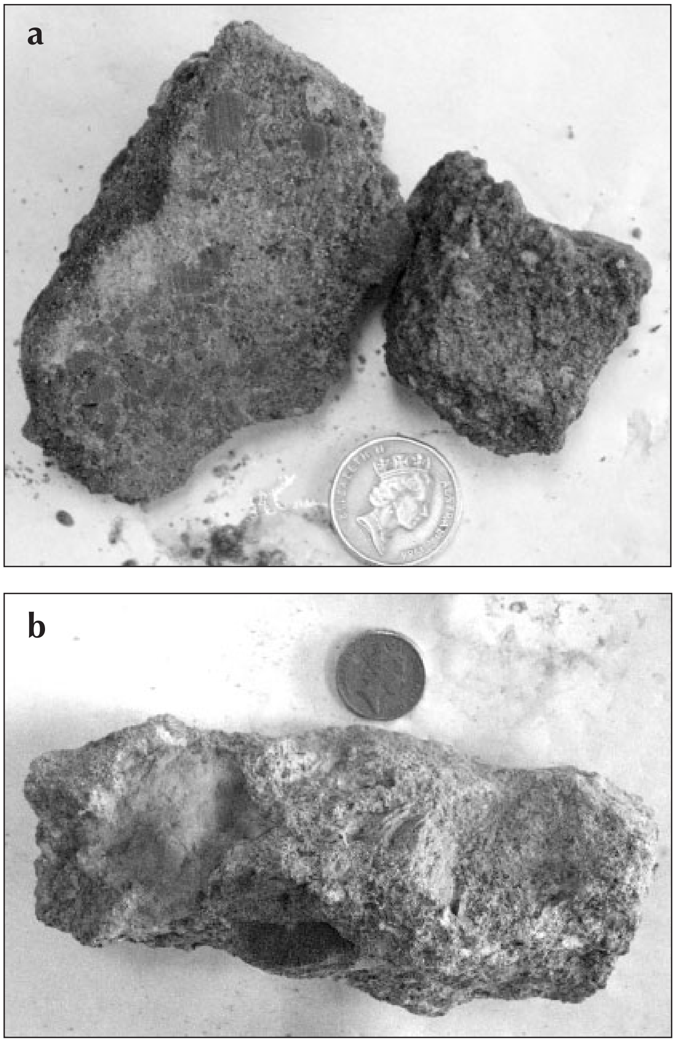


Figure 4. *(a) Type 2a breccia containing monotonous grey clasts set in a similar matrix of microbreccia and hydrothermal infill. (b) Type 2b breccia containing multi-coloured clasts within a similar matrix of microbreccia and hydrothermal infill.*

Type 2a breccia consists of monotonous grey clasts of mainly meta-siltstone and meta-silty dolomite set in a well-cemented, similarly coloured, porous matrix of microbreccia and hydrothermal precipitate (Fig. 4a). Having been invariably metasomatized, clast colour rarely reflects that of the parent lithology, and compositional layering, in most cases, is not discernable. The clasts and matrix are mostly quartzo-feldspathic, typically sub-angular to well-rounded and, on average, range in size from 1 to 10 cm.

Faulting took place prior to emplacement of the later Type 2b breccia (Fig. 4b). Faulting along the Type 2a breccia and meta-silty dolomite contact is evident by the presence of fault gouge. Type 2b breccia fingers into these faulted margins, and elsewhere intrudes along lithological contacts such as that of the earlier, Type 2a, breccia-host rock contacts (Fig. 3b). Type 2b breccia contains altered clasts of meta-siltstone, meta-silty dolomite and phyllite. Clasts are various colours, including pink, green, yellow and grey and are surrounded by a porous matrix composed of similar micro-rock fragments and hydrothermal infill. Clasts are sub- to well-rounded and range in size from less than 1 cm to 7 cm, and locally are well over 1 m. One such megaclast occurs as a 3 x 5 m block of crackle-brecciated meta-silty dolomite. Clasts of altered, laminated meta-siltstone commonly contain veins of, and disseminated, chalcopyrite.

ALTERATION ZONATION, VEINING AND MINERALIZATION

The Slab Creek breccia bodies form a locus for alteration, veining and mineralization, with breccia bodies themselves intensely altered. Three alteration zones were recognized within Slab Creek, an inner feldspar-rich alteration zone surrounded by a quartz-chlorite-carbonate zone, with an outer zone of localized sericite-chlorite alteration amongst relatively unaltered meta-sedimentary rocks. Previous work carried out by Laznicka and Edwards (1979), and Laznicka and Gaboury (1988) on similar alteration types indicate that feldspathic alteration is predominantly albite, however further work is required to define this in the Slab Creek area. Vein distribution and mineralogy also varies between the different alteration zones, and vein paragenesis has been established, based on field relationships, for each alteration zone (Figs. 5, 6, 7). The degree of veining and mineralization (copper, gold, iron oxide ± cobalt ± uranium; based on preliminary, unpublished geochemical analyses) increases markedly toward the feldspar-rich core where chalcopyrite, magnetite, hematite, minor Au, Co and U minerals are disseminated and occur as fracture fillings.

SERICITE ± CHLORITE ALTERATION ZONE

Sericite alteration occurs as discrete lenses within the meta-siltstone at the far-western section of the study area, as well as pervasively throughout finely laminated meta-siltstone, adjacent to phyllite located toward the eastern end of the study area. The pale sericitic bands overprint relict compositional layering and chloritiod porphyroblasts, and are concordant with the relatively unaltered to chloritic meta-siltstone. Bands are commonly 1 m to 1.5 m in length and 1 m to 5 cm wide, and alteration intensity within these bands decreases outward from their centres. Sericitic alteration overprints earlier chlorite and minor hematite alteration in the more silty horizons of the meta-siltstone. Distally, chlorite-dominated alteration of phyllite has produced intercalated bands of chlorite and muscovite in which the chlorite-rich bands contain regularly distributed, aligned magnetite crystals up to 3 mm in length.

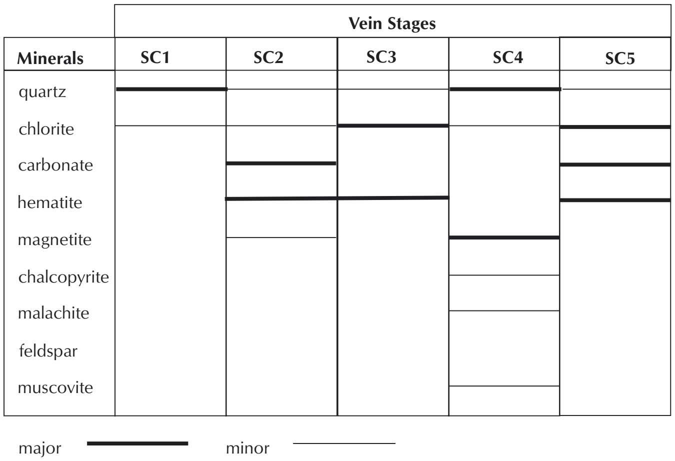


Figure 5. *Sericite ± chlorite alteration zone - preliminary vein paragenesis.*

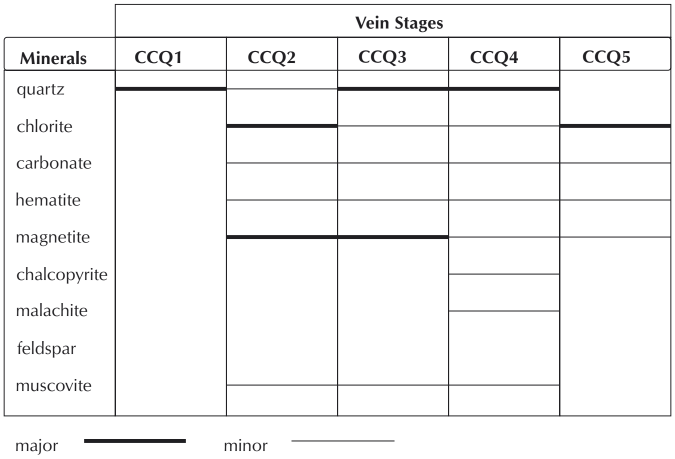


Figure 6. *Chlorite-carbonate-quartz alteration zone — preliminary vein paragenesis.*

There are five stages of veining within the sericite ± chlorite alteration zone (Fig. 5). Minor veining in Stage SC1 overprints sericite ± chlorite alteration and occurs as veinlets of vuggy textured quartz (<6 mm wide) surrounded by a thin chlorite selvage. These veinlets are crosscut by abundant (one vein approximately every metre) carbonate-hematite-chlorite ± magnetite ± quartz veins averaging 3 cm to 4 cm wide (Stage SC2). These veins are kinked (or exploit this fabric) within the more pervasively sericite-chlorite altered meta-sedimentary rocks (Fig. 8a). Stage SC3 veins, containing chlorite-hematite-quartz infill, crosscut SC2 veins and are locally kinked. SC3 veins have a similar abundance to SC2 veins. SC4 veins crosscut this kinking fabric and contain abundant quartz-magnetite with minor chlorite-chalcopyrite-malachite-muscovite. Unlike earlier veins,

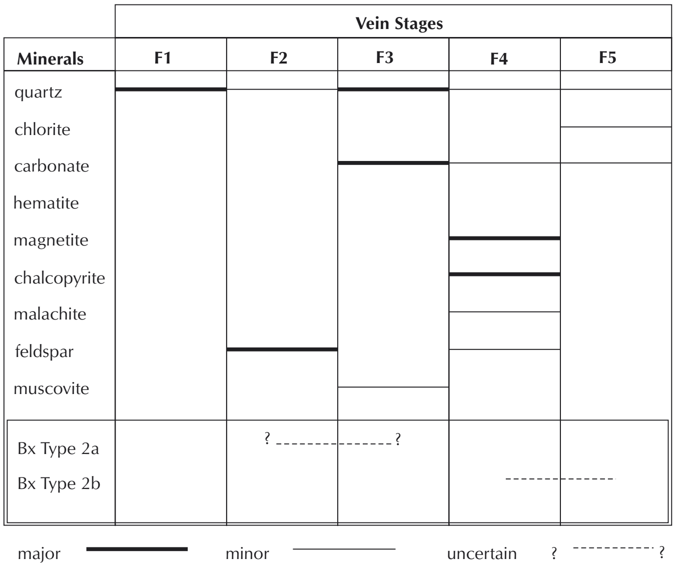


Figure 7. *Feldspar alteration zone — preliminary vein paragenesis and inferred timing of Type 2a and Type 2b breccia emplacement. Bx = breccia.*

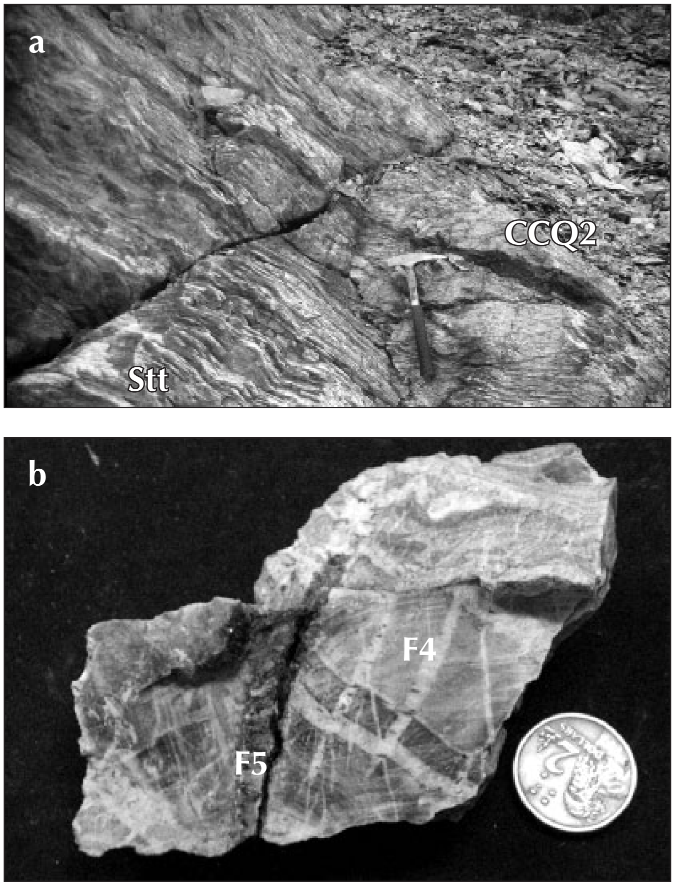


Figure 8. *(a) Chlorite-carbonate-quartz altered meta-siltstone containing a kinked stage CCQ2 vein of carbonate-hematite-magnetite-chlorite ± quartz. (b) Meta-siltstone of the feldspar alteration zone containing crosscutting Stage F4 veins of quartz-magnetite-chalcopyrite ± carbonate ± feldspar overprinted by F5 stage veins of carbonate-chlorite-quartz.*

Stage SC4 veins occur less frequently and are commonly less than 2 cm wide. There is an obvious exception to this, given that one of these veins (although lacking in any observable mineralization) is 20 cm wide and spans a third of the length of the Slab Creek outcrop (Fig. 2b). Stage SC5 veins of chlorite-carbonate-hematite ± quartz crosscut all other stages (Fig. 8b). Veins are typically 3 cm to 4 cm wide, although one SC5 vein of similar width and length to that of the large SC4 vein is easily recognized (Fig. 2b). The smaller SC5 veins are more common, occurring at a frequency of one vein to every 5 m.

CHLORITE-CARBONATE-QUARTZ ALTERATION ZONE

Chlorite-carbonate-quartz alteration is proximal to the feldspar alteration centre associated with the breccia bodies. The alteration occurs in meta-siltstone as preferential replacement of specific horizons with carbonate-quartz recrystallization of more carbonate-rich layers and chloritization of the more silty layers. In places, hematite forms specularite pods within patchy chloritic alteration. Toward the contact between the feldspar alteration zone and the chlorite-carbonate-quartz alteration zone, clasts and matrix of the Type 2b breccia are locally chlorite-carbonate-quartz altered and in places, contain perfectly formed rhombs of rare pyrite up to 1 cm in diameter. The more dolomitic horizons of the meta-silty dolomite are dominated by pervasive ferrous carbonatization with disseminated magnetite and quartz. Chlorite is present along cleavage planes and fracture surfaces.

Veins occur in five stages (Fig. 6). Early quartz veins (Stage CCQ1), commonly less than 1 cm wide and averaging four to every metre, are crosscut by chlorite-magnetite-carbonate-hematite ± quartz veins (CCQ2) of similar abundance, averaging 3 cm to 4 cm in width. A thin envelope of muscovite alteration rims these veins. In kinked host lithology, these veins contain a similar kinking fabric. Discordant veins of Stage CCQ3 are dominated by quartz-magnetite, are commonly rimmed by muscovite, and locally contain small (<2 cm) chloritized clasts of wall rock. Both Stage 2 and 3 veins are the most abundant in the chlorite-carbonate-quartz alteration zone. Less common are the chalcopyrite-bearing veins of Stage CCQ4 containing quartz-chlorite-magnetite-chalcopyrite-malachite and minor hematite-muscovite. Chalcopyrite mineralization is sparse, but when apparent, forms relatively well-defined crystals. This minor mineralization is followed by a final stage of chlorite-carbonate-hematite-magnetite ± quartz veins (CCQ5) similar to that of SC5 stage veining in the sericite-chlorite alteration zone.

FELDSPAR ALTERATION ZONE

Although not extensive, feldspar-rich alteration is one of the more conspicuous alterations of Slab Creek. This alteration zone is particularly prominent at the contact between breccia and meta-siltstone, where the latter is intensely bleached. Relict compositional layering is discernable in the meta-siltstone, however chloritoid porphyroblasts are no longer visible. Copper mineralization is the most dominant feature of this alteration zone, with the oxidized sulphide minerals discolouring weathering surfaces to rusty brown. Feldspathic alteration occurs pervasively throughout the Type 2a breccia and adjacent meta-siltstone, and as feldspar infill within the intensely fractured meta-siltstone.

Five stages of veining can be recognized within the feldspar alteration zone (Fig. 7). Quartz veins up to 5 cm in diameter (Stage F1) are common at the very centre of the alteration zone. Their size and number decrease dramatically outward within the space of 2 m to 3 m. The larger quartz veins (<5 cm) average four veins every 1 m and grade outward to smaller veins (<1 cm) and veinlets of less than one vein per metre. Crosscutting these veins are prominent vein sets of feldspar ± quartz infill (Stage F2). These veins (<3 cm wide) are similarly oriented with an average strike trending north-northwest and occurring at an average abundance of two veins to every 1 m. Stage F3 veins contain vuggy quartz with carbonate infill and crosscut feldspar veining. Iron oxide-copper mineralization occurs concurrently with carbonate-quartz ± feldspar veining (Stage F4). Stage F4 veins contain disseminated to massive chalcopyrite and magnetite. This is the first stage of veining observed to crosscut the Type 2a breccia. Late chlorite-carbonate-quartz veinlets (Stage F5) overprint all other vein stages, and are similarly seen to crosscut both Type 2a and Type 2b breccias.

DISCUSSION

Field observations indicate that the breccia bodies in Slab Creek play a significant role in the development of alteration zonation, associated veining and mineralization. The breccia bodies, hosted by meta-sedimentary rocks, form an alteration and mineralization locus about which three distinct alteration zones can be recognized: an inner feldspar zone, surrounded by a chlorite-carbonate-quartz zone, grading outward into a sericite-chlorite zone. Alteration zones are host to numerous crosscutting veins of which their relative timing, mineralogy and distribution varies between each zone. The most intense fracturing, vein infill and pervasive mineralization occurs within the feldspar alteration zone, coinciding with the extensive breccia bodies.

Several stages of veining took place prior to brecciation, including SC1, CCQ1 and F1 stage quartz veining, and SC2 and CCQ2 stage chlorite-carbonate-hematite ± magnetite ± quartz veining. These veins often appear kinked. The kinking event is inferred by Brideau et al. (this volume) to be related to late stages of Racklan orogenesis that took place prior to breccia emplacement. Type 2a breccia locally contains clasts with chlorite-carbonate-hematite ± magnetite ± quartz veins, which suggests the breccia postdates F1, SC1, CCQ1, SC2 and CCQ2 stage veins. The exact timing of Stage F2, feldspar ± quartz veins and feldspar alteration, and F3, quartz-carbonate veins relative to brecciation (Type 2a) remains unclear (Fig. 7). Further petrographic work is required to evaluate this relationship. Chalcopyrite mineralization dominates Stage F4 carbonate-quartz-magnetite- ± feldspar vein infill and clearly crosscuts Type 2a breccia. Furthermore, this mineralization stage is most abundant in the feldspar-altered meta-siltstone where in contact with Type 2a breccia, which suggests that the breccia may have been utilized as a channel for mineralizing hydrothermal fluids. Structural controls such as faults along the breccia-host rock boundaries may have also contributed to localizing mineralization. It is certainly evident that the Type 2b breccia also exploited these structures. The final stage of chlorite-dominated veining is clearly seen to overprint both breccias and all three alteration zones.

Field observations have helped constrain the relationship between breccia bodies and hydrothermal fluids involved in alteration, veining and mineralization. Petrographic and geochemical data are currently being evaluated to better define these relationships, and will be reported in April of 2002 in the form of a fourth year Honours thesis, being completed by the first author at James Cook University, Australia.

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