Nature and origin of copper-gold mineralization at the Minto and Williams Creek deposits, west-central Yukon: Preliminary investigations

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ABSTRACT

A new research project was begun in 2002, aimed at better understanding the nature and origin of copper-gold mineralization and its main host rocks at the Minto and Williams Creek (Carmacks Copper) deposits in west-central Yukon. This will also help to further constrain exploration models both on a property and a regional scale. Field work in 2002 confirmed that the main host rocks for both deposits are variably deformed plutonic rocks (diorite and quartz diorite at Williams Creek and mainly granodiorite at Minto). Mineralization formed prior to the ductile deformation that has affected these units. Mineralized granodioritic gneiss from Minto and apparently post-mineralization quartz diorite at Williams Creek yield U-Pb ages of ~194 Ma and ~191 Ma, respectively; thus the mineralization appears to have formed at essentially the same time as the host intrusions. Reconnaissance Pb- and S-isotope analyses of sulphide minerals from both deposits also indicate a likely magmatic source for the mineralization.

RÉSUMÉ

Un nouveau projet de recherche entrepris en 2002 visait à mieux comprendre la nature et l'origine de la minéralisation de Cu-Au et des principales roches encaissantes aux gisements de Minto et de Williams Creek (Carmacks Copper) dans le centre-ouest du Yukon. Il permettra d'affiner les modèles d'exploration tant à l'échelle d'une propriété qu'à l'échelle régionale. Les travaux exécutés sur le terrain en 2002 confirment que les principales roches encaissantes des deux gisements sont des roches plutoniques inégalement déformées (diorite et diorite quartzique au gisement de Williams Creek et surtout granodiorite au gisement de Minto). La minéralisation est antérieure à la déformation ductile de ces unités. Le gneiss granodioritique minéralisé de Minto et la diorite quartzique apparemment postérieure à la minéralisation des gisements de Williams Creek donnent par la méthode U-Pb des âges respectifs de ~194 Ma et de ~191 Ma; la minéralisation semble donc synchrone des intrusions encaissantes. Des analyses de reconnaissance des isotopes Pb et S dans les sulfures des deux gisements indiquent également une minéralisation d'origine probablement magmatique.

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INTRODUCTION

The Minto deposit in west-central Yukon (Yukon MINFILE 2002, 115I 021 and 022), located 240 km northwest of Whitehorse and owned by Minto Exploration Ltd., was discovered in 1971 and contains approximately 9 million tonnes with an average grade of 1.73% Cu, 0.48 g/t Au and 7.5 g/t Ag. The Williams Creek (Carmacks Copper) deposit (Yukon MINFILE 2002, 115I 008), located approximately 50 km to the southeast of the Minto deposit and owned by Western Copper Holdings Ltd., contains published reserves of approximately 15.5 million tonnes at 1.01% Cu. The Minto and Williams Creek deposits lie within a northwest-trending belt that includes numerous other copper (± gold) occurrences, some of which have been drilled (e.g., the Stu occurrence; Yukon MINFILE 2002, 115I 011). The Minto-Williams Creek area is unglaciated and has subdued topography, hence exposure is generally poor, and underlying rock units have been affected by deep surface weathering and oxidation by meteoric waters. Resolving original lithological contact relations in the vicinity of the deposits themselves depends largely on examination of drill core. The geology outside of the immediate deposit areas is poorly understood.

Although both the Minto and Williams Creek deposits are now at a pre-production stage of development, there is still no consensus regarding the nature or origin of mineralization in the deposits. Previous workers have assigned them to various different deposit types, including metamorphosed volcanogenic massive sulphide deposits, metamorphosed redbed Cu deposits and deformed Cu-Au porphyries (e.g., Pearson, 1977; Sinclair, 1977; Pearson and Clark, 1979). Any future exploration for similar Cu-Au mineralization in the region is greatly hampered by the lack of a descriptive model for the deposits, which is a basic requirement for developing genetic or exploration models for this style of mineralization.

The purpose of the current project is to gain a better understanding of the nature, age and origin of the main host rock units and copper-gold mineralization at the Minto and Williams Creek deposits. This information can then be used as a basis for developing an exploration model for similar mineralization elsewhere in the region. In this paper, the authors present some of the initial results of the study and describe the work that is presently underway and planned for the 2003 field season.

PREVIOUS WORK

Sinclair (1977) carried out six weeks of geological mapping in the vicinity of the Minto deposit and its surroundings, as well as reconnaissance level geochemical studies of intrusive rocks in the area. Pearson (1977; see also Pearson and Clark, 1979) completed a Master of Science thesis focused on the Minto deposit, which included petrographic, mineralogical and geochemical studies, as well as a limited amount of sulphur isotope work on the sulphide minerals. A 1:250 000-scale geological map of the Carmacks map sheet was published by Tempelman-Kluit (1984). In addition, the geology of the Minto and Williams Creek deposits is described in numerous unpublished mineral assessment reports prepared by various company geologists. A low-level magnetic and gamma ray survey was flown over the entire Minto-Williams Creek area by the Geological Survey of Canada and the Yukon Geology Program in 2001 (Shives et al., 2002). No geological interpretation of this new geophysical data set has yet been prepared.

REGIONAL SETTING

The Minto-Williams Creek area is underlain by three main lithological assemblages. Intermediate to felsic intrusive and meta-intrusive rocks of the early Mesozoic Granite Mountain Batholith underlie much of the area and are interpreted to be intrusive into the Yukon-Tanana Terrane (Fig. 1; Gordey and Makepeace, 1999). The batholithic rocks are in fault and/or intrusive relation with an unnamed package of altered mafic volcanic rocks to the northeast, and are unconformably overlain by sedimentary rocks and volcanic flows of the Late Cretaceous Tantalus Formation and Late Cretaceous Carmacks Group, respectively. Mineralization at Minto and Williams Creek is hosted by intrusive rocks assigned to the Granite Mountain Batholith, and/or deformed and metamorphosed rafts and pendants contained within the batholith. Regional structure is poorly understood because outcrop is very sparse (<1%) and the area is unglaciated and deeply weathered. In addition, there is a lack of detailed geological mapping in this area. However some significant steep faults have been recognized in the area (e.g., the DEF fault at Minto; see later discussion).

INITIAL RESULTS

Initial investigations of the Minto and Williams Creek deposits were carried out between July 30 and August 12, 2002. The following were examined and sampled: surface exposures of the Minto Main Zone; host rocks for the mineralization exposed in new cuts in the vicinity of the camp and along the access road at Minto; and core from several Minto and Williams Creek drill holes. This work included examining contact relationships, and sampling various rock units for petrographic, geochemical and geochronological studies. In addition, magnetic susceptibility measurements were taken on representative samples of the main lithological units to help constrain interpretations of ground and airborne magnetic surveys.

Preparation of standard and polished thin sections for petrographic study is underway, and a representative suite of deformed and undeformed intrusive rocks at both deposits has been submitted for whole rock geochemical analysis. In addition, slabs of almost all samples were cut and stained for K-feldspar in order to characterize the different rock types in the area and begin preparation of a digital 'atlas' of igneous rock textures and compositions in the Minto and Williams Creek areas. Samples are also being prepared for U-Pb and Ar-Ar dating studies of the main host rock units and various alteration assemblages, and common Pb analysis of sulphide minerals and host rocks. Results of work thus far are summarized in the following sections.

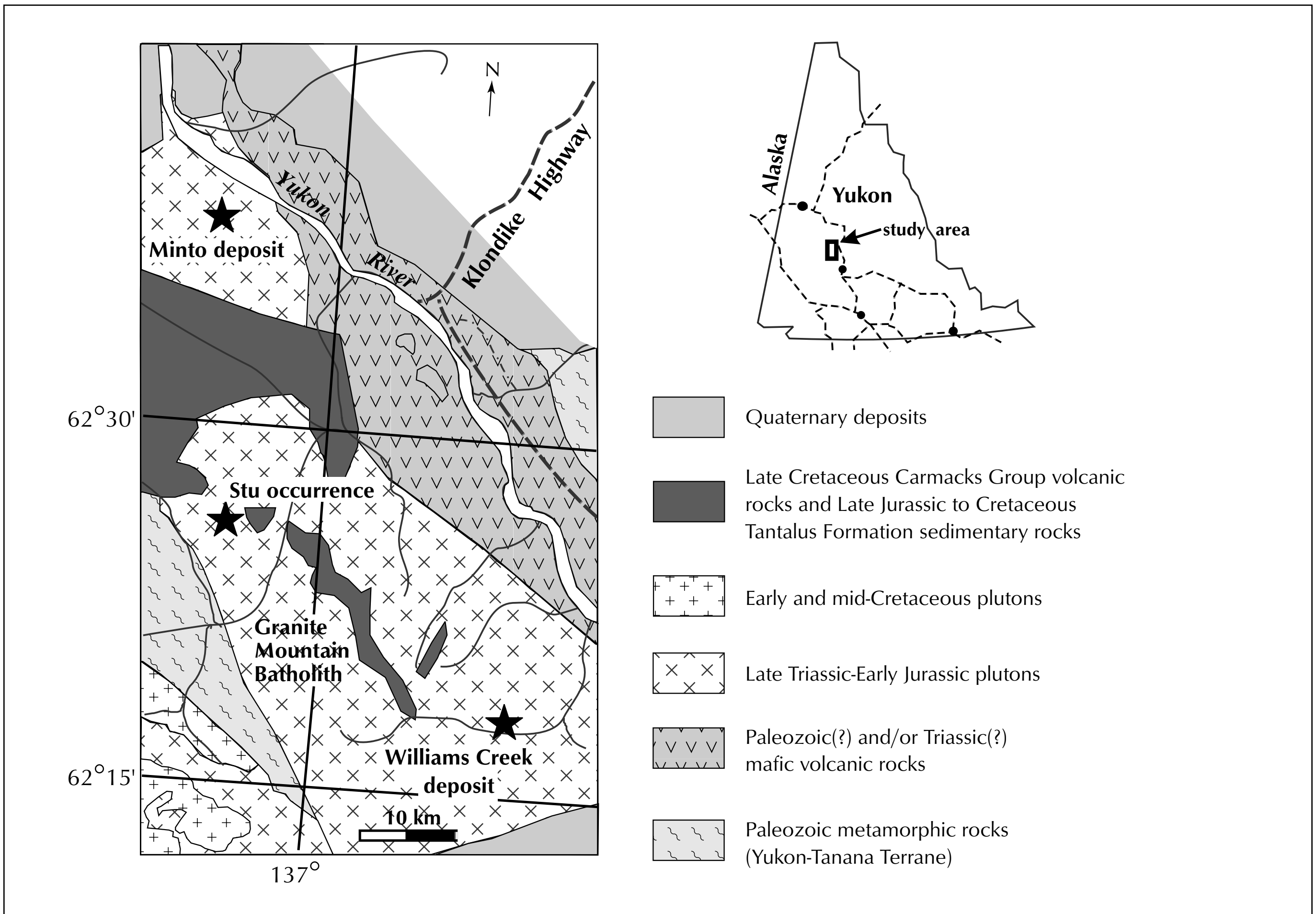

Figure 1. *Map showing the location and regional geological setting of the Minto and Williams Creek deposits and the Stu occurrence (Yukon MINFILE 2001, 115I 011; simplified from Gordey and Makepeace, 1999).*

LITHOLOGICAL ASSEMBLAGES IN THE MINTO-WILLIAMS CREEK AREA

A preliminary lithological breakdown of the main rock units was done based on field observations and modal analysis. Sample modes were calculated using digital image analysis methods on stained slabs, as described by Duncan (1999). Calculated modes for a range of intrusive and meta-intrusive rock units from Minto and Williams Creek are shown on an IUGS ternary diagram in Figure 2.

INTRUSIVE ROCKS

Ten distinct intrusive phases have been identified in the Minto and Williams Creek area based on preliminary work:

1. Fine-grained granitic orthogneiss (at Williams Creek only; possibly Paleozoic in age).
2. Massive K-feldspar-phyric granodiorite of the Granite Mountain Batholith.
3. Massive to moderately foliated porphyritic diorite/ quartz diorite of the Granite Mountain Batholith.

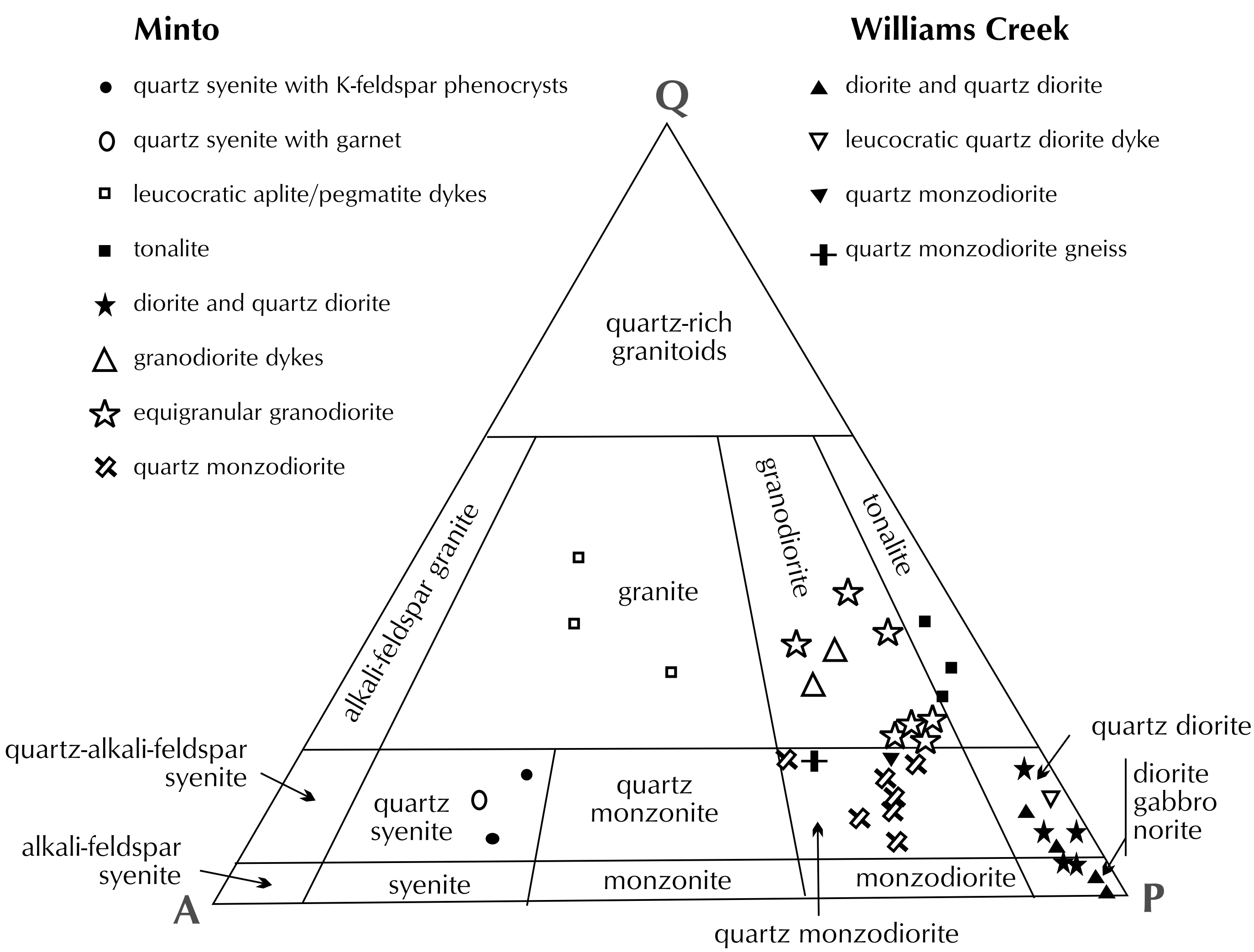

Figure 2. Calculated modes of quartz-alkali feldspar-plagioclase (QAP) for a range of representative intrusive and meta-intrusive rock units from the Minto and Williams Creek area.

4. Massive quartz-phyric granodiorite of the Granite Mountain Batholith.
5. Biotite-rich gneiss and quartzofeldspathic gneiss (main ore hosts at Minto).
6. Massive to moderately foliated diorite and quartz diorite (main ore host at Williams Creek).
7. Pink granitic pegmatite/aplite dykes.
8. Foliated, fine-grained, grey, biotite aplite dykes.
9. Equigranular biotite-quartz monzonite dykes.
10. Late mafic dykes (aphyric or hornblende-phyric).

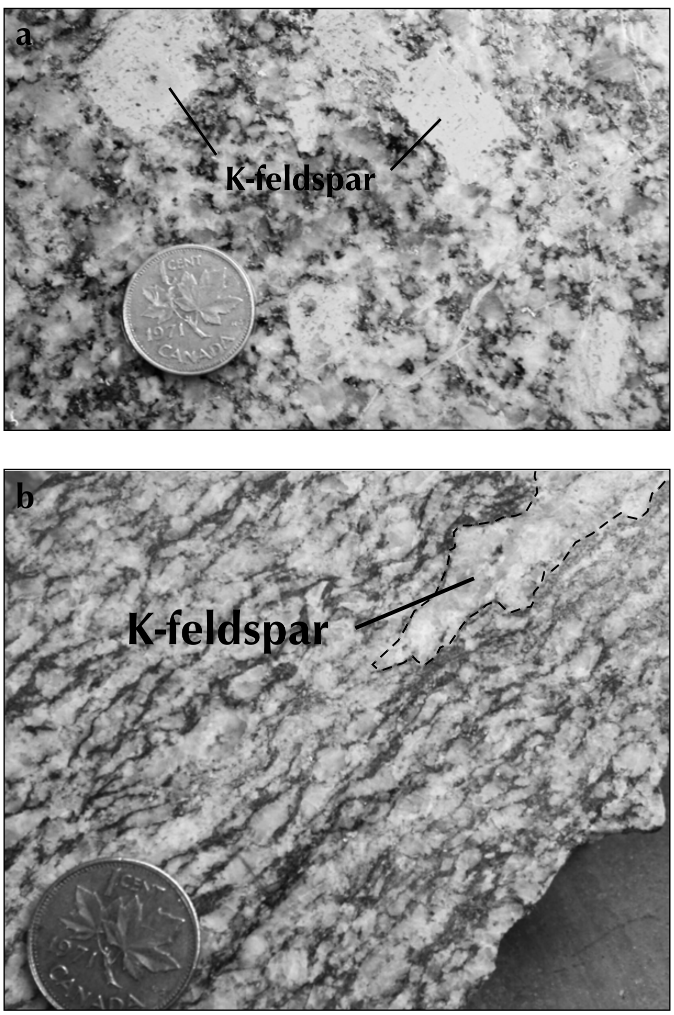

Figure 3. *Representative igneous rock units from Minto: **(a)** typical massive, K-feldspar-phyric hornblende-biotite granodiorite (phase 2) of the Granite Mountain Batholith; **(b)** strongly foliated and weakly mineralized biotite granodiorite meta-intrusive rock with broken and strung-out K-feldspar phenocryst (phase 5).*

Parts of phase 5 contain deformed and strung out pink K-feldspar augen, and are clearly a ductilely deformed equivalent of phase 2 (Fig. 3a,b). Phase 6 is also seen to pass gradationally into phase 3.

OTHER ROCK UNITS

Two other main rock units are recognized in the area:

1. 'Siliceous ore' at Minto and rarely at Williams Creek — the typically thinly banded structure seen in numerous intercepts of 'siliceous ore' in drill core, together with the quartz- (and magnetite-) rich composition, suggests derivation from a very different protolith than the 'quartzofeldspathic or biotite gneiss ore'. The quartz-rich bands could have been derived from siliceous layers in a thinly bedded supracrustal sequence or may be completely transposed quartz veins.
2. Fine-grained 'amphibolite' at Williams Creek — this unit is likely derived from a supracrustal rock unit, most likely an intermediate or mafic volcanic rock or a sedimentary rock derived from a volcanic source of this composition. The presence of banded 'siliceous ore' interlayered with the amphibolite in the Williams Creek core may support the sedimentary origin suggested above for this unit.

GEOCHRONOLOGY AND GEOCHEMISTRY OF INTRUSIVE ROCK UNITS

Only limited age information is available thus far for intrusive and meta-intrusive rocks from the Minto-Williams Creek area. However, two preliminary U-Pb dates shed critical light on the age of the deposits. A sample of mineralized, strongly foliated granodiorite from Minto contains a single population of igneous zircons that give an age of 194 ± 1 Ma (J.K. Mortensen, unpublished data, 2002). This is interpreted as the crystallization age for the intrusive host rock, and provides a maximum age limit for the mineralization at Minto. A sample of massive, porphyritic quartz diorite of the Granite Mountain Batholith at Williams Creek that is interpreted to post-date mineralization gives a U-Pb zircon age of approximately 192 Ma and a U-Pb titanite age of 191 ±1 Ma (J.K. Mortensen, unpublished data, 2002). These data provide a minimum age bracket for the mineralization at Williams Creek.

A detailed geochemical study of the intrusive and meta-intrusive rocks in the Minto-Williams Creek area is currently underway. A very limited amount of data from the study area indicate that the rocks are geochemically very similar to other Late Triassic and Early Jurassic intrusive rocks throughout the Yukon-Tanana Terrane in Yukon and eastern Alaska as described by Mortensen et al. (2000). This intrusive suite is generally metaluminous and sub-alkaline to slightly alkaline in composition. Concentrations of immobile trace, high field strength and rare earth elements are most consistent with generation in a continental magmatic arc.

STRUCTURAL GEOLOGY

The structural evolution of the Minto and Williams Creek areas, and the nature and origin of the foliation(s) within the various rock units, will be critical for understanding the genesis of the two deposits. Alignment of K-feldspar phenocrysts in the porphyritic granodiorite of the Granite Mountain Batholith is ascribed to magmatic flow and it is likely that some alignment of mafic minerals and mineral aggregates, and potentially the formation of mafic schlieren observed locally within the batholith, may have also occurred during emplacement of early phases of intrusion. However, these K-feldspar phenocrysts (and their host rocks) have themselves been involved in subsequent ductile deformation that coincided with, or post-dated, introduction of the sulphide minerals. Therefore at least two distinct phases of foliation development can be demonstrated. Feldspar phenocrysts (mainly plagioclase) in the main phase of porphyritic diorite and quartz diorite at Williams Creek are typically strongly recrystallized in both the massive and foliated phases. It is unclear what the nature, origin and timing of this recrystallization is; this will be resolved in part by petrographic studies.

Post-mineralization deformation includes brittle faults with several orientations, including the east-trending DEF fault which forms the northern boundary of the Main Zone at Minto. These young brittle faults have facilitated relatively deep circulation of surface waters and oxidation of the hypogene sulphide minerals and their host rocks, including the pervasive hematization noted throughout parts of the Minto deposit. This oxidation has made it possible to economically recover copper from the Williams Creek deposits by heap leach methods. In addition, substantial block rotation has occurred, at least locally. This is evidenced by the tilting of younger sedimentary units (probably Late Jurassic to Cretaceous Tantalus Formation), south of the Main Zone at Minto, by up to 60° (bedding/core angles as low as 30° in vertical drill hole 99-01). Such late fault block rotation may in part account for the anomalously shallow dips of the dominant foliation in gneissic host rocks in the Minto Main Zone.

MINERALIZATION

Results of the 2002 field work confirm that the main host rocks for both deposits are variably deformed plutonic rocks. Mineralization at Minto is hosted mainly within foliated biotite and quartzofeldspathic orthogneiss (‘quartzofeldspathic ore’), with a lesser amount of mineralization contained within a banded, relatively quartz-rich rock (‘siliceous ore’). The ‘ore zones’ are enclosed by massive to very weakly foliated granodiorite of the Granite Mountain Batholith. The main host rock for mineralization at the Williams Creek deposit is foliated intrusive rock of dioritic to quartz dioritic composition. As with Minto, the ‘ore zones’ at Williams Creek and their metamorphosed host rocks are enclosed by massive quartz diorite and granodiorite of the Granite Mountain Batholith. At both deposits, chalcopyrite, bornite and lesser pyrite are disseminated and occur as stringers. Mineralization occurred prior to the ductile deformation that has affected the host units. ‘Siliceous ore’ may represent either mineralized and deformed quartz-rich sedimentary wall rocks to the intrusions or possibly strongly transposed sulphide-bearing quartz vein sets.

Although most sulphide mineralization at Minto and Williams Creek was clearly emplaced early and was ductilely deformed along with its host rocks, trace amounts of chalcopyrite and bornite are also present within post-tectonic pegmatites and aplites, particularly within the ore zones but also in a few cases outside of the main mineralized intersections. This is currently interpreted to represent local, late remobilization of the sulphide minerals. Thin aplite, pegmatite and quartz veins within ‘quartzofeldspathic ore’ are commonly deformed into complex ptygmatic folds, and some of these veins also contain sulphide minerals.

Pyrrhotite is disseminated throughout significant sections of the fine-grained, garnetiferous amphibolite and schist in Williams Creek, and may be syngenetic (volcanogenic?) in origin. No base metals are known to be associated with the disseminated pyrrhotite. Pyrite is also locally associated with late mafic dykes, which may be feeders to overlying Late Cretaceous Carmacks Group volcanic rocks.

ALTERATION

A detailed petrographic study of alteration assemblages at Minto and Williams Creek is currently underway. The following observations are based mainly on examination of drill core. Biotite in massive intrusive phases is at least, in part, primary igneous in origin; however there may be secondary biotite replacing primary hornblende in some of the altered but undeformed phases. Biotite in the strongly foliated gneissic zones was recrystallized along with the sulphide minerals, and therefore, primary textural information relating to its origin is not preserved. However it appears likely that both primary igneous biotite and a substantial component of hydrothermal (hypogene) biotite were originally present in the rocks; and both phases of biotite were completely recrystallized during the ductile deformation.

Relatively coarse-grained sericite is only rarely developed as an alteration phase at Minto. It has been observed first as an alteration envelope around a late epidote-filled vein that cut non-porphyritic, massive granodiorite; and secondly as a narrow envelope surrounding a late aplite and pegmatite dyke. Fine-grained sericite alteration may be more extensive in the deposit; this will be determined by petrographic studies.

Hematite commonly replaces magnetite, stains feldspars along late fractures and fills late fractures. It is commonly accompanied by bleaching of the wall rocks, and appears to be entirely late in the alteration history, and is likely completely unrelated to the mineralizing process. Bleaching, accompanied by minor hematization, produces a rock that many previous workers have incorrectly called a syenite. Epidote is commonly associated with hematite on late fractures but also occurs as an earlier, disseminated style of alteration, commonly associated with mafic minerals.

Chlorite is widespread throughout the Minto and Williams Creek areas. Some chlorite is clearly associated with late faults and breccia zones. It is unclear at this point whether any of the chlorite is related to the mineralizing process or simply represents a post-mineral retrograde recrystallization of the metamorphic mineral assemblages. Clay alteration, mainly of feldspars, was noted in numerous drill intersections. Some clay minerals are spatially associated with late faults and fractures, but other early, syn-mineral clay alteration cannot be ruled out.

DISCUSSION

Sulphide mineralization at Minto and Williams Creek occurs mainly as blebs or is disseminated within moderately to strongly deformed intrusive rocks. The mineralization must be younger than the host rocks (dated at 194 Ma at Minto); however the sulphides clearly pre-date most if not all of the ductile strain fabric recorded by the host rocks. The mineralization is older than the apparently post-mineral Granite Mountain Batholith (dated at ~192 Ma at Williams Creek). The mineralization is therefore temporally very closely tied to the host rocks. In addition, lead isotopic analyses of sulphide minerals and igneous feldspars from Minto and Williams Creek by J.K. Mortensen (unpublished data), and sulphur isotopic studies by Pearson (1977) indicate magmatic sources, which suggest a possible genetic link between mineralization and the host intrusive and meta-intrusive rocks.

The protolith(s) for some of the minor 'ore' hosts remains uncertain. Fine-grained, locally garnetiferous amphibolite at Williams Creek and banded, quartz-rich 'siliceous ore' at Minto (and rarely at Williams Creek) are likely supracrustal rocks of the Yukon-Tanana Terrane. Alternatively the 'siliceous ore' could represent zones of dense quartz (+ sulphide mineral) veins that have been completely tectonically transposed.

Multiple generations of post-mineral dyke emplacement, brittle fault offsets and associated alteration obscure hypogene alteration assemblages, and textures that may be directly related to mineralization at Minto and Williams Creek. At this point, the only alteration that can be strongly argued to be directly related to the mineralization is introduction of secondary biotite into some of the biotite-rich, deformed plutonic ore hosts. Additional work will be required to better understand the alteration zonation and history in the study area.

FUTURE WORK

Numerous lines of investigation are currently underway or are planned for the 2003 field season, including

- Detailed petrographic studies of ore and host rocks
- U-Pb dating of all phases of host rocks and younger dykes
- Ar-Ar dating of alteration mineral assemblages to constrain the cooling and uplift history of the area
- Geochemical studies of all intrusive and meta-intrusive phases
- Additional Pb and S isotopic studies of the mineralization and its host rocks
- Relogging and sampling of selected drill holes from Minto, Williams Creek and other occurrences elsewhere in the Carmacks Copper Belt
- Structural studies of the Minto and Williams Creek area.

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