Geology Between the Toodoggone River and Chukachida Lake (Parts of NTS 94E/6, 7, 10 and 11), North-Central British Columbia

By L.J. Diakow and R. Rhodes

KEYWORDS: Toodoggone Formation, Junkers member, Graves member, Pillar member, Belle member, Mount Gordonia, Toodoggone Peak, Chukachida Lake, epithermal veins, skarn

INTRODUCTION

Geological mapping at 1:20 000 scale, carried out from 2003 to 2005 as part of the Toodoggone Geoscience Partnership (Diakow and Shives, 2004), has expanded the distribution of the Early Jurassic Toodoggone Formation eastward, and subdivided volcanic and sedimentary rocks in a previously unknown upper part of the formation. This new mapping and complementary geochronology have significantly improved understanding of the internal stratigraphy and intrusive events, and the setting of new mineral occurrences in the central Toodoggone River area (NTS 094E). In 2005, detailed geological mapping was extended northward into a remote mountainous region of the Metsantan and Peak ranges, between the Toodoggone River in the south and Chukachida Lake in the north, an area originally mapped at regional scale by the Geological Survey of Canada (Gabrielse *et al.*, 1977). Except for a general absence of stratigraphic units representing the lower part of the Toodoggone Formation (*i.e.*, Duncan, Metsantan and overlying Saunders members), the stratigraphic framework in the current study region is similar to that established south of the Toodoggone River (Diakow *et al.*, 2005a). This report emphasizes the lateral lithostratigraphic changes in recently recognized rock units that make up the upper Toodoggone Formation north of the Toodoggone River. Figure 1 shows the local geology, and representative stratigraphic sections are portrayed in Figure 2.

EARLY PERMIAN AND LATE TRIASSIC BASEMENT ROCK UNITS

Limestone, siltstone and chert (unit PAl) of the Carboniferous to Early Permian Asitka Group are the oldest recognized strata. With the more extensive basaltic volcanic rocks of the overlying Late Triassic Takla Group, they constitute the basement succession for the Early Jurassic Toodoggone Formation.

Sedimentary rocks of the Asitka Group are localized in the footwall block of an east-trending fault, which in turn is truncated by regional northerly-trending faults traversing the valleys of Midas and Junkers creeks. Greyish white crystalline marble occupies the lower 175 m of a near-vertical fault scarp. The marble is overlain by a sequence of rusty weathered, black mudstone, siltstone and chert, which is between 25 and 75 m thick.

Rocks of the Takla Group are widespread north of the Toodoggone River, where they typically form craggy ridges and precipitous cliffs dominated by massive, chlorite and epidote-altered basaltic lavas, minor pyroclastic rocks and rare pods of limestone. With the exception of locally mappable intervolcanic sedimentary rocks, the Takla volcanic rocks are inherently difficult to subdivide.

The Takla Group depositionally overlies interlayered mudstone and chert exposed along a fault between Midas and Junkers creeks. Here the Takla Group consists of a sequence of basalt lavas distinguished by abundant plagioclase laths up to 3 cm long (unit uTTbb). This flow succession is at least 400 m thick, inclined gently toward the south. East of Contact Peak, the upper several hundred metres of basalt displays generally smaller plagioclase laths, which are between 2 and 5 mm long, and also contains up to 7% pyroxene. East of Mulvaney Creek, this bladed plagioclase-phyric basalt forms an entire mountain and directly underlies nearby rocks of the Jurassic Toodoggone Formation. Similar flows mapped about 60 km to the southeast near the Kemess North mineral deposit are interlayered with clinopyroxene-phyric lavas near the top of the Takla Group and overlain directly by basal conglomerate of the Toodoggone Formation. Bladed plagioclase porphyritic basalt in the study area differs in that it is generally coarser, more crystal rich (up to 60%) and appears to occupy a relatively low stratigraphic position within the Takla succession.

The most common rocks in the Takla are fine to medium-grained porphyritic to aphanitic basalt and subordinate andesite flows containing medium-grained plagioclase and clinopyroxene phenocrysts (unit uTTb). They occur both stratigraphically above and below the distinctive, coarsely bladed plagioclase porphyritic basalt.

Sedimentary rocks (unit uTTs), comprising siltstone and sandstone in shades of green or reddish brown, form well-layered, internally laminated intervals between the monotonous volcanic rocks. Intervolcanic sedimentary sections vary from several metres to more than 250 m in thickness. Angular crystal grains of plagioclase and pyroxene dominate the sedimentary rocks and suggest a local provenance from Takla volcanic rocks. Limestone lenses up to 1.2 m thick occur with fine clastic sedimentary rocks in several widely spaced localities south and east of Mount Gordonia. These thin carbonate units consist of fetid, black, impure limy bands alternating with resistant siliceous laminations.

This publication is also available, free of charge, as colour digital files in Adobe Acrobat PDF format from the BC Ministry of Energy, Mines and Petroleum Resources internet website at http://www.em.gov.bc.ca/Mining/Geolsurv/Publications/catalog/catfldwk.htm

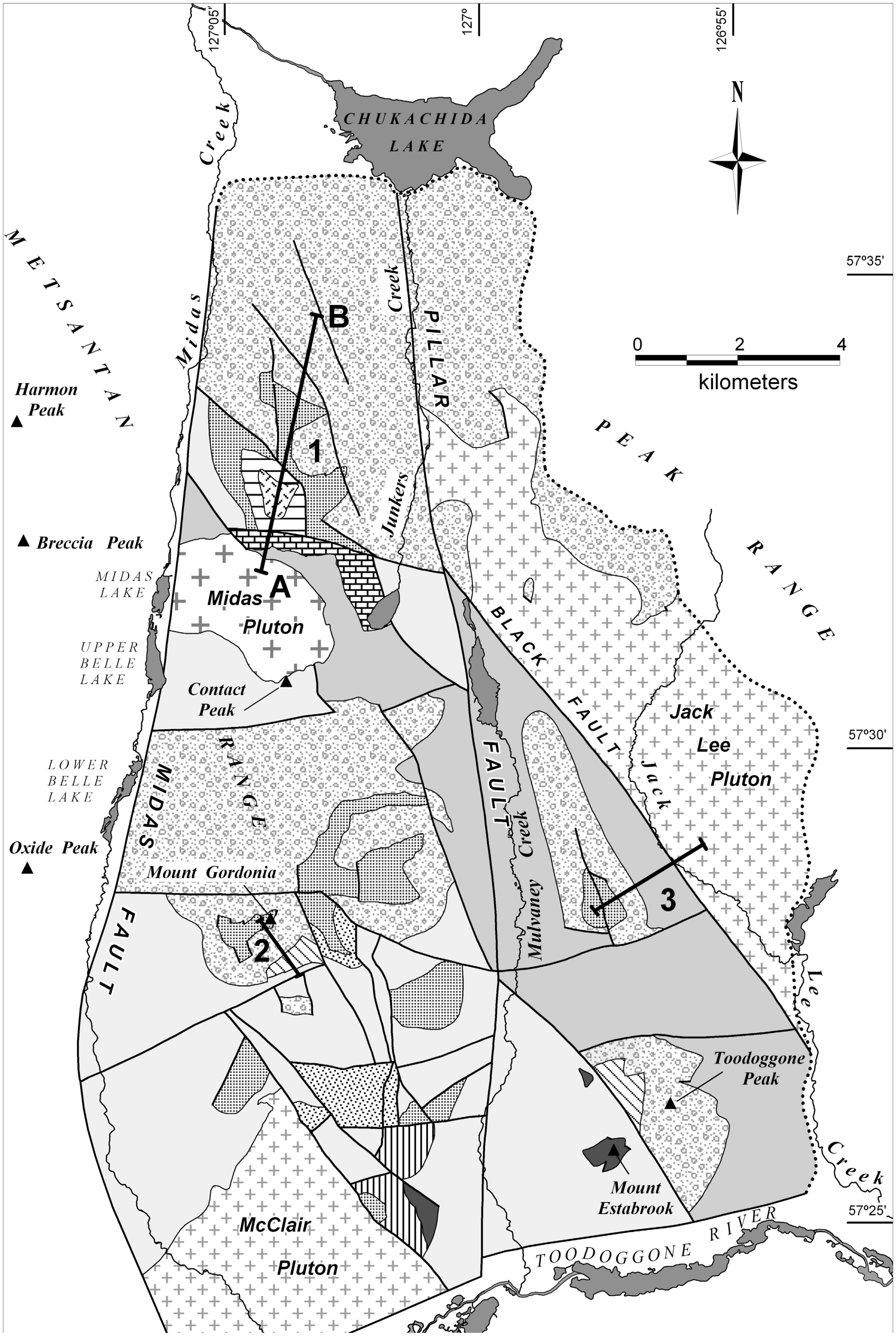
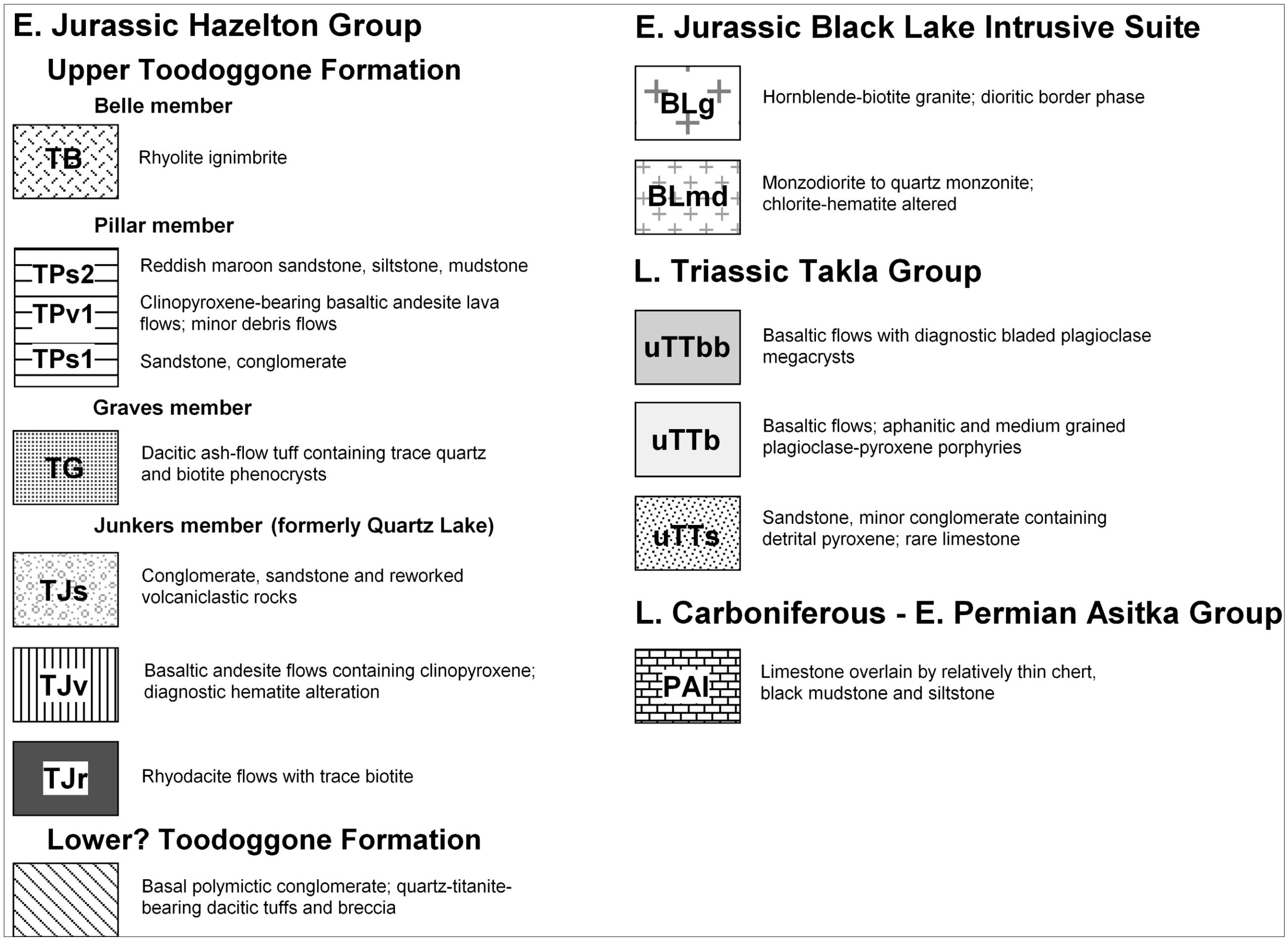


Figure 1. Simplified geology of the study region, located between the Toodoggone River in the south and Chukachida Lake in the north. Numbered transects correspond to representative stratigraphic sections shown in Figure 2 and schematic cross-section A–B, shown in Figure 3.



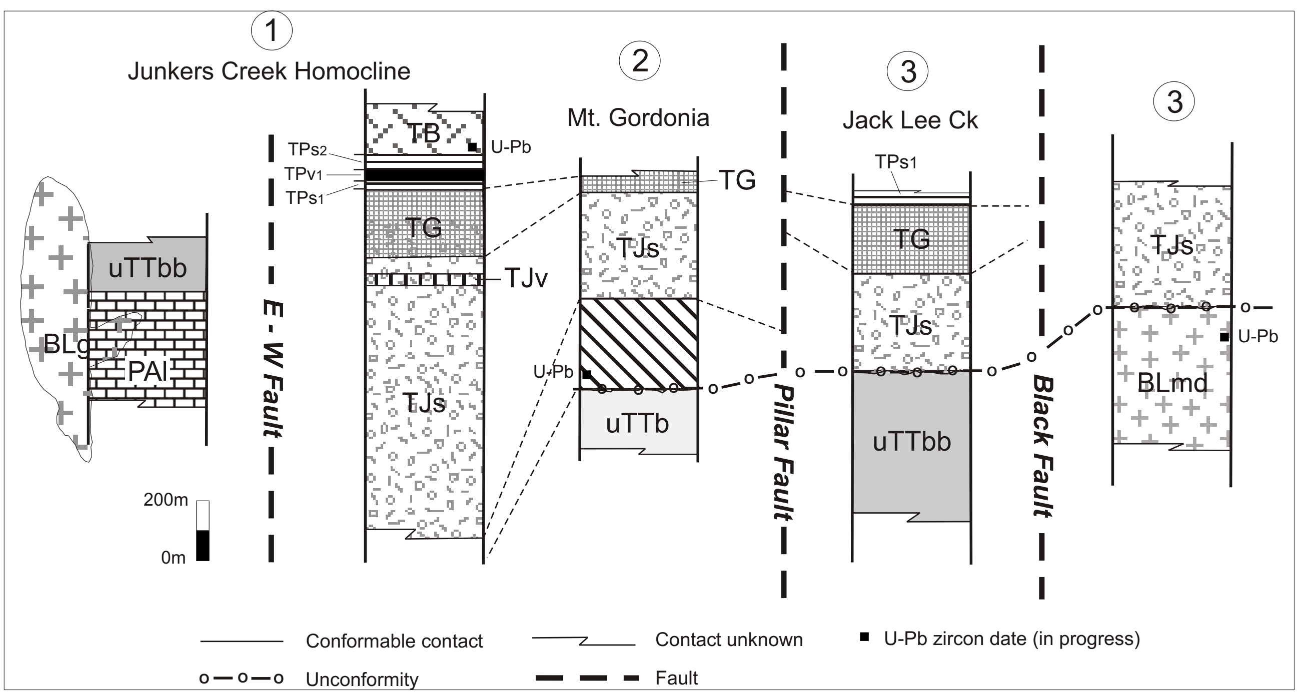


Figure 2. Generalized stratigraphic sections representative of the upper Toodoggone Formation. See Figure 1 for locations and legend.

EARLY JURASSIC TOODOGGONE FORMATION

The Pillar, Graves and Quartz Lake members, the latter renamed the Junkers member, represent much of the recently defined upper Toodoggone Formation (Diakow *et al.*, 2005a). The Belle member is a new unit proposed for an ignimbrite, which marks the highest volcanic member recognized in the Toodoggone Formation. The upper Toodoggone Formation dominates a region 40 km long, from southern localities near Jock Creek and east of the Pillar fault (Diakow *et al.*, 2005b) northwest into the current study area, east of the Midas fault and as far north as Chukachida Lake. These four members have stratigraphic continuity in a homocline immediately west of Junkers Creek and south of Chukachida Lake, shown in a north-south cross-section (Fig. 3). Several other localities containing exceptional sections of upper Toodoggone stratigraphy, which have not been significantly disrupted by faults, include the southeast slope of Mount Gordonia and the west slope of Toodoggone Peak. With the exception of the latter two sections, where upper Toodoggone stratigraphy apparently overlies strata presumed to be part of the lower Toodoggone Formation, the Junkers member rests unconformably on the Takla Group or Early Jurassic granitic rocks. This contrasts with the region south of the Toodoggone River, where Junkers (formerly Quartz Lake) strata overlie the Metsantan and Saunders members, subdivisions that form the upper two members of the lower Toodoggone Formation.

Lower (?) Toodoggone Formation

The base of the Jurassic section along part of the lower west slope of Toodoggone Peak is marked by a polymictic conglomerate up to 75 m thick, deposited upon mafic volcanic rocks assigned to the Takla Group. The conglomerate consists of rounded cobbles and boulders with mafic volcanic clasts derived from the Takla, scarce limestone pebbles from the Asitka and a variety of andesitic porphyries and red-brown volcanic rocks of uncertain provenance. Rare quartz grains in the red-maroon oxidized matrix suggest that it may have been derived, in part, from quartz-bearing volcanic rocks common in the lower Toodoggone Formation. Upsection from the conglomerate are various reddish lapilli tuffs and dacitic tuff-breccias that contain fine-grained porphyritic andesite and red-brown aphanitic volcanic fragments. Crystal fragments in these tuffs are plagioclase, rare quartz, minute yellow titanite and hornblende replaced by chlorite. The uppermost of these quartz-bearing beds is a dacitic lava-flow tuff, which was sampled to determine a U-Pb crystallization age (sample 05LDi 10.2). Based on the mineralogy of these rocks, they might be a remnant of the pre-193–194 Ma lower Toodoggone Formation. Similarly, at Mount Gordonia, dacitic tuff containing as much as 3% quartz and trace titanite phenocrysts, which occupies the lowest exposures below Junkers strata, resembles the lower Toodoggone Formation. This quartz-bearing tuff has also been sampled for a U-Pb age determination (sample 05LDi 30.1) that will establish a maximum depositional age for the overlying Junkers epiclastic-volcaniclastic succession.

Upper Toodoggone Formation

JUNKERS MEMBER (UNITS TJs, TJv, TJr; RENAMED AFTER QUARTZ LAKE MEMBER)

The Junkers member is proposed to replace the name 'Quartz Lake member'. This change reflects superior exposure of stratigraphy equivalent to the Quartz Lake member mapped north of the Toodoggone River, particularly on

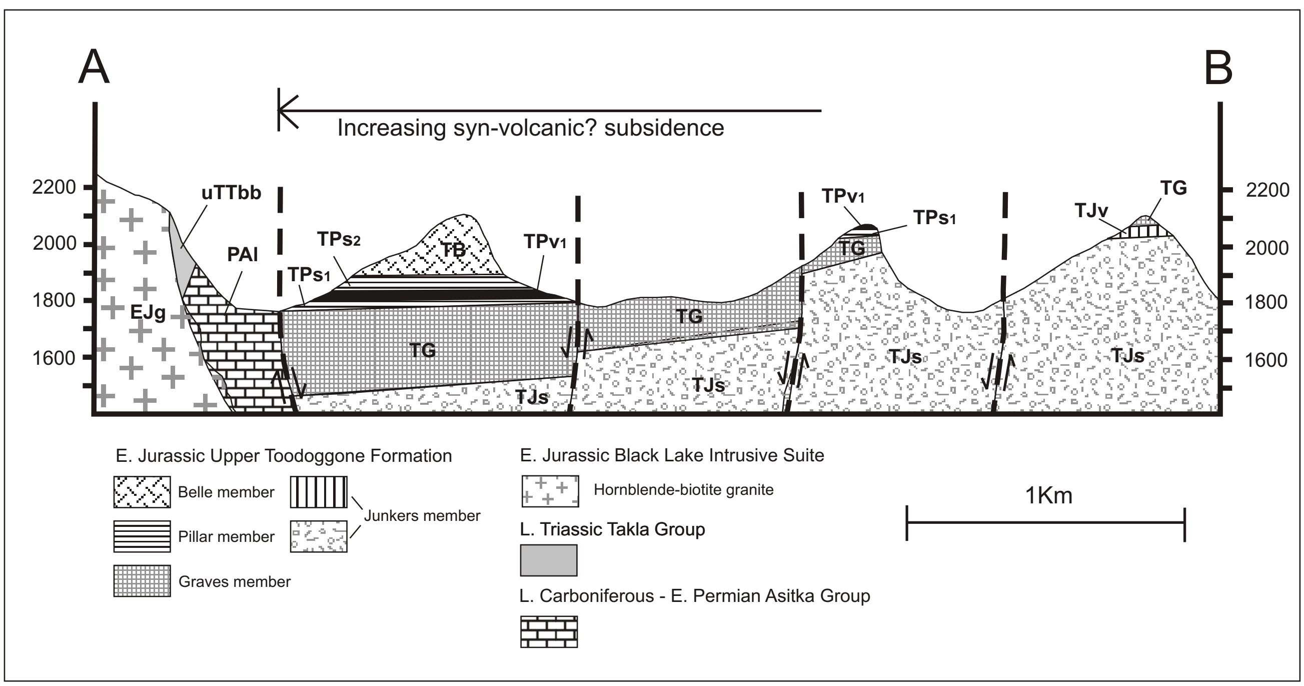


Figure 3. North to south cross-section of a homocline west of Junkers Creek that shows ash-flow tuff and epiclastic rocks increasing in thickness toward an east-trending fault that is interpreted to be synvolcanic with the Graves, Pillar and Belle members of the upper Toodoggone Formation.

ridges adjacent to Junkers Creek, which drains into the south side of Chukachida Lake. Strata of the Junkers member typically form thick, well-layered intervals that are locally more than 560 m thick at Toodoggone Peak and 370 m thick at Mount Gordonia. The unit thickens considerably farther north in the region of Junkers Creek, occupying the lower kilometre or more of a homocline. The lower contact of the Junkers unit is an unconformity, either above basaltic volcanic rocks of the Takla Group or an Early Jurassic (?) monzodiorite exposed east of Mulvaney and Junkers creeks. In sections at Mount Gordonia and Toodoggone Peak, the Junkers conformably overlies quartz-bearing dacitic tuff believed to be a vestige of the lower Toodoggone Formation.

Junkers strata are lithologically heterogeneous, composed of massively interbedded, reworked, polymict lapilli tuff, debris flows, volcanic conglomerate, sandstone-siltstone (95%; subunit TJs), pyroxene-bearing porphyritic basaltic andesite to andesite lava flows (5%; subunit TJv) and comparatively small-volume flows of rhyodacitic composition (subunit TJr). Unit TJs is dominated by conglomerate with interbedded sandstone and siltstone derived from basaltic lava flows and volcaniclastic rocks. Conglomeratic beds are typically poorly sorted and contain subrounded to subangular clasts that vary from cobble to boulder size. Except on weathered surfaces, the clasts are difficult to identify and blend into the dark green to maroon matrix. The clasts are wholly derived from a volcanic source, composed predominantly of fine-grained (0.5–2 mm) plagioclase-pyroxene-phyric basalt. Interbeds of maroon to reddish brown sandstone and siltstone are generally less than several metres thick. They display planar bedding, graded bedding and rare low-angle crosslaminations. Tube-shaped concretions have been found in some finer siltstone beds. Sandstone is typically rich in plagioclase with lesser amounts of pyroxene. However, locally common quartz, hornblende and titanite reflect different volcanic sources within the Toodoggone Formation. Clastic rocks containing mainly plagioclase and pyroxene grains with fine-grained basaltic lithic clasts may be derived locally from either basaltic flows that form part of the upper Toodoggone Formation or from the older Takla Group.

Rare accretionary lapilli tuff, found at the lowest exposure in the section south of Chukachida Lake, indicates the presence of ash fallout and suggests local deposition in a subaerial environment. Elsewhere, rocks suspected to have a pyroclastic origin include pyroclastic breccia and lapilli and finer, well-bedded ash-rich tuffs. Rounding of pyroclasts and mechanical sorting within these deposits, however, suggests varying degrees of syn to postdepositional reworking.

Pyroxene-bearing basaltic lavas (unit TJv) occur at the top of the Junkers unit in three localities and are sharply overlain by the Graves member. In the absence of intervening rocks of the Graves member, the Junkers basalt is indistinguishable in the field from a succession of similar flows stratigraphically higher within the Pillar member. At Mount Gordonia, these basaltic lavas are about 70 m thick and overlie a distinctive red epiclastic-volcaniclastic layered sequence about 100 m thick. In turn, they are sharply overlain by Graves ash-flow tuffs. The lavas are generally purplish grey-green, medium grained with plagioclase up to 4 mm (20–25%) and subvitreous pyroxene up to 3 mm (2%). Oxidation of the flows is apparent as reddish hematite staining that varies in intensity and manifests as Liesegang banding. Basaltic flows in the Gordonia section display a textural gradation not observed at any other locality. Near the bottom of this section, typical medium-grained porphyritic flows pass upsection into sparsely porphyritic to aphanitic lavas, then into a distinctive, coarse-bladed plagioclase-phyric variety at the top of the section. Slender plagioclase laths between 6 and 14 mm characterize these bladed flows. Although bladed plagioclase porphyry flows are locally voluminous in the Takla Group, those at Mount Gordonia are the only known occurrence in the Toodoggone Formation.

Lavas of dacitic to rhyodacitic composition (unit TJr) cap Mount Estabrook. Although unequivocal stratigraphic contacts have not been observed with nearby Junkers clastic rocks, these and other similar lavas west of Mulvaney Creek are believed to form lens-shaped deposits within the Junkers unit. Rhyodacite contains up to 20% plagioclase and several percent relict biotite and hornblende phenocrysts scattered in a dark reddish brown and greenish pink groundmass that commonly displays flow laminations.

Thick, lithologically varied and reworked volcaniclastic and epiclastic rocks characteristic of the Junkers member and resting on Takla and plutonic rocks likely coincided temporally with an interval of regional tectonic instability during which rocks of the lower Toodoggone succession were deeply eroded. The Junkers succession is interpreted as broad, low-angle alluvial fans built up along margins of uplifted fault blocks or, alternatively, represent the distal, largely clastic aprons of stratovolcano centres, prograding over older peneplaned rocks. Small-volume basaltic lava flows and their scattered distribution might suggest localization within irregular channels developed on coalescing fan surfaces. The Junkers member was deposited subaerially, with traction features in some sandstone beds suggestive of fluvial transport. The location of perceived central volcanoes, which fed the basaltic lavas and sourced the large volume of basaltic detritus occupying clastic deposits, likely lay east of present exposures of the Junkers member.

GRAVES MEMBER (UNIT TG)

The Graves member is named for lithic-rich ash-flow tuff deposits mapped within a series of half-graben fault blocks southeast of Mount Graves, south of the Toodoggone River (Diakow *et al.*, 2005a, b). The member consists primarily of a dacitic ash-flow tuff and locally prominent rhyolite lava flows or a rarely preserved, subaerial fallout, fine tuff facies. These rhyolitic flows and associated ash tuff deposits directly underlie a thick ash-flow sheet south of the Toodoggone River near the southern limit of the Graves member at Jock Creek. At a locality immediately north of Jock Creek, an ash-tuff bed about 1 m thick overlies thin intraformational conglomerate that was deposited at the top of pyroxene-phyric basalt of the Junkers member (Diakow *et al.*, 2005a). This ash layer yielded a U-Pb date of 192.0 +1/–2 Ma (sample 04LDi 22.9), corroborating the U-Pb date of 192.3 ±0.4 Ma on ash-flow tuff deposits (sample 03LDi 27.1) near Mount Graves.

North of the Toodoggone River, the Graves member is widespread, locally resting conformably on oxidized red-brown sections, up to 20 m thick, composed of bedded lapilli and fine tuffs. These rocks presumably are Plinian fallout deposits containing some synvolcanic reworking that produced minor crystal-rich sandstone at the base of overlying massive ash-flow tuff. This distinctly bedded interval is evident immediately beneath ash-flow tuff at Mount Gordonia and along a low northwest-trending ridge several kilometres north of Toodoggone Peak. West of Junkers Creek, the pyroclastic flows overlie resistant, relatively thin lava flows (unit TJv) found locally near the top of a thick succession of maroon siltstone, sandstone and conglomerate typical of the Junkers member. The rhyolite-flow facies, mapped beneath the pyroclastic flows south of the Toodoggone River (Diakow *et al.*, 2005b), has not been observed at the bottom of the Graves member in the study area. However, isolated rhyolitic rocks, tentatively assigned to the Junkers member (unit TJr) and unconformable on the Takla Group on Mount Estabrook, might actually be part of the Graves member.

Ash-flow tuff deposits in the Graves member are typically unstratified and display variations in their pyroclast content, internal welding and thickness. South of the Toodoggone valley, the ash-flow tuff deposits are generally lithic rich and, except for isolated thin welded zones, typically occupy nonwelded sections between 100 and 150 m thick (Diakow *et al.*, 2005a). In contrast, pyroclastic flows north of the river commonly show a striking internal zonation in the degree of welding and thickness variability. Differential welding is exhibited best in pyroclastic flows east of Mulvaney Creek and west of Junkers Creek, where these deposits apparently thicken to more than 200 m. Pyroclastic flows at these localities consist of a lower, nonwelded zone abruptly superimposed by a significantly thicker welded zone.

The nonwelded zone weathers recessively and contains up to 10% lithic fragments 2–10 cm in diameter. The fragments consist primarily of dark green and brownish red aphanitic and porphyritic andesite. However, the most diagnostic fragments, found in the Graves member throughout the region, consist of relatively scarce, pink, fine-grained porphyritic dacite-rhyolite and hornblende monzonite to quartz monzonite. Crystal fragments consist mainly of plagioclase and minor angular and resorbed quartz. Rare titanite and sparse (1–2%) altered biotite and hornblende also occur in the ash flows.

The welded upper part of the ash-flow succession locally develops columnar-jointed cliffs with the upper surface of the columns weathering in places to spheroidal lobes a metre or more in diameter. Relatively scarce lithic fragments and the comparatively massive, resistant weathered appearance distinguish the welded zone. Chloritic fiamme and elongate cavities, the latter presumably derived from preferential weathering and removal of compressed pumiceous fragments, define dense welding. The welded zone is also distinguished by formerly glassy juvenile pumiceous pyroclasts and cuspate and plate shards devitrified to fibrous quartz and feldspar. In localities where the pyroclastic flows were presumably very thick, ghost outlines of vitroclastic components are obscured during granophyric crystallization by a mosaic of anhedral interlocking quartz and feldspar.

Lithic-rich ash-flow tuff deposits, resembling those in sections south of the Toodoggone River, occupy the top 75 m of Mount Gordonia, overlying a well-bedded fallout sequence that thins laterally from about 20 m to several metres. The fallout sequence sharply overlies red reworked tuff-breccia or volcanic conglomerate and locally stratigraphically higher, bladed-plagioclase andesite porphyry lava flows at the top of the Junkers unit. The base of the fallout sequence consists of whitish ash tuff, containing quartz and biotite grains. This is overlain by red lapilli-rich beds alternating with crystal-ash tuff. In thin section, a dark red ash-tuff bed that resembles mudstone is noted to consist of cuspate and plate shards, which suggests they originated from a vapour-rich silicic magma that produced juvenile pumiceous fragments. Except for a thin welded zone at the base of the ash-flow tuff section at Mount Gordonia, the bulk of the deposit is nonwelded and contains 40–60% subangular lapilli and a few blocks, as well as rare accidental fragments of the distinctive bladed plagioclase-phyric lavas from immediately beneath the Junkers member.

In general, the Graves member north of the Toodoggone River consists of pyroclastic flows varying in thickness and degree of welding between the scattered depositional sites. Columnar-jointed, densely welded ash-flow tuff deposits east of Mulvaney Creek, and exposures localized adjacent to an east-west fault west of Junkers Creek, represent several of the thickest accumulations, possibly ponded in depressions. It is uncertain whether these thick welded ash-flow tuff deposits represent infilled valleys of an irregular topography or ponded within depressions produced during syn-eruptive subsidence.

PILLAR MEMBER (UNITS TPv, TPs)

The Pillar member forms the top of the Toodoggone Formation south to the Toodoggone River, where it consists of two successive cycles of interstratified lava flows and epiclastic and volcaniclastic rocks (Diakow *et al.*, 2005a, b). The Pillar member north of the Toodoggone River is comparatively thinner with a more limited distribution. The best exposure of the unit is in the upper part of the homocline west of Junkers Creek, where it is approximately 130 m thick and forms a medial volcanic subdivision that separates similar stratified sedimentary sequences (Fig. 3). Thinner (<50 m thick) isolated exposures of the unit cap several ridges east of Mount Gordonia and one ridge northwest of Mount Estabrook. Everywhere, rocks of this unit conformably overlie the upper welded zone of pyroclastic flows that form the Graves member.

Two isolated sections of the lower sedimentary interval, approximately 25–40 m thick, depositionally overlie the Graves unit west of Junkers Creek. The lowest beds consist of maroon-coloured conglomerate up to 5 m thick, consisting mainly of cobble-size porphyritic andesite set in a matrix dominated by plagioclase. The matrix also contains sparse quartz and biotite grains, suggesting local erosion of the underlying Graves member. Red-maroon sandstone, siltstone and minor mudstone dominate the upper part of these sections. The finer clastic beds display internal, faint parallel laminations and textural grading. They have the appearance of minimally reworked airfall crystal-ash tuff deposits, but their primary pyroclastic origin has not been proven.

This lower sedimentary interval is sharply overlain by about 50 m of basaltic andesite lava flows, which pass upward locally into dacitic volcaniclastic rocks (unit TPv). These flows are light grey-green and characteristically oxidized, imparting a reddish maroon colour and hematitic Liesegang bands. Locally, the tops of individual flows are oxidized red and display vesicular texture and amygdules infilled with calcite. Phenocryst mineralogy consists of clinopyroxene (2%) and plagioclase up to 4 mm (25–30%). A monomict breccia that contains block-size fragments of the underlying lavas encased in a muddy matrix is interpreted as a thin lahar locally overlying the lava flows. Because lava flows in the Pillar member closely resemble the appearance and mineralogy of those found locally near the top of the Junkers member (unit TJv), determining their respective stratigraphic positions is difficult without a reference relative to intervening pyroclastic flows of the Graves member. A 20 m thick dacitic pyroclastic flow, with a base of airfall crystal-ash tuff, locally overlies these lava flows. It contains small amounts of chlorite-altered biotite and quartz phenocrysts.

The volcanic interval passes upsection into an upper sedimentary sequence that, not unlike the lower one previously described, consists mainly of well-bedded brownish maroon sandstone and siltstone with minor interbeds of conglomerate. Siltstone in the section is friable, weathering recessively to angular fragments and displaying rounded, weathered forms. Sandstone commonly contains pyroxene grains and small lithic grains of basaltic lava, both possibly sourced from the underlying lava flows.

BELLE MEMBER (UNIT TB)

The highest subdivision presently recognized in the upper Toodoggone Formation is a rhyolitic ignimbrite occupying the top of the homoclinal succession located west of Junkers Creek and 3.5 km northeast of the more northerly of the Belle lakes (Fig. 1). The ignimbrite occupies a broad downwarp, defined by the shallow concave outline of underlying bedded epiclastic rocks that constitute the upper part of the Pillar member. The Belle ignimbrite covers an area of nearly a square kilometre, maintains a uniform thickness of approximately 125–150 m and dips gently southward. Extrapolating the ignimbrite sheet a short distance farther south, it is truncated by an east-west fault that juxtaposes the youngest strata of the Toodoggone Formation and oldest basement strata of the Asitka Group.

Ash and crystal-bearing tuff deposits containing juvenile bubble-wall shards occur in parallel-layered beds, locally 1 m thick at the base of the ash-flow tuff. These tuffs are interpreted as an airfall that preceded the overlying massive ash-flow tuff. The ash-flow contains mainly lapilli-size fragments and a few blocks, notably abundant aphanitic and laminated reddish and pink rhyolite. Also noted in thin section are juvenile devitrified glass fragments and shards scattered and deformed adjacent to broken crystal grains that include plagioclase, potassium feldspar and rare biotite.

A spectacular columnar-jointed cliff spanning the entire thickness of the ash-flow tuff is prominently displayed at the north-facing side of the deposit. Internally, the columns exhibit weak to moderate welded fabric. The glassy components at the base of the ash-flow tuff display granophyric crystallization, an interlocking mosaic of fine anhedral quartz and feldspar.

EARLY JURASSIC BLACK LAKE INTRUSIONS

Three stock-size intrusions mapped in the study area are assigned to the Black Lake intrusive suite. The McClair and Midas plutons exhibit sharp intrusive contacts with lava flows of the Takla Group. Unlike some mineralized plutons elsewhere in the Toodoggone region, which have attendant gossans in adjacent country rocks, the McClair and Midas plutons lack significant hydrothermal alteration on their margins. The Jack Lee is the largest of the plutons in the study area, covering roughly 30 km^2. In the west, it is extrapolated beneath the drift-covered valley of Jack Lee Creek, its contact coinciding with the trace of the Black fault. Several outliers of Junkers strata rest on the Jack Lee pluton, outboard of an extensively exposed nonconformable contact. Boulder-size clasts of monzodiorite, derived from the Jack Lee pluton, have been found at one locality in polymictic conglomerate deposited directly on the pluton.

The Jack Lee pluton consists mainly of medium-grained, inequigranular monzodiorite composed of plagioclase phenocrysts up to 4 mm set in a finer grained mosaic of anhedral potassium feldspar and quartz. Quartz constitutes up to 5% of plutonic specimens, and mafic minerals (hornblende, biotite and pyroxene, in decreasing relative abundance) make up 5–7%. Fresh exposures typically display a greenish coloration due to moderate to pervasive chlorite and epidote alteration of feldspars and mafic minerals, and coatings on joint and fracture surfaces. Locally intense oxidation of the pluton is imparted by hematite. Mineralogically this pluton resembles the Jock Creek pluton, a *ca.* 197 Ma monzonitic body mapped south of the Toodoggone River, where it is spatially and possibly genetically associated with important porphyry-style exploration targets at Sofia and Alexandra (Diakow *et al.*, 2005a). The Jack Lee pluton was sampled to determine a U-Pb crystallization age.

The McClair pluton, exposed in the southwest corner of the map area, intrudes mafic rocks of the Takla Group and, in the northeast, a steep fault places the intrusion against stratigraphy from the upper Toodoggone Formation. It is draped by a thin succession of pyroxene-phyric andesitic lava flows tentatively assigned to the Junkers member. Conglomeratic lenses that contain clasts derived from the underlying intrusion are found locally at the base of this flow unit, resting nonconformably on the McClair pluton. The McClair pluton is offset by the Toodoggone fault and, farther south, is bounded by the Pillar fault in the vicinity of the Pil North Au-Cu porphyry prospect. The intrusion contains xenoliths of fine-grained diorite, and aphanitic volcanic rocks presumably derived from the Takla Group.

The McClair pluton is composed of a pink hornblende-quartz monzonite with a medium to coarse-grained, equigranular texture. Subhedral and euhedral plagioclase phenocrysts up to 6 mm are variably replaced by sericite and calcite. Potassium feldspars occur both as phenocrysts and in an interlocking mosaic containing upwards of 15% quartz. Hornblende is the principal mafic mineral. Green unaltered prisms up to 8 mm may form 15% of the rock. Accessory titanite is visible in thin section.

Exposures of the Midas pluton cover 6 km^2, extending east from the valley bottom at Midas Lake into blocky-jointed, craggy ridges north of Contact Peak. The sharp intrusive contact dips steeply, with negligible contact metamorphism displayed in adjacent volcanic country rocks of the Takla Group. However, irregularly shaped exoskarns develop where the intrusion crosscuts nearby carbonate rocks of the Asitka Group.

The Midas pluton is mainly granite. A diorite phase is locally confined to the pluton margin and, nearby, also forms a plug-like apophysis that pierces the Asitka Group. The felsic main phase is light pink, medium grained, equigranular and composed roughly of subequal amounts of plagioclase and potassium feldspar, and 15% quartz. Weakly chlorite-altered hornblende (5%) and subordinate biotite are ubiquitous. The mafic border phase consists of a fine-grained, biotite-bearing diorite that locally contains disseminated pyrite.

Plutons with a bulk composition of granite are unusual in the Black Lake suite, as most are in the compositional range of quartz monzonite and monzonite. The exception is the Fredrikson pluton, a large monzogranite stock with a minor quartz monzodiorite phase, located southeast of the Kemess minesite (Diakow and Rogers, 1998). This is one of the youngest isotopically dated plutons in the Toodoggone region, yielding a U-Pb zircon crystallization age of 191.0 ±0.4 Ma. The authors speculate that the Midas pluton, also sampled for U-Pb geochronology, might yield an equivalent age. Furthermore, it might be comagmatic with nearby rhyolite pyroclastic flows that form the Belle member and represent the youngest extrusive event in the Toodoggone Formation.

Dikes and a few sills occur throughout the map area, crosscutting larger plutons and all stratigraphic units. However, none has been observed in the youngest Belle member. Dike orientations generally correspond to the regional north-northwest structural fabric defined by major faults. They typically range from 0.5 to 2 m in width, although there are a number that are tens of metres wide. The dikes can be associated with chalcopyrite-pyrite-bearing quartz veins and brecciated veins along their margins.

A variety of dikes with differing compositions and textures has been recognized but not systematically classified or studied in detail. In general, the most common dikes consist of pink-orange, sparsely plagioclase porphyritic monzonite to porphyritic quartz monzonite. Most contain chlorite-altered biotite and hornblende, and negligible quartz phenocrysts. Other common varieties include aphanitic or fine-grained basaltic dikes, quartz-biotite-phyric rhyolite and flow-laminated rhyolite dikes. A dark grey-green dioritic variety, containing plagioclase and pyroxene, forms a major sill and dikes crosscutting the Pillar member northeast of Midas Lake. These may be feeders to basaltic flows within the unit.

STRUCTURE

Layered stratigraphy and major plutons throughout the map area are disrupted by a complex pattern of high-angle fault structures trending generally north-northwest and east-northeast. Major northerly-trending faults, including the Black, Pillar and Midas faults, have inferred traces through broad drift-filled valleys occupied by Jack Lee Creek, Mulvaney and Junkers creeks, and McClair and Midas creeks, respectively.

The presence of the Midas fault is speculative, based on a pronounced negative magnetic discontinuity corresponding to a prominent valley bordering the study area in the west (Shives *et al.*, 2004). The Black fault delineates the western margin of the Jack Lee pluton, placing it against monotonous mafic volcanic rocks of the Takla Group. The extension of this structure farther south between the Toodoggone and Finlay rivers displaces the Graves and overlying Pillar members.

The Pillar fault is a regional-scale feature extending south from Chukachida Lake for approximately 70 km to the southern limit of the Toodoggone volcanic belt, mapped near the Kemess mine. In the northern part of the study area, the fault follows Junkers Creek, separating gently northeast-inclined Junkers strata in the east from equivalent and younger overlying Toodoggone strata that form a south-inclined homocline in the west. Immediately south of the Toodoggone River, this fault defines a significant break separating generally west-inclined volcaniclastic and epiclastic strata of the upper Toodoggone succession in the east from older volcanic units that make up the lower Toodoggone Formation in the west. Several outliers of upper Toodoggone strata overlie lower Toodoggone strata west of the Pillar fault. It is believed that the Pillar fault was active throughout deposition of much of the upper Toodoggone Formation, confining the dominantly pyroclastic flow, volcaniclastic-epiclastic succession within a series of fault-controlled half grabens that incrementally step up east of the Pillar fault.

Generally easterly-trending faults in the study area form comparatively shorter segments truncated by the northerly-trending faults. Several significant east-west structures emphasize their underlying importance, influencing the distribution and local variation in thickness of ash-flow tuff deposits. For example, a segment of the Toodoggone fault mapped south and west of the study area is believed to define the northern structural margin of an asymmetric volcanic subsidence feature in which more than 250 m of moderately to densely welded ash-flow tuff deposits of the Saunders member ponded *ca.* 194 Ma. A similar scenario of synvolcanic faulting is envisaged farther north within the study area, in regions where thick sequences of columnar-jointed, welded ash-flow tuff deposits are localized adjacent to several well-defined east-trending faults. For example, an east-west fault near Junkers Creek places Permian sedimentary rocks of the Asitka Group against a stratified, south-inclined volcanosedimentary succession representing much of the upper Toodoggone Formation. This relationship suggests significant north-side-down displacement. Within the downdropped block, moving north away from this fault, the thickness of successive columnar-jointed, welded ash-flow tuff sequences of the Belle and Graves members and intervening Pillar lava flow–sedimentary sequence rapidly diminish, inferring half-graben or asymmetric subsidence (Fig. 3). Another parallel structure immediately north of Mount Gordonia apparently extends east to the Pillar fault, where a similarly oriented fault segment continues and is truncated farther east by the Black fault. The north side of these east-west structures is downdropped relative to uplifted Triassic basement strata widely exposed on the south side. Within the downdropped blocks, shallowly inclined strata of the Junkers member are overlain by pyroclastic flows of the Graves member. They form spectacular columnar-jointed cliffs representing the upper welded zone. The proximity of thick, welded pyroclastic flows adjacent to these east-west faults suggests ponding in fault-controlled depressions, as opposed to paleovalley depressions.

MINERAL PROSPECTS

The study area has 17 mineral occurrences described in MINFILE (2005) and a number of new mineral prospects. These prospects consist primarily of sulphide minerals in quartz veins and isolated skarns.

Quartz veins and vein breccia prospects are commonly localized along north and northwest-trending faults. These faults also provide a locus for a variety of dikes, which share sharp contacts with adjacent quartz breccia and veins. Solitary veins typically vary from 10 to 50 cm in width. In broader fault zones, a series of narrow subparallel veins and veinlets occupy the zone. The veins generally consist of white, translucent crystalline quartz that sometimes displays diffuse banding and comb texture. Sulphide disseminations and less common massive crystalline concentrations include mainly pyrite, accompanied by generally small amounts of chalcopyrite, malachite, galena, sphalerite and pyrrhotite.

The tell-tale rusty gossanous surface expression prevalent adjacent to many porphyry occurrences south of the Toodoggone River is generally absent in the study area. This suggests the tract of mineralized monzonitic plutons might not extend beneath volcanic successions that underlie most of the study area. The Jack Lee and McClair plutons are biotite-hornblende-bearing intrusions more typical of large, sparsely mineralized plutons that constitute the Black Lake intrusive suite. These plutons generally contain only minor disseminated chalcopyrite and pyrite in quartz veinlets occupying fractures. The Midas pluton exhibits a sharp intrusive contact with either mafic flows of the Takla Group or limestone of the Asitka Group. This contact is weakly mineralized with malachite, which coats fractures in adjacent mafic country rocks. This feature is not necessarily unique to the contact zone of this intrusion, since malachite commonly coats fractures throughout the Takla volcanic succession.

Skarn mineralization occurs within limestone adjacent to a granite stock east of Midas Lake. Boulders, 40 cm in diameter and located in talus sourced from a rusty zone adjacent to a dioritic plug piercing limestone, consist of diopside-garnet-magnetite and rusty massive sulphide minerals. The sulphide boulders are composed of pyrrhotite, chalcopyrite, bornite and pyrite.

CONCLUSIONS

- The distribution of the Early Jurassic Toodoggone Formation extends into a previously little known region north of the Toodoggone River, where strata mainly representing the upper part of the formation unconformably overlie the Late Triassic Takla Group. Stratigraphy of the lower Toodoggone Formation is absent throughout most of the area. However, locally it consists of relatively thin volcaniclastic deposits that, in one locality, overlie a basal polymictic conglomerate containing clasts derived from older basement successions of the Takla and Asitka groups.
- The description of the upper Toodoggone Formation is revised from that in Diakow *et al.* (2005a) and is currently subdivided into four informal members. The lowest Junkers member replaces the earlier named Quartz Lake member. Conglomeratic and finer clastic beds containing fine porphyritic basalt clasts and pyroxene grains, and local volumetrically minor basalt and rhyodacite lava flows characterize crude, thick-bedded sections typical of the Junkers member. The overlying Graves member is composed of quartz-biotite-bearing dacitic ash-flow tuff deposits locally associated with rhyolitic flow and fallout facies. The Pillar member is a well-bedded, oxidized sequence dominated by clastic rocks that interfinger locally prominent basaltic flows and lesser dacitic volcaniclastic rocks. The newly recognized Belle member is composed of rhyolite ash-flow tuff that forms a columnar-jointed sheet in one locality at the top of Toodoggone stratigraphy.
- North-northwest-trending extensional faults extend from the south into the study area. These and smaller scale parallel features impart control regionally on intrusions and localize epithermal vein deposits in the Toodoggone Formation. East-west faults are thought to predate these northerly faults in the study area. These faults apparently demarcate the high wall of several half grabens in which ash-flow tuff deposits ponded and subsequently cooled, forming thick, welded, columnar-jointed exposures.
- The most common mineral prospects in the study area are pyrite-chalcopyrite±galena±pyrrhotite-bearing epithermal quartz veins and vein breccias. The veins are localized in northerly-trending faults and along dikes that crosscut strata of the upper Toodoggone Formation. Skarn is developed in Asitka limestone where it is intruded by an Early Jurassic granitoid.

ACKNOWLEDGMENTS

We thank Stealth Minerals Limited for their continued and significant financial and logistical support that enabled the mapping program to expand into more remote terrain of the Toodoggone region. We are grateful to the company for providing staff to assist in mapping, maintaining helicopter support and welcoming us in their base camp on the Finlay River. Stealth geologist April Barrios is gratefully acknowledged for her contributions and capable assistance during two weeks with the mapping team. Geological discussion with Dave Kuran, Paul Durring and Steve Rowins were always informative and appreciated. We also thank Northgate Minerals Corporation, particularly Carl Edmunds and Ron Konst at the Kemess mine, for geological discussions and their logistical support on our numerous trips to the minesite. Brian Grant is thanked for his editorial comments.

REFERENCES

Diakow, L.J., Nixon, G., Lane, B. and Rhodes, R. (2005a): Toodoggone Geoscience Partnership: preliminary bedrock mapping results from the Swannell Range: Finlay River – Toodoggone River area (NTS 94E/2 and 7), north-central British Columbia; *in* Geological Fieldwork 2004, *British Columbia Ministry of Energy, Mines and Petroleum Resources*, Paper 2005-1, pages 93–107.

Diakow, L.J., Nixon, G.T., Rhodes, R. and Lane, B. (2005b): Geology between the Finlay and Toodoggone rivers, Toodoggone River map area, north-central British Columbia (parts of NTS 94E/2,6 and 7); *British Columbia Ministry of Energy, Mines and Petroleum Resources*, Open File Map 2005-3.

Diakow, L.J and Rogers, C. (1998): Toodoggone-McConnell Project: geology of the McConnell Range — Serrated Peak to Jensen Creek, parts of NTS 94E/2 and 94D/15; *in* Geological Fieldwork 1997, *British Columbia Ministry of Energy, Mines and Petroleum Resources*, Paper 1998-1, p 8a-1–8a-13.

Diakow, L.J. and Shives, R.B.K. (2004): Geoscience partnerships in the Toodoggone River and McConnell Creek map areas, north-central British Columbia; *in* Geological Fieldwork 2003, *British Columbia Ministry of Energy, Mines and Petroleum Resources*, Paper 2004-1, p 27–32.

Gabrielse, H., Dodds, C.J., Mansy, J.L. and Eisbacher, G.H. (1977): Geology of Toodoggone River (94E) and Ware west-half (94F); *Geological Survey of Canada*, Open File 483.

MINFILE (2005): MINFILE BC mineral deposits database; *BC Ministry of Energy, Mines and Petroleum Resources*, URL <http://www.em.gov.bc.ca/Mining/Geolsurv/Minfile/> [Nov 18, 2005].

Shives, R.B.K., Carson, J.M., Dumont, R., Ford, K.L., Holman, P.B. and Diakow, L. (2004): Helicopter-borne gamma-ray spectrometric and magnetic total field geophysical survey (parts of NTS 94D/15, E/2,3,6,7,10,11); *Geological Survey of Canada*, Open File 4614.