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[1]

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KEYWORDS: P3, public-private partnership, Targeted Geoscience Initiative II (TGI-II), bedrock mapping, stratigraphy, Finlay River, Toodoggone River airborne gamma-ray spectrometric and magnetic survey, Toodoggone River, Finlay River, Toodoggone formation, Black Lake Intrusive Suite, Cu-Au porphyry, epithermal Au-Ag

INTRODUCTION

The Toodoggone Geoscience Partnership was initiated in 2003 to generate detailed geoscience information, including airborne geophysics and bedrock geology maps, that would support mining exploration in previously explored and more remote terrain in the east-central Toodoggone River and McConnell Creek map areas, which are considered highly prospective for Cu-Au porphyry and epithermal Au-Ag mineralization. The success of this partnership is based on the participation of all five mining companies actively exploring the program area (Stealth Minerals Ltd., Northgate Minerals Corp., Finlay Minerals Ltd., Bishop Gold Inc. and Sable Resources Ltd.), coupled with personnel from the British Columbia Geological Survey, the Geological Survey of Canada and the University of British Columbia.

In 2004, the Geological Survey of Canada released digital data and a series of maps from a low-level, high-resolution airborne gamma-ray spectrometric and magnetic survey that covered 1) most of the known porphyry and epithermal targets within the main area of prospective Early Jurassic rocks; and 2) a remote and relatively underexplored region farther east in the Swannell Ranges of the Toodoggone area (Shives *et al*., 2004).

Bedrock mapping continued in 2004, expanding the area of detailed 1:20 000-scale map coverage in two regions: 1) the southern region, located 55 km southeast of the Kemess South Cu-Au porphyry mine and centred on Johanson Lake (Schiarizza, 2004a, b; Schiarizza and Tan, this volume); and 2) the northern region, between the Toodoggone and Finlay rivers (Diakow, 2004). This paper summarizes the results of geological mapping conducted in a 250 km^2 area located east of the Pillar Fault (Diakow, 2004) and bounded by the Finlay River in the south and the Toodoggone River in the north and east (Fig. 1). The new results reported below emphasize changes in the Early Jurassic stratigraphy of the Toodoggone from west to east.

LITHOSTRATIGRAPHIC UNITS

Over the past two field seasons, nearly 600 km^2 of the Swannell Ranges, situated between the major drainages of the Toodoggone and Finlay rivers and their confluence, have been mapped in detail, thereby refining Jurassic stratigraphy that was, for the most part, previously assigned to an undivided Hazelton Group map unit (Diakow *et al.*, 1985, 1993). As a consequence of mapping in 2004, a region of previously undivided Jurassic rocks is now identified as part of the Toodoggone formation. These rocks have been subdivided *informally* into stratigraphic members, which collectively represent one of the most complete Early Jurassic sequences exposed anywhere in the Toodoggone River area. Volcanic rocks presumed to be near the bottom of the Toodoggone formation rest unconformably on either volcanic strata of the Late Triassic Takla Group or granitoid rocks of the Early Jurassic Black Lake Intrusive Suite. The oldest rocks consist of bedded sedimentary strata of the Upper Paleozoic Asitka Group; these are generally poorly exposed, locally intruded and thermally altered by Jurassic intrusions, and rarely observed to be overlain disconformably by the Takla Group.

The generalized geology of the study area is shown in Figures 2 and 3, and representative stratigraphic sections are given in Figure 4. The stratigraphy is transected by major northerly to north-northwesterly-trending high-angle faults, notably the Pillar and Black faults, intersected by easterly to northeasterly-trending cross-faults (Fig. 2). East of the Pillar Fault, the stratigraphy is consistently inclined to the west-southwest and has relatively shallow dips (15–25°).

Asitka Group (Unit PAs)

The Pennsylvanian to Early Permian Asitka Group comprises several large pendants resting on or adjacent to the Early Jurassic Duncan pluton near Drybrough Peak (west of the study area), where both volcanic and stratigraphically higher sedimentary rocks were mapped previously (Diakow, 2004). In this study, scattered outcrops of the Asitka Group were encountered near the

[1]*Contribution of the Federal-Provincial Targeted Geoscience Initiative-II (TGI-II)*

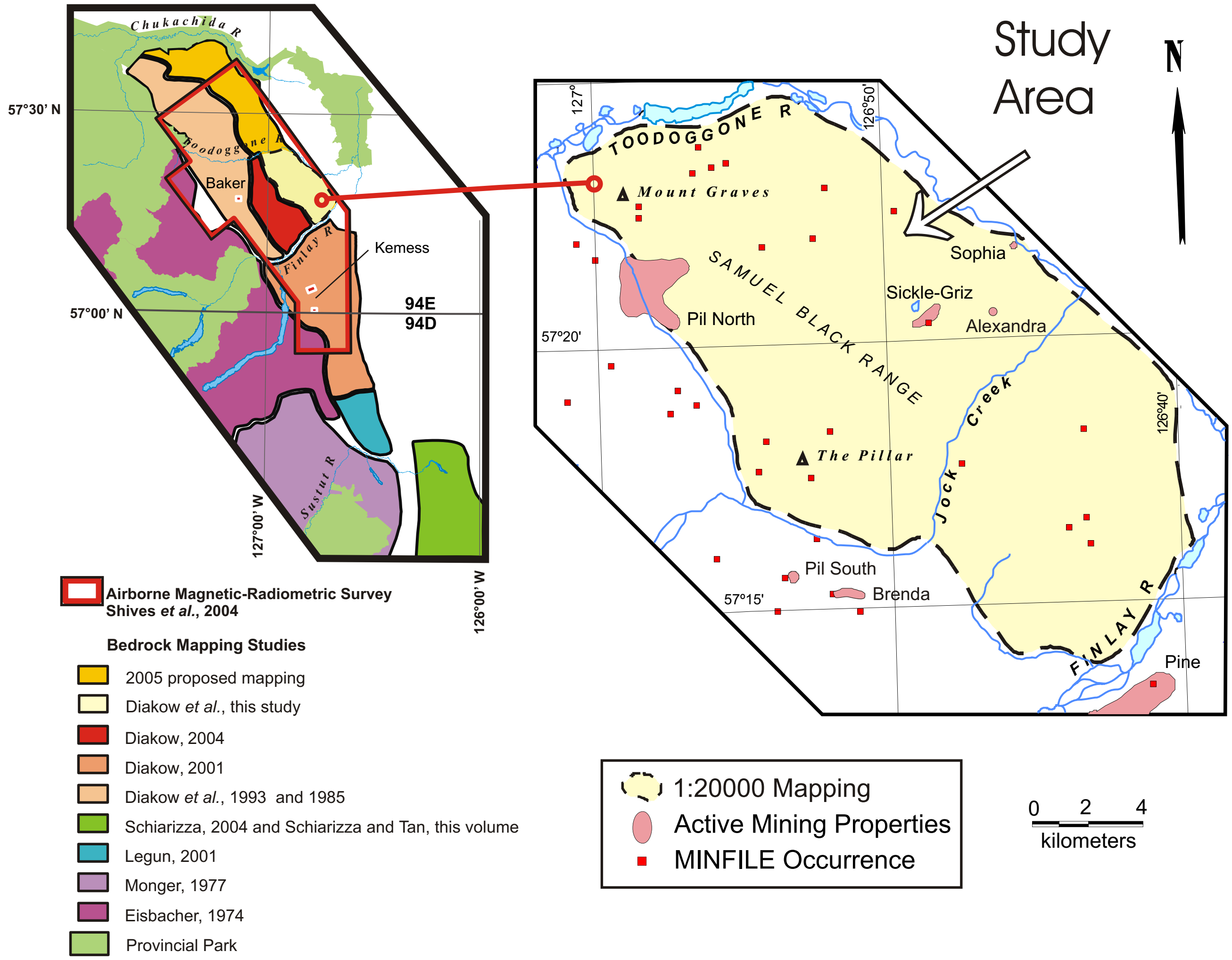

Figure 1. Location of bedrock mapping completed in 2004. Inset on the left shows published geological work in the Toodoggone River (94E) and McConnell Creek (94D) map areas (*see* references).

treeline in an area east of Jock Creek (Fig. 2). Here, the succession is about 130 m thick and intruded by an Early Jurassic quartz monzonite stock at the lower contact. Limestone adjacent to the intrusive contact is recrystallized and replaced locally by irregular zones of diopside-garnet-magnetite skarn, and carries patchy galena and chalcopyrite mineralization. Higher in the section, pale grey weathered limestone alternates with whitish chert in beds varying from 10 to 50 cm thick. Above the highest chert layers, siltstone interleaved with thin black mudstone partings occupies the uppermost 20 m of the section. The uppermost sedimentary strata are sharply overlain by pyroxene-bearing lavas of the Late Triassic Takla Group.

Takla Group (Unit uTTv)

The Late Triassic Takla Group is exposed along the lower north- and east-facing slopes of the mountains south of Jock Creek, and in nearby outcrops where it is juxtaposed against the Toodoggone formation by high-angle faults. South of Jock Creek, the lower contact of the Takla Group is marked by an unusually coarse clinopyroxene-phyric basalt flow that overlies siltstones considered to represent part of the underlying Asitka Group. This contact is interpreted as a disconformity, although there is little evidence of erosion. Above this contact, lavas more typical of the Takla Group predominate, and include a variety of porphyritic basalts containing abundant, medium to coarse (<6 mm) phenocrysts of clinopyroxene. Other, volumetrically minor flow varieties include distinctive porphyritic lavas with bladed-plagioclase textures and aphanitic basalts. Pyroxene-bearing sandstones occur as sparse, thin interbeds within the volcanic succession.

Basal Toodoggone Formation Unconformity

Bedded polymictic conglomerates and sandstones (unit Tc1) occur at a number of isolated localities in the southern Toodoggone map area, and occupy the interval between mafic volcanic rocks of the Takla Group and overlying quartz-biotite-bearing volcanic rocks of the Toodoggone formation. These deposits mark a basal unconformity of regional extent in the Jurassic succession, and record variable uplift and incision deep into pre-Jurassic strata and exhumed plutons.

The basal comglomeratic deposits may be traced discontinuously for almost 7 km west of the Pillar Fault south of Jock Creek (Diakow, 2004), and have been found farther east at two isolated localities in the study area. The conglomerates generally consist of sand-granule matrix- to clast-supported rounded cobbles and boulders derived from Takla, granitoid and, less commonly, Asitka sources. At one locality not visited by the authors, but portrayed schematically in section 1 of Figure 4, a mining company reported conglomerate dominated by granitoid debris resting atop an early quartz monzonite phase of the composite Jock Creek pluton (Fig. 2; described below). At the second locality, the unconformity is marked by a thin (<7 m) succession of basal, cobble to pebble conglomerates passing upwards into coarse to medium-grained, feldspathic to lithic sandstones containing detrital quartz.

Early Jurassic Toodoggone formation

The Toodoggone formation is an exclusively subaerial volcanic succession that comprises the sole subdivision of the Early Jurassic Hazelton Group in the Toodoggone River area. Together with cogenetic plutons of the Black Lake Intrusive Suite, these rocks host important Au-bearing epithermal and porphyry-style mineral deposits. Mapping of the Toodoggone formation has occurred episodically over several decades resulting in an evolving internal stratigraphy. A number of *informal* members have been proposed for locally mappable lithological units whose depositional ages are reasonably well constrained by more than 20 isotopic ages (Diakow, unpublished data).

Stratigraphic members of the Toodoggone formation exposed in the region between the Finlay and Toodoggone rivers include the Duncan, Metasantan and Saunders members, all of which have widespread distribution west of the Pillar Fault (Diakow, 2004). In places, rocks of the Duncan member are observed overlying Upper Triassic strata above a basal unconformity marked by erosion and typified by bedded epiclastic rocks. East of the Pillar Fault and north of Jock Creek, new stratigraphy is recognized resting upon volcanic rocks that resemble the Metsantan member. We include these new rock units as part of the Toodoggone formation and, in order of ascending stratigraphic position, *informally* name them the Quartz Lake, Graves and Pillar members. To the west, adjacent to Saunders Creek, the lower part of this new succession, tentatively correlated with the Quartz Lake member, forms several outliers, with one section resting unconformably on rocks of the Saunders member (western extremity of Fig. 2). This relationship indicates that the new stratigraphy is younger than the Saunders member, and a new U-Pb date from the study area confirms that these rocks belong in the upper part of the Toodoggone formation.

Typically, rocks of the Toodoggone formation have a narrow compositional range between high-silica andesite and dacite, and contain varying amounts of diagnostic quartz, biotite, hornblende and apatite phenocrysts. The new stratigraphy, however, is distinguished by locally abundant basalt to andesite porphyritic flows containing clinopyroxene, flow-laminated dacite to rhyolite lavas, and a generally greater proportion of volcaniclastic rocks of various origins. Unlike most of the Toodoggone formation, quartz and biotite phenocrysts are rarely observed in these younger rocks.

DUNCAN MEMBER (UNIT TD)

The Duncan member is well exposed in the southeastern part of the study area between the Finlay River and Jock Creek. It comprises a thick, crudely layered succession of predominantly nonwelded, dacitic lithic-crystal tuffs interbedded with minor crystal-rich volcanic sandstone and siltstone. The base of the succession is marked locally by quartz-bearing sandstones in gradational contact with conglomeratic beds that mark the basal unconformity of Toodoggone strata on the Takla Group. Elsewhere, however, incipiently to moderately welded ash-flow tuffs rest directly on erosional remnants of the Takla Group. Here, within a few metres of the contact, the plane of welding is more steeply inclined (>50°) and reflects the local attitude of the rugged paleosurface.

The lithic component (<10 vol. %; <3 cm across) of the pyroclastic beds constitutes subrounded to subangular clasts of finely porphyritic to aphanitic andesitic volcanic rocks. The crystal component (typically 1–3 mm) is dominated by broken plagioclase accompanied by minor to trace amounts of rounded (resorbed) quartz and oxidized, coppery flakes of biotite.

South of the study area in the vicinity of the Kemess North Cu-Au porphyry occurrence, pyroclastic flow deposits dominate sections unconformably overlying the Triassic volcanic rocks. A similar relationship is also observed south of Attycelley Creek, where nonwelded to incipiently welded tuffs overlie nearly 100 m of layered epiclastic rocks above the basal unconformity. At both localities, U-Pb isotopic dates determined for pyroclastic rocks assigned to the Duncan member are precisely established at 199 to 200 Ma.

METSANTAN MEMBER (UNIT TM)

The Metsantan member occupies much of the terrain north of the Finlay River, extending to the vicinity of The Pillar, where it is truncated by westerly-trending faults, and east of Mt. Graves to the Toodoggone River. The unit comprises a fairly homogeneous succession of andesitic lavas, including associated flow breccias, minor interbedded epiclastic and rare pyroclastic rocks. The basal contact with the Duncan member is abrupt and generally marked by massive flow sequences largely devoid of layering or internal flow features.

Lavas of the Metsantan member typically contain equant to subequant, blocky plagioclase phenocrysts (usually 3–5 mm), rarely found in glomeroporphyritic intergrowth (<8 mm), that commonly form 15–25 vol. % of the rock. Mafic phenocrysts include variably altered, prismatic hornblende and euhedral biotite (<5 mm) and generally constitute less than 5 vol. % of the rock. Unusually biotite-rich (8–10 vol. %) andesite lavas are comparatively rare though well exposed, for example, on a westerly-trending ridge just south of The Pillar. Accessory minerals include small (<1 mm) grains of resorbed quartz and reddish apatite prisms (<1 mm) which, though definitive of these lavas, are sparsely distributed. Based on phenocryst mineralogy and chemical composition, these rocks are commonly referred to as trachyandesite or high-silica andesite.

East of the Black Fault in the area between the Sickle Creek and Quartz Lake cirques, andesitic flows are interbedded with, or overlain by, well-sorted sandstones and cobble to pebble conglomerates with rounded clasts of porphyritic to aphanitic andesites and monzonitic granitoid rocks. These beds are tentatively included within the Metsantan member, although some of these clastic sequences may belong to the overlying Quartz Lake member (described below) due to fault repetition (Fig. 5).

Metsantan andesites cover an extensive part of the Toodoggone region and rest on ash-flow tuff successions that appear to have slightly different ages. Argon-argon dating of this flow sequence has been hindered by the paucity of fresh hornblende and biotite. However, the two Ar-Ar dates that have been obtained yield similar isotopic ages of approximately 196 and 194 Ma.

SAUNDERS MEMBER (UNIT Ts)

The Saunders member is a homogeneous dacitic ash-flow tuff sequence best exposed in the region west of Saunders Creek and northwest toward the Toodoggone River (Diakow, 2004). Other thick accumulations are found south of the Finlay River and northeast of the Kemess South mine (Diakow, 2001). South of Jock Creek,

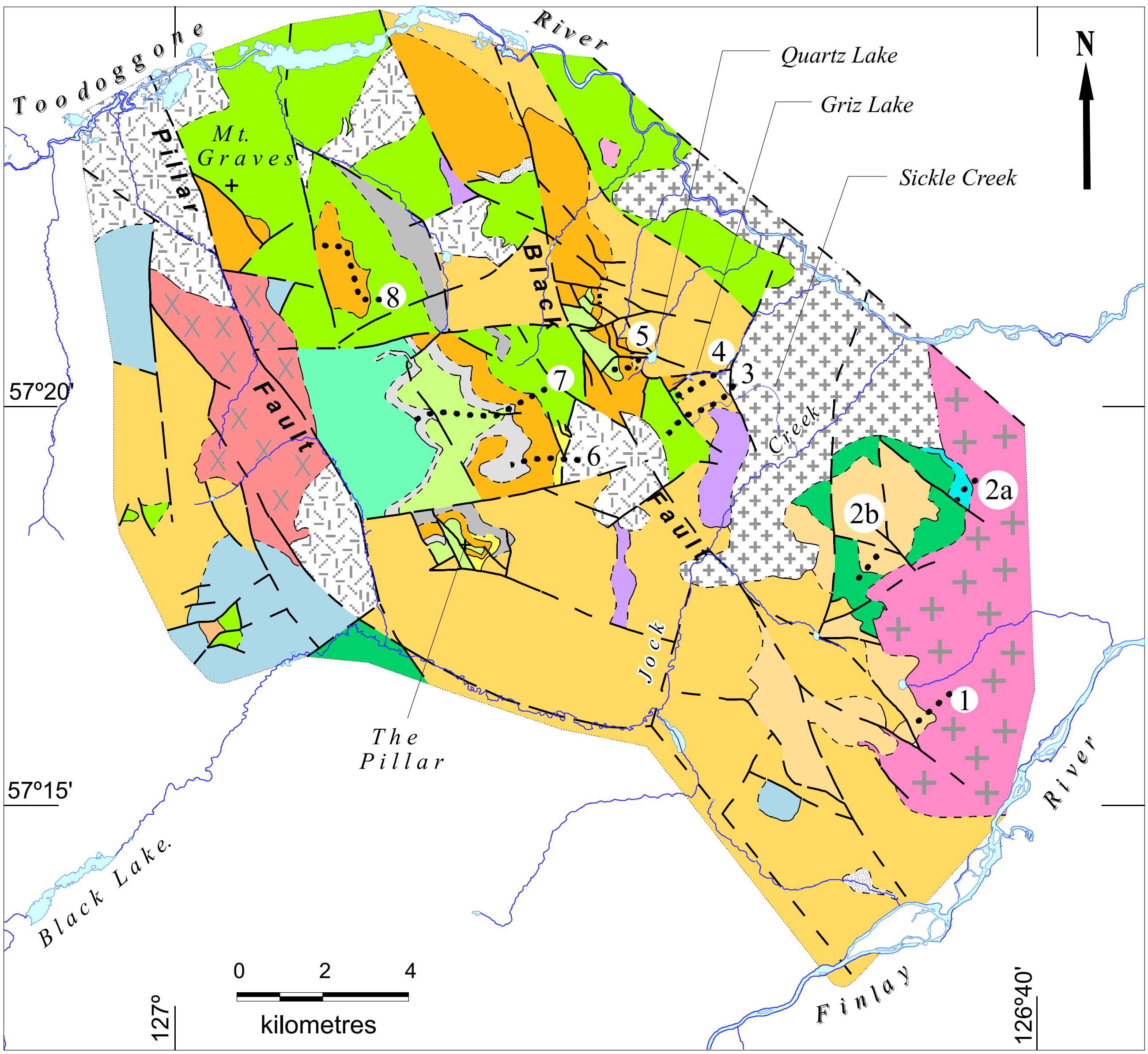

Figure 2. Generalized geology of the study area east of the Pillar Fault between the Finlay and Toodoggone rivers. Numbered transects locate the stratigraphic sections shown in Fig. 4. Informally named lakes and a creek referenced in the text are also indicated. The dash-double dot contact between early and late phases of the Jock Creek pluton is inferred from the aeromagnetic data of Shives *et al*. (2004).

an isolated occurrence of reddish oxidized pyroclastic flows form a cap less than 70 m thick on a ridge that, at lower altitude, exposes lavas of the Metsantan member. The highly variable thickness of the Saunders unit is attributed to the influence of pre-existing topography and synvolcanic faults.

Dacite ash-flow tuffs of the Saunders member are some of the least altered rocks in the Toodoggone area. These rocks exhibit a characteristic grey color and, because of their indurated character, generally form a resistant stratigraphic marker. The tuffs are noticeably enriched in broken crystals of plagioclase (up to 40 vol. %). Splendant crystals of hornblende (up to 7 vol. %) and lesser biotite and quartz (trace to 3 vol. %) make up the majority of the remaining crystal population. Dark grey to black, cognate vitrophyre fragments (5–45% of the rock) occur throughout the ash-flow deposit and locally become densely welded to define a pronounced eutaxitic texture. Although this unit is commonly oxidized to reddish hues, the primary mineralogy and vitrophyric textures are readily identifiable.

Seven Ar-Ar and U-Pb isotopic dates indicate that the Saunders member erupted during a brief interval between 194 and 193 Ma (Diakow, unpublished data).

New Rock Units Forming the Uppermost Toodoggone Formation

East of the Pillar Fault, a previously undivided succession of lavas and interbedded, well-stratified pyroclastic-epiclastic rocks forms a gentle west-southwest-dipping homocline. Epiclastic strata near the base of this succession near an informally named lake, Quartz Lake, overlie hornblende- and/or biotite-bearing andesite flows provisionally assigned to the Metsantan member (section 5 in Fig. 4 and Fig. 5). Since the Saunders member is apparently missing in this area, this contact is interpreted as a disconformity. Elements of the new stratigraphy, however, demonstrably overlie the Saunders member west of the Pillar Fault, where epiclastic rocks mark an erosional contact. From these relationships and a new U-Pb date derived from near the middle of the new sequence, it is evident that these rocks are time stratigraphic, in part, with dated strata in the

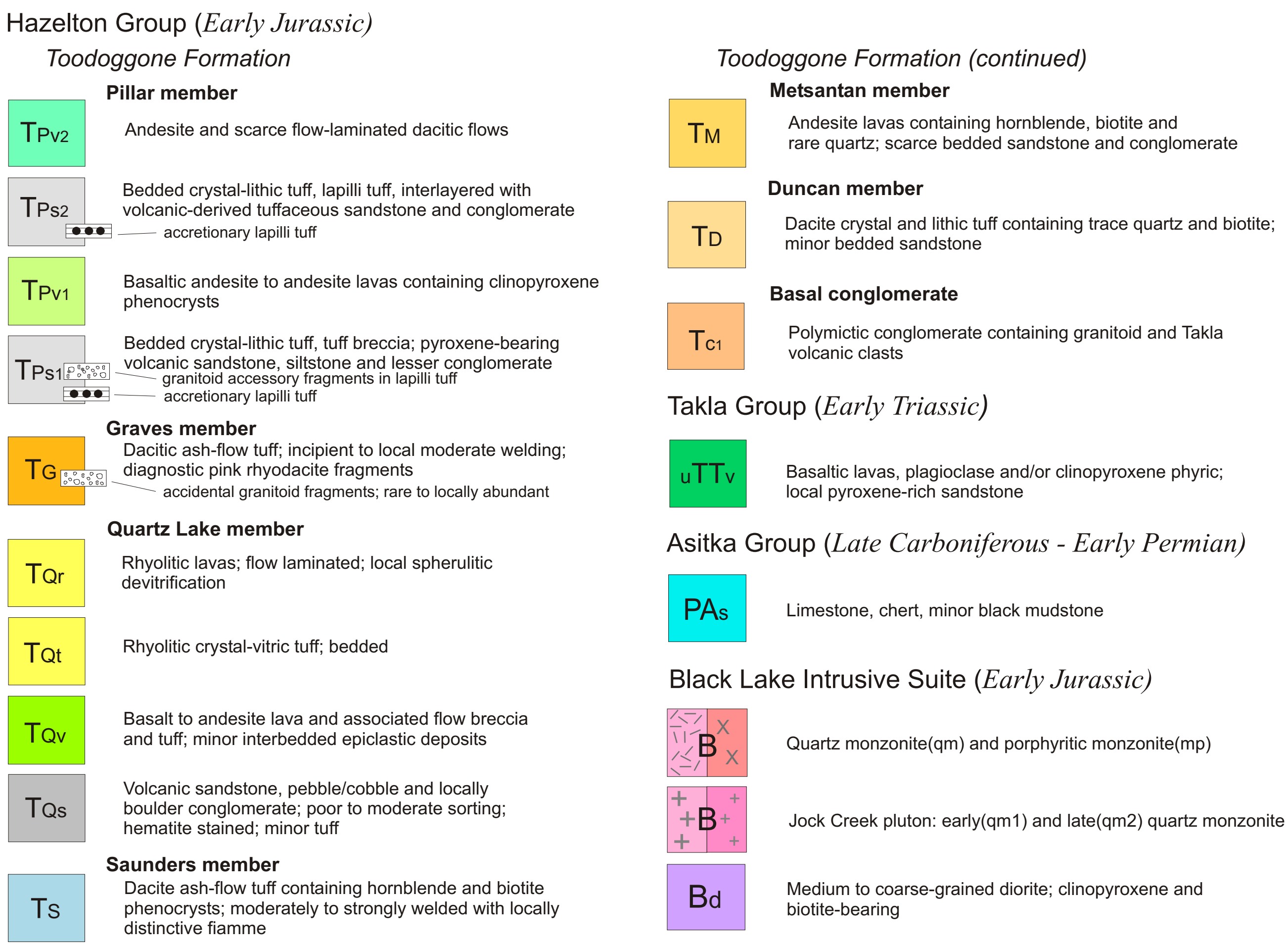

Figure 3. Legend to geology map in Figure 2 (opposite page). Additional stratigraphic elements and unit descriptions refer to sections shown in Figure 4.

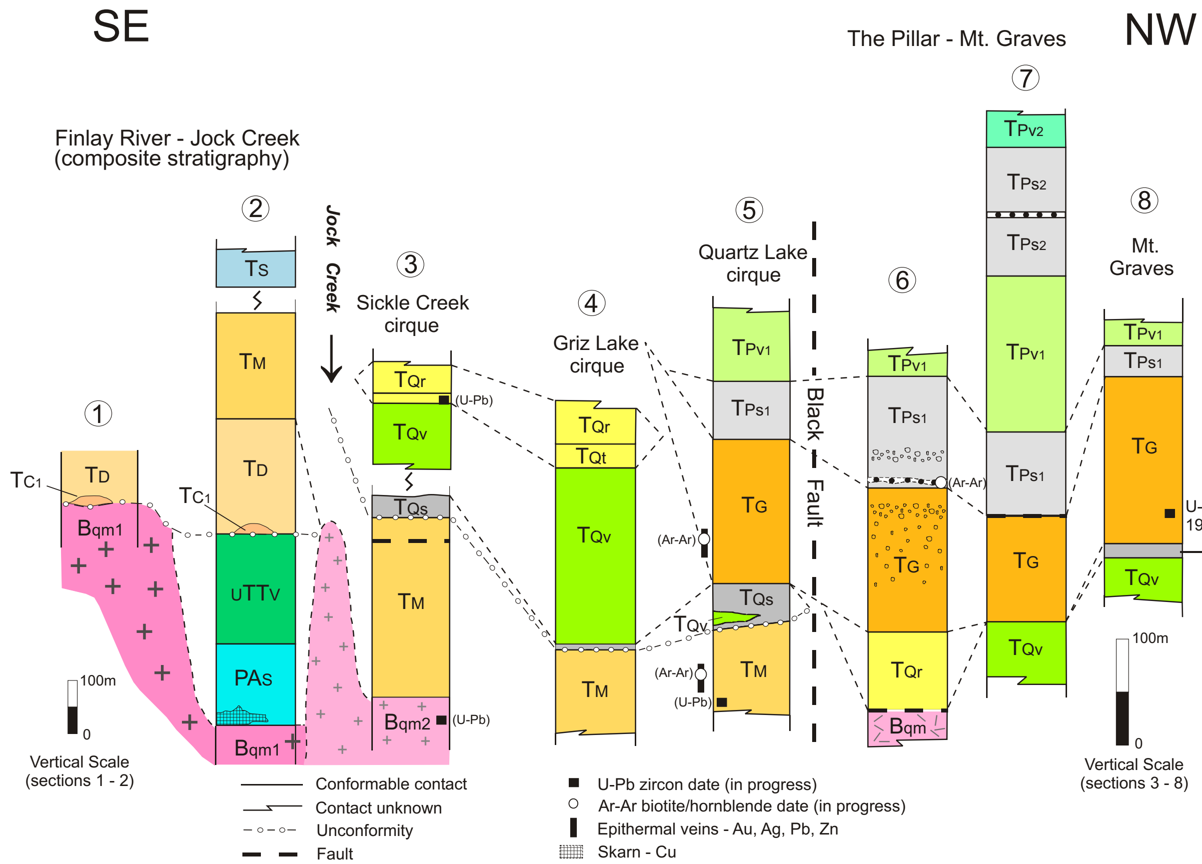

Figure 4. Generalized composite sections showing lithostratigraphic subdivisions for rocks east of the Pillar Fault, between the Finlay River and Toodoggone River. Location of sections are shown on Figure 2 and descriptions of map units are given in Figure 3.

upper part of the Toodoggone formation residing outside the map area.

The volcanic rocks in this package are compositionally diverse, comprising basalts and andesites distinguished by the presence of clinopyroxene, and aphanitic to sparsely porphyritic rhyodacite and rhyolite that represent the most differentiated rocks in the entire Toodoggone area. Other distinguishing features of the new stratigraphy include the notably reduced (trace) abundance of quartz, biotite and apatite in the flows and pyroclastic rocks, and the much higher proportion of volcanic-derived sedimentary rocks compared to other parts of the Toodoggone area.

The homoclinal succession described above is estimated to be about 1 km thick in the area between Quartz Lake, Mt. Graves and The Pillar. The rocks are subdivided *informally* into the Quartz Lake, Graves and Pillar members, listed in order of ascending stratigraphic position within the Toodoggone formation, beginning at the top of the Saunders member. Relationships between the new stratigraphy and older rocks are depicted in the reference sections shown in Figure 4.

QUARTZ LAKE MEMBER (UNITS TQS, TQV, TQR, TQT)

As noted above, the Quartz Lake member is a heterogeneous lithostratigraphic unit comprising interbedded volcanic and volcaniclastic rocks that, although complexly faulted, are well exposed in the cirque headwall and ridges surrounding Quartz Lake (Fig. 5). The mappable units shown in Figures 2 to 5 are designated according to their lithological characteristics rather than their exact stratigraphic context, which in many cases is not adequately known; thus, these units may occupy different stratigraphic horizons within the Quartz Lake member.

At Quartz Lake, a basal coarse clastic deposit (TQs) overlies biotite-bearing andesitic lavas of the Metsantan member. This dark reddish brown to maroon, poorly sorted deposit contains angular to rounded, pebble- to boulder-size (<5–30 cm) clasts of aphanitic to porphyritic Metsantan volcanic rocks in a fine to medium-grained sandy matrix locally containing biotite crystals (<2 mm). This basal unit probably represents a water-washed laharic breccia; however, this bed may also include weathered flow breccia. This deposit is separated from overlying dark reddish brown, moderately sorted, medium to coarse-grained volcanic sandstones (also TQs) by minor faulting and rhyolite intrusion (Fig. 5). These beds in turn are overlain by the basal part of the Graves ash-flow tuff member (described below), which contains diagnostic pink dacitic fragments (<4 cm) and broken plagioclase crystals (<2 mm) and, at this locality, hosts an extensive quartz±adularia–calcite–(?)barite stockwork with traces of sulphide mineralization. In the cirque wall west of Quartz Lake, a thin sequence of fine to medium (1–3 mm) plagioclase-phyric, pyroxene-bearing andesite flows (TQv, best developed elsewhere) are found at or near the hematitic base of this predominantly clastic unit (Fig. 5 and Fig. 4, section 5).

Other exposures of unit TQs, for example, are found approximately 4 km due west of Quartz Lake below the faulted base of the Graves member, in scattered outcrops along the western lower slopes of a broad valley to the northwest of the latter locality and in the vicinity of The Pillar (Fig. 2). At the former locality, these well-stratified, epiclastic and pyroclastic rocks are intercalated with variably porphyritic basaltic to andesitic lavas (TQv). The sedimentary rocks include buff to reddish brown weathering, waterlain volcanic breccias, volcanic cobble to boulder conglomerates locally enclosing large (up to 50 cm across) rounded monzonitic clasts, and coarse sandstones. Pyroclastic interbeds are dominated by grey-green lithic-crystal ash-flow tuffs of dacitic composition and their reworked equivalents. The associated lavas are commonly dark grey to red, finely porphyritic (<1.5 mm) plagioclase-phyric basaltic andesites with small amounts (<3 vol. %) of clinopyroxene; however, augite-rich variants (10–15 vol. %; <5 mm) and strongly amygdaloidal flows carrying subequant clinopyroxene megacrysts (<1 cm) are locally conspicuous.

At The Pillar, well-stratified sequences of volcanic conglomerates, sandstones, siltstones, ash-flow tuffs and tuffaceous breccias (TQs) underlie rhyolitic tuffs and lavas (TQr) resting directly below the Graves member. Similar rhyolitic rocks occur 3 km northeast of The Pillar and form small outliers at the top of cirque headwalls above Griz Lake and Sickle Creek (Fig. 4 and 5). Dark red to pale grey-green, spherulitic rhyolite lavas commonly exhibit flow laminations and contain plagioclase (<20 vol. %) and biotite (3 vol. %) phenocrysts. Thickly bedded sequences (<30 m) of vitric-crystal rhyolite tuff with sparse lithic fragments (<2 cm) locally underlie the rhyolite flows.

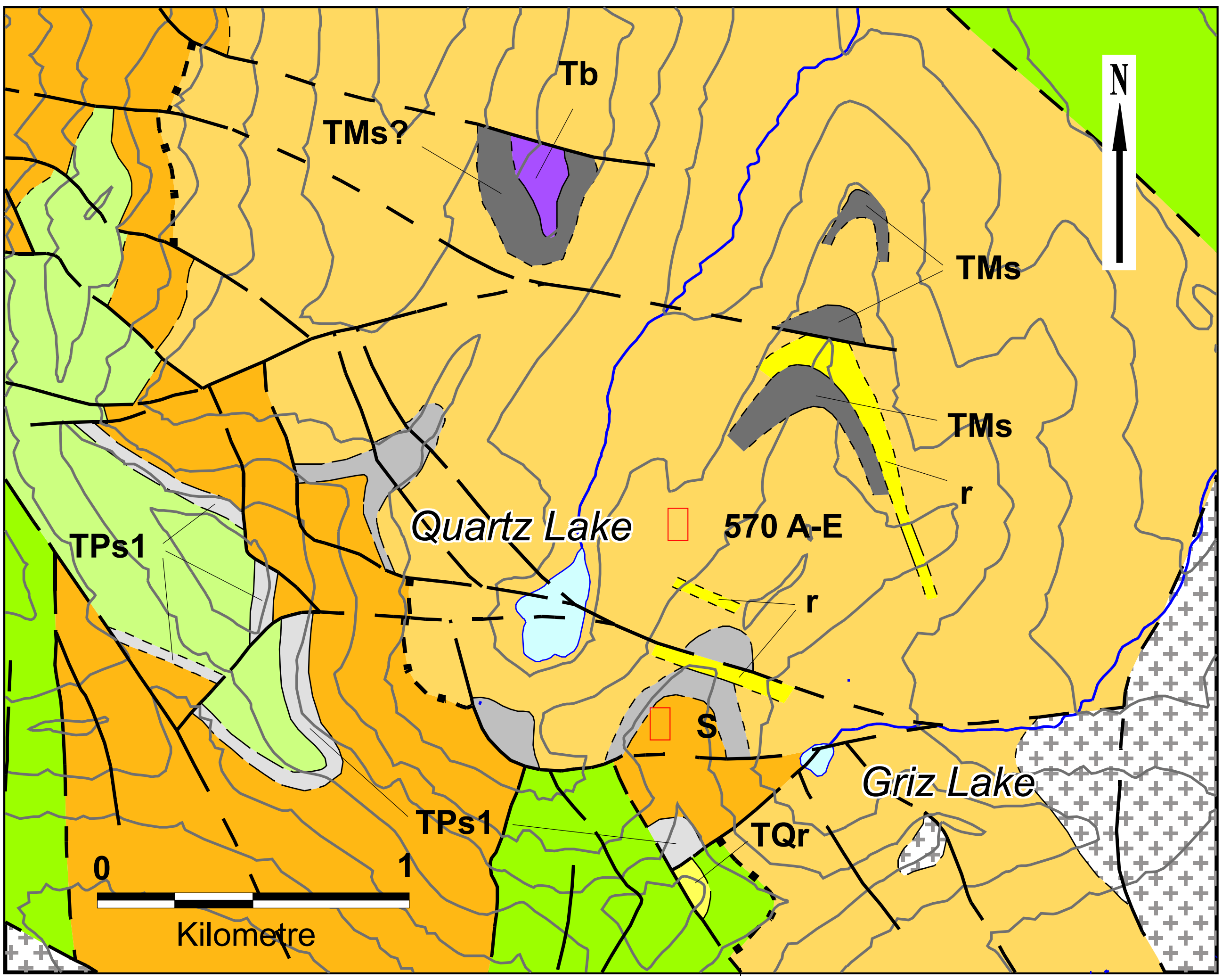

Figure 5. Geology of the Quartz Lake–Griz Lake area, showing stratigraphic elements of the Toodoggone formation not represented in Figure 2: the location of rhyolite sills and dikes (r); and epithermal quartz-sulphide veins (570A-E) and stockworks (S) of the Sickle-Griz showing. The stratigraphy dips 20–30° degrees to the west-southwest and map units are those of Figure 3, except for epiclastic beds within the Metsantan member (TMs) and a basaltic sill (Tb). The heavy dot-dash line represents volcaniclastic and/or volcanic sequences too thin to show at map scale.

Extensive exposures of basaltic and andesitic lavas (TQv) are found on the valley slopes and ridges north and south of Mt. Graves (Fig. 2). Some flows are finely porphyritic, carrying plagioclase (<1.5 mm; up to 15–20 vol. %) and clinopyroxene (<1 mm; 1–3 vol. %). Other lavas are more distinctly porphyritic, carrying euhedral phenocrysts of clinopyroxene (<4 mm; 10–15 vol. %) and subequant plagioclase (<3 mm with rare glomerocrysts up to 7 mm; up to 20 vol. %). Rarely, flows and/or near-surface dikes are encountered with euhedral megacrysts (<1.5 cm) of clinopyroxene (<5 vol. %) rarely accompanied by subequant plagioclase (<3 vol. %). Minor interbeds of volcanic breccias of diverse origins are found locally, including monomictic laharic breccias with poorly sorted volcanic clasts (<33 cm). It is interesting to note the radical change in thickness of this flow sequence to the east toward Quartz Lake, and to the south toward the Pillar where these lavas are apparently absent (Fig. 2).

GRAVES MEMBER (UNIT TG)

The Graves member is named for dacite ash-flow tuffs that are particularly well exposed in an isotopically dated section about 3 km southeast of Mt. Graves. These pyroclastic flows form resistant blocky exposures as much as 150 m thick, and exhibit little variability in thickness from one section to the next (Fig. 4, sections 5–8). The unit is a distinctive marker occupying a medial stratigraphic position between two internally heterogeneous members, each composed of generally similar rock types. The contacts between the Graves member and bounding rocks of the Quartz Lake and Pillar members are sharp and appear conformable throughout the reference area. The ash-flow tuff unit overlies a variety of different rock types at the top of the Quartz Lake member, including flow-laminated rhyolite (TQr), pyroxene-bearing andesite lavas interlayered with crystal tuffs and volcanic sandstone-siltstone layers containing pyroxene grains (TQv), and locally a hematite red monomictic boulder conglomerate with finer clastic interbeds or debris flow (TQs). In most sections, these massive ash flows contrast sharply with the overlying well-bedded, mixed pyroclastic-epiclastic strata (TPs1). This unit is dominated by vitric-crystal tuffs, sandstones, siltstones and conglomerates, and more localized accretionary lapilli tuff, lapilli tuff and tuff-breccia that are distinguished by abundant minute pyroxene grains. In a few places, this bedded unit is absent and stratigraphically higher pyroxene andesite lavas (TPv1) sit directly on the ash-flow deposits.

The ash-flow tuffs are rich in lithic fragments, which may constitute up to 45% of the rock. The clasts are subangular to angular and typically less than 2 cm in diameter. Zones within the ash-flow tuffs may contain concentrations of block-size fragments, but these are uncommon. The most abundant fragments are a mixture of fine-grained porphyritic and aphanitic volcanic rocks in varying hues of red, brown and green. However, pale pink to flesh-coloured dacitic fragments with minute hornblende and/or biotite grains are most diagnostic and useful for identifying this unit. Accidental fragments of pinkish biotite-hornblende monzonite and quartz monzonite are sparsely distributed, particularly in the upper part of the ash-flow sequence. Their subrounded to rounded shapes suggest that these clasts were likely derived from subaerial drainages and incorporated during the passage of the pyroclastic flows. Fragments of plagioclase (<2 mm) dominate the crystal fraction of the matrix, locally accompanied by sparse quartz and/or biotite grains.

The Graves member is well indurated and, although it has the general appearance of a nonwelded single cooling unit, was probably emplaced as multiple flow units. Locally, lithic-rich tuffs at the top of this unit appear to have been reworked to some degree. Incipient to moderate welding is observed in places and indicated by flattened reddish brown to dark green fiamme. Although welded texture is not widespread within these ash-flow deposits, one locality was discovered at the base of the unit where dense welding and, locally, a brown devitrified vitrophyre are well displayed. The welded zone, about a metre thick, overlies an additional 10 m of bedded crystal-vitric tuff and lapilli tuff in which weak welding is again evident in a metre-thick zone just 3 m from the base of this sequence. The latter beds overlie a layer-parallel, planar-crosslaminated lithic-vitric tuff that is interpreted to represent a surge deposit.

Based on a U-Pb zircon date obtained from rocks near the middle of a section southeast of Mount Graves (Fig. 4, section 8), this ash-flow unit erupted at approximately 192 Ma. This date firmly establishes the contemporaneity of these ash-flow tuffs with compositionally similar deposits dated outside the map area (the south of Attycelley Creek) and included in the Toodoggone formation as one of the youngest known members (i.e., Kemess member, Diakow, 2001).

PILLAR MEMBER (UNITS TPS, TPV)

The Pillar member constitutes the youngest stratigraphy presently recognized in the Toodoggone area. Excellent exposures are found at the locality for which this sequence is named, as well as farther north in a downdropped fault block between The Pillar and Mt. Graves (Fig. 2, 4). The base of this unit rests on the Graves ash-flow tuff member and the top is not seen (eroded). The unit is lithologically heterogeneous and has been subdivided, where possible, into mappable volcaniclastic (TPs1, TPs2) and flow (TPv1, TPv2) stratigraphy. Secondary alteration of lavas and clastic rocks to carbonate, prehnite and a distinctive pale pink zeolite (laumontite?) is locally apparent throughout this succession.

At The Pillar, unit TPs1 is represented by at least 30 m of well-stratified, maroon to grey-green epiclastic rocks including volcanic pebble to cobble conglomerate, internally laminated sandstone, siltstone and minor mudstone, locally exhibiting crossbedding and cut-and-fill channel structures. Similar stratigraphy 2 km north-northeast of The Pillar across a major westerly-trending fault contains a high proportion of pyroclastic material including well-bedded, coarse vitric-lithic tuff of airfall origin, planar-crosslaminated lapilli tuff containing abundant angular volcanic fragments (<3 cm) of probable surge origin, and laharic breccias with angular to subangular volcanic clasts up to 0.5 m across. Farther north, this succession is thicker (>50 m) and composed of thickly bedded, reworked volcanic breccias overlain by grey-green, thin to medium-bedded, moderately well sorted volcanic sandstones, underscoring the rapid nature of lateral facies changes.

The lower epiclastic-pyroclastic succession is conformably overlain by basaltic to andesitic lavas (TPv1) that form the peak of The Pillar and occupy lower ridges to the north. Dark reddish to purplish grey flows are moderately (10–15 vol. %) to strongly (25–30 vol. %) plagioclase phyric with subordinate clinopyroxene phenocrysts (commonly <1 mm but locally up to 3 mm, and typically comprising 1–2% but reaching 5 vol. % of the rock). The abundance and size distribution of plagioclase and clinopyroxene phenocrysts vary substantially from flow to flow. Amygdaloidal textures and thin flow breccias are observed locally.

The uppermost part of the Pillar member is preserved in the downdropped fault-block north of The Pillar. The base of the upper epiclastic-pyroclastic sequence (TPs2) appears broadly conformable with the underlying lavas. The lowermost beds comprise a buff to dark brown, clast-supported, volcanic cobble to pebble conglomerate and moderately well sorted pebbly sandstone. Higher in the section, these beds are intercalated with pale grey-green to pink weathering crystal-lithic lapilli tuffs and reworked tuffs. At the northernmost exposures, the top of the succession (>130 m) is dominated by grey-green to buff, laminated to medium-bedded volcanic sandstones and pebbly sandstones with minor interbedded siltstone and mudstone.

The overlying plagioclase- and pyroxene-phyric lavas (TPv2) are texturally and mineralogically similar to the older flows (TPv1) of the Pillar member, and would be difficult to distinguish in the absence of an intervening epiclastic-pyroclastic sequence (TPs2). However, some of these flows are distinctly viscous with well-developed flow laminations and have a rhyodacitic composition. Flow breccias are generally better developed than in the andesitic lavas and flow laminae locally bear pink devitrification spots.

Black Lake Intrusive Suite (Units Bqm, Bmp, Bd)

Plutons and minor intrusions (dikes and sills) of the Early Jurassic Black Lake Intrusive Suite are found throughout the map area; the largest bodies occur at the eastern margin of the map area and along the Pillar Fault. These intrusions are temporally and probably genetically related to extrusive rocks of the Toodoggone formation.

Typical Black Lake intrusions in the study area are biotite- and hornblende-bearing quartz monzonites with a medium to coarse-grained equigranular to porphyritic texture. These plutons differ slightly in composition from those associated with Au-Cu porphyry mineralization at the Kemess deposits in that the latter intrusions are less differentiated and comprise monzodiorites and medium to coarse-grained monzonite porphyries. These mineralized plutons also have a distinctly tabular geometry, and in the case of the Maple Leaf pluton at Kemess South, emplacement appears to be at a subvolcanic level. Monzonitic intrusions in the map area are related to porphyry-style mineralization (e.g., at the Pil North, Sophia and Alexandra prospects) and may have temporal and genetic links to epithermal precious-metal mineralization (e.g., at the Sickle-Griz showings, described below).

A large composite pluton is well exposed in the lower part of Jock Creek; to the north, this body probably underlies much of the low tree-covered region adjacent to the Toodoggone River and, to the south, it extends to the Finlay River. In order to rationalize field observations, it was necessary to subdivide the Jock Creek pluton into an older (Bqm1) and younger (Bqm2) phase. The lowermost element of the Toodoggone stratigraphy, a basal conglomerate below the Duncan ash-flow tuff member, rests nonconformably on the pluton in the extreme southeastern part of the map area, whereas monzonite intrudes the lowermost Toodoggone rocks farther north at Jock Creek. The location of the contact between younger and older phases of the Jock Creek pluton is uncertain, and has been taken to be delineated by a sharp contrast in the magnetic signature of the rocks east of Jock Creek (Fig. 2). A sample of the younger monzonite phase is currently being dated by the U-Pb technique.

The younger (Bqm2) phase of the Jock Creek Pluton is a pinkish grey, coarse-grained, equigranular to porphyritic, biotite-hornblende quartz monzonite with accessory titanite and opaque oxides. The porphyritic monzonite carries euhedral to subhedral plagioclase phenocrysts (up to 8 mm) set in a finer grained groundmass of potassium feldspar and quartz. Plagioclase crystals usually display oscillatory zoning and are flecked with sericite. Interstitial potassium feldspar is generally more strongly altered to sericite and clay minerals. Although little quartz is generally apparent in hand specimen, thin-section examination reveals some 10–15 vol. % of the mineral. The predominant ferromagnesian mineral is euhedral to subhedral hornblende (<7 mm) that is commonly altered to chlorite. Subhedral to anhedral biotite (<4 mm), also variably altered to chlorite, is present in minor amounts, along with accessory titanite (<1 vol. %) and opaque oxides.

The older phase (Bqm1) of the Jock Creek pluton is a medium-grained, equigranular quartz monzonite, mineralogically similar to the younger phase. However, the amount of quartz is notably higher (~20 vol. %) and occurs as anhedral grains clearly visible in hand sample. Anhedral potassium feldspar occurs as a late interstitial phase. Biotite is the dominant mafic mineral, accompanied by lesser amounts of hornblende and trace titanite and opaque oxides.

Plutons exposed along the Pillar Fault are quartz monzonite and porphyritic monzonite; the latter phase is associated with Cu-Au porphyry prospects in the vicinity of Pil North. The porphyritic phase of the pluton (Bmp) east of the fault cuts the youngest part of the Toodoggone stratigraphy (Fig. 2). This indicates that the intrusion is younger than 192.3 ± 0.4 Ma, the U-Pb isotopic age of the

Graves member in the upper part of the Toodoggone stratigraphy.

Small dioritic stocks and dikes of the Black Lake Intrusive Suite cut the Toodoggone formation as well as monzonitic rocks of the Jock Creek pluton. The largest diorite intrusions are northerly-trending, elongate bodies underlying valley slopes and ridge crests just west of Jock Creek. The rocks are pinkish grey to dark grey-green, fine to coarse-grained biotite-clinopyroxene diorites. Anhedral to subhedral crystals (<5 mm) of pyroxene and plagioclase are intergrown with biotite and minor (<2 vol. %) interstitial quartz and opaque oxides. Coarsely crystalline varieties locally contain fresh biotite oikocrysts up to 1.5 cm across. Secondary alteration minerals include sparse sericite, chlorite and epidote.

Minor intrusions in the form of dikes, sills and small plug-like bodies are prolific throughout the map area. The most common dikes are pinkish grey to buff weathering, medium-grained to porphyritic monzonite; pale pink to reddish weathering, aphanitic to porphyritic (rarely medium-grained) leucomonzonite (to syenite?) carrying small amounts (typically trace to 1 vol. %) of mafic minerals; and quartz± biotite porphyries. Basaltic to andesitic dikes similar in composition to pyroxene-bearing extrusive rocks in the upper part of the Toodoggone formation are also common. All dikes are generally steeply dipping and exhibit a regional, north to north-northwesterly preferred orientation.

MINERAL OCCURRENCES AND EXPLORATION

The Toodoggone area has a rich history of mineral exploration and is a successful mining district. The premier exploration targets have been, and continue to be, large tonnage Cu-Au porphyry systems and small, high-grade, precious-metal epithermal vein systems. A regional synopsis of previous exploration work is given below, along with descriptions of some of the newer discoveries and prospects in the study area.

Recent History of Toodoggone Mineral Exploration

The Toodoggone mining camp was systematically evaluated for its potential to host bulk tonnage mineral deposits in the mid-1960s by Kennco Explorations (Western) Limited. They conducted a regional geochemical sampling program that led to the discovery of the first known porphyry-style base-metal and vein-type precious metal targets in the Toodoggone region. Among the deposits found were Chappelle (Baker), Lawyers (AGB zone) and Kemess North. Follow-up exploration by Kennco and other companies began in the late 1960s and continued intermittently through the 1970s into the early 1990s. This exploration resulted in the development of small Au-Ag mines (Baker, Lawyers and Shasta) centred on epithermal quartz-vein systems and the Kemess South porphyry Au-Cu mine.

Dupont of Canada Exploration Limited commissioned the 100 tonnes/day underground Baker mine, the first mine to open in the region, in April, 1981 (Barr *et al*., 1986). It ceased operation in November 1983, after producing 1196 kg of gold and 23 085 kg of silver from 77 596 tonnes of ore mined and milled from the A vein (MINFILE). Multinational Resources Inc. purchased the property from Dupont in 1985 and Sable Resources Limited acquired the Baker mill from Dupont in 1989. Multinational outlined a small tonnage on the B vein and, with Sable as a partner, mined and processed modest tonnages from the vein until 1996 when Sable acquired the property outright from Multinational. Since that time, Sable has, on an intermittent basis, extracted and processed limited amounts of ore from both the A and B veins.

Sable Resources Limited brought the Shasta deposit, 8 km southeast of the Baker mine, into production in October 1989, continuously extracting ore from the Creek and JM zones until April 1991. During this time, 601 kg of gold and 32 932 kg of silver were produced from 122 533 tonnes of ore processed at the Baker mill. The two ore zones were first mined by small open cuts; underground development on each followed. Small tonnages of ore were mined from the JM and Creek zones in 2000, 2003 and 2004.

In 1986, Cheni Gold Mines Ltd. purchased the Lawyers property from Kennco Western Ltd. Cheni commissioned the mine in 1989 with a combined reserve for the AGB, Cliff Creek and Duke's Ridge zones of 1.757 million tonnes grading 6.72 g/t Au and 243 g/t Ag. The AGB deposit was mined until 1991 using underground shrinkage and blast-hole stoping methods, but the Cliff Creek and Duke's Ridge zones were not mined. The steeply dipping AGB deposit, with widths of up to 12 m, had been traced north along strike for about 550 m. Mineralization consisted of native gold, native silver, electrum, acanthite and lesser chalcopyrite, sphalerite and galena in quartz veins, stockworks and chalcedony-healed breccias. Approximately 620 000 tonnes of ore were milled, although this total includes an estimated 60 000 tonnes from the Al property (MINFILE 094E 091) located north of the Toodoggone River. A total of 5042 kg of gold and 113 184 kg of silver were recovered. Cheni reclaimed the property in the late 1990s and its tenure over the site was later relinquished. The property was staked by Guardsmen Resources Inc. in 2000 and 2001, and optioned the following year to Bishop Resources Inc. In 2004, Bishop followed up encouraging float anomalies with a 1000 m trenching program on the plateau immediately west of the Cliff Creek zone.

Porphyry mineralization was first identified in the area of the Kemess South deposit in 1983. Extensive drilling programs conducted by El Condor Resources Ltd. from 1990 to 1993 outlined a geological resource for the Kemess South deposit of 250 million tonnes grading 0.62 g/t Au and 0.22 g/t Cu (Rebagliati *et al*., 1995a). Royal Oak Mines Ltd. purchased the property and initiated site clearing and mine construction in July 1996. The mine was commissioned in October 1998. In the spring of 1999, Royal Oak became insolvent and the mine was purchased by Northgate Exploration Ltd. (now Northgate Minerals Corporation). The mine presently operates at rate of approximately 50 000 tonnes per day and produces about 300 000 ounces of gold and 75 million pounds of copper per year. Recent exploration in the area of the mine has focused on the Kemess North deposit, where diamond drilling to deeper levels has expanded the size of the deposit. A feasibility study on Kemess North, completed in October 2004, identified a resource of 414 million tonnes grading 0.31 g/t Au and 0.16 g/t Cu. The proposed open pit mining project has now entered the harmonized Federal/Provincial environmental review process.

Although the Kemess South mine is outside the current map area, it has contributed significantly to the rejuvenation of exploration throughout the Toodoggone mining camp. Its importance as a remote major open-pit mining operation serviced by hydroelectricity, a modern milling facility and a substantial in-ground mineral resource cannot be understated. This infrastructure is crucial for future mine development in the Toodoggone region, as it may become a central milling complex capable of supporting numerous satellite orebodies.

Epithermal Au-Ag Veins: Sickle-Griz (MINFILE 094E 237)

Stealth Minerals Ltd. discovered the Sickle-Griz Au–Ag–base-metal epithermal vein prospect in 2003. Two physically distinct, topographically separated vein systems are recognized cutting Toodoggone volcanic rocks. Five discrete parallel veins (named 570A to 570E) are found in the bottom of the cirque occupied by Quartz Lake (Fig. 5). They have an azimuth of 155° and dip 65° to the west. Several of the most prominent veins on surface (570A and 570B) are up to 13 m in width and over 100 m in length, and transect a monotonous sequence of grey-green porphyritic andesites assigned to the Metsantan member (Fig. 5, 6). Flow-laminated rhyolitic dikes and sills, a comparatively rare occurrence in the Toodoggone camp, are also a conspicuous feature of this area (Fig. 5).

The 570 veins vary in appearance from massive, diffusely layered white quartz to multiple layers of comb-textured quartz alternating with calcite spar (Fig. 7). Potassium feldspar alteration adjacent to the veins is widespread, varying in intensity from incipient to moderate, and imparts a pale pink to brownish hue on host andesites.

The second vein system, situated about 150 m higher on the ridge above the 570 veins, exhibits more of a stockwork character, with multiple generations of quartz veins and quartz-breccia veins occupying a zone more than 75 m wide and hosted by dacitic ash-flow tuffs near the base of the Graves member (Fig. 5). Adularia sampled from narrow alteration selvages adjacent to quartz veins at both the lower and upper vein systems is being used to obtain Ar-Ar isotopic ages for the mineralization. Since the Graves member has been dated at 192.3 ± 0.4 Ma, this establishes a maximum age for emplacement of the upper vein stockwork.

Sulphide minerals in the veins occur as fine disseminations, patchy aggregates and semimassive to massive layers up to several centimeters wide. In order of decreasing abundance, they comprise galena, sphalerite, tetrahedrite, chalcopyrite and pyrite. Chip samples across discrete veins have yielded grades as high as 9.5 g/t Au and 407 g/t Ag over 3 m. Assay results from the first two holes drilled into the lower vein system have returned encouraging results (e.g. 3.18 g/t Au and 107.8 g/t Ag over 2.5 m from the footwall portions of the 570A vein; *see* Stealth Minerals Ltd. news release, July 16, 2004).

Au-Cu Porphyries

PIL NORTH (MINFILE 094E 083) AND VICINITY

The Pil North property is located at the western margin of the map area (Fig. 6). It is underlain by a quartz monzonite to porphyritic monzonite stock that straddles the Pillar Fault and intrudes andesitic lavas of the Metsantan member in the west and some of the youngest stratigraphic units of the Toodoggone formation in the east (Fig. 6). Exploration by Finlay Minerals Ltd. has identified a number of Cu-Au geochemical anomalies that are coincident with induced polarization chargeability anomalies. Some of these anomalies coincide with pronounced propylitic and phyllic alteration zones and are thus prime targets for porphyry-style mineralization (i.e. the Northwest and Northeast zones, Fig. 6). Other geochemical anomalies have a polymetallic signature that may be indicative of buried vein systems (i.e. East, Milky Creek, NW Extension and WG Gold zones).

The Northwest zone is characterized by a 200 by 600 m geophysical anomaly that coincides with elevated Cu-Au soil values and locally intense silicification, bleaching and pyrite-sericite alteration of the monzonitic host rock. Chalcopyrite accompanies pyrite in narrow quartz stringers and in areas where more pervasive silica-flooding is developed. Late-stage, purple anhydrite stringers cut the mineralization. The Northeast zone lies east of the Pillar fault and is underlain by quartz-bearing flows of the Metsantan member that are weakly to moderately oxidized (Fig. 6). The hostrock displays locally intense quartz-sericite-pyrite alteration, with disseminated pyrite reaching up to 15 vol. %; in places, goethite and jarosite are well developed.

The East and Milky Creek zones have a polymetallic geochemical signature characterized by highly anomalous Au and Ag values accompanied by inconsistent Cu and Zn abundances. The East zone includes quartz stockworks and brecciated monzodiorite healed with silica; both are mineralized with small amounts of barite, galena and sphalerite. The Milky Creek zone is characterized by a potassic feldspar-magnetite-quartz stockwork within strongly clay-altered monzonite. Chip sampling across a 10 m wide segment of the Milky Creek showing averaged 0.52 g/t Au. The NW Extension, a quartz-barite stockwork anomalous in Cu and Pb, may represent a polymetallic vein on the periphery of a porphyry system. The WG Gold zone comprises quartz veins, stockworks and breccias confined to a steeply dipping, northwest-trending corridor that extends for over a kilometre. The veins are developed within quartz monzonite and locally carry variable quantities of barite and galena. Samples of quartz float carry up to 16.8 g/t Au.

SOFIA (MINFILE 094E 238)

Porphyry-style mineralization at Sofia was discovered in the summer of 2004. The showing is restricted to a single outcrop (25 by 25 m) which is located on the west bank of the Toodoggone River, approximately 2.7 km northwest of the mouth of Jock Creek (Fig. 6). . The main hostrock is a medium to coarse-grained equigranular monzonite (Bqm2), although mineralization also occurs within adjacent augite-phyric lavas that exhibit pronounced alteration to chlorite and pyrite (up to 8 vol. %). These lavas have tentatively been assigned to the volcanic unit of the Quartz Lake member. Mineralization consists of subparallel magnetite veinlets and subsequent layered quartz-magnetite(±specularite)-chalcopyrite stockwork veins enveloped by potassium feldspar alteration (Fig. 8). Narrow, drusy quartz stringers cut the other vein types. Intense pyrite-sericite alteration occurs locally within the outcrop. Grab samples from the prospect have produced assays of up to 0.22 g/t Au and 0.05 wt. % Cu (*see* Stealth Minerals Ltd. news release, July 16, 2004).

ALEXANDRA PROSPECT

The Alexandra Au-Cu porphyry prospect was also discovered in 2004. It is located on a ridge 3.3 km west-southwest of the confluence of Jock Creek and the Toodoggone River, close to the *informally* named Sickle Creek (Fig. 6). The showing consists of quartz-magnetite stringers cutting intensely bleached, clay-altered andesitic volcanic rocks of the Metsantan member. The alteration zone is coincident

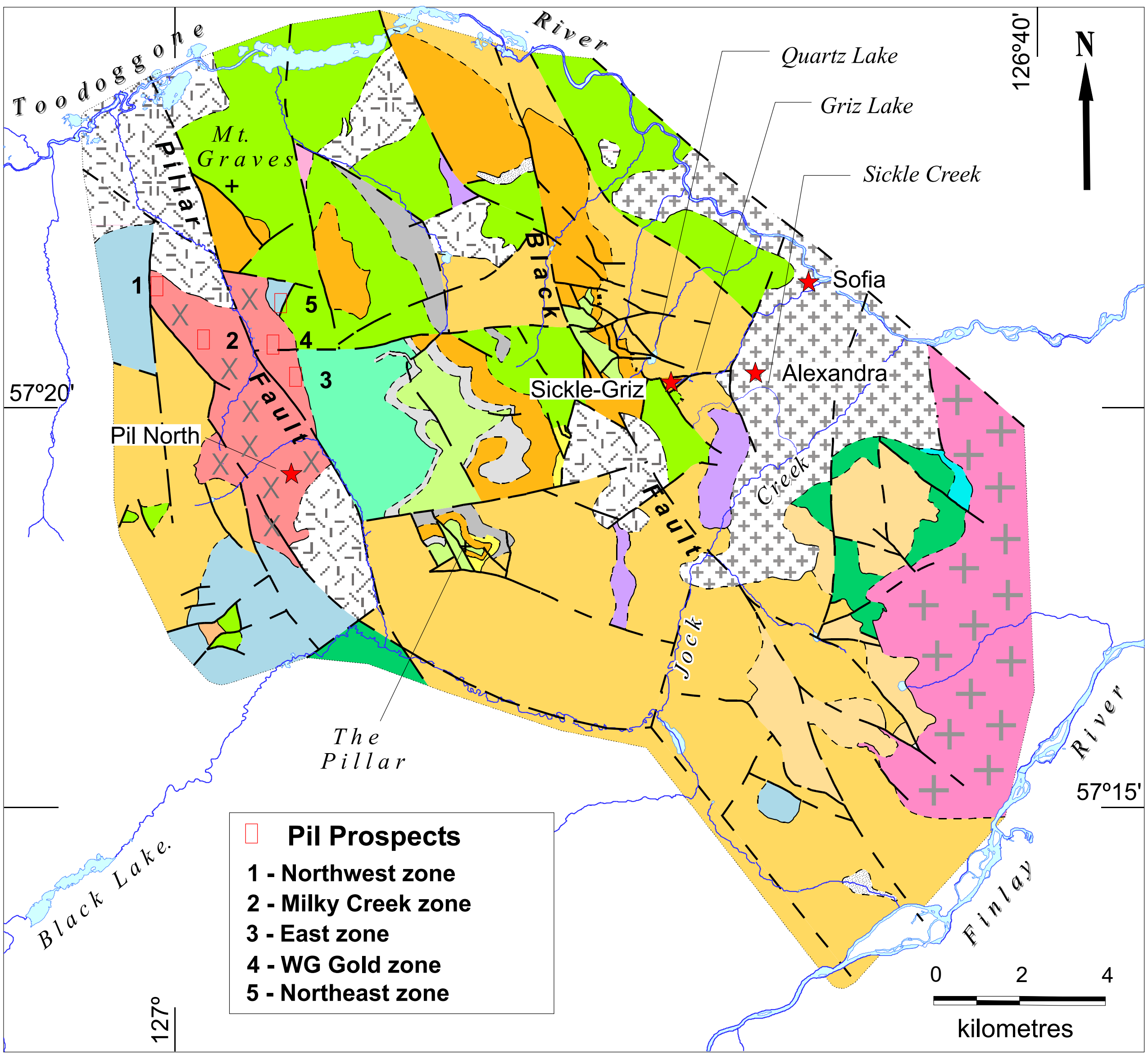

Figure 6. Location of selected Au-Cu porphyry and Au–Ag–base-metal epithermal prospects discussed in the text in relation to their geological setting as determined in this study. Legend for geological units is the same as Figure 3.

Figure 7. View of the 570A vein, displaying alternating bands of quartz and calcite spar, Quartz Lake, Sickle-Griz prospect.

with elevated Au, Cu and Ag values in soils that cover an 800 by 250 m area. The showing approaches within about 300 m of the Jock Creek monzonite (Bqm2) contact with Metsantan lavas, and extends downslope to the north and east of the ridge.

SUMMARY AND CONCLUSIONS

The main results of the 2004 field program can be summarized as follows:

The general stratigraphy of the Toodoggone region, namely rocks from the Late Carboniferous to Early Permian Asitka Group, Late Triassic Takla Group and Early Jurassic Hazelton Group, extends into the study area. The volcanic stratigraphy of the Toodoggone formation has been expanded in the upper part, stratigraphically above the Metsantan and Saunders members, to include three new *informal* members, the Quartz Lake, Graves and Pillar, from oldest to youngest, respectively. They constitute a diverse assemblage of lavas, ash-flow tuffs, and associated volcaniclastic rocks covering a wide compositional spectrum from basalt to rhyolite. Epiclastic volcanic sandstones and conglomerates interleaved with ash-flow and air-fall pyroclastic units form distinctly bedded sections within an otherwise massive flow stratigraphy. These new members contrast with older Toodoggone strata by the notable presence of clinopyroxene, and the scarcity of quartz, biotite and hornblende in the volcanic rocks. Their age is roughly that of the Graves member (~192 Ma), as established by U-Pb isotope systematics.

The principal intrusions in the map area are equigranular to porphyritic quartz monzonite and monzonite and minor diorite of the Early Jurassic Black Lake Intrusive Suite. A composite stock in the southeastern part of the study area, named the Jock Creek pluton, is formed by early and late monzonitic phases. Basal conglomerates of the Toodoggone formation rest nonconformably on the older phase (latest Triassic?), whereas the younger monzonite intrudes rocks as high in the Toodoggone formation as the Metsantan member (~198 Ma or slightly younger?).

These intrusions have a significant genetic association with Cu-Au porphyry mineralization south of the study area at the Kemess deposits. The new mapping extends the known distribution of potentially mineralized monzonitic intrusions north of the Finlay River, to include the Jock Creek pluton and their unnamed counterparts adjacent to the Pillar Fault at the Pil North property. The Jock Creek body apparently hosts two new Au-Cu porphyry prospects in the map area, the Sophia and Alexandra.

Mineralized epithermal quartz-calcite veins and stockworks, such as those discovered on the Sickle-Griz property, constitute a significant exploration target. These mineralized systems affect rocks as young as the Graves member (~192 Ma). Isotopic dating, using U-Pb and Ar-Ar systematics, is currently in progress in order to constrain potential genetic relationships between porphyry and epithermal base- and precious-metal deposits.

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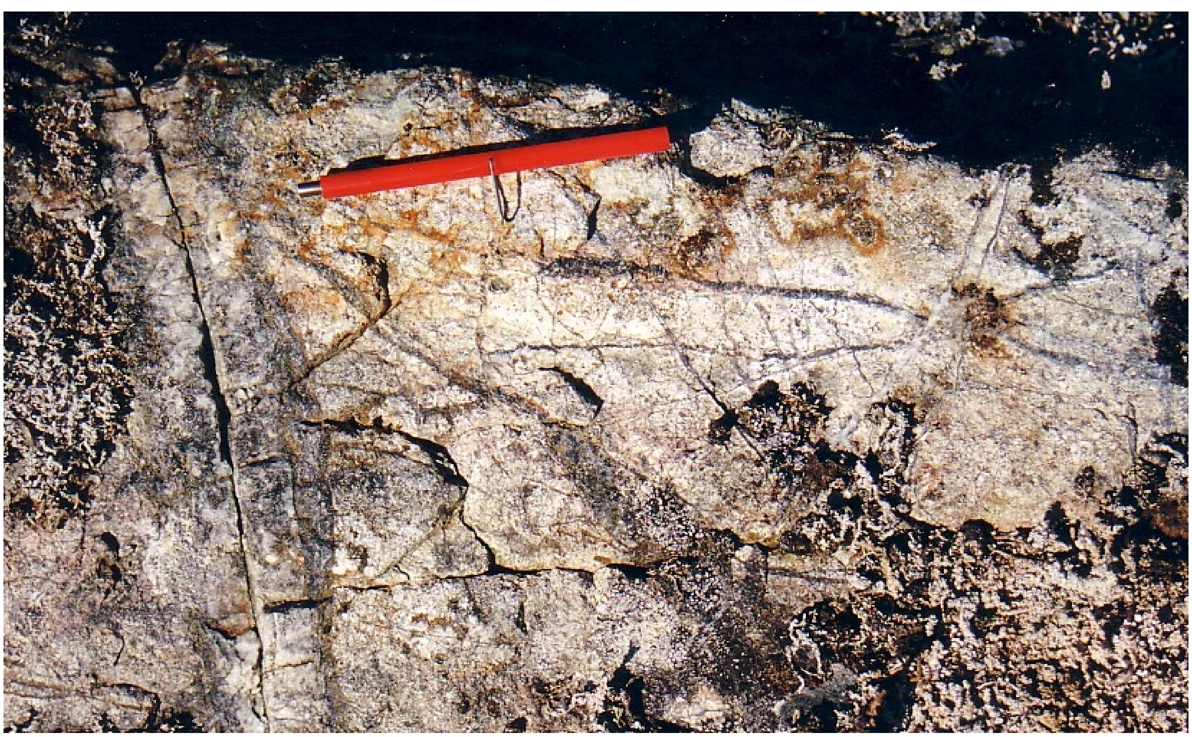

Figure 8. Stockwork Cu-Au mineralization at the Sofia showing.

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