Geology and Mineral Occurrences of the Quesnel Terrane between the Mesilinka River and Wrede Creek (NTS 94D/8, 9), North-Central British Columbia

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KEYWORDS: Quesnel Terrane, Takla Group, Triassic-Jurassic plutons, Hogem Batholith, volcanic sandstone, volcanic breccia, diorite, gabbro, pyroxenite, tonalite, granodiorite, copper, gold, magnetite, molybdenum

INTRODUCTION

The Johanson Lake project is a two-year bedrock mapping program initiated by the Geological Survey and Development Branch in 2003 as part of the Toodoggone Targeted Geoscience Initiative (TGI). The project is focused on a belt of Mesozoic arc volcanic and plutonic rocks of the Quesnel Terrane in the eastern part of the McConnell Creek (94D) map sheet. This area contains a number of MINFILE occurrences and numerous RGS sample sites that returned anomalously high values of gold and copper. The aim of the project is to improve the quality and detail of bedrock maps for the area and determine the setting and controls of mineral occurrences.

The initial mapping for the Johanson Lake Project was carried out in late July and August of 2003, and covered an area of about 150 km^2 between Kliyul Creek and Johanson Lake (Schiarizza, 2004a, 2004b). Fieldwork during the summer of 2004 extended this mapping northward to the headwaters of Wrede Creek and southward to the north margin of the Hogem Batholith, covering an additional 300 km^2 (Figure 1). Here, we summarize the geology of the entire project area, integrating the results of our mapping with previous geological studies within and adjacent to the area. The 2004 field program also included mapping and lithogeochemical sampling of gold occurrences in the upper Kliyul Creek and Mariposite Creek areas by contract geologists D. MacIntyre and G. Payie; the results of this work are documented separately (MacIntyre *et al.*, this volume).

The Johanson Lake project area encompasses rugged terrain within the Omineca Mountains about 350 km northwest of Prince George. The Omineca Resource Access Road provides access to a corridor through the central part of the map area, but most fieldwork was conducted from fly camps supported by the Canadian Helicopters base at the Kemess mine, 60 km north-northwest of Johanson Lake. Operating funds for the project are provided by the Toodoggone TGI and a private-public partnership agreement with Northgate Minerals Corporation.

Previous geological work within and adjacent to the Johanson Lake project area is summarized by Schiarizza (2004a). These studies include regional-scale mapping by Lord (1948) and Richards (1976a, 1976b); more detailed mapping directly east of the project area by Ferri *et al*. (1993, 2001b) and Ferri (2000a, 2000b); studies of the Takla Group by Monger (1977) and Minehan (1989a, 1989b); studies of Alaskan-type ultramafic-mafic plutons by Irvine (1974, 1976), Hammack *et al*. (1990) and Nixon *et al*. (1990, 1997); a study of granitoid intrusive rocks by Woodsworth (1976); and a study of structures related to the Finlay-Ingenika fault system by Zhang (1994), Zhang and Hynes (1991, 1992, 1994, 1995) and Zhang *et al.* (1996). In addition, the area has a history of mineral exploration dating from the early 1940s, and descriptions of many of the mineral showings are found in assessment reports on file at the offices of the British Columbia Ministry of Energy and Mines in Victoria and Vancouver.

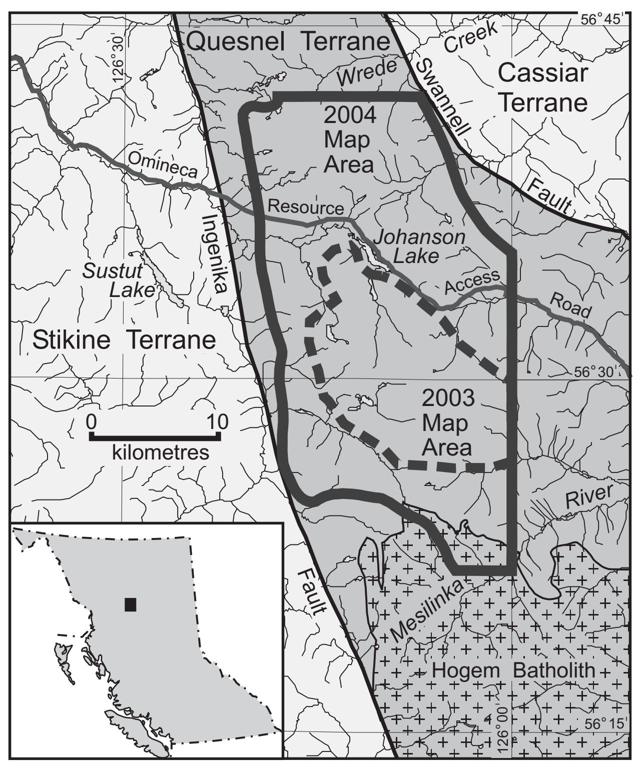

Figure 1. Location of the Johanson Lake project area, showing areas mapped during the 2003 and 2004 field seasons.

REGIONAL GEOLOGICAL SETTING

The Johanson Lake project area is underlain by the Quesnel Terrane, which includes Late Paleozoic through mid-Mesozoic volcanic, volcaniclastic and plutonic rocks formed in a system of magmatic arcs that developed along or near the western North American continental margin. East of Johanson Lake, the Quesnel Terrane is faulted against Proterozoic and Paleozoic carbonates and siliciclastics of the Cassiar Terrane, which formed part of the ancestral North American miogeocline (Fig. 2). To the south, however, the Quesnel Terrane is separated from miogeoclinal rocks by oceanic rocks of the Slide Mountain Terrane, commonly interpreted as the imbricated remnants of a Late Paleozoic marginal basin (Ferri, 1997). Along much of its length, the Quesnel Terrane is bounded to the west by the oceanic Cache Creek Terrane, which includes rocks that formed in an accretion-subduction complex related to the Quesnel magmatic arc (Travers, 1978; Struik, 1988). The Cache Creek Terrane is not present at the latitude of Johanson Lake, however, due to shuffling of terranes along Cretaceous-Tertiary dextral strike-slip faults (Gabrielse, 1985). Here, the Quesnel Terrane is juxtaposed against the Stikine Terrane, a markedly similar volcanic arc terrane, which may have originated as a northern extension of the Quesnel arc system, subsequently brought into its present position by counterclockwise oroclinal rotation and sinistral translation during the Late Triassic and Early Jurassic (Mihalynuk *et al*., 1994).

The Quesnel Terrane is in large part represented by Upper Triassic volcanic and sedimentary rocks, which are assigned to the Takla Group in northern and central British Columbia and to the Nicola Group in the south. These rocks are locally overlain by Lower Jurassic sedimentary and volcanic rocks, and are cut by several suites of Late Triassic through Middle Jurassic plutons. In north-central British Columbia, older components of the Quesnel Terrane comprise Late Paleozoic arc volcanic and sedimentary rocks of the Lay Range assemblage, which are restricted to the eastern margin of the Quesnel belt (Ferri, 1997).

Late Triassic–Early Jurassic intrusive rocks are a prominent and economically important component of the Quesnel Terrane. These include both calcalkaline and alkaline plutonic suites, as well as Alaskan-type ultramafic-mafic intrusions. Many of these plutonic suites are found within and adjacent to the Hogem Batholith (Woodsworth, 1976; Garnett; 1978; Woodsworth *et al*., 1991), which extends from the Johanson Lake project area more than 150 km south to the Nation Lakes area. In addition to Late Triassic–Early Jurassic rocks, the composite Hogem Batholith also includes younger granitic phases correlated with Early Cretaceous plutons that are common regionally and crosscut the Quesnel and adjacent terranes.

The structural history of the region included the development of east-directed thrust faults that juxtaposed Quesnel Terrane above Cassiar Terrane in late Early Jurassic time (Ferri, 1997, 2000a; Nixon *et al*., 1997). To the west, east-dipping thrust faults, in part of early Middle Jurassic age, imbricate the Cache Creek Terrane and juxtapose it above the adjacent Stikine Terrane (Monger *et al*., 1978; Struik *et al*., 2001). This thrusting was broadly coincident with the initiation of the Bowser basin (Ricketts *et al*., 1992), which formed above the Stikine Terrane and contains detritus that was derived, in part, from the adjacent Cache Creek Terrane. The subsequent structural history of the region included the development of prominent dextral strike-slip fault systems in Cretaceous and Early Tertiary time. These structures include the Finlay, Ingenika and Pinchi faults, which form the western boundary of Quesnel Terrane, and may have more than 100 km of cumulative displacement (Gabrielse, 1985).

TAKLA GROUP

All stratified rocks within the Johanson Lake map area are part of the Middle to Upper Triassic Takla Group (Lord, 1948; Monger, 1977). The Takla Group is a prominent and characteristic unit of the Quesnel Terrane throughout central British Columbia, although the namesake (Takla Lake) and type area of group are found to the west of the Quesnel belt, where the name is also applied to Upper Triassic rocks of the Stikine Terrane (for a brief history of nomenclature, *see* Schiarizza, 2004a).

The Johanson Lake map area is at the northwest end of a belt of recent, relatively detailed mapping within the Quesnel Terrane that extends almost 250 km southward to the Nation Lakes (Ferri *et al*., 1992, 1993, 2001a, 2001b; Ferri and Melville, 1994; Nelson and Bellefontaine, 1996). The Takla Group has not been subdivided into formal formations within this belt, although several lithologically distinct but partially coeval successions have been identified and named. The Takla rocks within the present map area are mainly or entirely Late Triassic in age, and pass eastward into equivalent rocks that Ferri *et al*. (1993, 2001b) assigned to the Plughat Mountain succession. Within the Johanson lake area, these rocks are subdivided into two main units: a heterogeneous succession of volcaniclastic, volcanic and sedimentary rocks assigned to the Kliyul Creek unit, and a more homogeneous assemblage of pyroxene-rich volcanic breccias assigned to the Goldway Peak unit (Fig. 3). Ferri *et al*. (1993, 2001b) recognized a similar subdivision of the Plughat Mountain succession to the east.

Kliyul Creek Unit

Most of the Takla Group within the Johanson Lake project area is assigned to the Kliyul Creek unit, which is equivalent to the volcanic sandstone unit of Schiarizza (2004a), and to units 1 and 2 of the Plughat Mountain succession, as subdivided by Ferri *et al*. (2001b). The Kliyul Creek unit consists mainly of volcaniclastic sandstone and breccia, but also includes limestone, siltstone and mafic volcanic rocks. Thick, somewhat arbitrarily defined packages that include conspicuous amounts of limestone have been broken out as the sandstone-carbonate subunit (in part equivalent to the sandstone-carbonate unit of Schiarizza 2004a). More discrete, relatively thin intervals dominated by thin-bedded siltstone and limestone are assigned to the

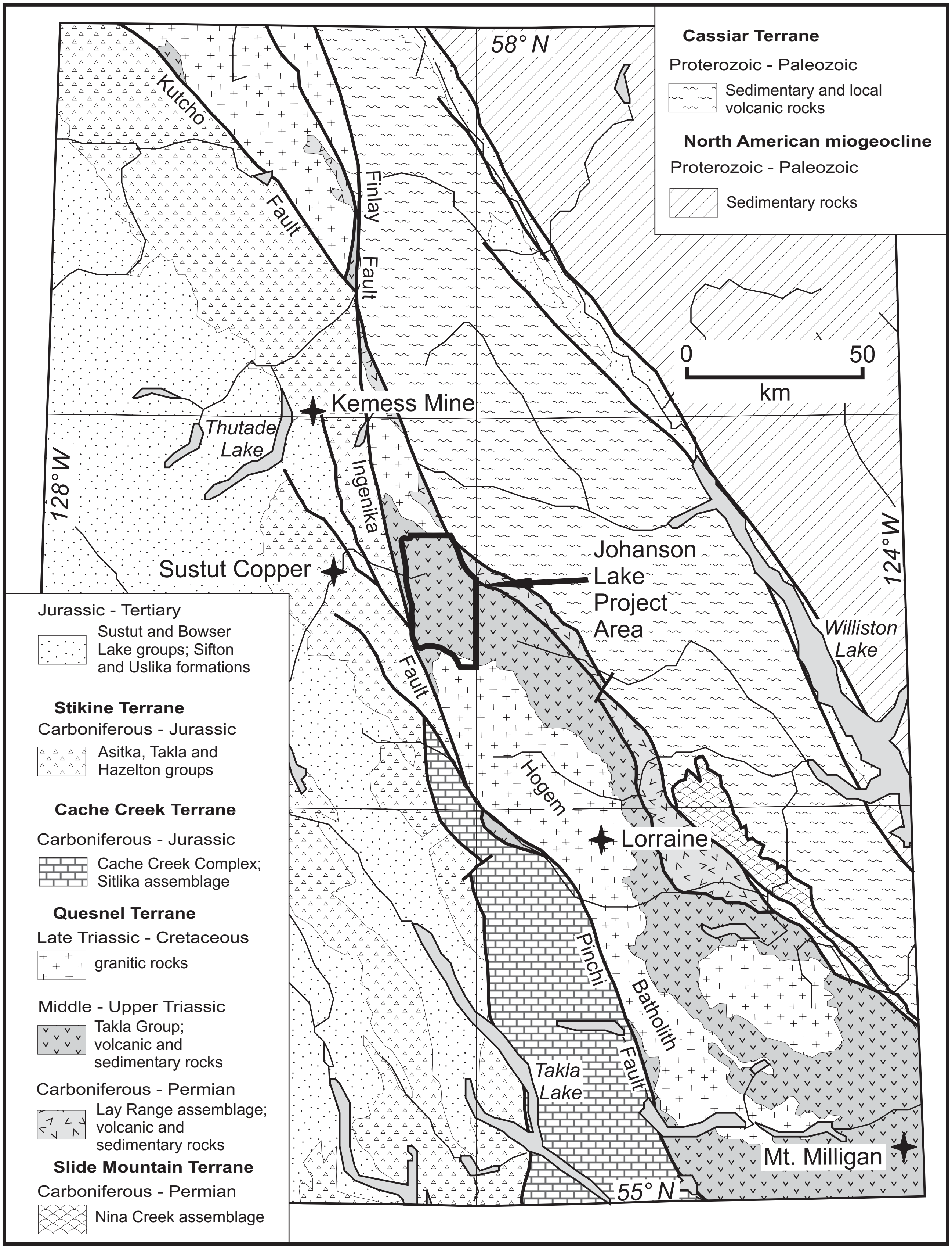

Figure 2. Regional geological setting of the Johanson Lake project area, showing locations of selected major mineral occurrences.

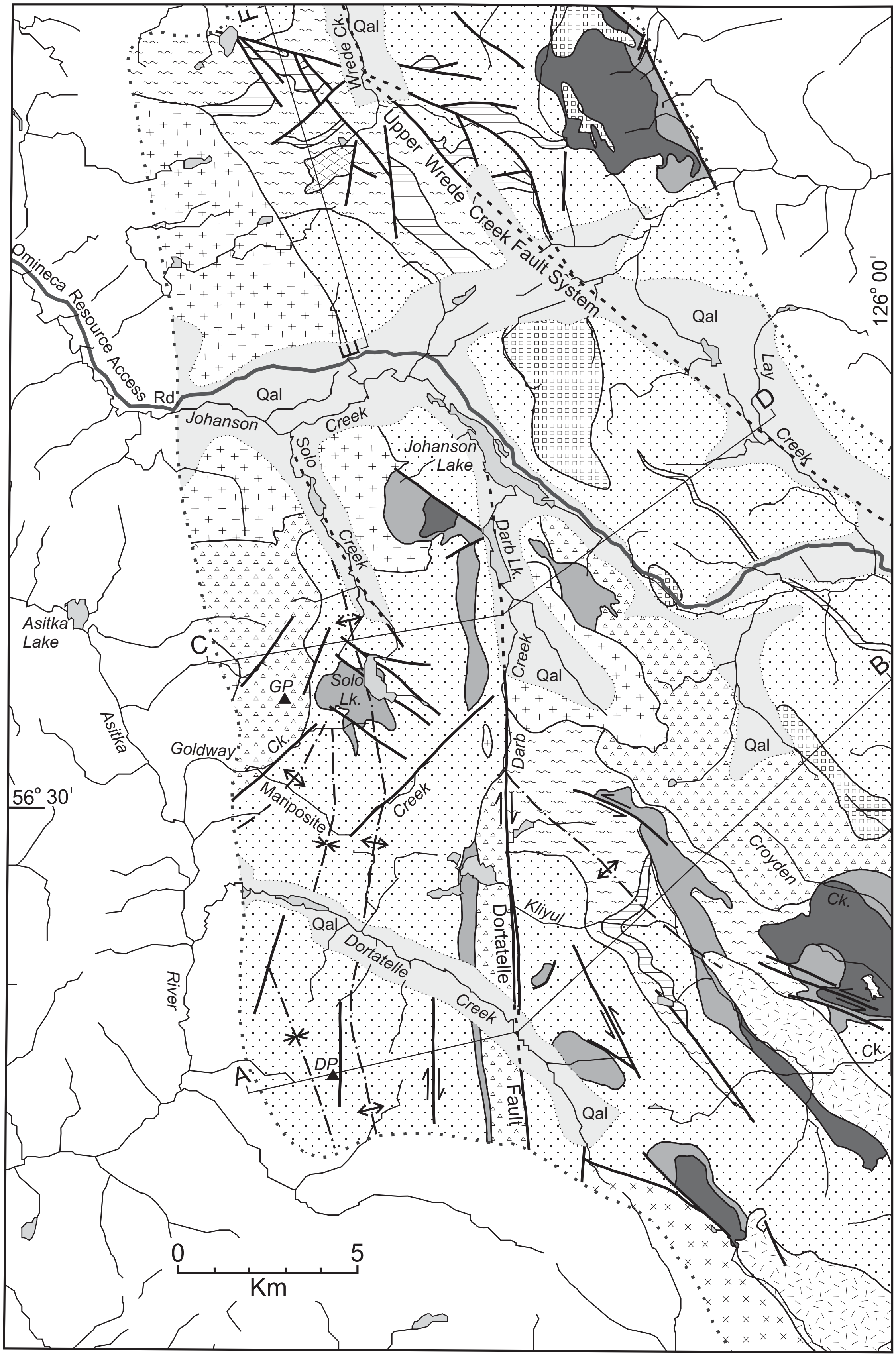

Figure 3a. Generalized geology of the Mesilinka River–Wrede Creek area, based on 2003 and 2004 fieldwork and published reports referred to in the text. Abbreviations: DP, Dortatelle Peak; GP, Goldway Peak.

siltstone-limestone subunit. These rocks generally correspond to the discontinuous sedimentary intervals within the Takla Group shown on the regional maps of Lord (1948) and Richards (1976b). The only other subunit large enough to be shown at the scale of Figure 3 is a lens of pillowed basalt that crops out in the northwest corner of the map area.

The Kliyul Creek unit is dominated by exposures of grey to green, fine to coarse-grained, commonly gritty, volcanogenic sandstone. Mineral grains of feldspar, pyroxene and less common hornblende, together with lithic fragments containing these same minerals, are the dominant constituents. The sandstone occurs partly as well-defined, thin to thick beds (Fig. 4) and partly as massive units, up to many tens of metres thick, in which bedding is not apparent. Sandstone beds within well-bedded intervals are commonly intercalated with green siltstone, also of

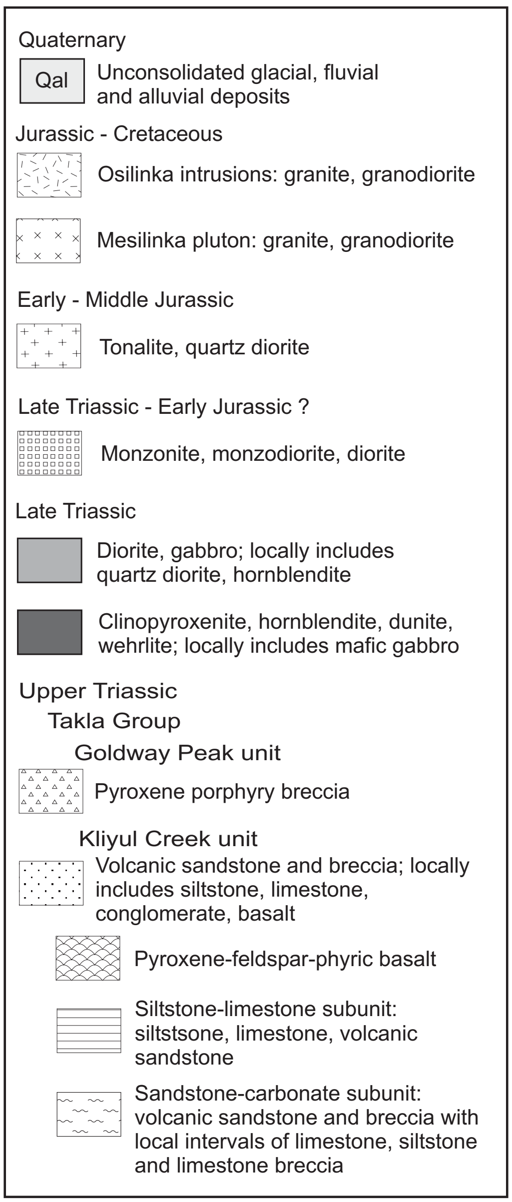

Figure 3b. Legend to accompany Figure 3a.

volcanogenic origin, and locally display graded bedding, scoured bases, flame structures and rip-up clasts.

Coarse-grained intervals, ranging from pebbly volcanogenic sandstone or lapilli tuff to coarse breccias containing fragments approaching a metre in size, are fairly common within the Kliyul Creek unit and typically form massive, resistant units tens of metres to hundreds of metres thick (Fig. 5). Volcanic rock fragments containing feldspar and/or pyroxene phenocrysts generally predominate, but clasts of aphyric volcanic rock, hornblende-feldspar porphyry, limestone, siltstone, diorite and tonalite were also observed. Locally, coarse breccia occurs as distinct layers, one to several metres thick, within intervals of much finer grained volcanic sandstone or fine breccia. These breccia units invariably contain mainly pyroxene porphyry fragments, which are supported by a matrix rich in pyroxene mineral grains. The clasts commonly range from a few centimetres to more than a metre in size, and some fragments have irregular amoeboid-like contacts and faintly chilled margins, suggesting that they were not completely cooled when they were incorporated into the breccia. These breccias probably represent mass flow deposits that tapped a different source than the finer grained sandstones with which they are intercalated.

Rocks assigned to the sandstone-carbonate subunit are generally similar to other parts of the Kliyul Creek unit, but include scattered layers and lenses of limestone. Most commonly, the limestone occurs in discontinuous intervals, from a few metres to several tens of metres thick, of interbedded limestone, grey siltstone and green volcanic sandstone to siltstone. Locally, as on the ridge south of the Darb Creek tonalite pluton, massive to bedded limestone forms lenses several tens of metres thick, but with limited strike length. Another variation occurs in the hinge area of the Kliyul Creek anticline, where dark grey limestone is mixed with volcanogenic sandstone in lenses and layers that were probably derived from slump deposits (Schiarizza, 2004a). Some of these lenses comprise subequal proportions of limestone and sandstone, as patches and blocks that are intimately mixed in a chaotic fashion. In other lenses, one rock type predominates and appears to form a matrix containing clasts of the other. Similar limestone breccias form a minor proportion of the sandstone-carbonate subunit elsewhere in the area; they were noted in the northwest corner of the map area, and in a cirque basin 5.5 km north of the northwest tip of Johanson Lake.

The siltstone-limestone subunit consists mainly of thinly interbedded dark grey siltstone and limestone, although thin to thick interbeds of volcanic sandstone and calcareous sandstone are also present (Fig. 6). It typically forms distinctive reddish-weathered outcrops that are easily traced in areas of good exposure. It forms a mappable subunit that underlies the sandstone-carbonate subunit along the upper reaches of Kliyul Creek, and a possibly correlative layer that has been traced for almost 10 km on the ridges southwest of Lay Creek. In the northern part of the area, rocks assigned to the siltstone-limestone subunit occur at two (or more) stratigraphic levels, which are repeated as numerous mappable segments that have been traced for short distances between faults related to the upper Wrede Creek system (Fig. 3).

Units of massive pyroxene porphyry and pyroxene-feldspar porphyry, derived from mafic sills, dikes and flows (?), are found at many locations within the Kliyul Creek unit but are not abundant. Pillowed basalt was observed only in the northwest corner of the map area, where it forms one mappable lens and several smaller lenses (Fig. 7). These feldspar-pyroxene-phyric pillowed flows are intercalated with volcanic sandstone, breccia and local units of siltstone and limestone of the sandstone-carbonate subunit.

Figure 4. Well-bedded volcanic sandstone of the Kliyul Creek unit, south of the west branch of Kliyul Creek.

Monger (1977) reported that macrofossils collected from various localities within the siltstone-limestone and sandstone-carbonate subunits of the Kliyul Creek unit are of Late Triassic (in part Late Carnian–Early Norian) age. These age assignments are corroborated by conodonts recovered from two samples collected during the 2003 field season. The samples were processed at the Geological Survey of Canada's micropaleontology laboratory in Vancouver, and the conodonts were identified by M.J. Orchard. Both collections were from the sandstone-carbonate subdivision. One, from a limestone lens about 2 m thick on the ridge between the two main forks of upper Kliyul Creek, contained conodonts of Late Triassic (probably Carnian) age. The other sample, from a thick limestone lens on the ridge south of the Darb Creek pluton, yielded conodonts of Late Triassic (probably Early Norian) age.

Figure 5. Volcanic breccia of the Kliyul Creek unit, on the ridge system between Dortatelle and Kliyul creeks.

Goldway Peak Unit

Breccias containing fragments of pyroxene-phyric basalt are fairly common within the Kliyul Creek unit, where they are intercalated with most other rock types within the unit. Pyroxene-rich volcanic breccias also occur as thick, monotonous accumulations of mappable extent in several places in the map area. These belts are assigned to the Goldway Peak unit, and are well represented on the mountain of that name, and on the ridge system north of the mountain. This unit is also well exposed in a northwest-trending belt that extends from the east edge of the map area at Croyden Creek to the southeast end of Johanson Lake, and as a narrow belt directly west of the Dortatelle fault in the southern part of the map area. In each of these exposure belts, the Goldway Peak unit rests stratigraphically above the more heterogeneous and better stratified Kliyul Creek unit, and represents the highest exposed levels of the Takla Group. The Goldway Peak unit is equivalent to the volcanic breccia unit of Schiarizza (2004a) and, at least in part, to unit 3 of the Plughat Mountain succession mapped by Ferri *et al.* (2001b) to the east.

Volcanic breccias of the Goldway Peak unit typically form resistant, blocky, green-brown to rusty-brown weathered exposures. Fresh surfaces are dark green to grey-green. Fragments are typically angular to subangular, and generally range from a few centimetres to 10 cm in diameter (Fig. 8). However, coarse, poorly-sorted breccias with fragments up to several tens of centimetres in size are not uncommon. The breccia fragments are dominantly pyroxene and pyroxene-feldspar–phyric basalt, with considerable textural variation among different clasts based on size, abundance and feldspar versus pyroxene proportions in the phenocryst population. Other clast types include feldspar porphyry, hornblende-feldspar porphyry, aphyric basalt, diorite and pyroxenite. The matrix typically consists of pyroxene, small pyroxene-bearing lithic grains and lesser amounts of feldspar. The matrix is locally calcareous and recessive, causing the fragments to stand out in relief. In some other places, the compositional similarity between clasts and matrix obscures the fragmental texture.

Figure 6. Interbedded siltstone, limestone and volcanic sandstone of the siltstone-limestone subunit, east of Wrede Creek in the northern part of the area.

Internal bedding contacts between individual breccia layers within the Goldway Peak unit are generally not evident, although a vague stratification can be observed in some cliff-face exposures. However, bedding is locally defined by thin intervals of pyroxene-rich sandstone, which occurs as thin to medium, locally graded beds. Also present in relatively minor quantities are units of massive pyroxene porphyry derived from sills, dikes and possibly flows.

The Goldway Peak unit is not directly dated. However, it overlies and interfingers with the Kliyul Creek unit, which contains Late Triassic fossils, and the lower part of the unit is locally cut by the Late Triassic Abraham Creek mafic-ultramafic complex. The Goldway Peak unit is therefore assigned a Late Triassic age with some confidence.

INTRUSIVE ROCKS

The Takla Group within the Johanson Lake project area is cut by a large number of intrusions. These are provisionally subdivided into four major suites, based on compositions and relative ages. These suites are 1) a Late Triassic ultramafic-mafic suite; 2) a monzonite-diorite suite of uncertain age; 3) early Middle Jurassic tonalite; 4) granite and granodiorite of, at least in part, Jura-Cretaceous age.

Figure 7. Pillowed pyroxene-feldspar–phyric basalt from the Kliyul Creek unit, northwestern corner of map area.

Late Triassic Ultramafic-Mafic Suite

The oldest intrusive suite within the map area comprises mafic and ultramafic rocks. These include typical Alaskan-type ultramafic-mafic complexes such as the Wrede Creek complex, similar but mafic-dominant complexes such as Johanson Lake and Abraham Creek, and diorite to gabbro stocks that do not include ultramafic rocks. Previously published K-Ar dates and new U-Pb dates indicate that these rocks are Late Triassic in age, consistent with Irvine's (1974) suggestion that the Alaskan-type complexes are subvolcanic intrusions associated with Takla volcanism.

WREDE CREEK ULTRAMAFIC-MAFIC COMPLEX

The Wrede Creek ultramafic-mafic complex crops out in the northwest corner of the map area (Fig. 3). It intrudes the Kliyul Creek unit of the Takla Group along its southern and western margins, and is faulted against the Takla Group along a splay of the Lay Range fault to the northeast (Ferri, 2000a, 2000b). It is locally intruded by younger granitic rocks assigned here to the monzonite-diorite suite. The Wrede Creek complex was described briefly by Irvine (1974, 1976) and Wong *et al*. (1985), prior to being mapped in more detail by Hammack *et al*. (1990) and Nixon *et al*. (1997). It was not remapped during the present study, but is shown on Figure 3, and briefly summarized here, after Nixon *et al*. (1997).

The Wrede Creek complex exhibits features common to many Alaskan-type ultramafic-mafic bodies, including a crude concentric zonation and gradation of rock types, from dunite in the core to gabbro along the margins; cumulate textures in olivine clinopyroxenites; and local modal layering in gabbro. Dunite forms more than half of the ultramafic part of the complex, and is locally in direct contact with Takla country rocks along the western and southern margins. The dunite contains local narrow pods and schlieren of chromitite, and is cut by pods and dikes of pegmatite composed of hornblende and calcic plagioclase. The dunite grades outward into a narrow zone of olivine clinopyroxenite and wehrlite along the southwestern margin of the complex, and grades into a more extensive zone of clinopyroxenites in the northeastern part of the complex. The latter zone in turn grades into gabbro and diorite that form much of the eastern and southeastern margins of the complex (Fig. 3).

Wong *et al*. (1985) reported that hornblende separates from a pegmatite within dunite in the southwestern part of the Wrede Creek complex yielded K-Ar isotopic dates of 219 ± 10 Ma and 225 ± 8 Ma, and inferred that these dates approximate the crystallization age of the complex. This interpretation is corroborated by the similarity of these dates to the U-Pb isotopic dates obtained during the present study from the Abraham Creek complex and Solo Lake stock.

DORTATELLE ULTRAMAFIC-MAFIC COMPLEX

The Dortatelle ultramafic-mafic stock crops out 2 km east of the divide at the head of Dortatelle Creek (Fig. 3). It intrudes the Kliyul Creek unit of the Takla Group to the north and northeast, is bounded by a fault and the Mesilinka phase of the Hogem Batholith to the southwest, and is truncated by the Osilinka phase of the Hogem Batholith at its southeast end. The southern part of the complex was described briefly by Irvine (1976) and was also mapped during the 2004 field season. The north end of the complex is shown after Cooke (1972).

Figure 8. Pyroxene porphyry breccia, Goldway Peak unit, upper Croyden Creek.

The Dortatelle ultramafic-mafic complex displays an imperfect zonation that is truncated by the fault and granitic rocks on its south and southwest margins. It is dominated by wehrlitic rocks that locally grade into dunite along the southwestern edge of the complex, and into clinopyroxenite to the northeast. The clinopyroxenite in turn passes northeastward into strongly lineated hornblende gabbro that forms the outer margin of the complex. Northeast-striking layering was observed at several locations within the wehrlitic zone, where it is defined by centimetre to decimetre-thick layers with contrasting modal proportions of olivine and clinopyroxene. Lord (1948) noted that there are grains and blebs of chromite within the Dortatelle complex; the presence of chromite grains within dunite was confirmed during the present study, but no significant concentrations (*i*.e., chromitite) were noted.

ABRAHAM CREEK MAFIC-ULTRAMAFIC COMPLEX

Ultramafic and mafic rocks exposed near the eastern edge of the map area, along Croyden and Porphyry creeks, form the northwestern end of a large, markedly elongate pluton, referred to as the Abraham Creek complex, that extends for 24 km into the adjacent Aiken Lake map area (Ferri *et al*., 1993, 2001b). Within the Johanson Lake map area, the Abraham Creek complex has been subdivided into a central unit of mainly clinopyroxenite, hornblendite and mafic gabbro, and a unit dominated by diorite, gabbro and microdiorite that flanks the ultramafic rocks to the north and south. Dikes of diorite, microdiorite, diabase, pyroxene porphyry, hornblende-feldspar porphyry and monzodiorite are common within both mappable units, and are thought to be an integral part of the intrusive complex (Schiarizza, 2004a). Although ultramafic rocks and associated mafic gabbro constitute about 50% of that part of the pluton exposed in the Johanson Lake area, these rocks are distinctly subordinate to dioritic rocks elsewhere within the complex (Ferri *et al*., 2001b).

A sample of diorite from the southern part of the Abraham Creek complex was collected during the 2003 field season and submitted to the geochronology laboratory at the University of British Columbia for isotopic dating. Zircons extracted from this sample yielded a U-Pb date of 219.5 ± 0.6 Ma (R. Friedman, University of British Columbia, personal communication, 2004), which is interpreted as a crystallization age for this part of the complex.

KLIYUL CREEK MAFIC-ULTRAMAFIC COMPLEX

The Kliyul Creek mafic-ultramafic complex is a narrow pluton, 13 km long, that extends from the ridges south of Kliyul Creek, near the eastern edge of the map area, northwestward to the headwaters of the creek (Fig. 3). It intrudes the Kliyul Creek unit of the Takla Group, and is itself cut by a granitic stock at its southeast end. The southeastern end of the Kliyul Creek complex was mapped by Irvine (1976) as mainly peridotite, locally with a border phase of hornblende gabbro. These rocks are inferred to continue northwestward, across the drift-covered lower reaches of two major tributaries of Kliyul Creek, into exposures of peridotite, gabbro, diorite and monzodiorite that crop out along the southwest slopes of Kliyul Creek (Noel, 1971b; Gill, 1994). From there the pluton crosses to the northeast side of Kliyul Creek and extends to the headwaters of the creek. The northwestern part of the pluton consists mainly of diorite, microdiorite, monzodiorite and gabbro, but includes local patches of clinopyroxenite and hornblendite (Schiarizza, 2004a).

JOHANSON LAKE MAFIC-ULTRAMAFIC COMPLEX

The Johanson Lake mafic-ultramafic complex is located in the central part of the map area, about 1.5 km southwest of Johanson Lake. These rocks were described briefly by Irvine (1976) and were subsequently studied in more detail by Nixon *et al*. (1990, 1997). They were not remapped during the present study, but are shown on Figure 3 after Nixon *et al*., who subdivided the complex into two units: a core of mainly clinopyroxenite and hornblendite, and a more voluminous outer unit consisting mainly of gabbro and diorite.

The Johanson Lake complex intrudes the Kliyul Creek unit of the Takla Group, and is itself cut by tonalite of the Johanson Creek pluton. Stevens *et al*. (1982, sample GSC 80-46) reported that unaltered hornblende from coarse-grained hornblendite of the Johanson Lake complex yielded a K-Ar isotopic date of 232 ± 13 Ma. This date has large analytical uncertainty but is, within error, the same as the Late Triassic K-Ar and U-Pb dates that have been obtained from the Wrede, Abraham Creek and Solo Lake complexes (Wong *et al*., 1985; this study).

DIORITE-GABBRO PLUTONS

Most of the diorite to gabbro plutons included within the ultramafic-mafic suite occur in the central part of the map area and are described by Schiarizza (2004a). These include a stock south of the east end of Johanson Lake, an elongate stock west of Darb Creek, the Solo Lake stock, and a sill-like body that occurs along the contact between the Kliyul and Goldway Peak units west of the Dortatelle fault (Fig. 3). A fairly large diorite stock that was mapped along a major west-flowing tributary to upper Dortatelle Creek during the 2004 field season is also included in this suite. These plutons are lithologically similar to the dioritic phases within the composite ultramafic-mafic intrusive bodies, and some host copper-gold mineralization similar to that associated with diorite of the Abraham Creek and Kliyul Creek complexes. Their inclusion in the ultramafic-mafic suite is corroborated by a U-Pb zircon date of 223.6 ± 0.8 Ma that was obtained on a sample of diorite collected from the Solo Lake stock in 2003 (Richard Friedman, University of British Columbia, personal communication, 2004).

Triassic-Jurassic Monzonite-Diorite Suite

Intrusive rocks assigned to the monzonite-diorite suite are represented by a fairly large monzonite pluton northeast of Johanson Lake, a small stock of similar composition that crops out along the Omineca Resource Access Road 3 km to the southeast, and an elongate diorite to monzodiorite pluton still farther to the southeast, along the eastern boundary of the map area (Fig. 3). Also tentatively included in this suite are dioritic and monzonitic rocks that intrude the Takla Group and Wrede Creek ultramafic-mafic complex in the northeast corner of the map area.

The Johanson Lake pluton and the small stock exposed along the road consist mainly of light grey to pinkish grey weathered, medium to coarse-grained hornblende monzonite, commonly with pink feldspar phenocrysts from 1 to 2 cm in size. Magnetite is a common accessory, and the Johanson Lake pluton has a prominent expression on regional aeromagnetic maps. Contacts with the adjacent Takla Group are generally sharp, but a zone of monzodiorite and diorite dikes extends for up to 1 km east of the Johanson Lake pluton. These monzonite bodies are not dated, but samples have been collected and submitted to the geochronology laboratory at the University of British Columbia for U-Pb isotopic dating. Monzonitic intrusions that have been dated by the U-Pb method elsewhere in the region include a latest Triassic stock at the Cat copper-gold porphyry deposit, and Early Jurassic stocks at the Mount Milligan copper-gold porphyry deposit (Mortensen *et al*., 1995).

The elongate pluton that intrudes the Takla Group at the eastern edge of the map area consists of medium-grey hornblende diorite, quartz diorite and quartz monzodiorite. The texture is typically medium grained, isotropic and equigranular to plagioclase porphyritic. Dikes of similar composition are fairly common within the Takla Group for several kilometres north of the pluton.

The rocks assigned to the monzonite-diorite suite in the northeast corner of the area were not examined during the present study, but are shown after Nixon *et al*. (1997), who described them as hornblende-bearing quartz monzonite, monzonite, quartz diorite and diorite. The northern intrusive body within this area may be continuous with the southern end of the Fleet Creek pluton, which extends for 25 km to the northwest and consists mainly of monzodiorite and diorite (Richards, 1976b). Wong *et al.* (1985) reported that hornblende from a diorite dike that cuts the Takla Group south of the Wrede Creek ultramafic-mafic complex yielded a K-Ar isotopic date of 172 ± 6 Ma. Farther north, biotite and hornblende separates from diorite collected from the main body of he Fleet Creek pluton have yielded discordant K-Ar dates of 156 ± 5 Ma and 142 ± 12 Ma, respectively (Wanless *et al*., 1979, samples GSC 78-14 and GSC 78-15). None of these K-Ar dates are likely to reflect crystallization ages for this intrusive suite.

Early Middle Jurassic Tonalite Suite

The tonalite intrusive suite is represented by two large plutons in the central and northwestern part of the map area, and by a number of smaller plugs of similar composition in the same geographic area. These rocks intrude the Takla Group as well as older plutonic rocks of the ultramafic-mafic suite.

DARB CREEK PLUTON

The Darb Creek pluton comprises light grey weathered, medium to coarse-grained hornblende-biotite tonalite that is well exposed on the slopes surrounding the prominent eastern tributary of Darb Creek (Schiarizza, 2004a). The pluton cuts the contact between the Kliyul Creek and Goldway Peak units of the Takla Group along its southern margin, and on its northeast margin truncates the southern margin of a dioritic stock that straddles this same stratigraphic contact (Fig. 3). Where observed, the contacts are sharp, although the tonalite commonly contains abundant xenoliths of country rock for a few tens of metres along its outer margin. The Darb Creek pluton is apparently truncated by the Dortatelle fault to the west, but this contact was not observed.

Zircon extracted from a tonalite sample from the southern part of the Darb Creek pluton has yielded a preliminary U-Pb isotopic date of 177 Ma, and titanite from the same sample gives a U-Pb date of 174.0 ± 2.0 Ma (R. Friedman, University of British Columbia, personal communication, 2004). These dates indicate that the pluton crystallized in the earliest Middle Jurassic (using the Jurassic time scale of Pálfy *et al*., 2000).

JOHANSON CREEK PLUTON

The Johanson Creek pluton is a large tonalitic intrusion with an outcrop extent of about 12 by 6 km along the northwest edge of the map area. It cuts the Kliyul Creek and Goldway Peak units of the Takla Group, and locally the Johanson Lake mafic-ultramafic complex. The western margin of the pluton is largely obscured by drift, but regional maps suggest that it is truncated by the Ingenika fault. The southern boundary of the pluton shows an apparent dextral offset of 2 km along the drift-filled valley of Solo Creek; a post-pluton dextral fault is therefore inferred to follow the valley.

The Johanson Creek pluton consists mainly of light grey, medium to coarse-grained hornblende-biotite tonalite, locally grading to quartz diorite. The texture is isotropic through most of the pluton, but locally it displays a weak, steeply dipping, west to northwest-striking foliation defined by the alignment of mafic grains and tabular feldspar crystals. Where observed, external contacts are sharp; xenoliths of country rock typically occur only within the outer few metres of the pluton, and narrow dikes of tonalite likewise extend for only a few metres into the adjacent country rock. At one locality along the pluton's eastern margin, however, the contact is defined by a border phase, about 200 m wide, of medium grey hornblende diorite cut by tonalite and quartz monzonite dikes.

Wanless *et al*. (1979, samples GSC 78-12 and GSC 78-13) reported that biotite and hornblende separates from a sample of the Johanson Creek pluton yielded discordant K-Ar dates of 121 ± 4 Ma and 142 ± 12 Ma, respectively. A sample collected during the 2004 field season is currently being processed for U-Pb dating of zircons. We suspect that the pluton will yield an Early to Middle Jurassic crystallization age, similar to that of the Darb Creek pluton.

Jurassic-Cretaceous Granite and Granodiorite

Exposures of granite and granodiorite are restricted to the southern part of the map area, where they constitute part of the northern tip of the Hogem Batholith and several related stocks and plugs north of the batholith. These granitic rocks are subdivided into two phases, the Mesilinka pluton and the Osilinka stocks, following Woodsworth (1976).

MESILINKA PLUTON

The western exposures of granitic rock at the south end of the Johanson Lake project area are part of the Mesilinka pluton, a prominent component of the northwestern part of the Hogem Batholith (Woodsworth, 1976). Within the Johanson Lake map area, the pluton consists mainly of coarse-grained biotite monzogranite to quartz monzonite, commonly with K-feldspar and plagioclase phenocrysts up to 2 cm in size. These rocks are characterized by a strong north-plunging lineation, defined by elongate biotite clots and stretched feldspar and quartz grains, and a less pronounced northeast-dipping foliation. The monzogranite is cut by numerous dikes of aplite and pegmatite along its northeast margin, some of which crosscut the foliation and lineation. It is not clear whether these dikes are related to the Mesilinka pluton or to the adjacent Osilinka stock. Where observed, the contact with adjacent ultramafic rocks of the Dortatelle complex is a steeply-dipping, northwest-striking fault defined by mylonitic granitic rocks. However, there are screens and xenoliths of ultramafic rocks within the northeastern margin of the pluton, suggesting an original intrusive relationship. The contact between the Mesilinka pluton and the Takla Group to the north was not observed, but is mapped as a fault after Woodsworth (1976).

The Mesilinka pluton was assigned an Early Jurassic age by Woodsworth (1976), but this was revised to Cretaceous by Woodsworth *et al*. (1991), in part because Eadie (1976) obtained K-Ar biotite dates of 101 ± 4 Ma and 112 ± 4 Ma from samples collected to the south and southeast of the Johanson Lake map area. A sample collected from the northern part of the pluton during the 2004 field season has been submitted to the geochronology laboratory at the University of British Columbia for U-Pb dating of zircons in order to determine a crystallization age for this part of the pluton.

OSILINKA STOCKS

Woodsworth (1976) considered several small, commonly elongate stocks of granite and granodiorite that he mapped within and adjacent to the northern Hogem Batholith to be the youngest granitic phases in the area, and Woodsworth *et al*. (1991) referred to these small plutons as the Osilinka stocks. Within the Johanson Lake project area, the Osilinka stocks are represented by the eastern part of the Hogem Batholith, an elongate pluton along Kliyul Creek and the small Davie Creek plug farther north, as well as by small plugs and dikes elsewhere in the southeastern part of the area that are too small to be shown on Figure 3. Collectively these stocks intrude the Takla Group and ultramafic-mafic plutons of the Dortatelle, Kliyul Creek and Abraham Creek complexes. The southern stock is also in contact with the Mesilinka pluton, but the relative ages of these two granitic bodies was not established by observed crosscutting relationships.

The Osilinka stocks within the Johanson Lake map area consist mainly of grey to pinkish weathered, medium to coarse-grained, equigranular biotite granodiorite to monzogranite. The stock within the Hogem Batholith locally includes a marginal phase of aplitic biotite-muscovite granite, and contains numerous dikes of aplite and pegmatite. Textures are for the most part isotropic, but the western part of the stock within the Hogem Batholith is weakly to moderately lineated and foliated, as are adjacent rocks of the Mesilinka pluton and Dortatelle ultramafic-mafic complex.

An Osilinka stock to the east-southeast of the Johanson Lake map area has yielded a biotite K-Ar date of 122 ± 6 Ma (Wanless *et al*., 1972, sample GSC70-11), and a stock to the south yielded a biotite K-Ar date of 120 Ma (G. Woodsworth, unpublished data, reported in Woodsworth *et al*., 1991). However, the latter stock has recently yielded a much older U-Pb zircon date of 192.3 +2.1/–4.8 Ma (Nelson *et al*., 2003; J. Nelson, personal communication, 2003), indicating an Early Jurassic crystallization age, whereas the Davie Creek stock, which was sampled in 2003 (Schiarizza, 2004a), has yielded a preliminary U-Pb zircon date of 132 to 150 Ma, indicating Late Jurassic or Early Cretaceous crystallization (R. Friedman, University of British Columbia, personal communication, 2004). These U-Pb dates suggest that the Osilinka stocks include rocks of at least two different ages. A sample collected from the Osilinka stock at the north end of the Hogem Batholith in 2004 has been submitted to the geochronology laboratory at the University of British Columbia for U-Pb dating in order to further constrain the crystallization ages of this suite of plutons.

STRUCTURE

Mesoscopic Structure and Metamorphism

The Takla Group within most of the map area is at greenschist-facies metamorphic grade. Mafic volcaniclastic rocks are characterized by the metamorphic assemblage chlorite-epidote-actinolite, commonly accompanied by carbonate and leucoxene. These minerals partially to completely replace original pyroxene crystals. Relict feldspar grains are albitized, at least in part, and partially replaced by epidote, calcite and white mica. The metamorphic assemblages observed within the Takla Group are also found within plutonic rocks of the Late Triassic mafic-ultramafic suite. Younger plutons show variable chlorite-epidote alteration but are generally not conspicuously metamorphosed. It is not clear whether this reflects the predominant age of metamorphism or the more felsic composition and massive nature of the younger plutons.

Outcrops within the project area are characterized by abundant fractures and brittle faults. These structures have highly variable orientations, although northwest to north strikes and steep dips predominate. Many of the northwest to north-striking faults show indications of dextral strike-slip movement, although northwest-striking faults in the Croyden Creek–Kliyul Creek area are mainly sinistral. Many east to northeast-striking mesoscopic faults also show a sinistral sense of displacement; these may be conjugate riedel shears related to the more abundant north to northwest-striking dextral faults.

Penetrative foliations occur mainly within high-strain zones associated with faults. However, a weak slaty cleavage of more regional aspect is apparent locally. In the southwestern part of the area, this cleavage is axial planar to mesoscopic folds that occur on the limbs of larger macroscopic folds. Mesoscopic folds are not common elsewhere in the area, and those seen are typically localized along faults.

Map-scale Structure

The macroscopic structure of the Johanson Lake map area will be discussed in terms of four domains and two fault systems that separate these domains. The southern part of the area is divided into southeast and southwest domains by the north-striking Dortatelle fault. The northern part of the area is divided into northeast and northwest domains by the northwest-trending upper Wrede Creek fault system.

DORTATELLE FAULT

The Dortatelle fault is a prominent north-trending structure in the south-central part of the map area. It has a prominent topographic expression and marks the truncation of the Darb Creek pluton and Kliyul Creek anticline on its east side, and localizes a narrow sliver of the Goldway Peak unit on its west side. Rocks adjacent to the fault are commonly strongly foliated for several hundred metres beyond the fault trace. Parts of the fault were studied in detail by Zhang and Hynes (1994), who demonstrated that it was a dextral strike-slip fault on the basis of the geometric relationships between S and C surfaces and associated folds. Richards (1976a, 1976b) showed the fault being truncated by, or merging with, the Ingenika fault 20 km south of Dortatelle Creek. The fault does not appear to continue as a prominent structure north of Johanson Lake (Fig. 3).

SOUTHEAST DOMAIN

The structure east of the Dortatelle fault is dominated by the northwest-trending Kliyul Creek anticline, which is defined by opposing dips and facing directions in the Kliyul Creek unit of the Takla Group (Fig. 9, section A-B). The extensive exposures of the overlying Goldway Peak unit to the northeast are presumed to be preserved in the core of an adjacent syncline, but this structure is not well defined due to the few bedding measurements obtained from the Goldway Peak unit.

Steeply dipping, northwest to west-northwest-striking faults with kinematic indicators showing predominantly sinistral strike-slip displacements are prominent features of the southeast domain (Fig. 10). Most of these were described by Schiarizza (2004a), but additional sinistral faults were mapped east of upper Dortatelle Creek during the 2004 field season, and MacIntyre et al. (this volume) show that a prominent structure cutting the north end of the Kliyul Creek mafic-ultramafic complex was also the locus of sinistral displacement. Most of the sinistral faults are within or peripheral to plutons of the Late Triassic mafic-ultramafic suite, which show a marked elongation parallel to the faults. It is suspected that the sinistral faults are broadly contemporaneous with intrusion of these plutons.

In the southern part of the domain, in the area of mutual contact between the two phases of the Hogem Batholith and the Dortatelle ultramafic-mafic complex, all rocks commonly display a strong L-tectonite fabric that plunges gently to moderately northward. Map-scale structures in this area include a north-northwest-striking brittle fault that marks an apparent dextral offset of the northern margin of the Osilinka phase, and a steep northwest-striking fault, locally defined by a narrow mylonite zone, that in part separates the Mesilinka pluton from the Dortatelle ultramafic-mafic complex. The latter fault, or a major splay from it, is inferred to extend to the west-northwest and define the contact between the Mesilinka pluton and the Takla Group,

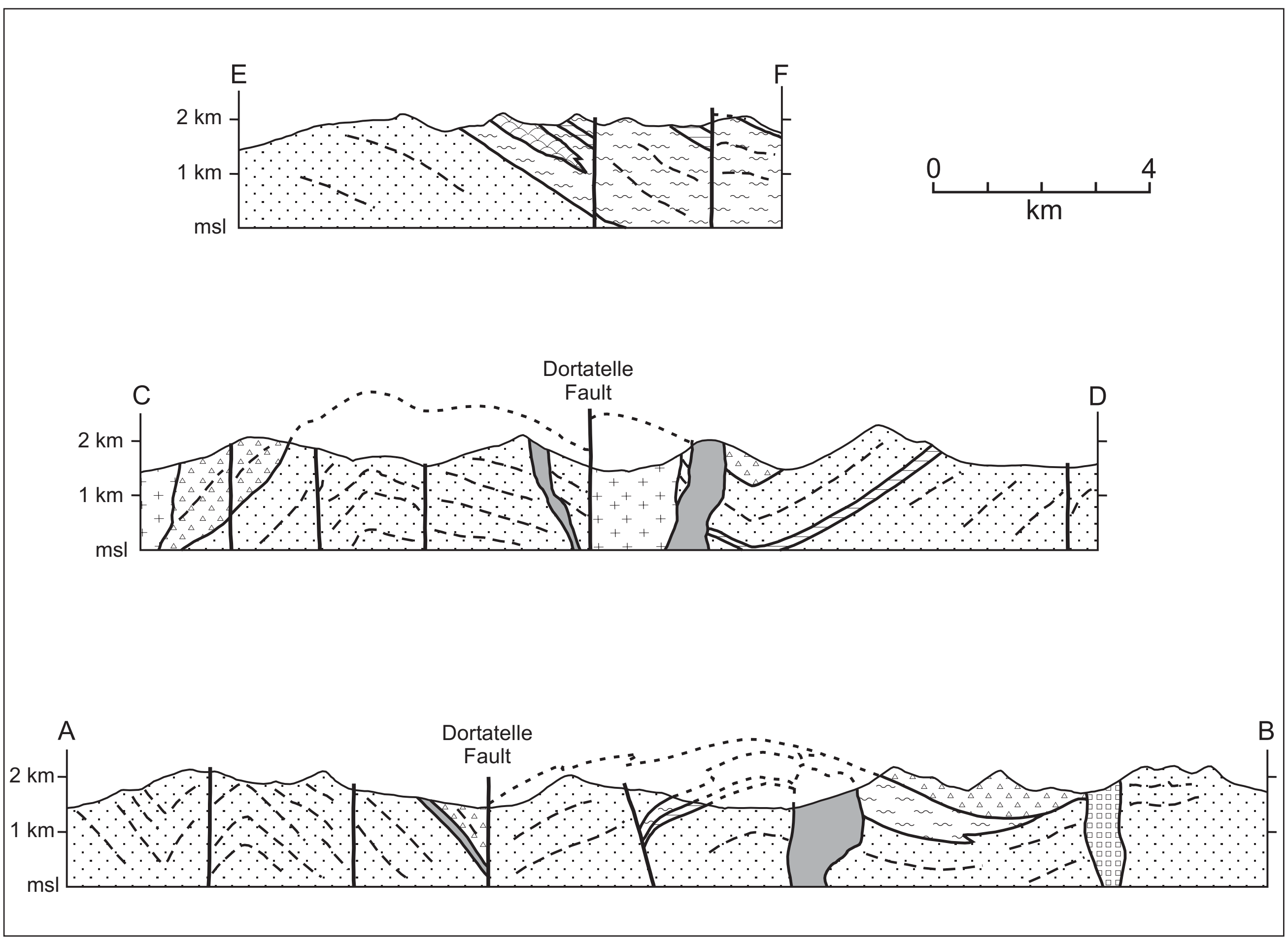

Figure 9. Schematic vertical cross-sections along lines shown on Figure 3a. See Figure 3b for legend.

Figure 10. Sinistral fault cutting south margin of the Abraham Creek mafic-ultramafic complex near eastern edge of map area, north of Kliyul Creek.

based on the observations of Woodsworth (1976), who reported that rolled K-feldspar megacrysts within mylonitized plutonic rock along this contact show that the Takla rocks moved southward over the pluton.

SOUTHWEST DOMAIN

The structure west of the Dortatelle fault is dominated by the north-trending Solo Lake anticline (Fig. 9, sections A-B and C-D). In the south, the eastern limb of the anticline consists of a homoclinal panel of the Kliyul Creek unit several kilometres wide that is overlain by the Goldway Peak unit adjacent to the Dortatelle fault. To the north, from Mariposite Creek to Solo Lake, this panel is disrupted by northeast and northwest-striking faults, and northward from there it comprises rocks that dip and face mainly to the north or northeast. The western limb of the Solo Lake anticline is folded across several, mainly north-plunging, subsidiary folds, including an anticline-syncline pair that is mapped south of Goldway Creek. These folds seem to die out to the north, and northwest of Solo Lake the Kliyul Creek unit forms a west-facing, locally overturned panel that is stratigraphically overlain to the west by the Goldway Peak unit.

Steeply dipping, north to north-northeast-striking faults are a prominent feature of the southern and western portions of the southwest domain. Many of these are marked by conspicuous orange-weathered zones of Fe-Mg carbonate alteration. Others exhibit quartz-pyrite alteration or are defined by zones, up to tens of metres wide, of strongly foliated chlorite schist. Shear bands cutting chlorite schist within one north-striking fault zone in the southern part of the domain indicate dextral strike-slip movement.

Northwest to west-northwest-striking faults are prominent structures around Solo Lake. A history of dextral movement along these faults is indicated by geometrical relationships at the Solo and Bruce mineral occurrences, where northwest-striking fault zones within the Solo Lake stock locally host en echelon arrays of more northerly striking gold-bearing quartz veins (Richards, 1991). Farther north, a north-northwest-striking dextral fault is inferred to occupy the drift-covered valley of Solo Creek, based on an apparent dextral offset of the southern margin of the Johanson Creek pluton (Fig. 3).

Zhang and Hynes (1991) inferred that a northeast-striking fault along the upper reaches of Mariposite Creek was the locus of sinistral displacement, based on the offset of local stratigraphy within the Takla Group. An east-northeast-striking fault west of Darb Lake may also be sinistral, if the elongate diorite stock to the south correlates with the diorite unit at the south end of the Johanson Lake mafic-ultramafic complex (Fig. 3). These sinistral faults, and northeast-striking sinistral faults elsewhere in the map area (Zhang and Hynes, 1991; Schiarizza, 2004a) are interpreted as conjugate riedel shears (R' of Tchalenko, 1970) within the system of mainly northwest to north-striking dextral faults that formed during regional motion along the Finlay-Ingenika fault system (Zhang and Hynes, 1991, 1994).

UPPER WREDE CREEK FAULT SYSTEM

A system of mainly northwest-striking faults, informally referred to as the upper Wrede Creek fault system, extends from the northwest corner of the map area southeastward to the broad drift-covered valley north of the Johanson Lake monzonite pluton (Fig. 3). Individual faults within this system are locally defined by abrupt truncations of subunits within the Kliyul Creek unit of the Takla Group. Unequivocal indications of movement sense were not documented during the present study, although Zhang and Hynes (1991) interpreted most northwest-striking faults in this area as dextral strike-slip faults. The fault system is inferred to extend southeastward along the upper reaches of Lay Creek to the eastern boundary of the map area, although it is not exposed over this distance. At the eastern edge of the map area, it apparently connects with a collinear system of faults mapped by Ferri *et al*. (2001b) as the Polaris Creek dextral strike-slip fault system.

NORTHWEST DOMAIN

The Kliyul Creek unit in the northwestern part of the map area, southwest of the upper Wrede Creek fault system, generally dips moderately to gently northward (Fig. 9, section E-F) but displays many local truncations and disruptions along north to northwest-striking faults. Most of these faults are spatially associated with the upper Wrede Creek system and are thought to be subsidiary dextral or extensional faults related to that system. A northeast-striking fault, defined by the apparent truncation of several northwest-trending structures, is shown as a sinistral fault by Zhang and Hynes (1991), and may be an antithetic riedel shear related to the dextral system.

NORTHEAST DOMAIN

The Takla Group northeast of the upper Wrede Creek fault system is represented by moderately to gently dipping strata of the Kliyul Creek unit. Dip direction is variable but, in contrast to the northwest domain, is mainly to the south. Steeply dipping, east-striking faults of unknown sense of displacement were mapped in several places, and are commonly marked by zones of orange-weathered carbonate-altered rock. A steeply dipping, northwest-striking fault near the north boundary of the map area is marked by several tens of metres of fractured and sheared chlorite-epidote-calcite–altered rock. Accretion steps associated with gently plunging mineral fibres on some fault surfaces within the zone indicate dextral displacement.

Ingenika Fault

The Ingenika fault marks the boundary between the Quesnel and Stikine terranes at the latitude of the Johanson Lake project area, and occupies a series of low, drift-covered valleys directly west of the map area. It forms part of a major system of dextral strike-slip faults that also includes the Finlay fault to the north and the Pinchi fault to the south (Fig. 2). Within the map area, the westernmost exposures of Takla rocks between Goldway Peak and the Johanson Creek pluton are characterized by a strong foliation that dips at moderate to steep angles toward the east. This foliation rapidly dies out eastward, and is suspected to be related to the adjacent Ingenika fault.

Zhang and Hynes (1994) analyzed the orientations of early-formed conjugate shear sets within and adjacent to the present map area, and concluded that fault-bounded domains had rotated clockwise about subvertical axes in response to progressive displacement along the Ingenika and related faults. Their analysis indicates rotations of up to 59° adjacent to the Finlay-Ingenika fault, decreasing systematically to zero about 20 km away from the main fault.

Timing of Deformation

The timing of deformation within the Johanson Lake project area is not well constrained, but is suspected to range from Late Triassic to Tertiary in age. The dominant structures within and adjacent to the map area are dextral fault systems. These include the north to northwest-striking Dortatelle and Upper Wrede Creek–Polaris Creek systems, as well as numerous smaller faults with similar orientations and documented dextral displacements. Dextral faults are known to cut the youngest rocks within the Johanson Lake project area, the Jura-Cretaceous Osilinka granites (Fig. 3; Richards, 1976b). They are related to the Finlay-Ingenika fault system (Zhang and Hynes, 1994), which is part of a Cordillera-wide system of dextral faults that was active mainly in Late Cretaceous through Late Eocene time (Gabrielse, 1985; Struik, 1993; Umhoefer and Schiarizza, 1996).

Macroscopic folds within the Johanson Lake project area deform the Upper Triassic Takla Group, and one of them, the Kliyul Creek anticline, is truncated by the Dortatelle fault. Most of the folding may have been related to the Late Cretaceous–early Tertiary dextral strike-slip faults of the area, as suggested by Zhang and Hynes (1994). However, some of the folds might be vestiges of older events, such as the late Early Jurassic thrusting of the Quesnel Terrane over terranes to the east.

The northwest-striking sinistral faults of the southeast domain show a strong spatial relationship with mafic-ultramafic plutons of the Late Triassic suite, which are typically markedly elongate parallel to the faults. Some sinistral faults are localized along dikes of the mafic-ultramafic suite, and some host copper mineralization that is thought to be genetically related to this suite of plutons (Schiarizza, 2004a). The sinistral faults are therefore thought to be mainly or entirely of Late Triassic age, and thus to predate the dextral faults.

Nelson *et al*. (2003) interpreted structures at the Hawk showing, 50 km southeast of the Johanson Lake project area, in terms of sinistral faulting overprinted by younger dextral faults related to the Pinchi system. There, however, the faults cut Early Jurassic granodiorite of the Hogem Batholith, so the sinistral faults are Early Jurassic or younger. An episode of sinistral faulting that predates the major dextral faults of the region was also proposed by Nixon *et al*. (1997) along the western boundary of Quesnel Terrane, 300 km north of the Johanson Lake area. There, the distribution of rocks correlated with the King Salmon allochthon suggests that the western strand of the Thibert fault accommodated about 100 km of sinistral displacement prior to its reactivation as a dextral fault. A general theme to the structural interpretations of Nixon *et al*. (1997), Nelson *et al*. (2003) and the present study is that there were one or more episodes of orogen-parallel sinistral faulting prior to formation of the Late Cretaceous–Tertiary dextral strike-slip faults that dominate much of the structural pattern of the region. These relationships are consistent with the analysis presented by Avé Lallemant and Oldow (1988), who suggested that the cordilleran margin was undergoing left-oblique convergence during Triassic to mid-Cretaceous time, and right-oblique convergence from the Late Cretaceous to the present.

MINERAL OCCURRENCES

The known mineral occurrences within the Johanson Lake map area are shown on Figure 11. These include a wide variety of occurrence types, which are grouped and discussed in the following sections according to their primary plutonic and/or structural controls. The occurrences that are not mentioned in this report are described by Schiarizza (2004a).

Chromite and Platinum Group Elements in Ultramafic Rocks

Lord (1948) noted that ultramafic rocks of the Wrede Creek and Dortatelle ultramafic-mafic complexes locally contain grains and blebs of chromite. He also described seams of chromite, up to 2.5 cm wide, within talus blocks of smooth-surfaced, buff-weathering serpentine from the Wrede Creek complex. These observations formed the basis for the Wrede Creek Chromite (094D 026) and Mesilinka River (094D 022) MINFILE occurrences (Fig. 11).

Nixon *et al*. (1997) documented in situ pods and schlieren of chromitite at several localities within dunite of the Wrede Creek complex. They range from 0.1 to 5 cm in width, from 5 to 40 cm in length, and commonly occur in clusters, forming chromitite-rich zones up to several metres wide. Five samples of chromitite were analysed for their noble element contents. All five samples were markedly enriched in platinum (from 123 to 2388 ppb), some had significant concentrations of rhodium (up to 72 ppb) and one contained anomalous gold (29 ppb). No subsequent studies have been undertaken to determine the extent and detailed grade characteristics of these PGE-enriched chromitites. However, Lett and Jackaman (2002) analyzed archived stream sediment samples from around the Wrede Creek complex for platinum, palladium and gold, and found anomalous platinum concentrations in a number of these samples.

Copper-Gold Mineralization Associated with the Late Triassic Mafic-Ultramafic Plutonic Suite

Copper-gold mineralization associated with plutons and related dioritic dikes of the Late Triassic mafic-ultramafic suite occurs in a belt that extends from the eastern edge of the map area between Kliyul and Croyden creeks northwestward to Johanson Lake (Fig. 11). Individual intrusive bodies known to host mineralization include the Abraham Creek, Kliyul Creek and Johanson Lake mafic-ultramafic complexes, the elongate diorite stock west of Darb Lake, and the diorite stock east of the Darb Creek tonalite pluton. The mineral occurrences within this belt have been described by Schiarizza (2004a) and are only briefly summarized in the following paragraphs.

The most common style of mineralization within the Kliyul Creek–Johanson Lake belt consists of pyrite-chalcopyrite disseminations and blebs within and along fractures, in narrow quartz and quartz-carbonate veins, and within local, commonly silicified shear zones. These modes of occurrence are commonly spatially associated, and porphyry-style mineralization of this type is documented over substantial areas within and peripheral to dioritic rocks near the south margin of the Abraham Creek complex (Grexton and Roberts, 1991), within the Kliyul Creek complex northeast of the major fork in the creek (Wilson, 1984b; Cross, 1985), and within the diorite stock east of Darb Creek (Leriche and Luckman, 1991a, 1991b; Gill, 1994). Significant gold values are associated with the copper mineralization in all of these areas (Schiarizza, 2004a).

The Croy occurrence comprises massive to disseminated magnetite-pyrrhotite-pyrite-chalcopyrite mineralization associated with quartz-calcite-chlorite gangue. It occurs as lenses within steeply dipping northwest-trending shear zones that cut the Takla Group near the north margin of the Abraham Creek complex. Copper-gold skarns at the Kliyul and Pacific Sugar occurrences comprise magnetite-pyrite-chalcopyrite mineralization within limestone-bearing sections of the Kliyul Creek unit of the Takla Group, and are associated with dioritic rocks related to the Kliyul Creek mafic-ultramafic complex. Stratabound layers of magnetite-pyrite-chalcopyrite at the Soup North and Soup South occurrences are likewise found in an area containing numerous dioritic dikes between the Abraham Creek and Kliyul Creek mafic-ultramafic complexes.

A zone of quartz-pyrite±sericite alteration encompasses the north end of the Kliyul Creek mafic-ultramafic complex, and extends intermittently for 5 km to the west-northwest, to the head of Darb Creek (Schiarizza, 2004a, 2004b). This zone includes the Kliyul skarn occurrence, and also hosts a number of gold-bearing quartz veins (Schiarizza, 2004a; MacIntyre *et al.*, this volume). Gold-bearing quartz veins, commonly containing pyrite and chalcopyrite, also occur within the northwestern part of the Abraham Creek mafic-ultramafic complex.

Porphyry Copper-Molybdenum Mineralization Associated with the Monzonite-Diorite Suite of Plutons

Porphyry-style mineralization documented at the Nik, Grapes and Breccia occurrences is associated with dikes that are part of the monzonite-diorite plutonic suite. Copper is the main commodity of economic interest but, in contrast to showings associated with the ultramafic-mafic suite, molybdenum is also present.

NIK (MINFILE 094D 109), GRAPES (MINFILE 094D 163) AND REDGOLD (MINFILE 094D 162)

The Nik claims were staked by BP Minerals Limited in 1976 to cover mineralization along the southwest margin of the Wrede Creek ultramafic-mafic complex. The claims were explored with geophysical, geochemical, trenching and drilling programs from 1976 to 1986. Porphyry-style copper-molybdenum mineralization was documented by diamond-drilling at the Nik showing (Bates, 1976), and by more extensive percussion and diamond-drilling programs covering the Grapes showing (Bates, 1977, 1979). The Redgold occurrence to the southeast lies in an area that yielded high contents of copper and molybdenum in overburden. An extensive trenching program, however, showed only rare traces of chalcopyrite and molybdenite in bedrock (Mustard and Wong, 1979).

Sulphide mineralization at the Nik and Grapes occurrences comprises pyrite, chalcopyrite, molybdenite and

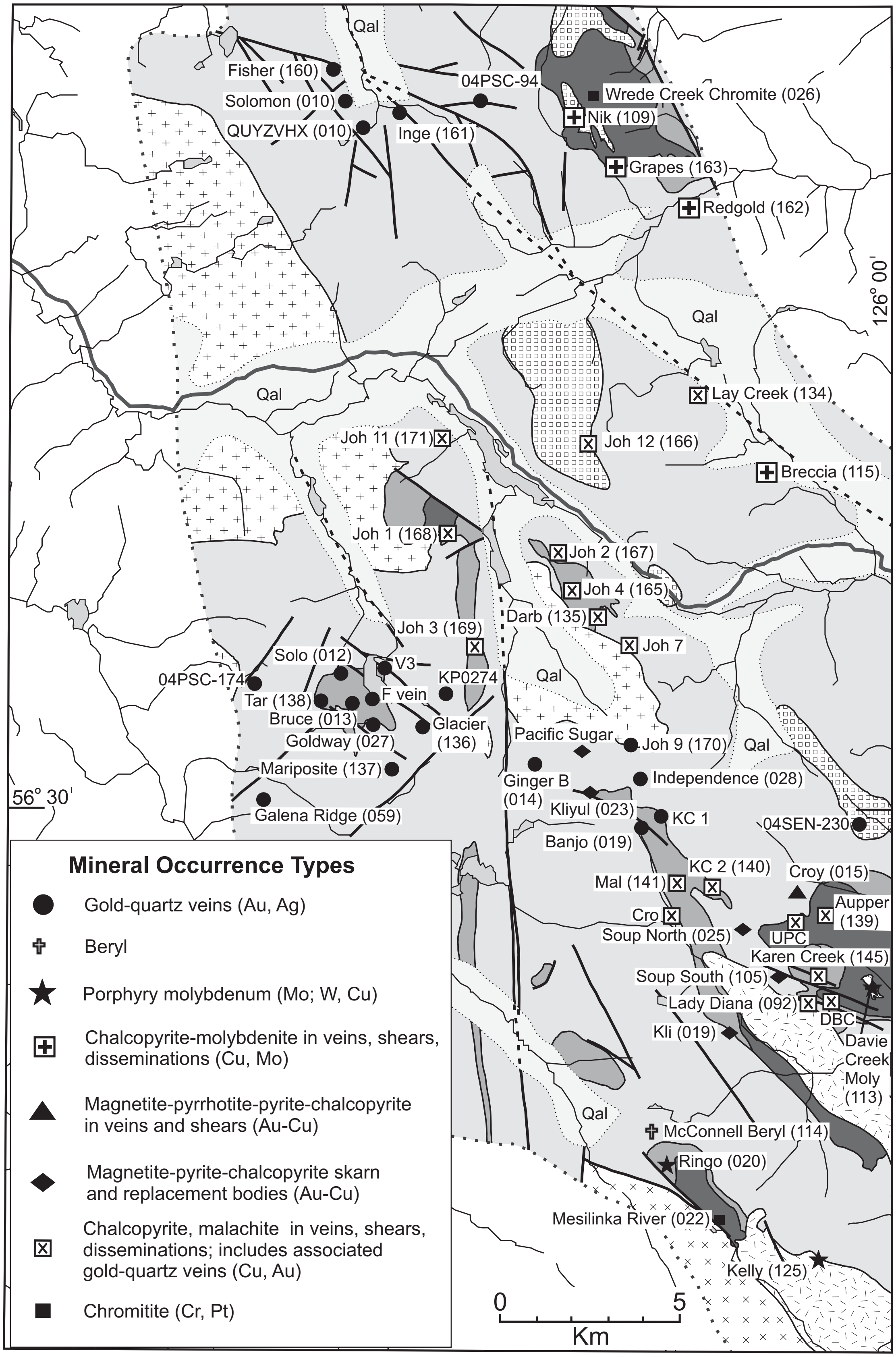

Figure 11. Locations of mineral occurrences in the Mesilinka River–Wrede Creek area. Occurrences found in the MINFILE database are shown with the 094D MINFILE number appended in brackets. Base map is derived from Figure 3, with only plutonic rocks and faults shown.

bornite as disseminations and fracture fillings (Wong *et al*., 1985). Mineralization occurs within dioritic to quartz dioritic dikes, here assigned to the monzonite-diorite suite, and within associated rocks of the Wrede Creek complex and Takla Group. Propylitic alteration characterizes pyritic zones and potassic alteration, consisting of sericite and biotite, is associated with chalcopyrite and molybdenite-bearing rocks. Wong *et al*. (1985) obtained K-Ar dates of 172 ± 6 Ma on hornblende from one of the diorite dikes, and 157 ± 5 Ma on secondary biotite from sulphide-mineralized pegmatite of the Wrede Creek complex.

BRECCIA (094D 115) AND LAY CREEK (094D 134)

The Breccia occurrence is located on the southwest side of the Lay Creek valley, 2.5 km north of the Omineca Resource Access Road. It was discovered in 1981, and subsequent exploration included geochemical and geophysical surveys and a three-hole diamond-drill program by Lornex Mining Corporation in 1982 (Christopher, 1982). This program demonstrated that porphyry-style copper-molybdenum mineralization occurs over a substantial area.

The mineralization at the Breccia showing is well exposed over an area about 100 m long, within and adjacent to a small creek, where natural exposures have been augmented by blasting. The mineralized rock is a distinctive sheeted breccia comprising angular slabs and plates within a matrix of chlorite, pink calcite and quartz. The sheet-like fragments within the breccia are mainly Takla volcaniclastic rock, but also include diorite and bleached/altered rock of uncertain protolith. Mineralization consists of pyrite and chalcopyrite, in part accompanied by malachite and azurite, as clots and veinlets within the matrix, as disseminations within chlorite-rich parts of the matrix, and as disseminations within some of the breccia fragments. The sheeted nature of the breccia is apparently the result of alteration having been focused along, but also crosscutting, a system of more or less planar joints spaced 2 to 10 cm apart. This jointing is well displayed in weakly altered Takla sandstone and breccia a short distance northwest of the mineralized outcrops, where it dips at moderate angles to the southwest.

A 152 m vertical diamond-drill hole, collared adjacent to the mineralized outcrops, encountered variably mineralized breccia throughout the entire length of the hole (Christopher, 1982). Hole 2, drilled 325 m to the east-southeast, cut Takla rocks and quartz diorite dikes, and was variably mineralized with pyrite, chalcopyrite and molybdenite, the latter occurring in narrow quartz veins and as coatings on fracture and shear surfaces. A third hole, collared 580 m southeast of the mineralized breccia outcrops, encountered Takla rocks mineralized with pyrite but only local traces of molybdenite and chalcopyrite. All core was analyzed in 10-foot sections. The highest copper (0.53%) and silver (0.14 oz./ton) assays came from a 10-foot section in hole 2, and the highest molybdenum assay of 0.012% came from 30 feet lower in the same hole (Christopher, 1982). The samples were also analyzed for gold, but no significant values were returned. The drillholes and mineralized outcrops of the Breccia showing occur within a northwest-trending zone, about 1500 m long and 300 m wide, of anomalous IP chargeability and copper in soils geochemistry (Christopher, 1982), suggesting that the area has untested exploration potential.

The Lay Creek showing is located 3 km northwest of the Breccia occurrence. This mineralization was discovered by Lornex Mining Corporation in 1983, during a program of prospecting and geochemical and geophysical surveys along a northwest extension of the Breccia exploration grid. Mineralization occurs in two in situ veins and numerous float occurrences scattered over a northeast-trending zone about 500 m long within mafic volcanic sandstone and breccia of the Kliyul Creek unit (Serack, 1983). The largest vein is vertical, strikes northwest and is about 70 cm wide. It contains coarse pyrite and chalcopyrite in a quartz-carbonate gangue. One grab sample of float contained 9500 ppb Au, 2.3 ppm Ag and 1190 ppm Cu (Serack, 1983, sample F47).

JOH 12 (MINFILE 094D 166)

The Joh 12 showing is located 2.5 km east of Johanson Lake, along the eastern margin of the Johanson Lake monzonite pluton. It was discovered in 1991 during exploration of the Joh property by Reliance Geological Services Inc. for Swannell Minerals Corporation (Leriche and Luckman, 1991a). Mineralization consists of several occurrences of pyrite-chalcopyrite-malachite along fractures within variably chloritized and potassically altered monzonite. Samples of this material yielded assay values of up to 3329 ppm Cu and 47 ppb Au. A float sample from a stream draining the Joh 12 area contained molybdenite, in addition to chalcopyrite and pyrite, along a dry fracture (Leriche and Luckman, 1991a).

Porphyry Molybdenum Occurrences Associated with the Osilinka Stocks

Porphyry molybdenum occurrences are restricted to the southern part of the map area, where they are associated with the Jura-Cretaceous Osilinka stocks. This type of occurrence is best represented by the Davie Creek Moly prospect (MINFILE 094D 113), comprising molybdenum mineralization within and peripheral to the small Davie Creek stock that intrudes hornblendite and associated rocks of the Abraham Creek complex on the south side of lower Porphyry Creek. The mineralized stock was discovered by Rio Tinto in 1963, and intermittent diamond-drill programs by various companies between then and 1982 have demonstrated that low-grade molybdenite mineralization occurs through much of the granite (Folk, 1979; Bowen, 1982; Norman, 1982). Molybdenite occurs in quartz veinlets with pyrite and local traces of chalcopyrite, and along dry fractures; it is commonly associated with strong K-feldspar alteration.

The Ringo showing (MINFILE 094D 020) comprises molybdenite disseminated in felsite, quartz and pegmatite veins at the north end of the Dortatelle ultramafic-mafic complex. The veins are probably related to the nearby Osilinka stock. The mineralization was first described by Lord (1948), who noted disseminated molybdenite in fragments of altered pyroxenite and quartz within the moraine at the north end of Dortatelle complex. Subsequent exploration by Stellac Exploration Ltd. between 1971 and 1973 outlined several dispersion trains of molybdenite-bearing material in float, and a single in situ occurrence, comprising a mineralized felsite dike about 1 m wide and 30 m long (Cooke, 1972). This exploration also led to the discovery of two quartz veins containing pyrite and chalcopyrite within the Takla Group about 800 m west of the in situ molybdenite occurrence. There has been no subsequent exploration recorded on the showing.

The Kelly MINFILE occurrence (094D 125) is located along the northern margin of the Osilinka phase of the Hogem Batholith, 5 km southeast of the Ringo showing. It is described as "molybdenite in pegmatite" on a Canadian Superior Exploration Ltd. map dating from the early 1970s (BC Ministry of Energy and Mines property file). There is no other information available regarding this showing.

Structurally Controlled Gold-Quartz Veins

Most mineral occurrences within the Johanson Lake project area have a spatial and inferred genetic relationship to one of three plutonic suites, as described in the previous sections. In contrast, gold-bearing quartz veins in the upper Wrede Creek area are not apparently related to plutonic rocks, but are localized along minor shear zones spatially related to the upper Wrede Creek dextral strike-slip fault system. These vein showings are therefore inferred to be relatively young occurrences that formed during Late Cretaceous–early Tertiary dextral strike-slip faulting in the region. Gold-quartz veins in the Solo Lake area are hosted by the Late Triassic Solo Lake stock but are controlled by dextral faults and have similar mineralogy to the Wrede Creek occurrences; it is suspected that they may also be of Late Cretaceous–early Tertiary age.

UPPER WREDE CREEK VEIN SYSTEMS

The QUYZVHX gold-bearing quartz vein (MINFILE 094D 010), located in the western headwaters of Wrede Creek, was discovered in the mid-1940s (White, 1948). The showing was restaked as part of the Inge Group in 1980 by Golden Rule Resources Limited, who conducted exploration programs on the claim group until 1990. This exploration led to the discovery of the Solomon vein and several other veins in the immediate vicinity of the original QUYZVHX vein, as well as the Fisher vein (MINFILE 094D 160), 2 km to the north-northwest, and the Inge vein (MINFILE 094D 161), 1 km to the east-northeast (Wilson, 1984a; Smith, 1985; Cruickshank, 1990).

The gold occurrences in the upper Wrede Creek area are hosted by volcaniclastic and local sedimentary rocks of the sandstone-carbonate subunit of the Takla Group. The general characteristics of the vein systems were summarized by Cruickshank (1990). Most comprise multiple lenses and veins of quartz (locally quartz-carbonate) within steeply dipping, mainly west-northwest-striking shear zones marked by variably schistose rocks altered with chlorite, sericite, epidote and carbonate. Individual shear zones are commonly several metres wide and locally more than 10 m wide, and have been traced for 50 to 60 m at the QUYZVHX and Solomon occurrences. Mineralized quartz veins within the shear zones are generally less than a metre wide but locally up to 5 m wide, and tend to splay, coalesce and terminate abruptly. Mineralization typically consists of erratically distributed pyrite and chalcopyrite, but the Fisher and Solomon veins also contain galena, and native gold has been reported from the Solomon vein (Wilson, 1984a; Smith, 1985). The best gold values have been reported from the Solomon vein system. These include a grab sample that returned 7.933 oz./ton Au, 2.46 oz./ton Ag, 0.19% Cu, 1.51% Pb and 1.40% Zn (Wilson, 1984a), and a 15 cm chip sample across vein material heavily mineralized with galena and chalcopyrite that yielded 3.14 oz./ton Au and 2.0 oz./ton Ag (Smith, 1985).

SOLO LAKE VEIN SYSTEMS

Gold-bearing quartz veins associated with the Solo Lake stock include the Solo (MINFILE 094D 012), Bruce (MINFILE 094D 013) and Goldway (MINFILE 094D 027) occurrences, discovered in the mid-1940s (White, 1948), and the F vein, V3 and Tar (MINFILE 094D 138) occurrences, discovered during renewed exploration in the 1980s and 1990s (Pawliuk, 1985; von Rosen, 1986; Richards, 1991). The vein systems associated with the Solo Lake stock were well described by Richards (1991). Each occurrence shown on Figure 9 comprises a number of veins, with individual veins ranging from several metres to more than 100 m in length, and from a few centimeters to several metres in width. Gold and silver ratios are commonly near one to one, and the precious metals are associated with pyrite, and locally galena and sphalerite. Visible gold has been reported from the A and C veins of the Bruce occurrence. The A vein has returned assay values up to 74.19 g/t Au over 29 cm (Phendler, 1984).

The geometry of the vein systems is most apparent at the Solo and Bruce occurrences, where individual veins are arranged en echelon within northwest-striking zones that approach 1 km in length. Individual veins strike more northerly than the overall system, and are inferred to occupy extensional fractures within dextral shear systems (Richards, 1991). Alteration related to the veins is minimal, and Richards (1991) suggested that the veins may be related to fault movements during the late stages of emplacement and cooling of the Solo Lake stock. Alternatively, the veins may be considerably younger, and the Solo Lake stock may have been a favourable mechanical and chemical host for vein systems that were localized along components of the regional system of Late Cretaceous–early Tertiary dextral strike-slip faults.

Other Occurrences

MCCONNELL BERYL (MINFILE 094D 114)

The McConnell beryl occurrence comprises a single float block located in a moraine a short distance north of the Dortatelle ultramafic-mafic complex (Fig. 11). The block was derived from a pegmatite dike at least 1 m wide and contains scattered grains of garnet and a few crystals of pale green beryl up to 2 cm in diameter (Lord, 1948). Similar pegmatite dikes (without beryl) occur in situ within the Dortatelle complex and adjacent Takla group; they are presumably related to the nearby Osilinka stock at the north end of the Hogem Batholith. Associated aplitic dikes host molybdenite mineralization of the Ringo (MINFILE 094D 020) occurrence.

The spatial association of beryl-bearing pegmatites with chromium-bearing ultramafic rocks suggests that there was potential for the formation of emeralds within or adjacent to the Dortatelle complex. Legun (2004) conducted a brief survey of the original discovery area to evaluate this potential, but did not find any beryl or anomalous beryllium concentrations in stream sediments collected from the basin. The south end of the Dortatelle complex was mapped during our 2004 field program. Aplitic and pegmatitic dikes, apparently derived mainly from the Osilinka stock, were observed cutting the ultramafic rocks, but none of these contained beryl.

04PSC-94

Sample 04PSC-94 was collected from a mineralized quartz vein that cuts the Takla Group on the ridge crest east of the head of Wrede Creek (Fig. 11). The vein is about 50 cm wide, strikes north-northwest, and dips steeply. It consists mainly of white bull quartz cut by rusty hairline fractures, but also includes scattered vugs containing quartz crystals and patches of pyrite-chalcopyrite-azurite mineralization. The sample of well-mineralized vein material contained 1771 ppb Au, 61.529 ppm Ag and greater than 10 000 ppm Cu. It also yielded anomalous values of Zn (257 ppm), Mo (14.46 ppm), As (41.5 ppm), Sb (2.74 ppm) and Hg (133 ppb).

04PSC-174

A northerly-striking fault zone identified during the 2004 field season, on the ridge about 900 m northwest of Goldway Peak, is marked by 3 m of quartz-pyrite–altered rock. A grab sample of this material (sample 04PSC-174, Fig. 11) yielded 1134 ppb Au and 3.496 ppm Ag. A different northerly-trending alteration zone, 360 m to the southeast, comprises about 5 m of foliated quartz-sericite-chlorite-pyrite–altered volcanic sandstone. A sample of this material contained 138 ppb Au, 1.821 ppm Ag and 240 ppm Cu.

04SEN-230

Sample 04SEN-230 was collected from a system of subhorizontal mineralized quartz veins that cut the southeastern part of the elongate monzodiorite pluton along the eastern margin of the map area near Croyden Creek (Fig. 11). Individual veins are up to 15 cm thick and are locally mineralized with pyrite, galena, chalcopyrite and malachite. The grab sample collected from mineralized vein material yielded 940 ppb Au, greater than 100 ppm Ag, greater than 10 000 ppm Pb, 2562.8 ppm Cu and 26.2 ppm Mo.

SUMMARY

The Takla Group within the Johanson Lake project area comprises Upper Triassic rocks that have been separated into two major units. Most of the group is assigned to the Kliyul Creek unit, which consists of massive to well-bedded, feldspar±pyroxene–rich volcanic sandstones, intercalated with volcanic breccias and local mafic flows. A sandstone-carbonate subunit includes significant amounts of limestone, either as a component of slump breccias or as coherent layers interbedded with the volcaniclastic rocks. Another mappable subunit consists mainly of thin-bedded siltstone and limestone. The Kliyul Creek unit is overlain by the Goldway Peak unit, which consists mainly of massive pyroxene-rich volcanic breccias.

The Takla Group is cut by numerous plutons that are tentatively subdivided into four suites. The oldest intrusive suite includes Alaskan-type ultramafic-mafic complexes as well as diorite-gabbro stocks that are similar to the mafic phases within the Alaskan complexes. These rocks are Late Triassic in age and probably represent subvolcanic intrusions associated with Takla volcanism. Younger intrusive rocks include a monzonite-diorite suite of suspected Late Triassic–Early Jurassic age; an early Middle Jurassic tonalite suite; and granite to granodiorite stocks and plutons that are, at least in part, of Jura-Cretaceous age.

The oldest structures in the area are northwest-striking sinistral shear zones that are common around Kliyul Creek in the southwestern part of the map area. These faults are spatially associated with a belt of Late Triassic ultramafic-mafic plutons that show marked elongation parallel to the faults. It is suspected that sinistral faulting was broadly contemporaneous with Late Triassic plutonism and therefore with construction of the Takla volcanic-plutonic arc. Younger structures are dominated by steeply dipping, north to northwest-striking dextral strike-slip faults. These faults probably formed during displacement along the Ingenika fault to the west, which is part of a regional system of dextral strike-slip faults that was active mainly during the Late Cretaceous and early Tertiary. North to northwest-trending folds occur between, and are locally truncated by, dextral strike-slip faults. These may be broadly contemporaneous with the dextral faulting or be vestiges of older deformation events, such as the early Middle Jurassic thrust faulting that is documented at this latitude along the eastern margin of the Quesnel Terrane.

The Johanson Lake project area hosts a large number of mineral occurrences with a variety of plutonic and structural controls. Dunite of the Wrede Creek ultramafic-mafic complex contains chromitite pods that are enriched in platinum. Dioritic rocks of the Late Triassic mafic-ultramafic suite host porphyry-style copper-gold mineralization as pyrite-chalcopyrite disseminations in veins and fractures. Magnetite-pyrite-chalcopyrite lodes occur in shear zones peripheral to the Late Triassic suite, and copper-gold skarns and replacement bodies occur where these intrusions cut calcareous units of the Takla Group. Porphyry copper-molybdenum mineralization is locally associated with the monzonite-diorite suite, and porphyry molybdenum occurrences are associated with Jura-Cretaceous granitic rocks. Systems of structurally controlled gold-quartz veins are spatially associated with dextral strike-slip fault systems that are thought to be Late Cretaceous or early Tertiary in age.

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