Geology and mineral occurrences of the Quartet Lakes map area (NTS 106E/1), Wernecke and Mackenzie mountains, Yukon

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ABSTRACT

The Quartet Lakes map area is underlain by rocks that range in age from Early Proterozoic to early Paleozoic. Stratified rocks include, from oldest to youngest, the Lower Proterozoic Fairchild Lake and Quartet groups (Wernecke Supergroup), the Middle to Late Proterozoic Tsezotene Formation, Katherine Group, and Little Dal Formation (Mackenzie Mountains Supergroup), and the Cambrian Slats Creek Formation. Five igneous units are recognized, including the Early Proterozoic Bonnet Plume River Intrusions, the Middle Proterozoic Bear River dykes, the Late Proterozoic Tsezotene Sills, Late Proterozoic to Cambrian lamprophyre, and Late Proterozoic to early Paleozoic diorite. Older rocks (Wernecke Supergroup, Wernecke Breccia and Bonnet Plume River Intrusions) were thrust northward over the Mackenzie Mountains Supergroup along a portion of the Knorr Fault. This part of the fault may be a restraining bend in an otherwise dextral strike-slip system. Copper-gold-uranium mineral occurrences in the area include disseminated and vein mineralization associated with zones of Wernecke Breccia.

RÉSUMÉ

La zone cartographique de Quartet Lakes repose sur des roches dont l'âge varie du Protérozoïque précoce au Paléozoïque précoce. Les roches stratifiées sont composées, des plus anciennes aux plus récentes, des groupes de Fairchild Lake et de Quartet (Supergroupe de Wernecke) du Protérozoique inférieur, de la Formation de Tsezotene, du Groupe de Katherine, de la Formation de Little Dal du Protérozoïque moyen à tardif (Supergroupe de Mackenzie Mountains) et de la Formation de Slats Creek du Cambrien. On distingue cinq unités ignées : les intrusions de Bonnet Plume River du Protérozoïque précoce, les dykes de Bear River du Protérozoïque moyen, les filons-couches de Tsezotene du Protérozoïque tardif, un lamprophyre du Protérozoïque tardif au Cambrien et une diorite du Protérozoïque tardif au Paléozoïque précoce. Les roches plus anciennes (Supergroupe de Wernecke, Brèche de Wernecke et intrusions de Bonnet Plume River) chevauchent vers le nord le Supergroupe de Mackenzie Mountains le long de la faille de Knorr. Cette partie de la faille de Knorr pourrait constituer une courbure restrictive dans un système de décrochement autrement dextre. Les indices minéraux de Cu-Au-U dans la région sont des filons ainsi que des minéraux disséminés de Cu-Au-U associées à des zones de la Brèche de Wernecke.

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INTRODUCTION

Geological mapping and research was undertaken in the summer of 2002 in the northern Wernecke and Mackenzie mountains (NTS map area 106E/1), located approximately 180 km north-northeast of Mayo and herein called the study area (Fig. 1). The region is rugged and remote, with mountain peaks typically elevated 1000 m above valley bottoms. Vegetation ranges from mixed coniferous and deciduous forest at lower elevations to lichen and bare rock on the mountaintops. The map area is drained by the Bonnet Plume River, which flows northward as part of the Arctic watershed (Fig. 2). The area is most easily accessed by helicopter but fixed-wing aircraft on floats can land on the Quartet Lakes and some reaches of the Bonnet Plume River. Fixed-wing aircraft on wheels can land on the 'copper point' airstrip approximately 1 km south of the map area in the northeastern corner of map area 106D/16. An unmaintained track called the Wind River trail, and related routes, lead into the study area. They are most useful as snowmobile trails in the winter after the rivers and wet ground in the region have frozen.

This study is a rejuvenation of the Wernecke Mountains Project initiated in 1992 by the first author and the Canada/Yukon Geoscience Office. Field work was carried out in map areas 106D/16, 106C/13 and 106C/14 from 1992-1995 (Fig. 1). Supplemental field and laboratory studies based from Simon Fraser University continued until 1998. A comprehensive report with three 1:50 000-scale maps was published subsequently (Thorkelson, 2000). The current program included regional mapping of map area 106E/1 by Thorkelson and Laughton, and detailed investigations of breccia-hosted mineral occurrences by Hunt and Baker. Products from the current study include this report and a companion 1:50 000-scale map (Thorkelson et al., 2002). The new findings will contribute to the PhD study of Hunt at James Cook University in Australia, and the MSc thesis of Laughton at Simon Fraser University in British Columbia.

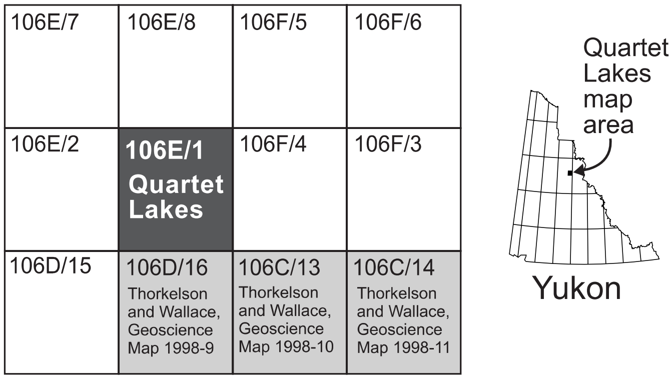


Figure 1. *Location of study area in context of previously released 1:50 000-scale maps.*

In this report, frequent reference is made to mineral occurrences as defined in Yukon MINFILE 2002 and reproduced in the legend of Figure 2. Note that where a mineral occurrence is identified on the map of Figure 2 or mentioned in the text of the report, the occurrence number has been abbreviated, for simplicity, to show only the last three digits (e.g., 029).

PREVIOUS WORK

Geological investigations in the map area have largely revolved around mineral exploration, and several mineral assessment reports detailing this activity are available from the Indian and Northern Affairs Canada library in Whitehorse. Maps from government agencies include a 1:250 000-scale map of 106E (Norris, 1981) and a 1:100 000-scale map covering the southern part of 106E/1 and nearby areas (Bell, 1986a). Hunt et al. (2002) mapped a small area in the southeastern corner of the map area. Reports and articles containing regional overviews include those by Delaney (1981), Norris (1997), Norris and Dyke (1997), and Thorkelson (2000). Papers focusing on specific aspects of the geology in and near the study area are cited where appropriate in the following text.

GEOLOGICAL FRAMEWORK

As outlined in Norris (1997) and Thorkelson (2000), rocks of the northern Wernecke Mountains range in age from Early Proterozoic to Paleozoic (Fig. 3). Most of the rocks are clastic and carbonate sedimentary strata that were deposited in basinal to platformal environments along the western shores of ancestral North America. These strata host hydrothermal breccias, dykes, sills and small stocks. Events of deformation involving contraction, transcurrent displacement and extension affected the region. The first major deformational event was the Early Proterozoic Racklan orogeny (Fig. 3), which produced southeasterly directed folds, foliations, crenulations and kinks. The last major event was the Laramide orogeny, which involved north- to northwest-directed folding and thrusting in Late Cretaceous to Paleocene time.

In the study area, the rocks consist of two main sedimentary successions crosscut by numerous small igneous intrusions and zones of hydrothermal breccia. The older succession is the Lower Proterozoic Wernecke Supergroup (Delaney, 1981), and the younger is the Middle to Upper Proterozoic Mackenzie Mountains Supergroup (Atiken et al., 1982). The Wernecke Supergroup has greater potential to host mineral occurrences because it has a greater abundance of mineral occurrences, particularly ones with iron oxide-copper-gold affinity. These successions are separated by the Knorr Fault, a strand of the Richardson Fault array (Fig. 2, 4; Norris, 1984).

Rocks that form the basement to the successions in the Wernecke Mountains are not exposed (Fig. 3). However, they are likely to be as old, or older than, the Early Proterozoic Wopmay orogeny and Fort Simpson magmatic belt (ca. 1.84-1.9 Ga) in the Northwest Territories. Conceivably, part of the lithospheric infrastructure beneath the Wernecke Mountains and neighbouring regions could be Archean (>2.5 Ga).

STRATIGRAPHY

WERNECKE SUPERGROUP

The Wernecke Supergroup is the oldest sedimentary succession exposed in the Wernecke Mountains (and probably all of western North America). It consists of three groups with an aggregate thickness of approximately 13 km (Delaney, 1981; Thorkelson, 2000). In the study area, only the lowest unit, Fairchild Lake Group, and the middle unit, Quartet Group, are exposed southwest of the Knorr Fault (Fig. 2, 3). The highest unit, Gillespie Lake Group, is exposed 3 km to the south of the map area.

In the study area, the Fairchild Lake Group consists mainly of weakly to moderately metamorphosed grey- to brown-weathering siltstone, shale, very fine-grained sandstone, and brown-, grey- and white-weathering dolostone. Following Thorkelson (2000), the succession is divided into two main parts, simply named the 'lower' and 'upper' Fairchild Lake Group (more detailed divisions were provided by Delaney, 1981, but are not followed in this report). The lower part consists mainly of siltstone, fine-grained sandstone and shale, with minor dolostone, and their metamorphosed equivalents. The upper Fairchild Lake Group consists mainly of siltstone, shale and dolostone. A prominent 10-m-thick white marker unit of dolostone lies near the top of the group where it grades into the Quartet Group (Delaney, 1981). The Fairchild Lake succession in the study area is at least 1 km thick.

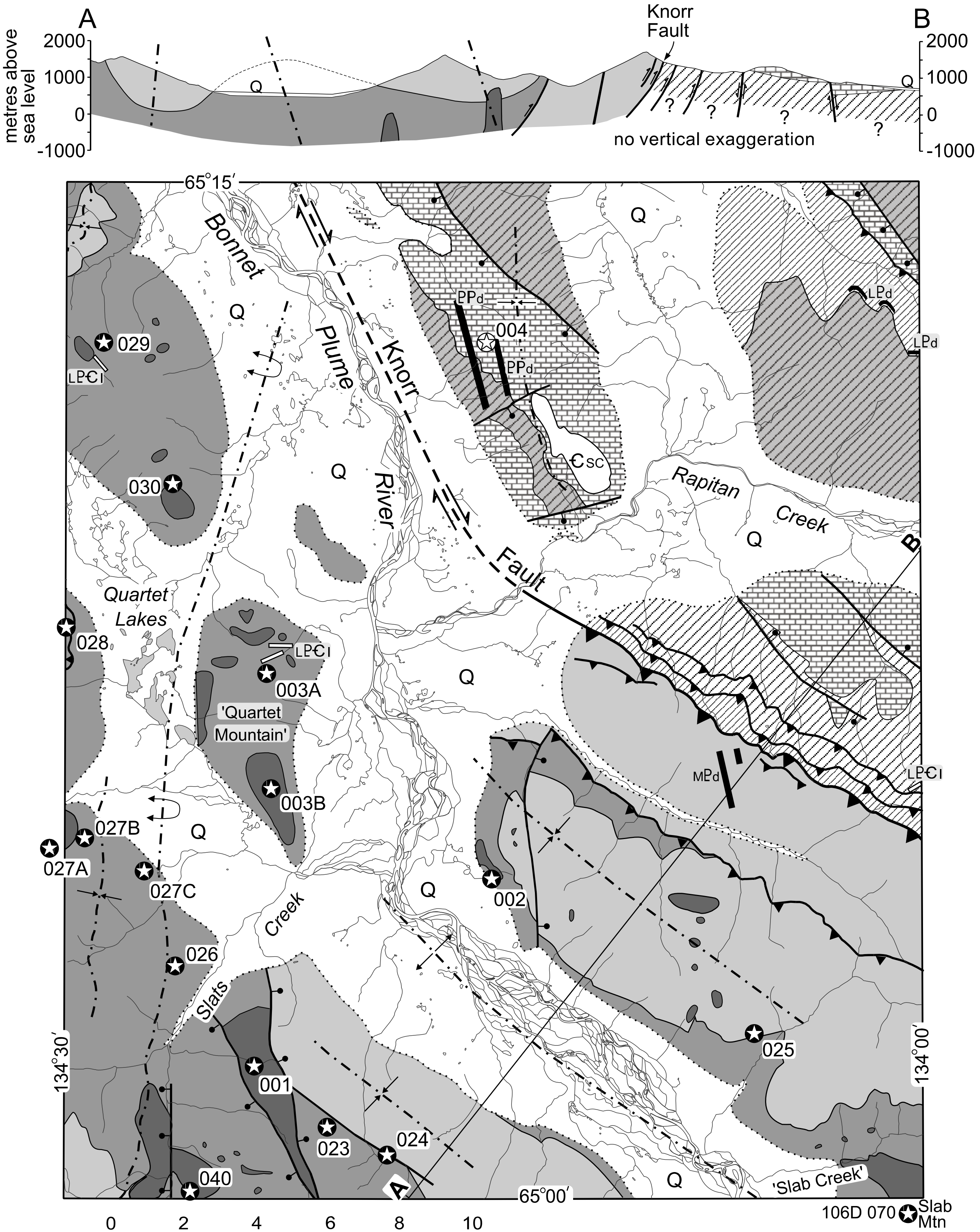
In most places, the Fairchild Lake Group rocks display slaty cleavage, and locally host porphyroblasts of chloritoid or, less commonly, garnet (Fig. 5). Sedimentary features such as plane- and ripple-laminations and syneresis cracks are typically preserved. In other localities, the rocks have undergone greater strain and mineral growth, and have been metamorphosed to bluish-grey-weathering chlorite- and muscovite-rich phyllite, and fine-grained chlorite-muscovite-quartz schist, which also hosts choritoid or garnet porphyroblasts (Fig. 6). In addition to being schistose, these rocks are commonly crenulated and kink-banded. Brideau et al. (2002) described the metamorphic grade of the schist as lower greenschist, with peak temperatures near 550°C.

The Quartet Group grades from black-weathering shale and siltstone at its base, where it conformably overlies the upper Fairchild Lake Group, to more siliceous rocks including quartz-rich siltstone with interbedded fine- to medium-grained white-weathering quartzite up to 12 m thick (Fig. 7). Although the most siliceous rocks are not foliated, most Quartet Group rocks display slaty cleavage. The most fine-grained Quartet rocks are typically cleaved, crenulated and locally kink-banded, and host tiny (<0.5 mm) porphyroblasts of chloritoid. The preserved thickness of the Quartet Group in the study area, based on the cross-section in Figure 2, is approximately 1.5 km. The top of the succession is not preserved in the study area.

MACKENZIE MOUNTAINS SUPERGROUP

Northeast of the Knorr Fault, strata of the Mackenzie Mountains Supergroup are exposed. Lithologically, these strata range from dolostone to siltstone and quartz arenite, similar to protoliths of the Wernecke Supergroup but generally devoid of cleavage. The three main units of the Mackenzie Mountains Supergroup, the Tsezotene Formation (lowest), the Katherine Group, and the Little Dal Formation (highest), are all present in the study area. At some locations, these units were identified with confidence, following the descriptions of Aitken et al. (1982). However, distinguishing the Tsezotene Formation from the Katherine Group in fault panels near the Knorr Fault was difficult, and the two units in that area have been grouped together (Fig. 2).

The Tsezotene Formation consists mainly of brown-, grey- and purple-weathering siltstone, shale and wacke; buff-,


A
B
Knorr Fault
metres above sea level
2000
1000
0
-1000
Q
?
no vertical exaggeration
65°15′
65°00′
134°30′
134°00′
Bonnet Plume River
Knorr Fault
Rapitan Creek
Quartet Lakes
'Quartet Mountain'
Creek
Slats
'Slab Creek'
Q
PPd
LPd
LPCl
MPd
Csc
004
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003A
003B
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001
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002
025
106D 070
Slab Mtn
0
2
4
6
8
10
km
Quartet Lakes map area 106E/1

STRATIFIED ROCKS

QUATERNARY

Q alluvium, colluvium and glacial deposits

MIDDLE CAMBRIAN (?)

SLATS CREEK FORMATION (?)

Єsc grey-weathering dolostone and purple-weathering mudstone interlayered with carbonate-rich conglomerate and olistostrome; brown-weathering, thin- to medium-bedded, plane- to cross-bedded, coarse sandstone and chert-rich granule conglomerate in carbonate matrix

MIDDLE TO UPPER PROTEROZOIC

MACKENZIE MOUNTAINS SUPERGROUP

▦ *LITTLE DAL FORMATION*: grey- to yellow-weathering, medium- to thick-bedded micritic dolostone; minor black mudrock

▨ *KATHERINE GROUP*: grey- to white- and pinkish-white-weathering, fine- to medium-grained quartz arenite; black-, brown- and purple-weathering siltstone and wacke, locally micaceous, mudcracked and ripple-marked; minor dolostone

▨ *TSEZOTENE FORMATION*: black- to brown-weathering siltstone and wacke, commonly micaceous, mudcracked and ripple-marked; brown- to orange- and grey-weathering, medium- to very thick-bedded dolostone; black-, grey- and maroon-weathering mudrock; minor grey- to white- and pinkish-white-weathering, plane-bedded quartz arenite

▨ *TSEZOTENE FORMATION* and/or *KATHERINE GROUP*

LOWER PROTEROZOIC

WERNECKE SUPERGROUP

□ *QUARTET GROUP*: black-weathering shale; grey-weathering, thin- to medium-bedded, finely laminated to cross-laminated siltstone; light-grey-weathering, thick-bedded, fine- to medium-grained quartz arenite.

■ *FAIRCHILD LAKE GROUP*, undivided
(includes upper and lower successions)
Upper Fairchild Lake Group: black-weathering shale, silstone and dolomitic siltstone, locally crenulated and kink-banded; orange-, brown-, grey-, and white-weathering dolostone
Lower Fairchild Lake Group: black- to grey-weathering, thin- to medium-bedded, siltstone, shale, and slate, commonly laminated; brown-weathering, thin-bedded silty dolostone; bluish- to greenish-grey-weathering phyllite and fine-grained muscovite-chlorite-quartz schist, commonly hosting chloritoid porphyroblasts, crenulations and kink bands

- ～ stratigraphic contact
- ⋯ contact with Quaternary sediments
- fault: strike-slip, reverse, normal, inferred
- fold trace: syncline, anticline, overturned anticline
- A B line of cross-section

INTRUSIVE ROCKS

LATE PROTEROZOIC TO EARLY PALEOZOIC

PPd dark-green-weathering, fine- to medium-grained diorite dykes crosscutting Little Dal Formation and Katherine Group; dykes locally host veins of epidote, calcite, hematite and malachite

LATE PROTEROZOIC TO CAMBRIAN

LPЄl *QUARTET LAKES LAMPROPHYRE:* brown-weathering, aphyric to phlogopite-phyric dykes crosscutting Wernecke and Mackenzie Mountains supergroups, and locally hosting abundant xenoliths

LATE PROTEROZOIC

LPd *TSEZOTENE SILLS*: dark-green-weathering, fine- to medium-grained diorite within Tsezotene Formation; locally, diorite is plagioclase-phyric and hosts veins of calcite, quartz and pyrite

MIDDLE PROTEROZOIC

MPd *BEAR RIVER DYKES*: dark-green-weathering, fine- to medium-grained diorite crosscuting Quartet Group; locally, diorite hosts veins of epidote, quartz, calcite, pyrite, chalcopyrite and hematite

WERNECKE BRECCIA

● grey-weathering, or mottled red-, pink-, brown- and grey-weathering hematitic breccia containing clasts of Wernecke Supergroup and, locally, megaclasts of the Early Proterozoic Bonnet Plume River Intrusions (greenish-grey-weathering, fine-to medium-grained diorite locally hosting disseminations and veinlets of hematite or magnetite, and chalcopyrite). Includes metasomatized country rock of the Wernecke Supergroup. Breccia crosscuts foliations, crenulations and kink bands in the Fairchild Lake Group and locally hosts enrichments of Cu (as chalcopyrite), Au, U, Co and Mo (as molybdenite). Tentatively includes rusty-weathering pyritic breccia with matrix of vein quartz.

MINERAL OCCURRENCES
Yukon MINFILE 2002

Wernecke Breccia
Cu and/or U (+/- Co, Au, Mo, Ba, Ag)

106 E/001	✪	Otis	drilled prospect
106 E/002	✪	Irene	drilled prospect
106 E/003	✪	Quartet	showings
106 E/023	✪	Radio	prospect
106 E/024	✪	Break	prospect
106 E/025	✪	Mountaineer	showing
106 E/026	✪	Helikian	prospect
106 E/027	✪	Five	prospect
106 E/028	✪	Rapitan	showing
106 E/029	✪	Ikona	showing
106 E/030	✪	Bell	showing
106 E/040	✪	Eaton	showing

Unknown affinity
Zn, Pb

106 E/004	☆	Farion	showing

Figure 2. *Geological map (facing page) and legend (this page) of study area, simplified from Thorkelson et al. (2002). Mineral occurrences are taken from Yukon MINFILE 2002 except for locality 003B which was identified by the authors and has been proposed as an addition to future versions of Yukon MINFILE.*

orange-, and grey-weathering dolostone; and minor grey- to white-weathering quartz arenite. The siltstone and sandstone are commonly ripple-marked and mud-cracked, and locally contain abundant detrital muscovite. The dolostone is generally micritic, is commonly crosscut by veins of red-weathering dolomite spar, and locally hosts nodules of red- and white-weathering dolomite cored by granular to sparry quartz crystals. In the study area, the Tsezotene succession is at least 1.2 km thick.

The overlying Katherine Group is distinguished from the Tsezotene by its greater abundance of sandstone, particularly grey- to white-weathering and locally pink-weathering quartz arenite. In many places, the arenite contains grains of pyrite that have partly or completely altered to limonite, leaving a spotty and locally rusty appearance in an otherwise 'pure' quartz sandstone. Although the Katherine Group is generally coarser grained than the Tsezotene, it contains some layers of carbonate and thick successions of siltstone, including muscovite-rich varieties. For example, on a peak 2 km west of the

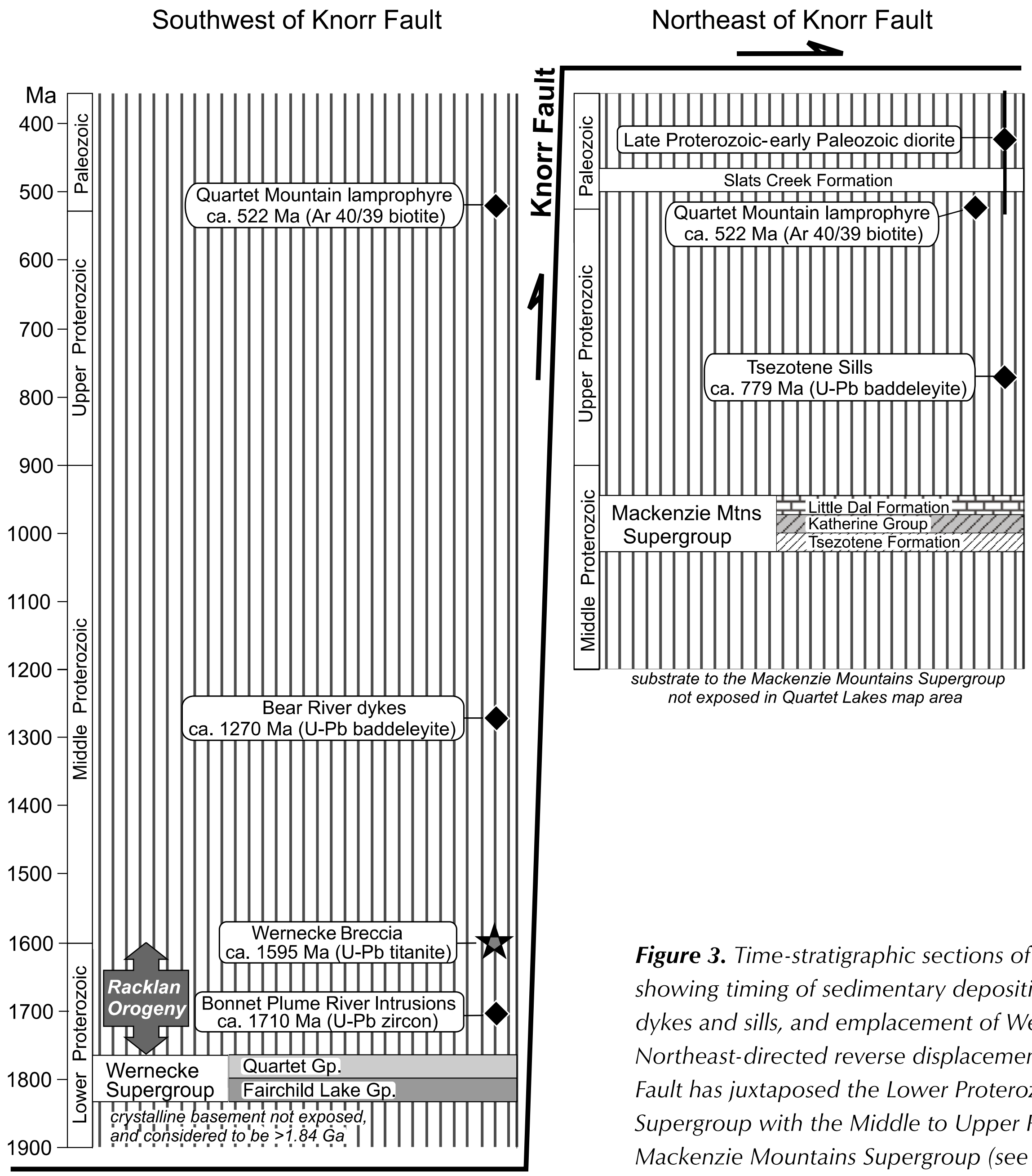

Figure 3. *Time-stratigraphic sections of the study area showing timing of sedimentary deposition, intrusion of dykes and sills, and emplacement of Wernecke Breccia. Northeast-directed reverse displacement along the Knorr Fault has juxtaposed the Lower Proterozoic Wernecke Supergroup with the Middle to Upper Proterozoic Mackenzie Mountains Supergroup (see Figs. 2, 4).*

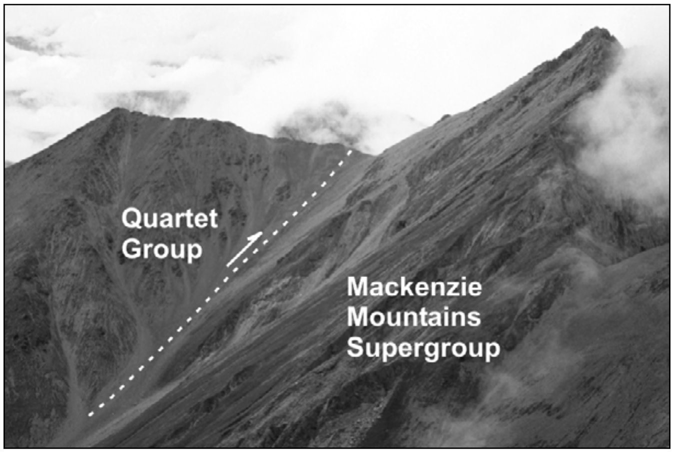

Figure 4. *Knorr reverse fault separating Quartet Group (hanging wall) from Mackenzie Mountains Supergroup. View to west. Width of area is approximately 500 m.*

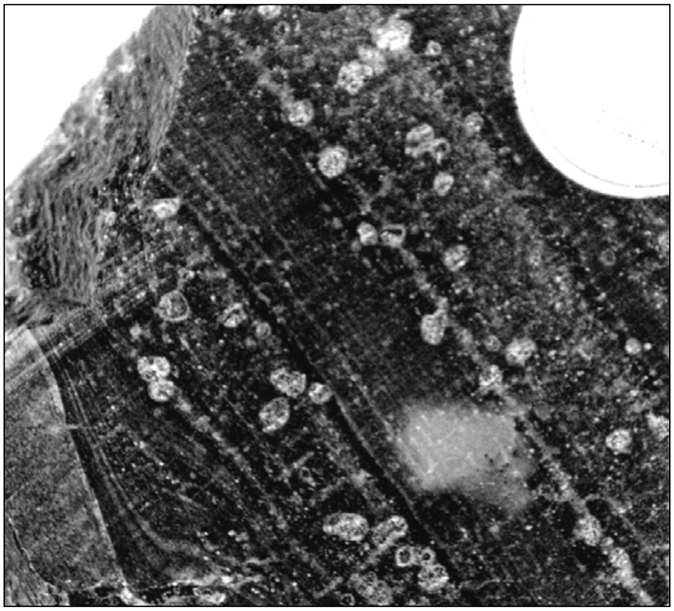

Figure 5. *Garnet porphyroblasts in metamorphosed Fairchild Lake Group siltstone with relict plane- and cross-laminations, near the Irene mineral occurrence (002). Width of rock is 6 cm.*

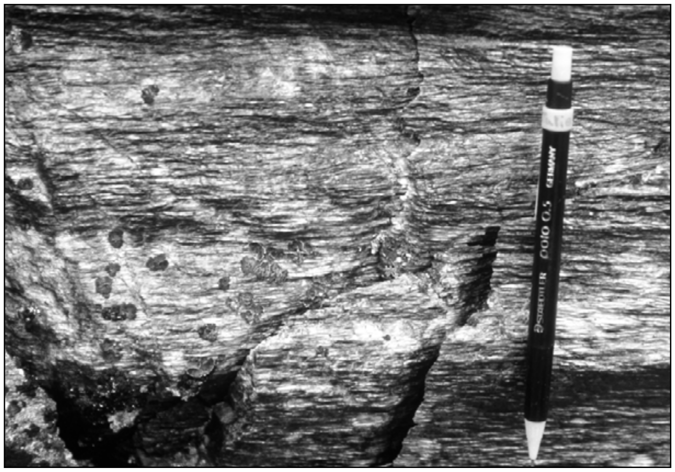

Figure 6. *Crenulated, fine-grained chloritoid-muscovite-chlorite-quartz schist of the lower Fairchild Lake Group, between Ikona (029) and Bell mineral occurrences (030).*

Figure 7. *Gently dipping succession of Quartet Group siltstone and fine-grained sandstone, 3 km north-northeast of Mountaineer mineral occurrence (025). Thickness of strata in photograph is approximately 900 m. View to the north.*

eastern map boundary and 3 km north of Rapitan Creek, a thick (150 m) succession of micaceous, purple-weathering siltstone is interbedded with more siliceous strata. In the study area, the Katherine Group is at least 800 m thick.

The Little Dal Formation, which conformably overlies the Katherine Group, is well exposed in the study area. The unit consists of grey- to yellow-weathering grey micritic dolostone interbedded with subordinate black-weathering shale. More coarsely grained varieties of dolostone, as described by Aitken et al. (1982), were not observed. The thickness of the Little Dal in the study area ranges up to 500 m.

Taken together, the Tsezotene-Katherine strata are lithologically and stratigraphically similar to the Hematite Creek Group (formerly units D-F of the Pinguicula Group), located 40 km east-southeast of the study area (Thorkelson, 2000). They apparently belong to the same regional sedimentary succession, ca. 1 Ga, and are derived, in part, from the Grenville orogen (Rainbird et al., 1997; Thorkelson, 2000).

SLATS CREEK FORMATION (?)

A succession of varied sedimentary strata, approximately 250 m thick, is exposed on the top of a mountain approximately 7.5 km northeast of the confluence of Rapitan Creek and the Bonnet Plume River. These strata overlie the Little Dal Formation above a gentle angular unconformity (10-20°). Norris (1981) suggested a correlation between these strata and the Knorr Ranges succession, whereas Norris (1984) included the strata in the Rapitan Group. However, it is suggested here that the succession is better correlated with the lithologically similar Middle Cambrian Slats Creek Formation as described by Norris (1981). A lower succession of interbedded brown-, grey- and maroon-weathering dolostone, dolostone conglomerate and dolostone diamictite (interpreted as olistostrome), and an upper succession of brown- to purple-weathering siliciclastic sandstone and granule conglomerate set in a carbonate matrix is recognized. The granule conglomerate contains abundant clasts of chert. The contact between the lower and upper successions is gradational.

IGNEOUS ROCKS

INTRODUCTION

Several generations of magmatism from Early Proterozoic to early Paleozoic have affected the study area through the emplacement of numerous dykes and sills. All of the igneous units are low in volume relative to their sedimentary host rocks; however, greater volumes of correlative plutonic rock may exist at depth.

BONNET PLUME RIVER INTRUSIONS

The Bonnet Plume River Intrusions (Thorkelson et al., 2001a) exist almost entirely as megaclasts in Wernecke Breccia (Fig. 9; Wernecke Breccia is discussed below) and rarely occur as dykes and small stocks within the Wernecke Supergroup. In the study area, the intrusions consist of fine- to medium-grained diorite which has been variably altered, veined and metasomatized. Samples from elsewhere in the Wernecke Mountains have been dated at 1.71 Ga, which provides a minimum age for the Wernecke Supergroup. The intrusions may be correlative with the Slab volcanics, which also occur as megaclasts in Wernecke Breccia, 500 m south of the southeastern corner of the study area (Laughton et al., 2002). The Bonnet Plume River Intrusions have compositions indicative of a rift origin and imply extension of Yukon crust in the Early Proterozoic.

BEAR RIVER DYKES

Two mafic dykes located approximately 1 km south of the Knorr Fault are tentatively regarded as Middle Proterozoic Bear River dykes (an alternative and equally plausible possibility is that they belong to the unnamed Late Proterozoic to early Paleozoic diorite dykes, described below). In the study area, the larger and better-studied of the two dykes is up to 15 m wide, extends for nearly 2 km, and dips to the west at approximately 60°. Its composition ranges from aphanitic greenstone to fine-grained diorite, and it hosts veins of quartz, calcite, epidote, pyrite, chalcopyrite, malachite and hematite. The dyke and veins are similar to those at a Bear River dyke locality 5 km south of the study area (Schwab and Thorkelson, 2001). The Bear River dykes have been dated at 1.27 Ga by the U-Pb method on baddeleyite (Thorkelson, 2000). They are scattered throughout much of the northern Wernecke Mountains and appear to be a westerly manifestation of the Mackenzie dyke swarm (Schwab and Thorkelson, 2001).

TSEZOTENE SILLS

Four exposures of diorite are regarded as Late Proterozoic Tsezotene Sills, which are common in the Mackenzie Mountains to the north and west of the study area (Aitken et al., 1982). In the study area, the sills were emplaced near the top of the Tsezotene Formation. In the Northwest Territories, Tsezotene Sills have been dated at ca. 779 Ma by the U-Pb method on baddeleyite (Heaman et al., 1992). Regionally, they are regarded as an early expression of Windermere-aged rifting and continental break-up.

QUARTET MOUNTAIN LAMPROPHYRE

Numerous lamprophyre dykes, herein collectively termed the Quartet Mountain lamprophyre, crosscut the Wernecke and Mackenzie Mountains supergroups in the study area. The dykes are particularly common on 'Quartet Mountain' (informal name), near the original Quartet mineral occurrence (003A; Fig. 2) but also crop out near the Ikona occurrence (029; Fig. 2). One lamprophyre that crosscuts the Mackenzie Mountains Supergroup at the eastern edge of the study area hosts altered xenoliths of apparent crustal and mantle provenance. Only a few lamprophyre dykes were seen in outcrop, but many more exist, as indicated by the local abundance of lamprophyre blocks in talus cones. The intrusions are brown-weathering, mafic, and host phenocrysts of phlogopite and clinopyroxene. Laznicka and Gaboury (1988) also reported perovskite phenocrysts in lamprophyre from Quartet Mountain, but this finding has not been verified. The most reliable age of lamprophyre emplacement in the region was provided by an $^{40}Ar/^{39}Ar$ biotite determination of ca. 522 Ma from a locality approximately 12.5 km south-southwest of the study area (this age determination was incorrectly assigned to the Slab volcanics by Thorkelson, 2000). Slightly older K-Ar biotite ages of ca. 613 Ma and ca. 552 Ma from lamprophyres north of the study area were reported by Delaney (1981). Taken together, these ages indicate a Late Proterozoic to Cambrian age of magmatism. The cause and significance of the Quartet Lakes lamprophyre is unknown.

LATE PROTEROZOIC TO EARLY PALEOZOIC DIORITE

Two large north-striking dykes up to 3 km long and 18 m wide crosscut the Katherine Group near the Farion mineral occurrence, east of the Bonnet Plume River. The longer, more westerly dyke was studied in greater detail. It dips approximately 70° to the west and is composed of chlorite-altered fine-grained diorite with aphanitic chilled margins. It is cut by epidote-quartz veins and thin veinlets composed of grey-weathering calcite, specular hematite and malachite. A K-Ar whole-rock age of ca. 398 Ma was reported by Norris (1981), and we suggest that this is the minimum age of the dyke. Its maximum age is that of the Katherine Group, approximately 1 Ga (Rainbird et al., 1997).

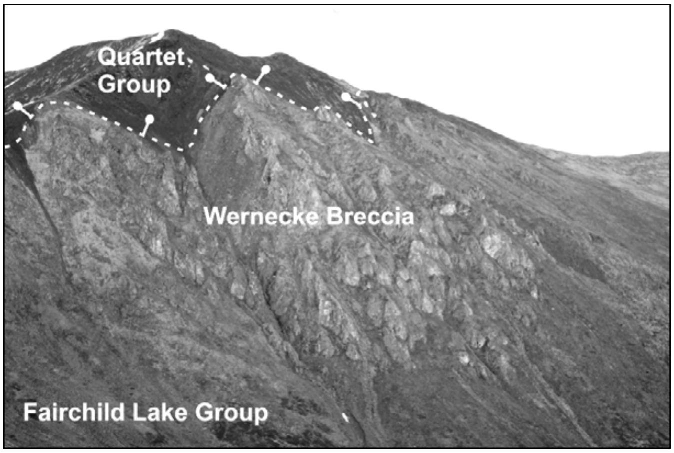

Figure 8. *Normal fault separating Quartet Group from Fairchild Lake Group and zone of castellate-weathering Wernecke Breccia and related metasomatically altered siltstone near the Otis mineral occurrence (001). View to southeast. Width of area is approximately 1 km.*

WERNECKE BRECCIA

Zones of hydrothermally generated breccia, collectively termed Wernecke Breccia, are present in the study area (Fig. 8). The breccias are regionally extensive, host numerous mineral occurrences and have been targets for mineral exploration for decades (Bell, 1986b; Thorkelson et al., 2002; Hunt et al., 2002). The breccias are

Figure 9. *Megaclast of diorite (approximately 6 x 9 m), outlined by white dashed line, on cliff face of Wernecke Breccia near newly recorded showing of the Quartet mineral occurrence (003B).*

Figure 10. *Weathered surface of Wernecke Breccia showing clasts of metasomatically altered siltstone in hydrothermally precipitated matrix, near newly recorded showing of the Quartet mineral occurrence (003B).*

characterized by clasts of metasomatized siltstone in a hydrothermally precipitated matrix containing abundant specular hematite (Fig. 10). All breccia zones host clasts of granule- to cobble-size, but some also contain megaclasts ranging from small boulders to blocks tens of metres wide, or larger. Locally, clasts and megaclasts of the Bonnet Plume River Intrusions are also present in breccia zones (Fig. 9). At 'Slab Mountain' (informal name), 500 m south of the study area, a 250-m-wide megaclast of the Slab volcanics lies within a megaclast-rich breccia (Laughton et al., 2002).

The oldest published date on Wernecke Breccia, ca. 1.60 Ga, was obtained from U-Pb analysis of titanite from breccia at Slab Mountain (Thorkelson et al., 2001b), and is presently regarded as the time when most of the brecciation occurred. Younger ages (Archer et al., 1986; Parrish and Bell, 1987) probably reflect either open-system behaviour of radioisotopes or younger pulses of hydrothermal fluids (cf. Schwab and Thorkelson, 2001).

STRUCTURE

Several events of structural deformation have affected the rocks in the study area. The ages of these events range from Early Proterozoic to early Tertiary. Brideau et al. (2002) examined the Fairchild Lake Group and Wernecke Breccia in the southeast corner of the study area (Fig. 2) and nearby parts of neighbouring map areas, and concluded that the first three deformational events in the region produced (1) a foliation in the Wernecke Supergroup (ranging from slaty cleavage to schistosity); (2) crenulations and a localized crenulation cleavage; and (3) kink bands. The regions of greater foliation development and metamorphic mineral growth (Fig. 6) appear to represent zones of greater strain and recrystallization, commonly in the cores or overturned parts of tight folds. Wernecke Breccia crosscut these structural features at 1.60 Ga, a relation that constrains the age of foliation, crenulation and kink-banding to Early Proterozoic. Collectively, these structures are regarded as manifestations of Racklan orogeny (Brideau et al., 2002).

Macroscopic folds are also likely to have developed during Racklan orogeny, and the most likely folds of Racklan age are north-trending structures in the western part of the study area. The most prominent of these folds is an east-verging overturned anticlinorium whose main hinge extends northward from near the Eaton mineral occurrence (040) along the west side of Quartet Mountain toward the Knorr Fault (Fig. 2). Regions of strong foliation and overturned beds exposed on Quartet Mountain and to the northeast near the Ikona mineral occurrence (029) are interpreted as products of minor folding associated with this anticlinorium. An east-verging syncline to the west of this anticlinorium, and another syncline in the northwestern corner of the study area, share the same structural trend and likely formed synchronously. Other folds of probable Racklan age include overturned anticline-syncline pairs in the Quartet Group, south and east of the Break mineral occurrence (024). Post-Racklan faulting and folding in the region is likely to have affected the geometry and orientation of the Racklan folds, and may be largely responsible for their tight, overturned structural style.

Development of Wernecke Breccia by repeated explosions of hydrothermal solutions (Thorkelson et al., 2001b; Hunt et al., 2002) produced localized but widespread shattering of the Wernecke Supergroup. Some steep faults with apparently normal displacements are spatially associated with zones of Wernecke Breccia (near the Otis mineral occurrence (001), for example), and may be broadly coeval with the brecciation.

Folding and faulting of post-Wernecke Breccia age have affected much of the study area. The most prominent features produced by these events are large-wavelength, west-northwest-trending folds and reverse faults in the Wernecke and Mackenzie Mountains supergroups. Three main folds are present, centred by a large south-verging anticline that trends along the Bonnet Plume River valley. This anticline extends for 25 km to the east-southeast into map area 106C/13 where it progressively tightens and becomes overturned (Thorkelson, 2000). In the study area, this anticline and its pair of flanking synclines appear to be related to, or are affected by, a set of north-northeast verging reverse faults. The Knorr Fault is the main fault in this set (Fig. 2). Reverse motion along the Knorr Fault has brought the Quartet Group alongside the Mackenzie Mountains Supergroup (Fig. 4). The immediate footwall of this fault consists of mylonitic carbonate breccia, locally tens of metres thick, which developed through fault-brecciation and shearing of bedded dolostone of the Tsezotene Formation. According to Norris (1984), the western end of the Knorr Fault curves toward the north and merges with the Richardson Fault array where it accommodates dextral strike-slip displacement (Fig. 2). In that framework, the part of the Knorr Fault exposed in the study area may be viewed as a restraining bend in an overall dextral transcurrent system. All of these folds and faults probably occurred during the Cretaceous to Tertiary Laramide orogeny and subsequent dextral transpression (Norris, 1997).

Another set of five folds is present in the Mackenzie Mountains Supergroup and Slats Creek Formation near the Farion mineral occurrence (004). The folds are tightly spaced, and for clarity, only one of the fold traces is identified in Figure 2; all are shown in Thorkelson et al. (2002). These structures trend at a moderate angle to the other post-brecciation folds, and the relation between these sets is uncertain. They could have been generated at different times under separate regimes or they could have developed at the same time, a possibility which is supported by the curvature in the Knorr Fault and the large anticline-syncline structures to the south. This curvature is most evident in the large anticline that lies in the Bonnet Plume River valley, south of the Irene (002) and Mountaineer (025) mineral occurrences. In map area 106C/13, to the southeast, the trend of this fold is nearly west, but it progressively curves northwestward as it extends into the study area. The same sense of curvature (concave to the northeast) is present in the folds near the Farion mineral occurrence (004), and this similarity may be evidence of structural continuity.

MINERAL OCCURRENCES

INTRODUCTION

All mineral occurrences in the area, except the Farion, occur southwest of the Knorr Fault and are classified in Yukon MINFILE 2002 as Wernecke Breccia-type. Mineral enrichments at these occurrences include copper in the form of chalcopyrite and malachite; uranium as uraninite, brannerite and pitchblende; thorium as thorite; molybdenum as molybdenite; and native gold. These enrichments occur in three general styles. Firstly, they occur as intrinsic parts of breccia bodies, as disseminated minerals, veinlets, or pods (e.g., the Irene occurrence, 002). Secondly, they occur within country rock or megaclasts as disseminated minerals, veinlets or pods (e.g., the Quartet occurrence, 003). Thirdly, they occur mainly in veins near or within zones of Wernecke Breccia (e.g., the Eaton occurrence, 040; the Ikona occurrence, 029; and the Five occurrence, 027A).

Some vein occurrences in the area may have been generated by hydrothermal activity during emplacement of nearby zones of Wernecke Breccia, whereas others may be younger (or older) features which developed from unrelated events of fracturing and fluid flow. This complexity raises a challenge for exploration geologists who wish to understand the origin of vein mineralization in regions affected by Wernecke Breccia. Geological and geochronological investigations may be useful in determining which vein occurrences are truly related to Wernecke Breccia, and which, if any, should be reclassified.

NEW SHOWING OF QUARTET OCCURRENCE

A new showing was identified by the authors on the southern part of Quartet Mountain, and is herein regarded as part of the Quartet mineral occurrence. The new showing will be assigned occurrence number 106E 003B in future editions of Yukon MINFILE; the original Quartet occurrence will be changed from 003 to 003A (Fig. 2). The new showing is located at the intersection of the following UTM grid coordinates (NAD 83): Zone 8; 529133 east; 7219734 north. The showing consists of abundant clots of chalcopyrite in highly metasomatized and veined Fairchild Lake Group siltstone in outcrop and an adjacent talus field. Cursory investigations of the area suggest that this exposure is a megaclast of country rock engulfed by a zone of dark-grey-weathering, grey Wernecke Breccia approximately 2.5 km long and 1 km wide. The surrounding breccia

(Fig. 10), which hosts several blocks of Bonnet Plume River diorite (Fig. 9), is generally rich in specular hematite but barren of chalcopyrite. Near a megaclast of diorite 400 m to the north of the showing, the breccia is mottled red and grey and hosts octahedral grains of magnetite up to 2 cm long.

The new showing is an example of how country rock and megaclasts are, in some instances, more enriched in copper than the host breccia. The change in breccia colour and iron oxide mineralogy in proximity to the diorite suggests that the igneous rock locally affected the geochemical character of the mineralizing fluids. These findings, which build upon those of Thorkelson (2000), highlight the importance of considering the distribution and type of clasts and wallrock when prospecting for Wernecke Breccia-type deposits.

'SLAB CREEK' AREA

The 'Slab Creek' area, in the southeast corner of the study area, is underlain by Fairchild Lake Group fine-grained sedimentary rocks, their schistose equivalents, and Wernecke Breccia (Hunt et al., 2002). Wernecke Breccia in this area has been divided into two units, known informally as Type 1 and Type 2, based on crosscutting relationships (ibid.). Type 1 Wernecke Breccia is limited in extent and consists of grey sedimentary clasts and locally abundant fragments of massive magnetite, in a matrix of carbonate mineral(s) and magnetite. Type 2 Wernecke Breccia cuts Type 1 and is made up of dominantly sedimentary clasts in a matrix that is itself fragmental. Type 2 breccia also contains rare clasts of fragmental matrix (Fig. 11), indicating that more than one phase of Type 2 brecciation occurred. Detailed information on this area is available in Brookes et al. (2002) and Brookes (2002).

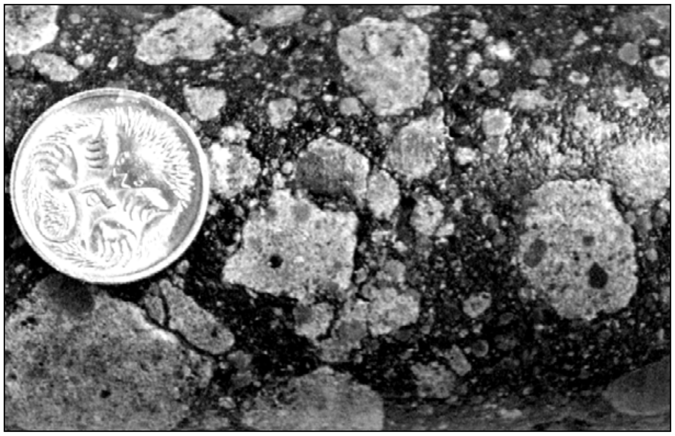

Figure 11. *Core sample of rebrecciated Wernecke Breccia (light grey) from the Irene mineral occurrence (002). Clasts of Wernecke Breccia are hosted in a dark, hydrothermally precipitated matrix.*

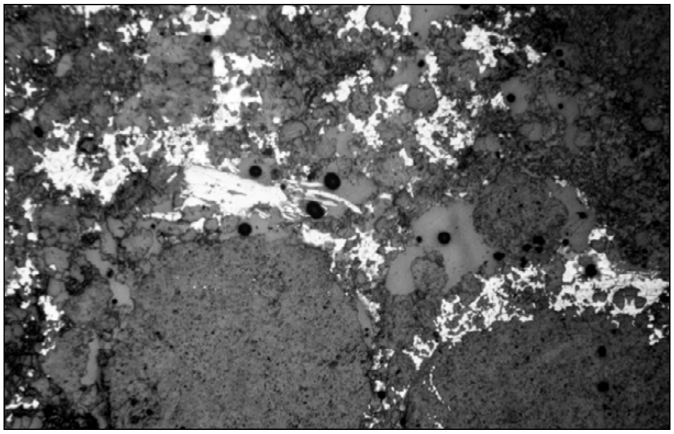

Figure 12. *Reflected-light photomicrograph of chalcopyrite (bright) within matrix to metasomatized siltstone clasts in Wernecke Breccia 5 km southeast of the Mountaineer mineral occurrence (025). Width of rock surface is 5.6 mm.*

Mineralization occurs in two zones about 500 m apart on the south side of Slab Creek, and may be regarded as part of the Slab mineral occurrence to the south, 106D 070 (Yukon MINFILE 2002). In these zones, iron oxide-copper-gold mineralization, dominantly hematite-magnetite-chalcopyrite (with minor molybdenum and uranium), is associated with breccia and occurs in five styles: (1) disseminated in quartz-carbonate veins cutting metasomatized sedimentary rocks proximal to the breccia bodies; (2) as up to 10-cm-thick, pyrite-chalcopyrite veins that cut Type 1 breccia; (3) as rare sulphide clasts in Type 2 breccia; (4) disseminated locally in the matrix and/or forming the matrix of Type 2 breccia (Fig. 12); and (5) as rare sulphide veinlets that crosscut Type 2 breccia.

Table 1. *Significant drill intercepts in the Slab Creek area. Information is from Vance et al. (1995, unpublished company report), Owerko (1995, unpublished company report), and Montgomery (1998, unpublished company report).*

DDH number	Length of intersection (m)	Cu %	Au (ppb)
SB95-5	13.8	0.42	150
SB95-6	9.7	0.57	110
SB95-8	12.7	0.03	410
SB97-9	213.05	0.175	36

Crosscutting relationships indicate that sulphide mineral deposition likely occurred after the emplacement of Type 1 breccia and continued until after the emplacement of Type 2 breccia (ibid.).

Diamond drilling in Slab Creek intersected mineralization associated with Wernecke Breccia in both zones, and significant results from this drilling are shown in Table 1. Slab Creek is approximately 1 km northwest of Slab Mountain which has a potential of 20 million short tons (18 million tonnes) grading 0.35% Cu and 0.17 g/t Au (with small zones of 0.1% MoS_2) based on three diamond drill hole penetrations and surface sampling (Vance et al., 1995, unpublished company report).

IRENE MINERAL OCCURRENCE

Introduction

At the Irene mineral occurrence (002; Fig. 2), iron oxide-copper-gold mineralization and minor uranium and cobalt enrichments are associated with Wernecke Breccia (Jones and Stammers, 1995, unpublished company report). Two regions of breccia are present: a lower one at the base of the mountainside at least 100 m thick, between 600 and 750 m elevation; and an upper, discontinuous one, 1-20 m thick, at approximately 1300 m elevation. The upper breccia zone is truncated by a thrust fault (Bell, 1986a; Thorkelson et al., 2002). Descriptions of the breccias and the mineral enrichments they host, based on observations of outcrops and polished sections, are summarized below.

Lower breccia

The lower breccia weathers tan to brown and hosts white- to cream-weathering clasts. It is hosted by phyllite and siltstone of the Fairchild Lake Group. The breccia is clast- to matrix-supported with a dominantly fine-grained, hard, white, pink or pale grey matrix. Locally the matrix consists of coarse-grained quartz and albite (locally with crystal faces – indicating open space filling) and lesser carbonate, magnetite, hematite, biotite, chlorite, muscovite, and minor pyrite and chalcopyrite and accessory apatite. Locally, disseminated fine-grained specular hematite and abundant pyrite porphyroblasts up to 3 cm across occur in the matrix.

Clasts in the lower breccia are dominantly sub-angular (rarely angular) to sub-rounded, fine-grained, purple-, grey- or white-laminated siltstone from 0.2 cm-2 m across (average 0.5-10 cm). Other clast types include sub-rounded sulphide + carbonate, 1-12 cm across (Fig. 13); rounded sulphide about 5 cm across; fine-grained carbonate; chloritic phyllite; and diorite clasts up to 12 x 10 m across which occur only locally. They are strongly chloritized, moderately magnetic and are cut by fractures coated with hematite. The diorite clasts are commonly crackle-brecciated on the margins by feldspar-quartz veins. The breccia also contains rare clasts of earlier breccia that are made up of fine-grained siltstone clasts in a medium-grained matrix of albite + quartz + muscovite + carbonate + minor disseminated hematite + accessory apatite. Rare 1-4 cm clasts of massive fine-grained specular hematite are also present in the breccia.

Figure 13. *Sulphide clast (black) in Wernecke Breccia, Irene mineral occurrence (002).*

Contacts between siltstone and breccia vary from sharp to gradational. Where gradational, the siltstone varies from being completely replaced by feldspar-quartz alteration, to being crackle-brecciated, to containing feldspar-quartz veins with increasing distance from the breccia body.

Copper mineralization in the lower breccia occurs as

- rare rounded sulphide-carbonate and sulphide clasts up to 12 cm across in the breccia (Fig. 13);
- disseminated minerals in feldspar-quartz-pyrite-chalcopyrite veinlets within siltstone clasts in the breccia and replacement layers in siltstone clasts;
- chalcopyrite blebs in the carbonate matrix of the breccia; locally, chalcopyrite-pyrite forms the breccia matrix;
- sulphide blebs approximately 5 cm across in carbonate-chlorite-muscovite-pyrite-chalcopyrite-hematite ± magnetite veins and alteration that crosscut the breccia;

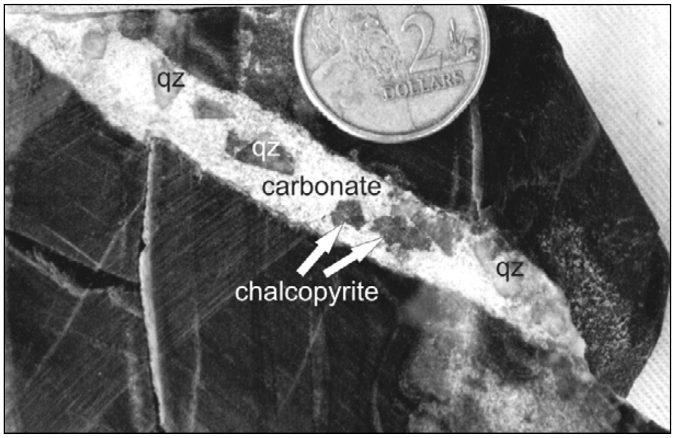

Figure 14. *Carbonate-quartz vein hosting chalcopyrite grains, Irene mineral occurrence (002); qz = quartz.*

- disseminated minerals in quartz-hematite-pyrite-chalcopyrite veins that cut Fairchild Lake Group siltstone and Wernecke Breccia;
- small blebs in coarsely crystalline carbonate ± chalcopyrite veins that cut Wernecke Supergroup sedimentary rocks and Wernecke Breccia;
- blebs and disseminated minerals in quartz–muscovite-hematite-chalcopyrite veins that cut Fairchild Lake Group siltstone. Quartz and muscovite crystals in these veins are up to 1 cm long and 0.5 cm across (Fig. 14);
- small blebs and disseminated minerals in feldspar-quartz-chalcopyrite veinlets that parallel and crosscut calcareous layers (layers are 5 to 20 cm thick) in siltstone, and as small blebs in the calcareous layers adjacent to the veins.

Massive chalcopyrite mineralization is exposed in a trench about 45 m above the valley floor. Samples of drill core from this location returned average grades of 3.6% Cu over 3.1 m in a fault zone, and 0.23 % Cu over 64.9 m in breccia (Yukon MINFILE, 2002). Other drill results in this area indicate there are large zones of low-grade copper-gold mineralization; samples from the best intersection returned results of 0.32 g/t Au and 0.42% Cu over 73 m (Jones and Stammers, 1995, unpublished company report).

Upper breccia

The upper breccia occurs as small discontinuous outcrops hosted in the Quartet Group, near the top of the ridge. Overall, the breccia weathers cream to light brown with local iron staining. Outcrops have a pitted appearance due to weathered-out clasts. The breccia is matrix-supported with a matrix of carbonate ± magnetite ± hematite ± quartz ± chlorite ± pyrite ± chalcopyrite. Clasts are dominantly composed of sub-rounded, laminated, brown, rusty-weathering carbonate 1 to 3 cm across. The remaining clasts (about 50%) are sub-rounded, <1 to 3 cm across and composed of fine-grained, light grey laminated siltstone/phyllite; fine-grained white clasts; fine-grained beige clasts; and fine-grained dark grey slate. Some of the siltstone/phyllite clasts have bleached alteration rims. Locally the breccia is crosscut by magnetite veinlets, carbonate-magnetite-chlorite veins, quartz veins and chlorite-biotite veins.

The breccia is in sharp contact with surrounding siltstone and locally crosscuts layering. White quartz veinlets cut the siltstone for up to 30 cm from the margin of the breccia. The siltstone is bleached for up to 10 cm from the breccia. Slate in contact with the breccia has round, black spots. In the upper breccia body pyrite-chalcopyrite mineralization occurs as a narrow vein, and as blebs and disseminated within the breccia matrix.

EATON MINERAL OCCURRENCE

The Eaton mineral occurrence (040) is located in a large region of Wernecke Breccia which spans the Slats Creek valley near the southwestern corner of the map area (Fig. 2). The Fairchild Lake and Quartet groups, and bodies of Bonnet Plume River diorite, host the breccia. Two distinctive types of mineral enrichments are present. One consists largely of chalcopyrite and uranium enrichments, which are typical of many Wernecke Breccia-hosted occurrences. The other consists of visible gold within quartz veins, which may be related to Wernecke Breccia formation or may represent an unrelated event of fluid flow and metallogenesis.

Breccia zone

Breccia near the Eaton occurrence, on the east side of Slats Creek, weathers dark green to brown (locally pink to red) and varies from clast- to matrix-supported. Clasts are sub-angular (rarely angular) to sub-rounded (rarely rounded) and made up dominantly of grey, maroon, pink and red fine-grained sediments, and banded to laminated siltstone. Clasts average about 5 cm across but larger clasts, up to 1 x 3 m, occur locally. Rare clasts of fine-grained brown-weathering carbonate up to 5 cm across occur locally. The breccia matrix is itself fragmental and is made up of micro-breccia with a carbonate matrix and fine-grained sedimentary clasts. Locally, there is abundant

Table 2. *Select anomalous results from surface sampling at the Eaton mineral occurrence (Montgomery and Stammers, 1995, unpublished company report; Montgomery, 1995, unpublished company report).*

Type	Au (ppb)	Cu	Co (ppm)	Sampled material
1.3 m chip	780	1.46%	43	mineralized potassium and silica metasomatized sedimentary rocks
8.4 m chip	45	4380 ppm	107	weakly mineralized breccia and metasomatized sedimentary rocks
2.0 m chip	1380	9650 ppm	63	mineralized potassium and silica metasomatized sedimentary rocks
select grab	140	1.66%	39	mineralized potassium and silica metasomatized sedimentary rocks
select grab	95	3.90%	253	malachite-stained contact between dolomitic shale and breccia

patchy fine-grained disseminated specular hematite in the matrix (Fig. 15).

Locally, breccia is fine-grained with sub-rounded to sub-angular fine-grained grey and pink sedimentary clasts <1 cm across. The matrix is dominantly made of carbonate and specular hematite. The breccia is generally non-magnetic and non-calcareous. Locally it is strongly chlorite- or sericite-altered, but is more typically stained pink to red, probably due to potassium feldspar and/or hematite alteration. The breccia is cut by brown-weathering carbonate-quartz ± chalcopyrite ± hematite veins up to 3 cm wide; some of these are tension veins.

In general, Wernecke Breccia in this area appears to occur as numerous narrow bands (that pinch out along strike), up to 1.5 m thick, emplaced parallel to layering in the sedimentary rocks. Locally, the breccia occurs in zones 20 to 80 cm wide that cut across siltstone and are roughly parallel to prominent jointing in the sediments. Contacts between siltstone and breccia vary from sharp to gradational (crackle-brecciated). Locally there is a strong fabric in the breccia and some clasts are elongate parallel to the fabric.

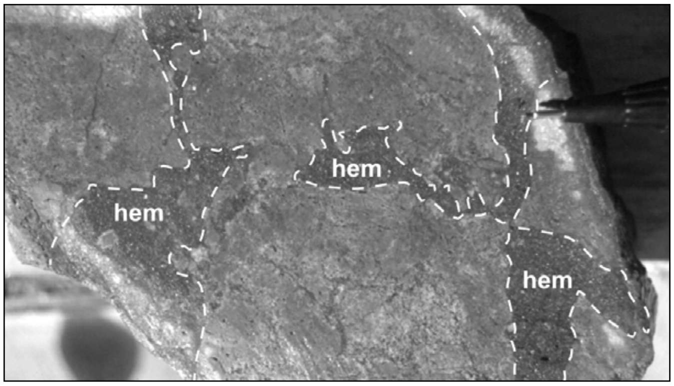

Figure 15. *Polished slab of Wernecke Breccia from near the Eaton mineral occurrence (040), featuring metasomatized siltstone clasts in matrix of massive specular hematite (labelled 'hem'). Width of surface is 7.5 cm.*

Mineralization

Iron oxide-copper ± gold ± cobalt mineralization is associated with Wernecke Breccia, metasomatically altered sedimentary rocks and diorite at the Eaton occurrence. A selection of results from this style of mineralization is shown in Tables 2 and 3.

The mineralization is widely distributed and generally low-grade with sporadic high-grade occurrences (Montgomery, 1995, unpublished company report). In general, it is dominated by chalcopyrite that occurs as disseminated fine- to coarse-grained patches and in veins and fractures. Pyrite occurs locally. Cobaltite and bornite occur rarely. Pods of massive specular hematite up to 2 x 3 m are also associated with the breccia zones. They contain rare euhedral pyrite approximately 1 mm across, and rare tiny blue specks tentatively identified as bornite. A 2- to 4-m-wide vein of massive medium-grained magnetite + very coarse-grained specular hematite + carbonate + quartz extends for at least 50 m within brecciated phyllite of the Fairchild Lake Group.

Table 3. *Select results from analysis of diamond drill core from the Eaton mineral occurrence (Montgomery, 1995, unpublished company report).*

Width (m)	Cu (ppm)	Au (ppb)
29.5	1080	spot highs to 310
7.5	2093	
5.75	1270	< 20
1.8	8	875

Gold-quartz veins

Gold-rich, brannerite-bearing, quartz-vein material containing up to 10% gold by volume is present in a float train. Lower grade samples typically returned results of 686-10 285 g/t Au (Yukon MINFILE, 2002). The source of this material has not been found.

FARION MINERAL OCCURRENCE

According to Yukon MINFILE 2002 and our investigations, the Farion occurrence (004) is a showing of sphalerite, galena and marcasite near a fault and a Late Proterozoic to early Paleozoic dyke. No additional mineralization in this region was found in the course of mapping.

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