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MINERAL RESOURCES DIVISION
Geological Survey Branch

GEOLOGY OF THE EARLY JURASSIC TOODOGGONE FORMATION AND GOLD-SILVER DEPOSITS IN THE TOODOGGONE RIVER MAP AREA, NORTHERN BRITISH COLUMBIA

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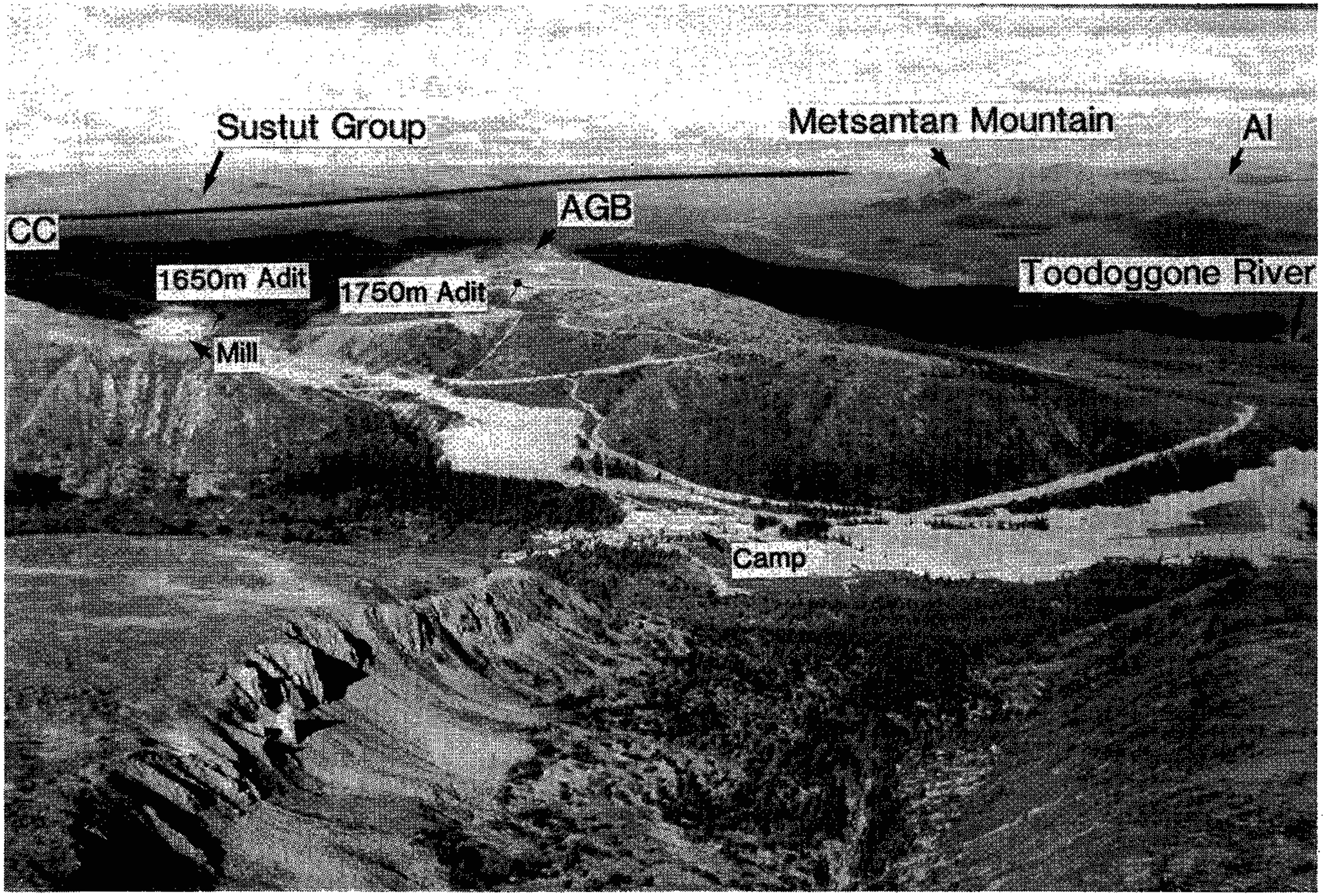

Lawyers gold-silver deposit looking northwesterly with Amethyst Gold Breccia (AGB) and Cliff Creek (CC) zones indicated. Cheni Gold Mines camp is in the lower centre and the mill site at the left of the photograph. Flat-lying ash-flow tuffs of the Saunders Member (Unit 6) form the dissected plateau and scarps in the foreground. Silica-clay-alunite capping Alberts Hump, similar to nearby precious metal bearing advanced argillic altered rocks of the Al deposit (Al), are barely visible to the north of Toodoggone River and 5 kilometres beyond Metsantan Mountain. Gently inclined terrigenous sedimentary beds of the Late Cretaceous Sustut Group are unconformable on the Toodoggone Formation to the west and northwest.

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SUMMARY

The Early Jurassic Toodoggone Formation is a new stratigraphic division of the Hazelton Group in the Toodoggone River map area, north-central British Columbia. The Toodoggone Formation consists of six lithostratigraphic members comprising high-potassium (3.1% K_2O at 57.5% SiO_2), calcalkaline latite and dacite subaerial volcanic rocks. Hornblende-biotite-quartz ± sanidine phenocrysts and metamorphic minerals indicative of the zeolite facies characterize the volcanic rocks. Basalt and rhyolite occur only as rare, late dikes and sills. Toodoggone extrusive and intrusive magmatism is intimately associated with the structural development of an elongate, regional volcano-tectonic depression. Basal strata of the Toodoggone Formation unconformably overlie submarine island-arc volcanic rocks and sediments of the Permian Asitka and Upper Triassic Takla groups and, in turn, are capped unconformably by Cretaceous continental clastic rocks of the Sustut Group.

Potassium-argon and argon-argon dates from the Toodoggone Formation span about 7 Ma between late Sinemurian and early Pliensbachian time; they define two discrete eruptive cycles with an intervening brief period of uplift and erosion. Shallow-marine clastic rocks with middle to late Toarcian fossils were deposited locally after volcanism ceased. The lower cycle began with widespread plateau-forming eruptions of dacitic ash-flow and air-fall tuffs. These were in part synchronous with and superseded by latite flows and lahars that formed constructional point-source volcanoes. Comagmatic plutons, emplaced during this early eruptive period, were partly unroofed and eroded prior to inception of the upper volcanic cycle. The upper cycle began with mainly explosive, dacite pyroclastic eruptions. Volcanism culminated with voluminous outpourings of ash-flow tuffs within an asymmetric collapse feature – the central Toodoggone depression.

Toodoggone Formation lithologies provide a record of island-arc magmatism but both the style of volcanism and major element compositions suggest a continent-margin arc setting. A thick, "continent-like" substrate might underlie the Toodoggone area. It perhaps extends beneath much of the ancestral Hazelton island-arc system that presently occupies the northeastern margin of Stikinia. The arc segment in the Toodoggone area appears to be east-facing and related to steep, oblique, westward subduction that initiated synvolcanic intra-arc extension and shallow crustal subsidence.

Hydrothermal circulation and the formation of a variety of mineral deposits are related to the extensional tectonic setting and the protracted magmatic history of the Toodoggone arc. Gold and silver in the Toodoggone district are most commonly found in quartz veins with associated adularia, sericite and calcite. Locally gold-barite veins cut clay-altered volcanic rocks containing varying proportions of fine-grained silica, dickite and natroalunite.

Fluid inclusions in quartz from the precious metal vein deposits are typical of epithermal environments. They contain low temperature, dilute hydrothermal fluids of predominantly meteoric origin (T_h <200 – 300°C and approximately 3 equivalent weight per cent NaCl). Light stable isotope analyses show marked ^{18}O enrichment of about +8 per mil in the volcanic hostrocks, hydrothermally altered rocks and mineralized vein quartz (with adularia or sericite). The isotopic composition of the hydrothermal fluid is calculated to be about 0 per mil ^{18}O. These hydrothermal fluids are isotopically evolved mixtures of meteoric and magmatic waters with possible metamorphic input.

Potassium-argon age determinations on alunite from several zones of intensely acid-leached rocks suggest that an early mineralizing episode occurred around 190 Ma or earlier. This hydrothermal event coincides with uplift and cooling of the Black Lake and possibly other stocks. Potassium-argon dates on adularia and sericite from precious metal bearing quartz veins, some of which are found in volcanic rocks of the upper cycle, suggest that there was also a younger mineralizing event. Argon step-heating dates indicate that the major gold-silver vein deposits with adularia-sericite range from 189.7±2.6 Ma to 186.7±1.7 Ma (Clark and Williams-Jones, 1991). This closely follows the latest stages of Toodoggone volcanism and fault-block subsidence.

A depth zoning model for mineralization illustrates two types of epithermal regime: adularia-sericite and acid-sulphate (alunite-kaolinite). Gold-barite in the extensive, advanced argillic and argillically altered zones at the Al deposit represent near-surface acid-sulphate alteration formed on the flanks of a stratovolcano. The advanced argillic altered zone at Silver Pond, next to the major Lawyers adularia-sericite deposit, represents a downfaulted acid-leached outflow (*i.e.* the upper steam-heated portion of the Lawyers hydrothermal system). The Lawyers deposit and most of the other occurrences are adularia-sericite type deposits formed at slight depth. These deposits all occur in grabens or half-grabens within the central Toodoggone depression, a synvolcanic structure nested within a broader, segmented volcanic field.

CHAPTER 1: INTRODUCTION

Volcanic and sedimentary strata of the Early and Middle Jurassic Hazelton Group occur throughout north-central British Columbia. In the Toodoggone River map area (NTS 094E) a distinctive succession of quartz-bearing dacite and latite flows and pyroclastic rocks, called the Toodoggone Formation, are time-equivalent with strata of the Telkwa Formation of the Hazelton Group. The Toodoggone Formation and related intrusive rocks apparently occupy an elongate structural depression. Basement for this depression is dominated by volcanic rocks of the Late Triassic Takla Group, and less well exposed carbonates of the Permian Asitka Group. Significant gold and silver concentrations occur both in quartz veins and broad argillic alteration zones that are hosted by volcanic rocks of the Toodoggone Formation.

Despite the economic importance of these mineralized rocks very little was known about their regional stratigraphic and tectonic setting prior to this study. Consequently, a regional mapping project was initiated by the British Columbia Geological Survey Branch in 1981 to study the Toodoggone Formation and the geologic setting of precious metal concentrations. The purpose of the Toodoggone Project is threefold:

1. Prepare a geologic and mineral occurrence map with particular emphasis on the stratigraphy of Jurassic volcanic rocks underlying the south-central Toodoggone River map area.
2. Interpret the volcanic rock sequence in terms of environment of deposition.
3. Describe the salient features, fundamental controls and relative time of ore deposition in quartz veins and zones of advanced argillic alteration.

LOCATION AND ACCESS

The study area encompasses about 1100 square kilometres in a northwest-trending belt 90 kilometres long and 15 kilometres wide, between latitudes 56°59′00″ and 57°40′00″ north, and longitudes 126°38′00″ and 127°45′00″ west (Figure 1). The town of Smithers, 270 kilometres to the south, is the principal centre of commerce and supplies for mining companies working within the study area.

Access until 1979 was by float plane to Black, Metsantan, Moosehorn and Toodoggone lakes, fixed-wing aircraft to the now abandoned airstrip near Black Lake, or helicopter. In 1979, DuPont of Canada Exploration Limited and the British Columbia government built a gravel airstrip 1620 metres long on the east bank of the Sturdee River. This airstrip has since served as the transportation focal point for development and exploration activities in the area. Extension of the Omineca Resource Road in 1987, as a consequence of the planned opening of the Lawyers mine, presently provides access from Moosevale Flats in the McConnell Creek map area (NTS 094D) to the Sturdee River airstrip about 70 kilometres northwest and for 35 kilometres beyond, with its terminus at the Lawyers mine. Branch roads lead to the Baker minesite, Bonanza, Shasta, Brenda and Kemess properties.

PHYSIOGRAPHY, VEGETATION AND CLIMATE

The study area is in the northern Omineca Mountains where peaks rise on average more than 900 metres above a general valley elevation of 1100 metres along the northeast and south perimeter of the area. Alpine glaciers have modified the mountains, carving steep-sided ridges which separate cirques that pass at lower elevation into broad valleys. The west-central area, characterized by rounded mountains and gentle southwest-sloping cuesta ridges of low relief, forms part of the Spatsizi Plateau (Figure 2).

The Stikine River and the Chukachida River are part of the west and north boundary of the area, respectively. The Toodoggone, Sturdee and Firesteel rivers, and Attycelley and Kemess creeks, dissect the central and south parts. They form a trellice network of drainages at the headwaters of the Finlay River. Conifer forests and small pockets of deciduous trees occupy the main river valleys up to 1600 metres elevation, above which short grass and lichen dominate an alpine environment. Rock exposure is confined to the steep slopes of mountains above treeline or to deeply incised drainage channels in the valleys.

Field mapping at all elevations can begin in mid-June and continue effectively until the end of September during most field seasons. Precipitation varies considerably between field seasons, and it can form light snow at higher elevations

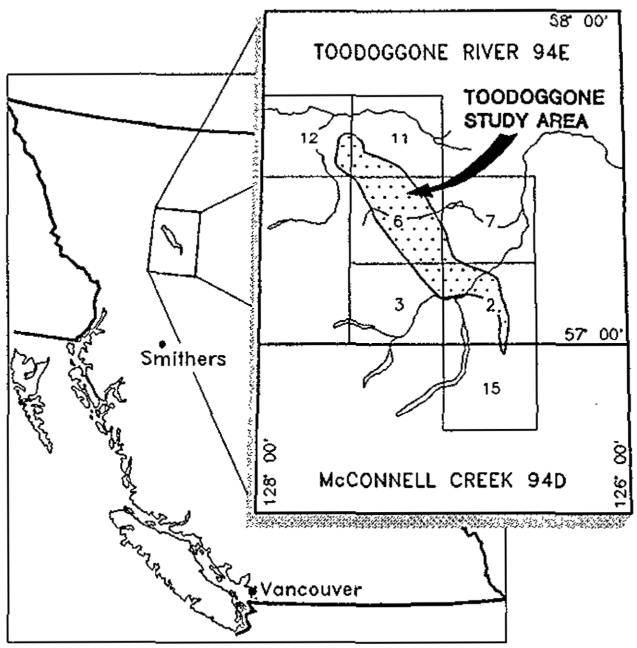

Figure 1. Location of study area within the Toodoggone River map area (NTS 094E), north-central British Columbia.

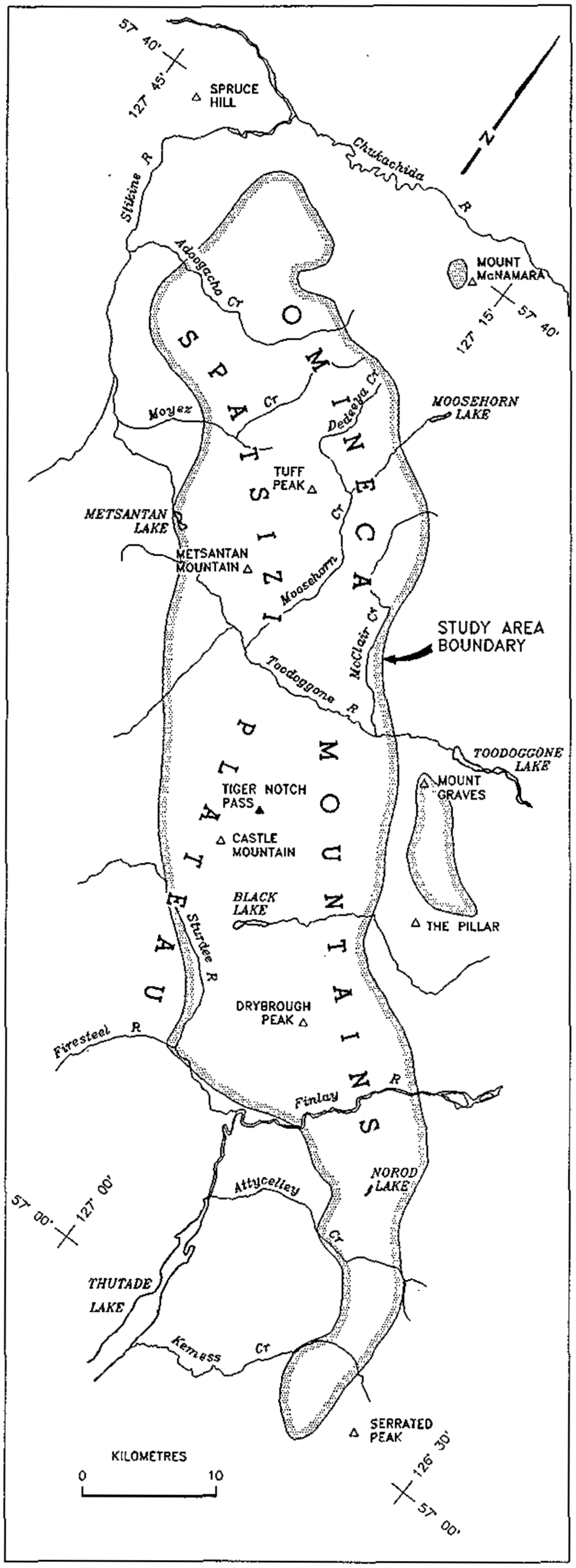

Figure 2. Major physiographic features in the study area.

anytime during the summer. Daytime temperatures during the summer months average between 15°C and 20°C, although temperatures around 25°C may persist for intervals of several weeks.

PREVIOUS MAPPING

Carter (1972) recognized a distinctive sequence of vari-coloured latite lava flows and pyroclastic rocks unconformably overlying volcanic rocks of the Upper Triassic Takla Group in the Toodoggone River map area. He informally named this sequence the Toodoggone volcanics. During Operation Finlay, a mapping project conducted by the Geological Survey of Canada from 1973 to 1975, the regional distribution of these volcanic rocks was mapped. These geological data are published at 1:250 000 scale as the Toodoggone River map sheet, NTS 094E (Gabrielse *et al.*, 1977).

PRESENT WORK

In 1980, with the start of production at the Baker mine, there was a resurgence in exploration of known deposits and a search for new epithermal precious metal occurrences in the Toodoggone area. This activity, and recognition by Ministry geologists of the classic characteristics of epithermal deposits in the district, prompted the British Columbia Ministry of Energy, Mines and Petroleum Resources to begin a regional mapping project in 1981. The aim of this work was to establish the stratigraphic framework of the Toodoggone volcanic rocks and their time-space relationship to precious metal occurrences in the area.

Field data were compiled on 1:25 000-scale topographic maps during 22 weeks of mapping by L.J. Diakow, and roughly 5 weeks of mapping by A. Panteleyev between 1981 and 1984. This fieldwork, corroborated by radiometric ages from volcanic rocks, indicates that six stratigraphic members comprise the newly named Toodoggone Formation in a 1100 square kilometre area that encompasses parts of map sheets NTS 094E/2, 3, 6, 7, 11 and 12 (Diakow, 1990). Diakow *et al.* (1991) describe the geologic setting and the time of deposition of epithermal precious metal concentrations in the Toodoggone mining district.

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CHAPTER 2: REGIONAL GEOLOGY

TECTONIC SETTING

The Toodoggone River map sheet (NTS 094E) spans two major morphogeological belts of the Canadian Cordillera; the Omineca Belt on the east and the Intermontane Belt on the west (Figure 3 inset). The western margin of the Omineca Belt approximates the pre-Mesozoic boundary of North America, which was later involved in orogenesis during accretion of the allochthonous Insular and Intermontane superterranes (Monger *et al.*, 1982). The Omineca Belt consists of clastic and chemical sedimentary rocks that prograded from the west margin of the North American craton during Proterozoic and Paleozoic time. These rocks are variably deformed and regionally metamorphosed to greenschist and locally amphibolite grade (Mansy and Dodds, 1976; Gabrielse *et al.*, 1976; Evenchick, 1988) during protracted orogenic events of roughly mid-Jurassic to mid-Cretaceous and Late Cretaceous to Eocene age. Quartz monzonite plutons of Middle Cretaceous age intrude miogeoclinal rocks of the Omineca Belt in the eastern Toodoggone map area. These intrusions are dextrally displaced along a regional system of transcurrent faults that presently separate tectonostratigraphic elements in the Intermontane Belt from the Omineca Belt.

By comparison the Intermontane Belt is a composite of four tectonostratigraphic terranes each having internal structural-stratigraphic integrity and a complex evolution in terms of depositional setting, amalgamation and subsequent accretion to North America (Coney *et al.*, 1980; Monger

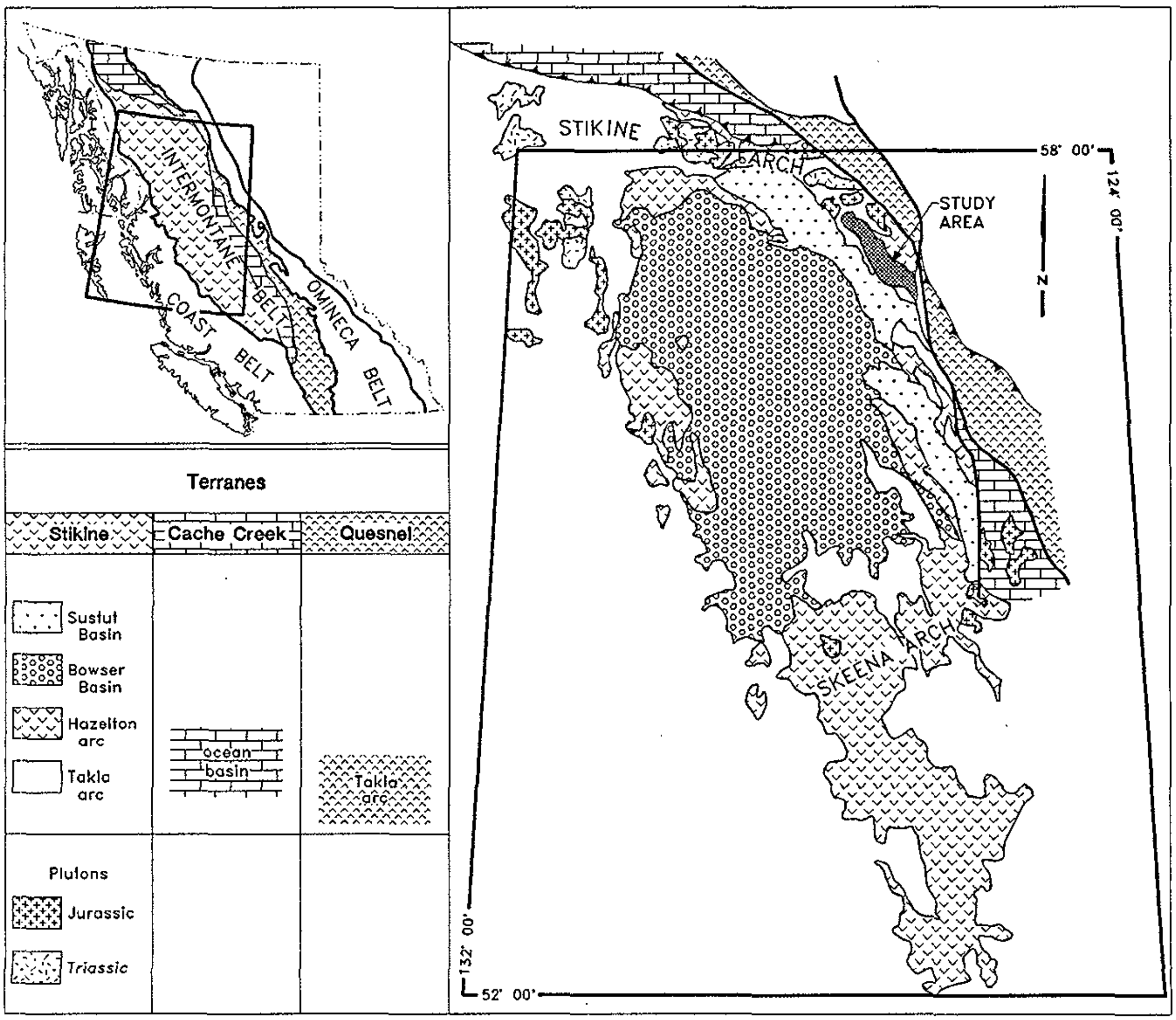


Figure 3. Accreted terranes of the Intermontane Belt (inset) and tectonic elements of the Stikine Terrane in north-central British Columbia.

et al., 1982). These terranes include the Slide Mountain and Cache Creek in the east, characterized by dismembered oceanic crust ranging from Devonian to Late Triassic in age. In the southern Intermontane Belt, chert from the Cache Creek Terrane contains radiolaria as young as Middle Jurassic (Cordey *et al.*, 1987). Stikinia and Quesnellia contain mainly island-arc volcanic, plutonic and sedimentary rocks of Late Triassic and Early Jurassic age. Basement to Stikinia is presumed to be Devonian to Permian island-arc volcanic and platformal carbonate rocks that crop out intermittently along the western part of the terrane. Much of Stikinia in north-central British Columbia is overlapped by molasse infilling successor basins. This molasse was derived mainly from the Cache Creek Terrane and the Omineca Belt which were elevated and eroded during accretion of the Intermontane Superterrane to the North American margin by early Middle Jurassic time.

Geology along the east-northeast margin of the Stikine Terrane is dominated by successive volcano-plutonic arcs which were constructed from Permian time, locally represented by the Asitka Group, but mainly during the Late Triassic and Early Jurassic. The Toodoggone study area lies within this north-northwest trending corridor of Mesozoic island-arc magmatism, between the east end of the east-trending Stikine arch in the north and the east-northeast trending Skeena arch in the south (Figure 3). The Stikine arch is cored by Late Triassic and Early to Middle Jurassic calcalkaline plutons, and flanked by volcanic rocks of similar age and composition. These volcanic rocks, the Late Triassic Stuhini and Takla groups, are remnants of the Stuhini-Takla arc, and superposed Early Jurassic Hazelton Group of the Hazelton arc(s). Jurassic strata assigned to the Hazelton Group are widely distributed throughout the allochthonous Stikine Terrane (Figure 3). Recent mapping in Jurassic volcano-sedimentary successions on the periphery of the Bowser basin has resulted in numerous informal stratigraphic divisions of the Hazelton Group, however, the time-space inter-relationship and tectonic implications of these successions, as they relate to the evolution of Stikinia, are conjectural (Marsden and Thorkelson, in press). Clastic rocks of the Spatsizi Group, believed to be basinal equivalents of the Hazelton Group, crop out on the south flank of the Stikine arch (Thomson *et al.*, 1986).

A clastic marine and nonmarine succession of Middle Jurassic (Callovian) to locally Cretaceous age underlies the Bowser basin and overlaps Mesozoic arc-volcanic rocks. In general, early deposits of marine shale are succeeded by nonmarine conglomeratic rocks, dominated by chert clasts, derived mainly from Cache Creek Terrane uplifted north of the Stikine arch (Eisbacher, 1981). The Skeena arch provided a local influx of granitoid and volcanic clasts in the southern Bowser basin. Early and Late Cretaceous strata of the Sustut basin overlap the east margin of the Bowser basin. The Sustut basin is underlain mainly by continental clastic detritus derived initially from the Omineca Belt on the east, changing later to a western provenance from which conglomerates of the Bowser Lake Group and possibly the lower part of the Sustut Group were reworked together with clasts from uplifted parts of the Stikine arch (Eisbacher, 1974; Evenchick, 1986). Strata in the Sustut basin are tightly folded and thrust northeast along the basin's western margin in the Skeena fold belt (Evenchick, 1991), but they form open folds and monoclinal beds at the east margin in the Toodoggone River map area.

The Toodoggone River map area is underlain by layered rocks ranging in age from Permian to Cretaceous. In the study area the general stratigraphic succession, listed in order of decreasing age, includes: the Asitka Group, Takla Group, Toodoggone Formation of the Hazelton Group, and the Sustut Group (Table 1; Figure 4). Sedimentary rocks of the Middle Jurassic to Cretaceous Bowser Lake Group are not exposed within the study area. Either the Toodoggone study area lay beyond the eastern depositional margin of the Bowser basin or, alternatively, strata of the Bowser Lake Group were deposited but have been eroded. Granitic rocks, mainly of Early Jurassic age, and cogenetic dikes intrude the crudely layered volcanic successions.

STRATIGRAPHY

Lower Permian Asitka Group

The Asitka Group was assigned by Lord (1948) to marine sedimentary and volcanic rocks exposed in the McConnell Creek map area (NTS 094D). Near Dewar Peak, in the northern McConnell area, Monger (1977) subdivided the Asitka Group into a lower section of basalt, argillite, chert and tuffaceous carbonate, a middle section of basalt to rhyolite flows, and an upper section of basalt flows, chert and tuffaceous limestone.

Rocks of the Asitka Group in the study area are exposed intermittently in fault-bounded wedges around the periphery of Black Lake stock underlying Castle Mountain. Farther south, near Drybrough Peak, similar rocks form several small roof pendants in the same pluton. South of the Finlay River, the Asitka Group and younger Takla Group strata form imbricated panels which are thrust from opposing directions toward a northwest-trending central area underlain by volcanic strata of the Toodoggone Formation.

At Castle Mountain, the Asitka Group is more than 150 metres thick. It is massive, grey-white limestone with nodular chert beds overlain by 10 metres of green and black pyritic chert. Beds in the chert are nearly horizontal and between 10 and 15 centimetres thick. The layers locally define recumbent folds with subhorizontal axes. Fold hinges are commonly offset by shear planes parallel to the fold axes. The upper contact of the chert is sharply defined and overlain by porphyritic augite basalt of the Takla Group. Bedding of strata suggests that the contact is conformable, although folds and shearing in the underlying chert indicate that it could be a low-angle reverse fault. South of the Finlay River and 2.5 kilometres southwest of Norod Lake, green and black chert layers, interbedded with grey limestone, argillite and a basalt flow, are folded within panels imbricated with Triassic volcanic rocks. The structural pattern in this area is related to northeast transport of panels upon southwest-dipping thrust faults. To the southeast, a similar structural-stratigraphic relationship exists, however thrusting there is directed toward the west.

TABLE 1
REGIONAL STRATIGRAPHY OF THE TOODOGGONE RIVER MAP AREA (NTS 094E), NORTH-CENTRAL BRITISH COLUMBIA

Period	Group	Formation	Lithology
Upper and Lower Cretaceous	Sustut	Brothers Peak Tango Creek	Nonmarine conglomerate, siltstone, shale, sandstone; minor ash-tuff
			Cassiar Intrusions: Quartz monzonite and granodiorite
Major Unconformity			
Lower Cretaceous to Middle Jurassic	Bowser Lake		Marine and nonmarine shale, siltstone and conglomerate
Conformable Contact			
Middle and Lower Jurassic	Spatsizi		Marine equivalent of the Hazelton Group; shale siltstone and conglomerate, subordinate fine tuffs
	Hazelton	Toodoggone	Subaerial andesite to dacite flows and tuffs, rare basalt and rhyolite flows; subordinate volcanic siltstone to conglomerate; rare limestone lenses
			Black Lake Intrusive Suite: Granodiorite and quartz monzonite
Unconformity			
Upper Triassic	Takla		Submarine basalt to andesite flows and tuffs, minor limestone and argillite
Unconformity			
Lower Permian	Asitka		Limestone, chert, argillite
Major Terrane Boundary Fault			
Cambrian and Proterozoic			*Siltstone, shale, sandstone, limestone; regionally metamorphosed to greenschist and amphibolite grade*

(Compiled from Gabrielse *et al., 1977*)

The Asitka Group has an Early Permian age based on fossils in the McConnell Creek area (Lord, 1948; Rigby, 1973; Ross and Monger, 1978). Solitary corals and crinoid columnals are preserved in limestone at Castle Mountain, and in the same area pelecypods occur in thinly laminated, green tuffaceous carbonate rocks. Ages of these fossils are not known, however, the hostrocks are tentatively correlated with Monger's (1977) lower division of the Asitka Group on the basis of similar rock types.

Upper Triassic Takla Group

Despite the apparent similarity in lithology, stratigraphy, and age of Late Triassic successions across major terrane boundary faults immediately south of the Toodoggone River map area, these successions have been called the Stuhini Group in Stikinia and the Takla Group in Quesnellia. Although the Toodoggone study area lies within Stikinia, the Triassic rocks described in this report are called the Takla Group in consort with similar strata that are mapped in detail just 30 kilometres to the south in McConnell Creek map area.

The history of Takla Group nomenclature from its original definition by Armstrong (1949) in the Fort St. James map area, to its redefinition in a type area centred on Sustut Peak, McConnell Creek map area, is reviewed comprehensively by Monger and Church (1977). At the type locality near Sustut Peak, the Takla Group consists of three formations. The lowest is bedded argillite and tuff of the Dewar Formation that are partly coeval with flows and breccias of coarse-grained augite and plagioclase-porphyritic basalt of the middle, Savage Mountain Formation. The upper, Moosevale Formation, is a varicoloured volcanic breccia interlayered with sandstone and mudstone in its lower part that is replaced upsection by reddish volcanic breccia and conglomerate and finer grained volcaniclastic rocks.

In the study area, rocks of the Takla Group form rugged mountainous terrain south of the Chukachida River, and throughout much of the area south of the Finlay River. There are isolated outcrops adjacent to the Stikine and Sturdee rivers near the west boundary of the area, and between the headwaters of Adoogacho and Moyez creeks. From Castle Mountain to Drybrough Peak the Takla rocks are uplifted along the margin of the Black Lake stock, where in many places they are strongly oxidized and form broad limonite-altered zones.

Rocks of the Takla Group are generally massive, dark green, coarse-grained porphyritic augite basalt, fine-grained aphyric basaltic andesite lava flows with subordinate interbeds of lapilli tuff and volcanic breccia. Less common are flows with amygdules or platy plagioclase phenocrysts up to 1.5 centimetres long. Pillow lava interbedded with hyaloclastite and well-bedded sandstone and conglomerate are mapped south of Jock Creek, east of the Black Lake stock (Marsden, 1990). In all the flows, epidote replaces plagioclase and chlorite is pseudomorphous after mafic minerals. Amygdules are commonly filled by interlocking epidote, chlorite and quartz, and rimmed by pumpellyite crystals.

Sedimentary rocks between flows are uncommon, but there are discontinuous limestone lenses present locally. About 6 kilometres southeast of the confluence of the Stikine and Chukachida rivers, limestone rests on basalt flows of the Takla Group and is separated from overlying bedded Cretaceous sedimentary rocks by an angular unconformity. This limestone is grey, recrystallized, and has faint elliptical outlines of fossils less than 1.5 centimetres long. On Claw Mountain pods of limestone are enclosed by Takla volcanic rocks.

Although a very gentle angular unconformity may be locally present, contacts of Takla Group volcanic rocks with Jurassic sequences are generally faulted. Southwest of Claw Mountain, a gently undulating topography, underlain by Jurassic volcanic rocks, rises across an east-trending contact into steep peaks underlain by Triassic volcanic rocks. The easternmost exposure of the contact is marked by a massive

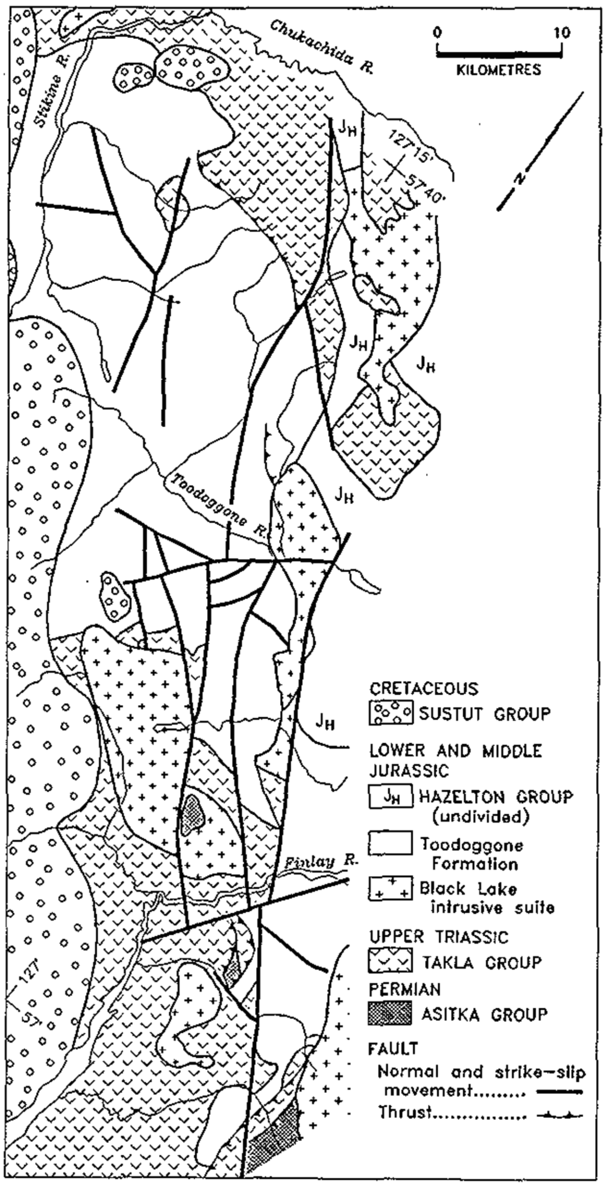


Figure 4. Regional distribution of Permian to Upper Cretaceous stratigraphy and intrusions in the study area.

basaltic flow or subvolcanic intrusion of probable Triassic age, faulted against interbedded lahar and latite flows of Jurassic age. The contact is apparently a reverse fault that dips steeply north-northeast and flattens toward the west, where basalt flows and tuffs of the Takla Group are cut by a small granodiorite intrusion and appear to structurally overlie Lower Jurassic volcanic rocks. South of the Finlay River, flows and subordinate tuffs of the Takla Group are exposed in fault blocks adjacent to Jurassic volcanic rocks or thrust slices imbricated with probable Paleozoic sediments of the Asitka Group.

Marsden (1990) describes conglomerate and interbedded finer clastic sedimentary rocks, as much as 80 metres thick, that mark an erosional surface on the Takla Group south of Jock Creek. The conglomerate is characterized by clasts derived from the Takla Group and a secondary, granitic source.

In the type area rocks of the Takla Group have yielded upper Carnian and lower Norian fossils (Monger, 1977). The Takla Group in the study area contains massive lava flows similar to those that characterize the Savage Mountain Formation. They represent a buildup of dominantly basaltic lava flows, and associated fragmental and epiclastic rocks in a shallow-marine setting.

A small pluton of porphyritic hornblendite and hornblende diorite, about 300 metres across, intrudes an inlier of Takla Group augite basalt flows outcropping between the headwaters of Adoogacho and Moyez creeks. The hornblendite is a dark green rock with fresh, prismatic zoned hornblende up to 1.0 centimetre long. Commonly, fine-grained granules of magnetite forms a diffuse rim on resorbed grain boundaries, and scarce secondary biotite patches partially replace hornblende. The matrix consists of finely disseminated magnetite grains in a mesostasis of plagioclase microlites arranged in a felty or locally a trachytic texture.

The contact between hornblendite and hornblende diorite is not exposed, however the northeast diorite contact with Early Jurassic volcanic rocks is a fault. The diorite is a grey-green, medium-grained rock consisting mainly of plagioclase, hornblende with subordinate quartz, biotite and augite. Anhedral poikilitic hornblende is the dominant mafic mineral comprising between 20 and 30 volume per cent of the rock. It generally occupies angular interstices between plagioclase laths, imparting an intergranular texture. The plagioclase crystals range in composition from An_{43} to An_{58}; oscillatory zoning is common. Discrete primary biotite grains contain minor chlorite alteration on cleavage surfaces. Augite occurs in rare solitary clusters.

The close spatial relationship and similarity of primary minerals in both intrusive phases suggests that they are genetically related. This intrusive activity is Late Triassic based on a K-Ar date of 210±8 Ma on hornblende from the hornblendite (Diakow, unpublished data).

Lower and Middle Jurassic Hazelton Group

The Hazelton Group, as redefined by Tipper and Richards (1976) in the Smithers (93L), Hazelton (93M) and McConnell Creek (94D) map areas, is subdivided into three formations of nonmarine and marine volcanic and volcaniclastic rocks in north-central British Columbia. The Telkwa Formation is the oldest, succeeded by the Nilkitkwa and then the Smithers formations. The upper two formations are dominantly shallow-marine, fine-grained epiclastic and tuffaceous rocks. The Telkwa Formation is further divided in five depositional facies composed predominately of nonmarine flows and pyroclastic deposits and less voluminous submarine flows and interlayered epiclastic rocks (Tipper and Richards, 1976). From southwest to northeast they include: the Howson subaerial facies, Babine shelf facies, Kotsine subaqueous facies, Bear Lake subaerial facies and Sikanni clastic-volcanic facies. Tipper and Richards (1976) describe the Sikanni facies as mainly well-bedded epiclastic and pyroclastic rocks that in places rest unconformably on rocks of the Takla Group. The Bear facies consists of reddish tuffs, breccias and flows that are mainly of intermediate composition.

Within the Toodoggone River map area, Early Jurassic strata that are time equivalent to the Telkwa Formation extend for more than 80 kilometres from Attycelley Creek in the south to Chukachida River in the north. These rocks, called the Toodoggone Formation, have been mapped in detail and are described in Chapter 3 of this report. Jurassic volcanic successions also extend from the study area, northeastward, into the Peak Range, which is situated between the southern terminus of the Kutcho fault and the Finlay fault (Gabrielse *et al.*, 1977). However, with the exception of detailed mapping in two relatively small areas near Mount Graves and Mount McNamara, the Jurassic strata underlying this area are undivided. The general lithologic similarity of rocks with the Toodoggone Formation suggests that they represent an easterly facies variation.

The Jurassic succession south of Toodoggone Lake, between Mount Graves and The Pillar, is a west-facing homocline of well-bedded tuffs and conglomeratic rocks intercalated with massive flows. Lava flows, with subordinate tuff intercalations, constitute the base and uppermost parts of the general succession. The flows are mainly maroon porphyritic andesites with plagioclase, hornblende and augite phenocrysts. Dark green flows are locally transitional into maroon flows or discrete members interlayered with conglomeratic rocks near The Pillar. The green colour is generally accompanied by unoxidized magnetite granules in the matrix. Basalt and rhyolite are present, but uncommon. At one locality vesicles at the top of a basalt flow 2 metres thick, are infilled and overlain by 50 centimetres of fetid grey limestone. Elsewhere, a rhyolite flow about 15 metres thick has columnar joints and quartz and feldspar phenocrysts.

Tuff breccia is the dominant rock type within a sequence of well-bedded tuffs 190 metres thick that conformably overlies maroon flow rocks 3 kilometres southeast of Mount Graves. Brown tuffaceous mudstone at the base of the succession grades upward into 4 metres of partly welded lithic-crystal tuff. Conspicuous textural banding at the base of this section is imparted by aligned plagioclase phenocrysts, flattened accessory fragments and graded beds. The overlying, major component of the section is unwelded; it contains subangular and subrounded fragments 2 to 30 centimetres in diameter set in a light green matrix of ash and crystal fragments. Fragments are mainly pink and maroon porphyritic andesite resembling the underlying flows, and a few fine-grained feldspar-phyric basalts.

The tuffs thin southward, and 3 kilometres to the south they are subordinate members within a sequence of interlayered volcanic conglomerate, sandstone and mudstone. Conglomerate is widespread with subrounded and rounded porphyritic andesite clasts, generally less than 15 centimetres but locally up to 40 centimetres in diameter, supported by a pink, laumontite-rich matrix. Sandstone beds derived by reworking of older volcanic rocks are grey-green. Tuffaceous mudstones in shades of maroon locally contain round accretionary lapilli less than 1 centimetre in diameter. The mudstone is interlayered with sandstone in graded and crosslaminated beds averaging 0.5 to 1 metre in thickness. Limestone occurs as isolated lenses 0.5 metre thick that are interlayered with marl and green tuffaceous sandstone. These grey, thinly laminated carbonate beds are overlain by porphyritic flows.

South of the Chukachida River and 4 kilometres west of Mount McNamara, volcanic conglomerate is overlain by a succession of tuff beds and rhyolite flows. This conglomerate is distinctive because of its red coloration caused by pervasive hematite dust in the matrix, and porphyritic volcanic clasts as large as 1 metre in diameter. These conglomeratic beds fine upward into an alternating series of lapilli tuff beds and recessive weathering volcaniclastic sandstone. Bedding averages from 10 to 15 centimetres thick; graded bedding and crossbedding are locally prominent. The overlying acidic flows are brown and green obsidian that commonly contains pea-size spherulites of quartz, plagioclase and laumontite. Perlitic cracks in the glass have incipient devitrification or minute spherulites and axiolitic texture. These glassy rocks form stout, lens-like bodies apparently restricted to shallow depressions developed on the upper surface of the underlying tuffs. Rhyolite near the top of the succession is flow banded and contains abundant lithophysae that weather to balls 1 to 2 centimetres in diameter with a white illite-quartz rind.

Plagioclase is the dominant phenocryst in flow rocks; it forms laths up to 5 millimetres long variably replaced by shreds of clay minerals, fine-grained albite, quartz, epidote and chlorite. Prismatic augite commonly less than 2 millimetres long is partly or completely pseudomorphed by granular epidote and carbonate. Quartz phenocrysts occur only in the rhyolites, or as rare crystal fragments in tuff interlayered with conglomerate. Commonly they are less than 1 millimetre in diameter with angular and embayed outlines.

The matrix of flow rocks contains plagioclase microlites that are randomly oriented with a felty texture. Quartz fills interstices between plagioclase microlites and forms anhedral, interlocking grains encompassed by chlorite lining minute vugs. Prismatic apatite is present in trace amounts and magnetite granules, averaging 0.5 millimetre in diameter, constitute 3 to 5 per cent of the rock by volume. Magnetite shows varying degrees of oxidation, from grains with a rim of hematite to pervasive, finely disseminated hematite that imparts a maroon colour to flows. In dark green flows unoxidized magnetite grains occur with abundant chlorite in the matrix.

Dikes of dark green, fine-grained porphyritic basalt, that are seldom more than 2 metres wide, intrude all rock types. In turn these are crosscut by porphyritic andesite dikes which weather to hues of pink or red and vary from 4 metres to more than 15 metres wide. These dikes form an en echelon pattern striking at 125° to 145°, a trend that is consistent with regional northwest faults. Individual dikes are continuous for more than 800 metres along strike; contacts are sharp with little contact metamorphism.

Mafic dikes have tabular plagioclase crystals with incipient calcite-quartz-albite alteration. The matrix contains a large proportion of chlorite mixed with quartz, and granules of magnetite between randomly oriented plagioclase microlites. Porphyritic dikes of intermediate composition have sausseritized plagioclase laths up to 3 millimetres long. Locally, amphibole phenocrysts ranging from 0.5 to 1 millimetre long have pervasive chlorite and epidote alteration of crystal cores and magnetite rims. Biotite occurs as sparse flakes less than 1 millimetre in diameter; it is replaced by chlorite and, in places, rods of rutile.

In general, flows in the Hazelton Group, east of the main study area, range from basalt to rhyolite; andesite predominates. The lavas have subordinate interbeds of volcanic breccia and tuff that grade laterally into dominantly fine to coarse-grained volcaniclastic layers. The preponderance of finely dispersed hematite dust throughout most rocks suggests that deposition took place in a subaerial environment. Shallow subaqueous conditions were present locally; inferred by impure limestone lenses associated with dark green, unoxidized lava flows and crosslaminated intravolcanic sedimentary rocks. Widespread conglomerate beds with interfingered tuffs attest to widespread reworking of older tephra, possibly on topography steepened by block faults.

Interlayered volcanic and epiclastic rocks near Mount Graves are most similar to the Bear facies of the Telkwa Formation in the McConnell Creek area. A K-Ar date of 352±12 Ma on whole rock was obtained from obsidian in a flow dome near the top of the well-layered section west of Mount McNamara. The general lithologic similarity of the strata underlying the rhyolite flows with well-dated strata of the Toodoggone Formation farther west casts doubt on the validity of this age determination. The whole-rock date, which is significantly older than expected, may be attributed to an excess abundance of initial argon in the melt prior to quenching.

Lower and Upper Cretaceous Sustut Group

The Sustut Group was named by Lord (1948), for well-bedded continental sedimentary rocks outcropping near Sustut River, in the McConnell Creek map area. The Sustut Group is best exposed in the Sustut basin, which underlies much of the west part of the Toodoggone River map area (Figure 3). Eisbacher (1974), formally defined and subdivided the group into two formations. The oldest is the Tango Creek Formation, which lies unconformably on deformed Jurassic sedimentary strata of the Spatsizi Group and Bowser Lake Group near the northeast margin of the Bowser basin (Evenchick, 1987; p.725). It has a lower member of conglomerate and interlayered green-red mudstone, and an upper member of chert-rich pebbly sandstone and grey mudstone. The younger Brothers Peak Formation is divided into two members, the lower is dominated by coarse conglomerate beds interlayered with ash-tuff, which fines upward into an upper member of intercalated sandstone, ash-tuff and mudstone.

The east margin of the Sustut basin is in the western part of the Toodoggone River map area, where several isolated outliers of Sustut sediments rest unconformably on older volcanic successions. Southeast of the confluence of Stikine River with the Chukachida River, 16 square kilometres of Sustut Group sedimentary rocks partly overlie limestone and augite basalt of the Takla Group, and partly tuffs of the Toodoggone Formation. This contact is a profound angular unconformity, above which Sustut Group rocks are gently folded about northwest-trending upright axes.

This succession consists of well-bedded green and maroon siltstone and mudstone interbedded with coarse-grained sandstone and conglomerate unconformably resting on marlstone and fetid grey limestone of the underlying Takla succession. A dark green, basaltic sill or flow, 15 metres thick, occurs in sharp contact with interbedded siltstone about 100 metres above the contact. In places, fine-grained clastic rocks are interbedded with polymictic conglomerate containing mainly cobble-sized subrounded and subangular clasts of granite, black and grey chert, fine-grained basaltic clasts resembling Takla flow rocks and white vein quartz.

Three kilometres west of Castle Mountain, approximately 7 square kilometres of sedimentary rocks of the Sustut Group rest unconformably on a gentle west-sloping pediment developed on rocks of the Toodoggone Formation. The section consists of more than 110 metres of conglomerate with sandstone interbeds, overlying a base of mainly dark green and grey-black mudstone of undetermined thickness. The underlying rocks contain carbonaceous plant debris. The conglomerate has rounded clasts composed mainly of grey and black chert, some quartzite, and scarce granite. The sandstone commonly has planar foresets within parallel beds 1 to 3 metres thick.

Fossil plants and palynomorphs from fine-grained clastic beds of the Tango Creek Formation indicate it was deposited between Late Cretaceous and Paleocene time (Eisbacher, 1974). Fauna of Albian age are reported for the Tango Creek Formation in the Spatsizi map area (Evenchick, 1986). The overlying Brothers Peak Formation has an Eocene age, as determined by K-Ar dates on ash-tuffs (Eisbacher, 1974; p.31). The Sustut strata south of the Chukachida River and west of Castle Mountain are correlated with the Tango Creek Formation (Eisbacher, 1974; Gabrielse *et al.*, 1977).

QUATERNARY DEPOSITS

Deposits of sand and gravel are generally confined to major valleys where they are a veneer of variable thickness mantling bedrock. Vestiges of formerly extensive strandline deposits occur in a series of flat, narrow berms between 1650 and 1780 metres elevation, west of the headwaters of Moyez Creek, west of Deedeeya Creek, and about 3 kilometres east of the Lawyers mine. These ancient beach deposits indicate that a large glacial lake covered much of the subdued topography south of the Chukachida River, and at least as far south as the Toodoggone River.

CHAPTER 3: DETAILED GEOLOGY OF THE TOODOGGONE FORMATION

GENERAL STATEMENT

The "Toodoggone volcanics" (Carter, 1972) are in the Toodoggone River map area (Gabrielse *et al.*, 1977), and in this study it is proposed to name this volcanic succession the Toodoggone Formation. The Toodoggone Formation is described in this report in terms of distribution, contacts, rock type, major oxide abundances, potassium-argon and argon-argon age determinations, and structure.

Strata of the Toodoggone Formation occupy a belt which tapers southeastward from 15 to 2 kilometres wide over a distance of 90 kilometres (Figure 5; Map 1, back pocket). These strata unconformably overlie volcanic rocks of the Upper Triassic Takla Group, and in turn, are unconformably overlain by sedimentary rocks of the mid-Upper Cretaceous Sustut Group. Contacts with older rocks are generally steep faults that strike northwest. Thrust faults superpose strata of the Asitka and Takla groups on volcanic rocks of the Toodoggone Formation at the north and south ends of the study area. Stratified rocks of the Toodoggone Formation are faulted against Early Jurassic intrusions and are cut by cogenetic northwest-trending dikes.

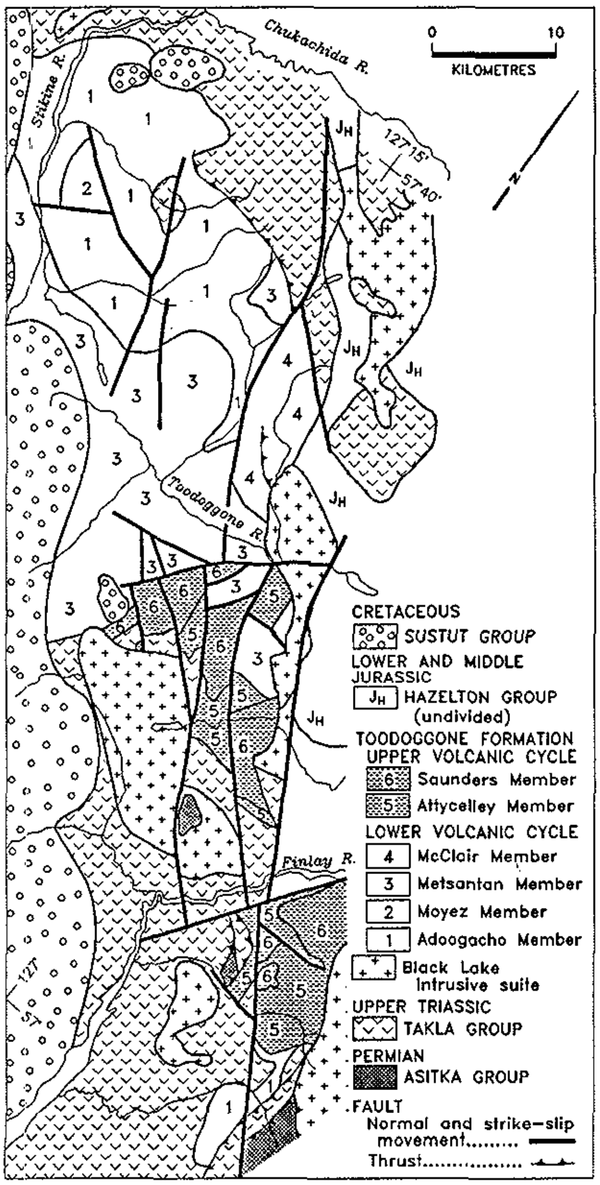


Figure 5. Distribution of volcanic strata from lower and upper volcanic cycles of the Toodoggone Formation in the Toodoggone River map area.

The Toodoggone Formation is estimated to be more than 2200 metres thick, and consists dominantly of interstratified red and maroon flow and pyroclastic rocks. They are broadly divided into lower and upper volcanic cycles that are further subdivided into six members (Figure 6). These members are established on the basis of rock type, mineral assemblage, texture and field relationships. The Saunders, Metsantan and Adoogacho members are named for readily recognizable, areally extensive successions of ash-flow tuffs and lava flows. In contrast, the Attycelley, McClair and Moyez members are mainly intercalated pyroclastic and epiclastic rocks that are mappable on a local scale but vary markedly in thickness.

Descriptions of pyroclastic rocks in the next section follow the classification by grain size of Fisher (1961). This scheme provides descriptive names for pyroclastic deposits in accordance with recommendations by the IUGS Subcommission on the Systematics of Igneous Rocks (Schmid, 1981). Features diagnostic of ash-flow tuff deposits follow the nomenclature of Ross and Smith (1961) and Smith (1980).

LOWER VOLCANIC CYCLE

The lower volcanic cycle has four stratigraphic divisions: the Adoogacho, Moyez, Metsantan and McClair members. The Adoogacho Member, the lowest, consists of variably welded dacitic ash flows exposed at the south and north ends of the study area. The Moyez Member outcrops only in the northwest and is a well-layered succession of ash tuffs that unconformably overlie rocks of the Adoogacho Member. The Metsantan Member is predominately latite lava flows; most occur along the east boundary of the area north of the Finlay River. The McClair Member consists of heterogeneous lava flows and fragmental rocks that interleave with the Metsantan Member north of the Toodoggone River.

ADOOGACHO MEMBER (UNIT 1)

The Adoogacho Member is the lowest stratigraphic division of the Toodoggone Formation. It consists of at least 350 metres of reddish and mauve, variably welded ash-flow and lapilli-ash tuffs. Subordinate block-lapilli tuff, epiclastic rocks and rare andesitic lava flows are locally interbedded with the ash-flow tuff deposits. These strata are best exposed within a 200 square kilometre area dissected by Adoogacho Creek near the north end of the study area. Correlative strata of undetermined thickness outcrop within a 20 square kilometre area south of Attycelley Creek at the

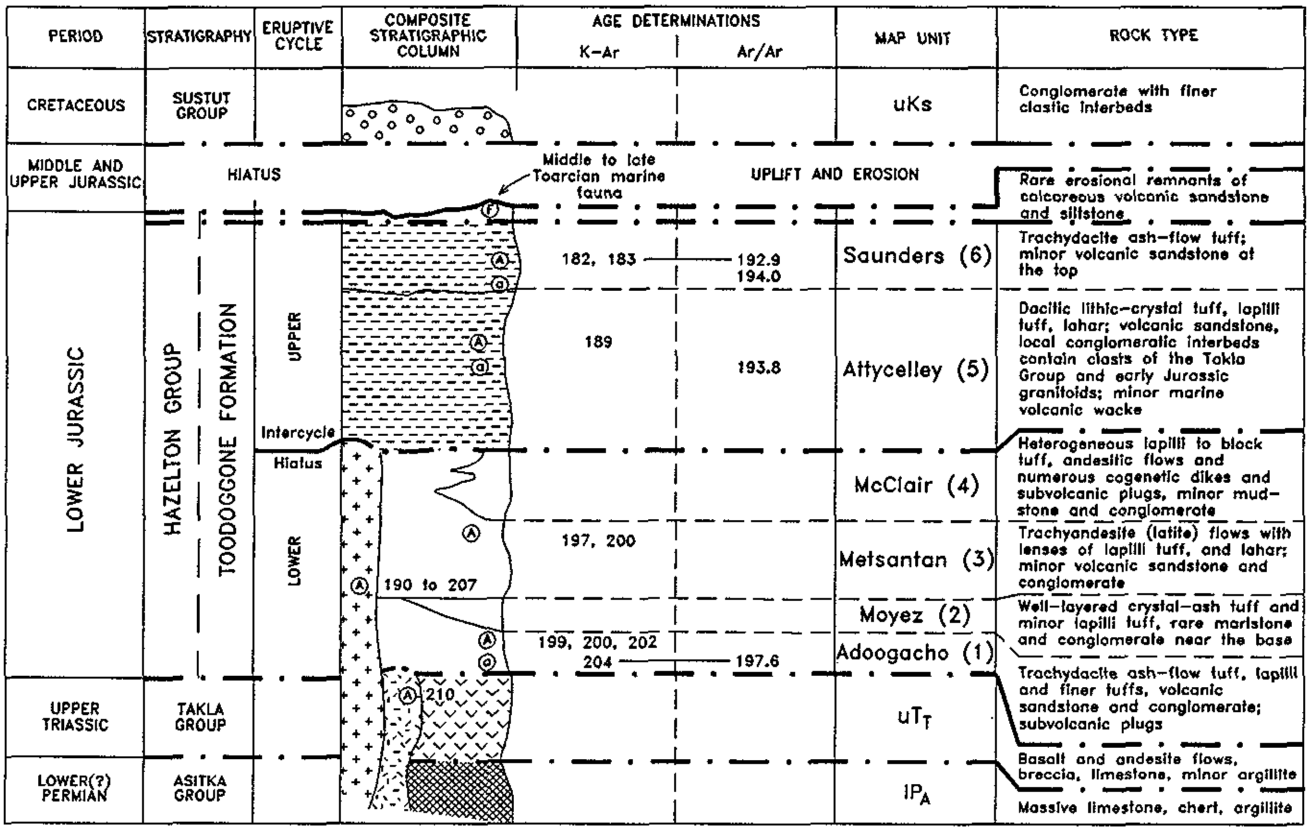


Figure 6. Composite lithostratigraphic column of stratigraphy in the study area. Unconformities are indicated by dot-dash lines. K-Ar dates denoted "A", in million years (Ma), are listed in Appendix B; "a" refers to $^{40}Ar/^{39}Ar$ dates by Shepard (1986) and Clark and Williams-Jones (1991). Mineral separates connected by tie lines have been reanalyzed by the Ar-Ar method. Macrofossils "F" were identified by Dr. H.W. Tipper of the Geological Survey of Canada and are reported in Appendix C.

south end of the study area. These rocks are absent within the area bounded by Toodoggone River and Attycelley Creek.

The Adoogacho Member has an unconformable lower contact with the Upper Triassic Takla Group; the contact is exposed in two localities. Adjacent to Adoogacho Creek, an inlier of Takla Group augite-bearing lava flows is unconformably overlain by lapilli-ash tuff of the Adoogacho Member. Near Kemess Creek in the south, a disconformity or gently inclined angular unconformity separates similar strata (Panteleyev, 1982). There is no field evidence for a major erosional event during the hiatus that separates the Upper Triassic from Lower Jurassic rocks within the study area.

In the type area near Adoogacho Creek, the ash-flow tuffs form gently inclined layers in knolls separated by broad valleys (Plate 1A). Differential load compaction and postdepositional welding in the ash-flow deposits causes blocky jointing within intervals that are up to 10 metres thick. These resistant layers merge imperceptibly into compositionally similar, but less indurated lapilli-ash tuff. Partial welding produces massive layers (Plate 1B), in which a planar fabric of flat and aligned dark reddish brown fragments (Plate 2A) is supported by a lighter coloured matrix of crystals and ash (Plate 2B). Unwelded lapilli-ash tuffs are also well indurated but distinguished from more welded rocks by lighter hues of purple and equidimensional fragments without a pronounced compaction foliation (Plate 2C).

Fragments in the ash flows are generally less than 5 per cent, but range up to 15 per cent of the rock. They are almost exclusively porphyritic cognate lithics made up of phenocrysts within a devitrified matrix of coalescing spherulites. Plate-like glass fragments have features resembling fluidal laminations or are devitrified to intergrowths of cristobalite and alkali feldspar with axiolitic texture. They are a few millimetres to 10 centimetres long and have lenticular shapes with wispy ends. The fragments commonly have light-coloured rims and bend plastically around crystal fragments in the matrix.

Broken crystals and a few intact phenocrysts constitute between 30 and 40 per cent of the ash-flow tuffs (Plate 3A,B). The crystal assemblage is consistent throughout the Adoogacho Member, however, relative mineral proportions vary. Plagioclase ranges in composition from An_{24} to An_{55} and is typically turbid and very fractured. Albite twinning and scarce oscillatory zoning are commonly obscured by exsolution of irregular patches of unaltered alkali feldspar. A mixture of clay minerals, zeolites, sericite and clots of carbonate partly replaces plagioclase. Sanidine and resorbed quartz crystals, averaging 1 millimetre diameter, are 1 to 3 per cent of the rock, respectively. Green hornblende and

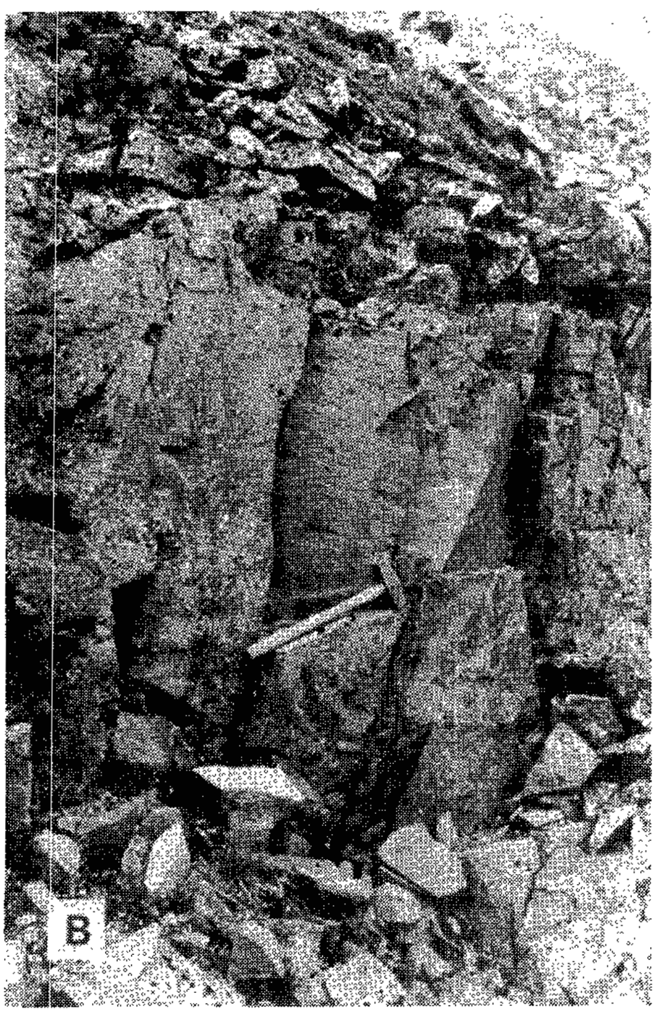


Plate 1. Adoogacho Member. A. Flat-lying dacite ash-flow tuff of the Adoogacho Member looking southwest from Adoogacho Creek across low-lying topography of the Spatsizi Plateau. Note the resistant habit of partially welded ash-flow tuff deposits exposed on the north-facing slope in the foreground. B. Massive, blocky weathered appearance of ash-flow tuff within the zone of partial welding.

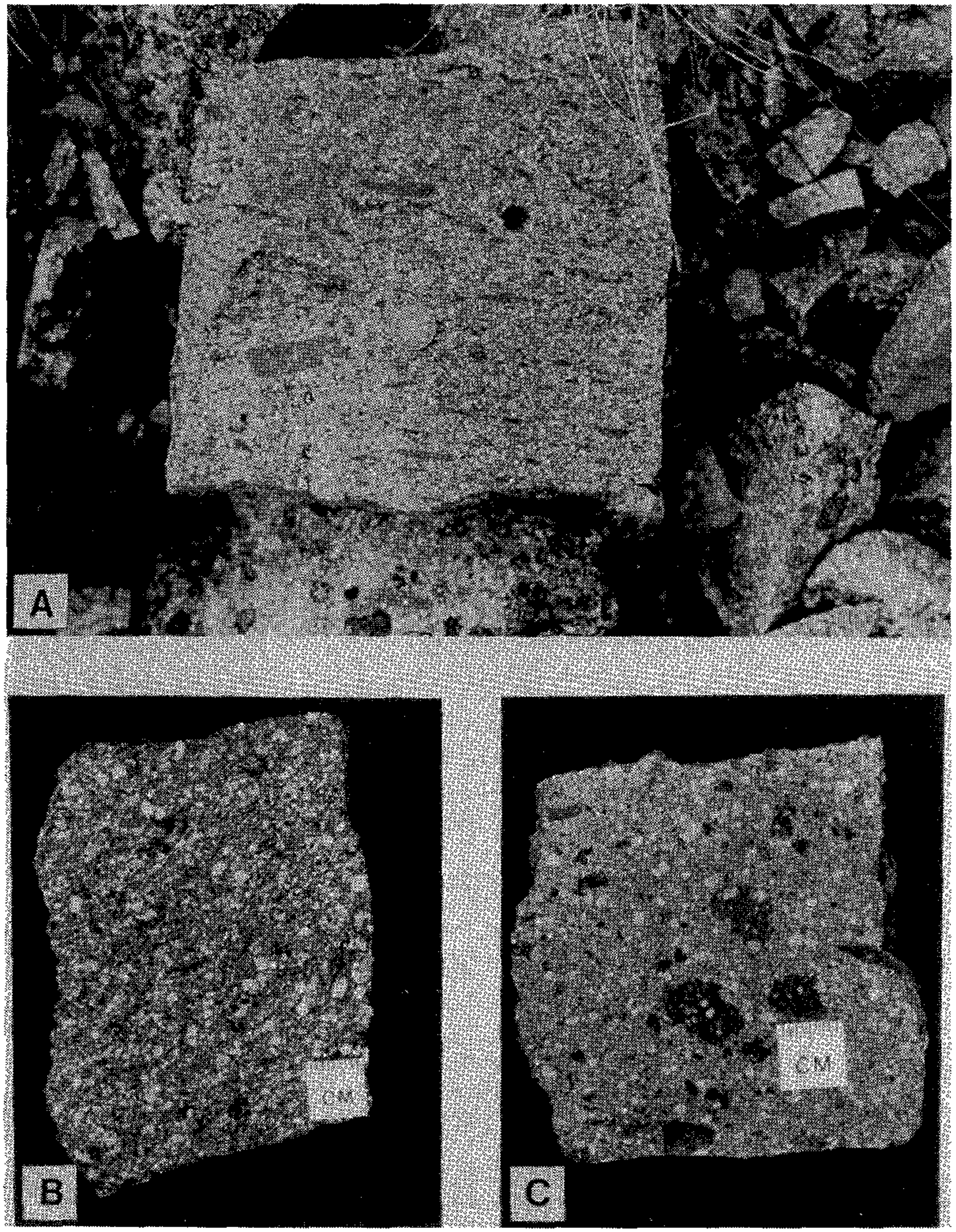


Plate 2. Adoogacho Member. A. Compaction foliation defined by cognate lithic fragments in partly welded, dacite ash-flow tuff. B. Hand specimen showing the crystal-rich and lithic-poor texture common to many dacite ash-flow tuff deposits of the Adoogacho Member. Phenocrysts are set in an ash matrix charged with hematite. C. Unwelded ash-flow tuff with abundant crystals and equidimentional cognate lithic fragments.

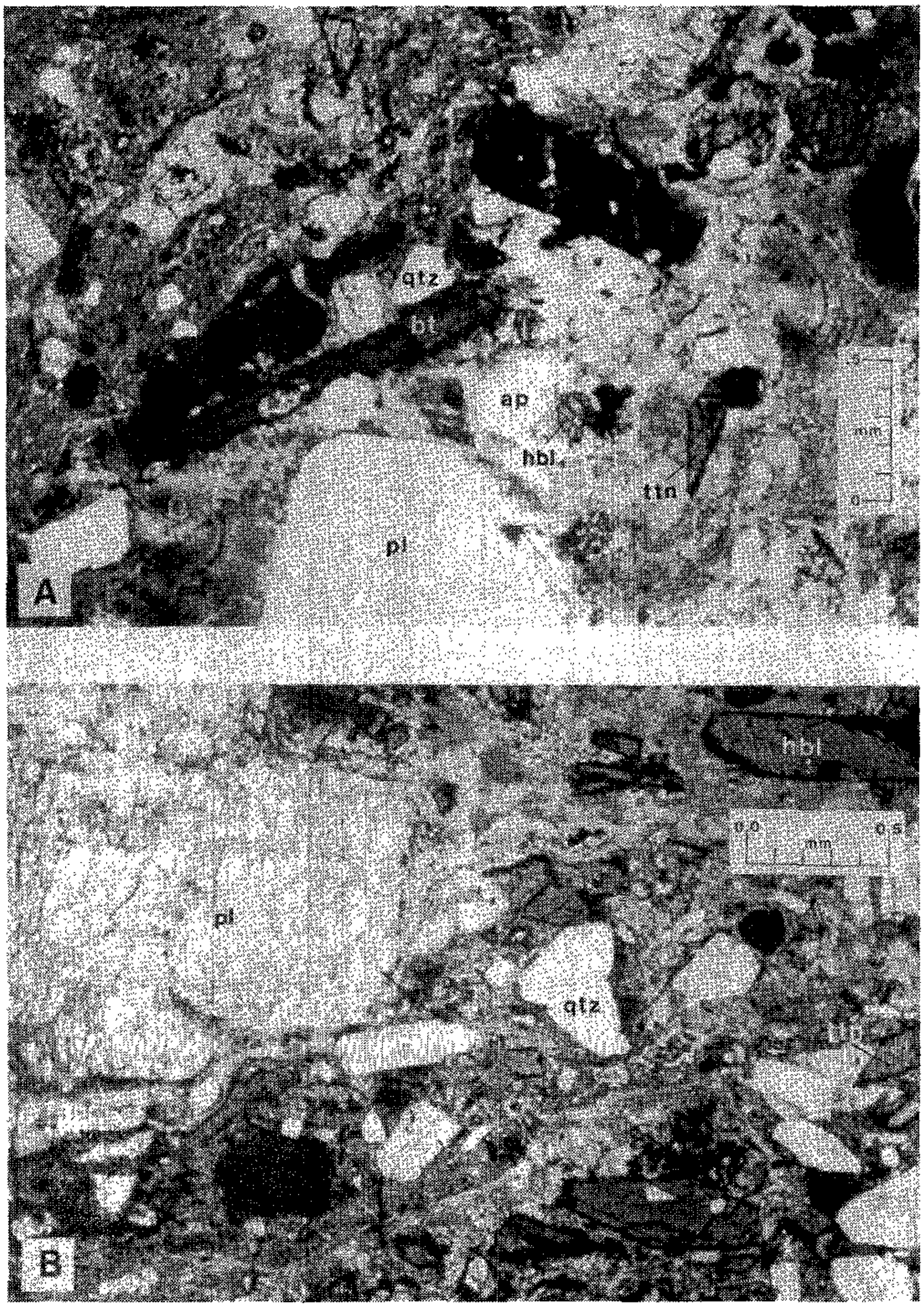


Plate 3. Adoogacho Member. A. Photomicrograph (ppl) of partly welded, dacite ash-flow tuff containing diagnostic crystal fragments of quartz (qtz), plagioclase (pl), biotite (bt), oxyhornblende (hbl), apatite (ap) and titanite (ttn) in a fine-grained matrix of interlocking quartz and alkali feldspar. Note the spherulites formed during devitrification of the glassy groundmass. B. Photomicrograph (ppl) of partly welded, dacite ash-flow tuff in which aligned subhedral crystal fragments occur in a cloudy anhedral groundmass of silica and alkali feldspar. Deposition of hot pyroclasts is indicated by the deformed lithic fragment with a light-coloured rim that is situated at the lower right side of the labelled quartz fragment (qtz).

dark red oxyhornblende vary from 5 to 10 per cent. They commonly have a granular rim of fine-grained magnetite, and are variably occupied by carbonate, epidote, chlorite and quartz. Biotite crystals, partly pseudomorphed by rutile, muscovite and magnetite, rarely exceed 2 volume per cent. Augite is usually absent; however, pale green, unaltered crystal fragments less than 0.5 millimetre across comprise 1 per cent by volume locally. Euhedral titanite and apatite occur as ubiquitously dispersed prisms. Solitary zircon grains are uncommon. The matrix of the ash flows is fine ash charged with crystals and vitric fragments and stippled by hematite. A cloudy, interlocking mosaic of unidentified silicate minerals is common within the matrix of some rocks. Stilbite, laumontite and calcite partly replace vitric fragments, infill voids in the matrix, and line steep fractures.

Air-fall lapilli tuffs with interlayered crystal-rich beds are locally interspersed within ash-flow tuff. They typically have parallel planar beds that weather recessively; uncommonly they form hoodoo columns. Beds are generally composed of subangular and subrounded accessory fragments between 1 and 5 centimetres in diameter, however there are blocks as large as 1 metre diameter. Rare accidental fragments of Takla basalt and quartz monzonite have been found. One ash-tuff bed 1 metre thick overlying ash-flow tuff has planar crossbedding, a feature resembling base-surge deposits associated with pyroclastic flows (Fisher, 1979).

Lava flows are rare in the Adoogacho Member. South of Kemess Creek, hornblende-feldspar-porphyritic andesite forms thin flows interspersed with flat-lying ash-flow tuffs. The largest of the flows is between 50 and 70 metres thick over a 2 square kilometre area. These rocks contain augite and hornblende phenocrysts set in a dark maroon-coloured groundmass that contains plagioclase microlites arranged in pilotaxitic texture.

Intravolcanic sedimentary rocks are grey-green and maroon tuffaceous sandstone, siltstone and mudstone. They are uncommon discontinous beds, rarely more than 1 metre thick. Siltstone interlayered with green ash-lapilli tuff in a section 3 metres thick, south of Adoogacho Creek, contains well-preserved plant imprints. Palynomorphs identified from this site are nonmarine fern species that correlate most closely with Upper Triassic assemblages (G.E. Rouse, written communication, 1984; Appendix C). Isotopic dates on tuffs from the Adoogacho Member suggest they crystallized during Sinemurian to Pliensbachian time (refer to Age Determinations section). These dates refute a pre-Jurassic age for the Adoogacho Member implied from palynomorphs.

Moyez Member (Unit 2)

The Moyez Member is a well-bedded succession of ash tuff, conglomerate and local impure limestone that unconformably overlies the Adoogacho Member (Plate 4A). It is restricted to a ridge between Moyez and Adoogacho creeks, where it is at least 200 metres thick. The upper contact is not exposed. A basal conglomerate infills paleotopographic depressions on underlying pyroclastic rocks of the Adoogacho Member. Conglomerate beds as thick as 4 metres are interlayered locally with lapilli-ash tuff over an interval of about 40 metres at the base of the succession.

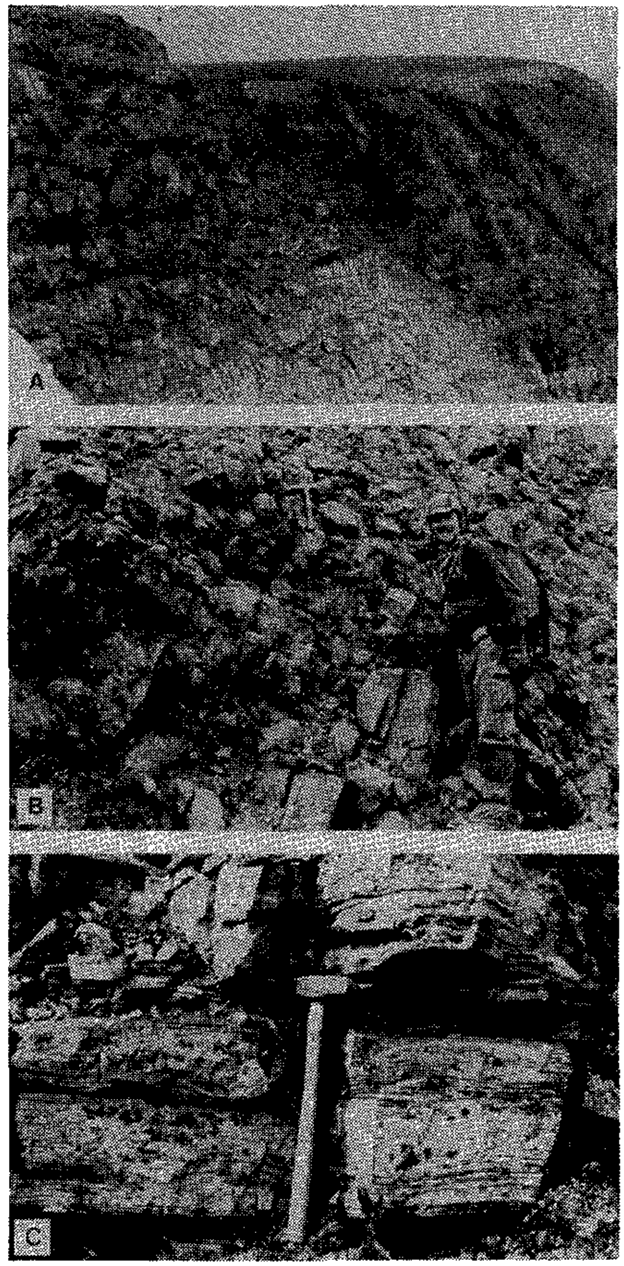


Plate 4. Moyez Member. A. Well-layered medium to thick-bedded lapilli-ash tuff in the type area of the Moyez Member, south of Adoogacho Creek. B. Massive conglomerate at the base of the Moyez Member, composed of rounded cobbles and boulders that are derived from ash-flow tuffs of the underlying Adoogacho Member. C. Thin-bedded impure limestone with chert and mudstone laminae.

Laterally, tuff intercalations are absent and the conglomerate has a maximum thickness of about 30 metres. The clasts are rounded, poorly sorted, and range from cobbles to boulders over 1 metre in diameter (Plate 4B). Clasts are derived exclusively from the underlying Adoogacho Member.

Ash-tuff and lesser lapilli-ash tuff are interlayered with and overlie the conglomeratic beds. These tuffs are internally graded, distinctly layered beds between 0.5 and

2 metres thick. They consist of shattered crystal fragments several millimetres long, and have a few subangular to subrounded lapilli, set in a groundmass of green and brownish red ash.

Phenocrysts consist of between 15 and 25 per cent turbid plagioclase, and 1 to 2 volume per cent each of quartz, green hornblende, magnetite and apatite. Pale green augite, biotite and titanite are uncommon. Secondary epidote, chlorite and clay minerals are widespread as alteration products of feldspar, mafic minerals, and as groundmass components. Radiating clusters of laumontite commonly occupy voids in the matrix and selectively replace vitric fragments in tuffs.

Impure limestone forms several discrete beds, each up to 3 metres thick, over a 25-metre interval immediately above the highest conglomerate bed and near the top of the exposed succession. The limestone is tan weathering with layers of more resistant siltstone and chert between 0.5 and 1.5 centimetres thick (Plate 4C). Limestone was collected for microfossil analysis, but no fossils were found.

Metsantan Member (Unit 3)

The Metsantan Member is mostly latite lava flows with interflow lahar, and mixed epiclastic and pyroclastic rocks. It has no type section, but is named for more than 600 metres of flows, interspersed layers of tuff, and epiclastic rocks between Metsantan Mountain and Tuff Peak. The Metsantan Member is extensively exposed on mountain ridges and discontinuously in valleys from upper Moosehorn Creek in the north, to the Finlay River in the south. Correlative strata are absent in the area south of the Finlay River except for andesitic flows of similar composition but areally limited within the Adoogacho Member south of Kemess Creek. Exposures of the rocks of the Metsantan Member are readily accessible by road near the Lawyers deposit. The lower contact of the Metsantan Member is a gently inclined unconformity with the Adoogacho Member on the northwest flank of Tuff Peak. A similar contact relationship is postulated for several flat-lying outliers west of Moyez Creek, although no contacts are observed. Elsewhere, most contacts are faults.

The latite lava flows characteristically form resistant outcrops that weather in hues of green and purple. They have a porphyritic texture, with 20 to 30 volume per cent phenocrysts, dominated by plagioclase, and subordinate mafic minerals (Plate 5A). Orthoclase megacrysts and quartz are uncommon but diagnostic phenocrysts within the flows. Plagioclase, An_{24-38}, is typically light pink and orange subhedral solitary crystals averaging 2 or 3 millimetre long; they commonly occur in glomerophyric clusters up to 6 millimetres in diameter. Sparse, pink vitreous orthoclase phenocrysts average 1 centimetre, but may be 2 centimetres long (Plate 5B). Dark green augite and less abundant hornblende prisms average 3 millimetres long, and are between 3 and 5 volume per cent. Biotite plates less than 1.5 millimetres in diameter average about 1 volume per cent. Quartz is scarce in the flows, rarely more than one or two visible grains in a hand specimen. They are generally partly resorbed and vary from 0.5 to 1.0 millimetre in diameter. Red apatite prisms up to 2 millimetres long are ubiquitous in trace amounts in flows. Rare zircon is found as stout grains or inclusions within plagioclase and apatite phenocrysts.

The groundmass of lava flows is plagioclase microlites arranged in a pilotaxitic texture, with anhedral aggregates of chlorite, quartz and carbonate between plagioclases. Dispersed opaque granules and blebs account for up to 3 volume per cent of the rock.

The rocks have a dull green or mauve-coloured matrix enveloping feldspar and mafic phenocrysts. Turbid plagioclase is incipiently occupied by varying proportions of sericite, illite, laumontite and heulandite. As well, epidote, piedmontite, calcite and chlorite partly pseudomorph plagioclase and pyroxene minerals and the groundmass. These secondary minerals are commonly accompanied by granular magnetite and cloudy patches of sphene pseudomorphous after biotite and amphibole phenocrysts (Plate 5C).

Lahar, epiclastic sandstone, siltstone and lapilli-ash tuff are locally thick interlayers between lava flows. Lahar exposed on the ridge between Deedeeya Creek and Moosehorn Creek, is more than 100 metres thick above a sharp lower contact with lava flows. This deposit is unstratified and poorly sorted, subrounded to subangular monolithic fragments up to 1.5 metres diameter that are derived from flows of the Metsantan Member, and supported by a recessive muddy matrix. Rare discontinous interbeds of alternating siltstone and sandstone layers, in places graded and crosslaminated, are up to 2.5 metres thick. Lahars of similar character and thickness are well exposed on the north-facing slope of Tuff Peak. On the mountain's northwest flank, they are supplanted by well-bedded epiclastic rocks. This section consists of oligomictic conglomerate up to 7 metres thick resting above an erosive base on flows of the Metsantan Member. The clasts are rounded cobbles and boulders derived from underlying flows. In turn conglomerate is overlain by about 30 metres of purple and green, laminated and graded tuffaceous siltstone and celadonite-cemented sandstone beds. The beds are as thick as 0.5 metre, and have scour-and-fill structures, crosslaminations, ripples, mudchip breccias, dessication cracks and rainprints. Similar stratified reddish brown mudstone and siltstone at Metsantan Mountain contain plant debris.

Well-bedded epiclastic rocks more than 200 metres thick occupy a downdropped fault block 1.5 kilometres south of the Lawyers AGB zone. This block consists primarily of oligomictic conglomerate separated by beds of graded feldspathic sandstone-siltstone. The conglomerate layers have rounded and subangular, poorly sorted clasts between 1 and 50 centimetres in diameter. The provenance of framework and matrix material is exclusively from lava flows of the Metsantan Member. Other significant exposures of conglomeratic epiclastic rocks crop out on the south-facing slope above Cloud Creek, 3.5 kilometres southwest of the Amethyst Gold Breccia (AGB) mineralized zone at the Lawyers deposit.

Pyroclastic deposits are not voluminous and most grade into epiclastic rocks. The latter undoubtedly are derived by periodic reworking of pyroclastic rocks and flows by streams.

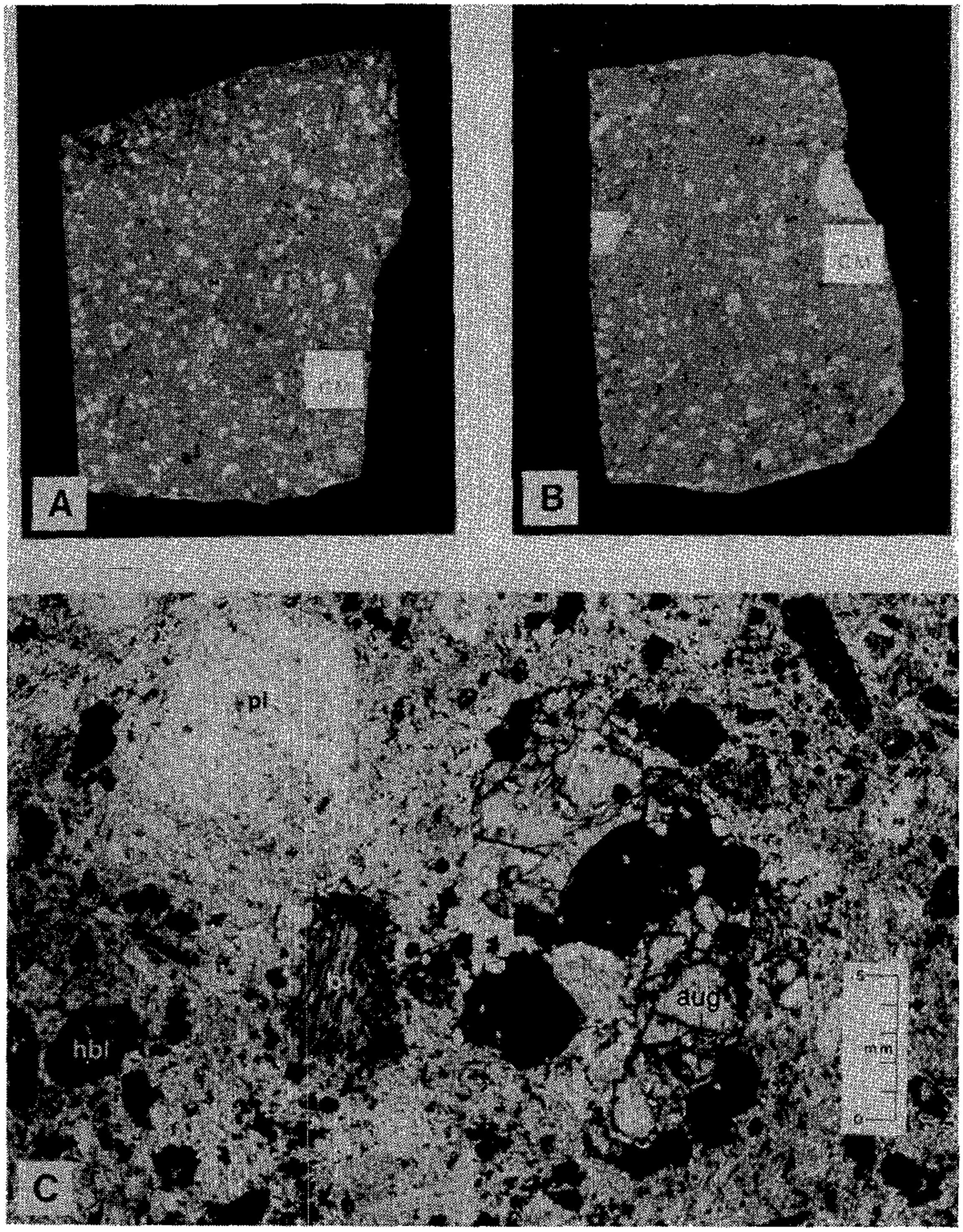


Plate 5. Metsantan Member. A. Typical porphyritic latite flow from the Metsantan Member with equant, subhedral to euhedral plagioclase and smaller dispersed mafic phenocrysts. B. Variation of porphyritic latite flows containing sparse, subhedral orthoclase megacrysts (above scale). C. Photomicrograph (ppl) of porphyritic latite flow with diagnostic plagioclase (pl), augite (aug), and subordinate biotite (bt) and hornblende phenocrysts (hbl). Note the pristine appearance of augite (right of centre) in comparison to the partial to complete replacement of biotite and hornblende by opaque granules.

McClair Member (Unit 4)

The McClair Member is a succession of grey and greyish green andesitic lava flows interlayered with pyroclastic and epiclastic deposits; it is restricted to an area bounded by McClair Creek on the east, by Moosehorn Creek on the west and Toodoggone River to the south. These rocks interleave or have faulted contacts with coarser porphyritic flows of the Metsantan Member northeast of Kodah Lake. The McClair Member has an estimated minimum thickness of 250 metres; neither the top nor bottom contacts are exposed.

The lava flows form homogeneous, blocky jointed outcrops. The flows commonly have subtrachytic flow texture and local deposits of flow breccia. Interflow pyroclastic rocks are bedded and up to 10 metres thick. They are generally crystal rich but may contain lapilli and block-size fragments.

Crowded porphyritic textures, with 35 to 50 volume per cent of phenocrysts averaging 2 millimetres diameter are characteristic of the volcanic rocks. Phenocrysts and groundmass are typically altered with carbonate and clay minerals partly replacing plagioclase. Vestiges of prismatic amphibole and pyroxene, comprising roughly 7 volume per cent, are pseudomorphed by granular opaque minerals, with or without chlorite and carbonate. The groundmass contains similar secondary minerals and rarely has brown glass devitrified to spherulites.

Oligomictic conglomerate is at the base of interlayered tuffs and epiclastic rocks on the ridge crest between Moosehorn and McClair creeks. The conglomerate consists of about 5 metres of unsorted cobbles and boulders. The overlying rocks include beds of lapilli-ash tuffs 5 to 10 centimetres thick, interleaved with brownish red mudstone containing plant debris. Plant fossils are also found in tuffaceous siltstone interbeds between breccia and lava flows near the top of the mountain north of Kodah Lake.

UPPER VOLCANIC CYCLE

The upper volcanic cycle is represented by the Attycelley and Saunders members, which are restricted to a broad area south of the Toodoggone River. The Attycelley Member is mainly interlayered pyroclastic and epiclastic rocks that are generally in sharp contact with overlying, thick homogeneous dacitic ash-flow tuffs of the Saunders Member.

Volcanic sequences of the upper cycle in the southwest-central map area, rest unconformably on basement rocks of the Takla Group uplifted adjacent to the Black Lake stock. The contact between the Attycelley and Saunders members is gradational with little change in bulk rock composition.

Attycelley Member (Unit 5)

The Attycelley Member is a heterogeneous mixture of green, grey and mauve lapilli-ash tuff, subordinate lapilli-block tuff, a few interspersed ash flows and lava flows, and interbedded epiclastic rocks and rare lenses of limestone. The volcanic rocks are similar in texture and mineral constituents to pyroclastic rocks of the Adoogacho Member. Rocks of the Attycelley Member are only distinguishable from the Adoogacho Member by stratigraphic position relative to distinctive bounding strata of the overlying Saunders Member and the underlying Metsantan Member. The diverse texture of volcanic rocks and the complex internal stratigraphic relationships of the Attycelley Member are documented through detailed mapping in the vicinity of the Shas gold-silver deposit at Jock Creek (*see* "Jock Creek volcanics" in Marsden, 1990).

The Attycelley Member is widespread south of the Toodoggone River, but is absent to the north. In the type area, where it is dissected by Attycelley Creek, the succession has an estimated minimum thickness of 500 metres. The lower contact is arbitrarily placed at the base of well-layered epiclastic and pyroclastic rocks overlying the Adoogacho Member south of Attycelley Creek (Plate 6A). The Attycelley Member unconformably overlies the Upper Triassic Takla Group northeast of Drybrough Peak. The upper contact is inferred by a change in the general resistance of outcrops from recessive, generally crumbly and platy weathering rocks in the Attycelley Member to resistant, blocky weathering cliffs in the Saunders Member. Between the Finlay and Toodoggone rivers, fault-bound blocks underlain by the Attycelley Member are commonly juxtaposed with rocks of the Metsantan Member. Several recessive weathering exposures of tuffs from the Attycelley Member crop out along the road about 1.5 kilometres west of Tiger Notch Pass.

The Attycelley Member is predominately unwelded, lapilli-ash tuff which contains reddish brown porphyritic feldspar lapilli (Plate 6B). In places, partly welded tuffs are more resistant and have variably flattened chloritic fragments which define an incipient to moderate compaction foliation (Plate 6C). Lapilli-block tuff is locally important as interbeds within lapilli-ash tuffs and tuffites east of Black Lake airstrip, and at the north end of the ridge east of Saunders Creek. The tuffs generally weather with phenocrysts and fragments protruding from a recessive matrix. Layered tuff sections contain either a mixture of lithic and crystal fragments or parallel layers of sorted and graded pyroclasts. Rare planar crossbeds and graded ash, in intervals less than 25 centimetres thick, may represent surge deposits.

Except in the area between Drybrough Peak and immediately north of Jock Creek, lava flows are uncommon in the Attycelley Member. They are generally grey-green massive layers of undetermined thickness, interlayered with tuffs. They have up to 40 volume per cent plagioclase phenocrysts which impart a crowded seriate texture, and several volume per cent quartz phenocrysts. Latite flows (Unit 5b, Map 1; back pocket) that resemble the texture and composition of those from the Metsantan Member, are locally interspersed with typical pyroclastic deposits of the Attycelley Member immediately adjacent to Saunders Creek. The thickest accumulation of these flows occurs on the ridge due north of the east end of Black Lake, where they appear to form an eastward-thinning wedge between pyroclastic rocks of the Attycelley and overlying Saunders members.

Epiclastic beds composed mainly of volcanic sandstone, siltstone and conglomerate are interlayered with lapilli-ash tuffs to form differentially weathered, distinctly bedded successions. These successions are locally prominent, particularly northeast of Drybrough Peak in the vicinity of Jock Creek, and also south of Attycelley Creek. About 2 kilometres northeast of Drybrough Peak, conglomerate and redbed sandstones and siltstones are interstratified with tuffs and a few flows, which make up a well-layered succession at least 175 metres thick that rests unconformably on basaltic flows of the Takla Group. A similar contact is mapped 4 kilometres north of Drybrough Peak, where more than 250 metres of bedded lapilli tuff, volcanic conglomerate and finer grained epiclastic interbeds are disconformable on pyroxene-bearing lava flows of the Takla Group (M. Gunning, written communication, 1988). Recent mapping in this area documents conglomerate, characterized by the preponderance of Takla and subordinate granitic clasts, occupying the basal part of a succession of thinly bedded fragmental and sedimentary rocks (Marsden, 1990). This conglomerate presumably is near the base of the Attycelley Member, which in turn unconformably overlies flows, breccias and intraformational conglomerates of the Takla Group. South of Kemess Creek, an 80-metre section of layered and variably reworked fine-grained tuffs and intercalated tuffaceous sandstone has a conglomeratic basal bed which rests nonconformably on a porphyritic subvolcanic pluton. Clasts in the conglomerate are mainly cobbles and boulders of feldspar porphyry and sparse granodiorite. Limestone, which weathers smoke grey, forms a lens 4 centimetres thick and several metres long within lapilli-crystal tuff at a single locality on the second ridge east of Saunders Creek.

Crystal pyroclasts in tuffs of the Attycelley Member are plagioclase, sanidine, quartz, amphibole, pyroxene, biotite, apatite and titanite. Plagioclase, the most abundant phenocryst, is rarely more than 3 millimetres in diameter. It

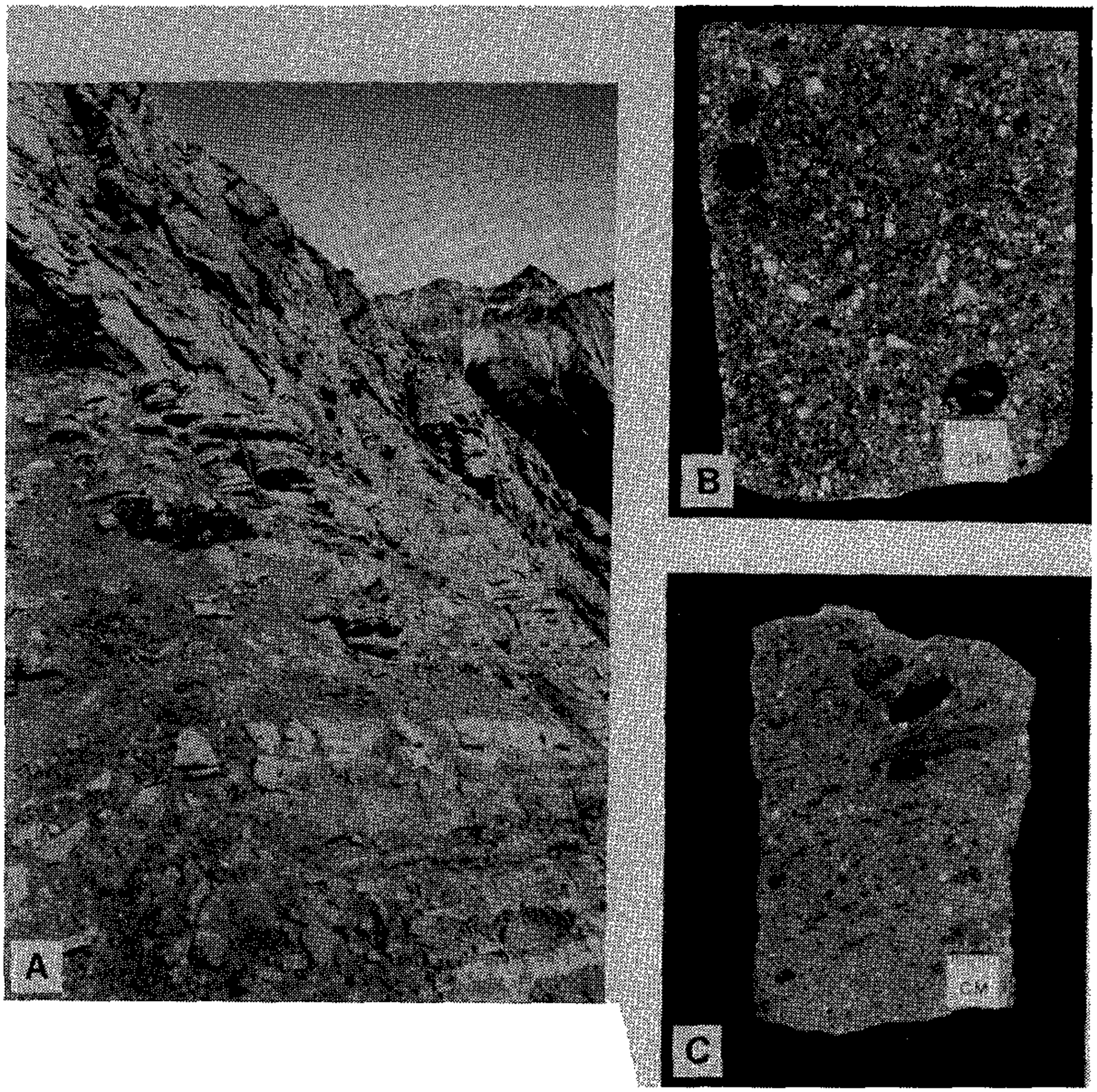


Plate 6. Attycelley Member. A. Typical bedded outcrop of the Attycelley Member; volcanic sandstone and tuffite overlain by more massive ash tuff and breccia, 4 kilometres south of Attycelley Creek. B. Typical unwelded, dacitic lapilli-ash tuff. Rounded lithic fragments suggest reworking of poorly lithified air-fall tuffs. C. Partly welded air-fall tuff with chloritic fragments defining a pronounced compaction foliation.

generally has a turbid appearance because of partial replacement by sericite, calcite and epidote. Sanidine crystals up to 1.5 millimetres in diameter are generally present in amounts of 1 volume per cent or less. Quartz, a ubiquitous phenocryst, is between 0.75 and 2.5 millimetres in diameter with resorbed and scarce bipyramidal outlines; it averages 2 volume per cent of the rocks. Relict amphibole, commonly with a core of interlocking chlorite and carbonate and a rim of granular magnetite, is up to 3 volume per cent of most rocks. Pyroxene, a rare constituent of these rocks, is pseudomorphed by carbonate. Biotite sites are generally occupied by chlorite and magnetite with or without muscovite, sphene and epidote. It accounts for between 1 and 2 volume per cent of the tuffs. Microscopic prisms of apatite and less common titanite are also present.

SAUNDERS MEMBER (UNIT 6)

The Saunders Member comprises the stratigraphically youngest rocks of the Toodoggone Formation, and is composed almost exclusively of partly welded, crystal-rich, dacitic ash-flow tuffs which typically form cliffs that weather to angular talus blocks (Plate 7A). In the type area, bounded to the east by the west tributary of Saunders Creek and an unnamed southeast-trending tributary of Jock Creek, a succession of compositionally and texturally homogeneous ash-flow tuffs more than 300 metres thick caps mountain peaks 2100 metres in elevation. These strata gradually thin westward to an erosional edge 8 kilometres away, near the headwaters of Pau Creek. In the north, the Saunders Member is areally confined to a solitary block-faulted section at Kodah Creek, immediately north of the Toodoggone River. At their southern extent identical strata more than 200 metres thick cap mountain peaks above 2000 metres elevation between Attycelley Creek and the Finlay River, more than 25 kilometres southeast of the type area. Typical strata of the Saunders Member are well exposed along the north side of the access road through Tiger Notch Pass.

The lower contact of the Saunders Member appears to be conformable with the Attycelley Member. However, the contact is erosional with lava flows of the Takla Group about 1.5 kilometres northwest of Castle Mountain, where conglomerate interstratified with tuffites forms the base of the Saunders Member. The basal conglomerate, which is about 15 metres thick, has subrounded clasts up to 20 centimetres in diameter supported by a pyritic green matrix with scarce quartz phenocrysts. The provenance of clasts is mainly from lava flows of the Takla Group. The tuffaceous interbeds are reworked lapilli-ash tuffs in unsorted to graded beds between 4 and 10 centimetres thick. Rare accretionary lapilli locally form discontinous layers several centimetres thick. The upper contact of the Saunders Member is with fine-grained sandstone and pebble conglomerate found locally west of Pau Creek. These discontinuous beds have abundant quartz grit and lithic detritus which is thought to be eroded from ash-flows of the Saunders Member. Similar sandstone deposits are also reported by Marsden (1990; map unit 11c) north of Jock Creek at Mount Todd, where they apparently are conformable with, and contain rock and crystal fragments derived from pyroclastic flows of the Saunders Member.

Ash-flow tuff that characterizes the Saunders Member is typically grey green with a large proportion of broken crystal and nonvesiculated juvenile fragments with porphyritic texture (Plates 7B,C). These rocks have subtle variations in texture and relative mineral abundance; they resemble a homogeneous, weak to moderately welded, single cooling unit in cliff sections as much as 300 metres thick. Compressed cognate fragments, rounded fine-grained inclusions, and scattered accidental granitic fragments are diagnostic features.

The ash-flow tuffs typically have 35 to 50 volume per cent crystals of plagioclase, hornblende, quartz, biotite, sanidine and scarce augite (Plate 8A). Plagioclase varies from 1 to 4 millimetres in diameter, is between 25 and 45 volume per cent of the rock, and has a composition of An_{29-54}. It is generally fractured with irregular patchy extinction or multilamellar twinned crystals. Plagioclase crystals are generally turbid because of selective occupation by variable amounts of calcite, illite, chlorite, laumontite and epidote. By contrast, sanidine is broken phenocrysts several millimetres in diameter in concentrations of up to 3 volume per cent. Sites are commonly occupied by incipient secondary clay minerals. Green hornblende, the dominant mafic mineral, accounts for between 3 and 10 volume per cent of the rock. It generally is corroded euhedral crystals with resorbed edges mantled by a diffuse rim of opaque granules with or without fine-grained clinopyroxene and chlorite. Biotite rarely exceeds 1 volume per cent and is most commonly pseudomorphed by combinations of muscovite, chlorite, epidote, carbonate, magnetite and sphene. Rounded and bipyramidal embayed quartz crystals from 1 to 4 millimetres in diameter average 2 volume per cent, but may be 5 volume per cent. Titanite and apatite are dispersed in trace amounts throughout the rocks as prisms less than 1 millimetre long. Zircon occurs as rare, solitary prisms up to 0.07 millimetre long.

The tuffs have a glassy mesostasis which is devitrified to an aggregate of interlocking anhedral feldspar and quartz stippled with fine-grained opaque granules and less common crystallites. Rare vestiges of brown glass are preserved in the interstices between coalescing spherulites (Plate 8B). Faint parallel laminae in the original glass curve around the phenocrysts. These laminae are discontinuous and locally separate crystal-rich layers.

Cognate fragments between 1 and 7 centimetres long have distinct parallel alignment. The fragments are dominantly vitrophyric and darker greenish grey, but identical to the host vitric-ash tuff. Fine-grained, greyish green xenoliths are common in the Saunders Member. These inclusions are subrounded, between 1 and 5 centimetres in diameter, and speckled by light and dark minerals. Accidental granitic fragments as large as 25 centimetres diameter are sparsely distributed in ash-flow tuffs in the type area, and east and southeast of the Lawyers AGB zone.

POSTVOLCANIC SEDIMENTARY ROCKS (Unit 7)

Sedimentary rocks unconformably overlie strata of the Adoogacho Member at two localities in the northern part of the study area. However, evidence which suggests that these sections may be time-equivalent is lacking.

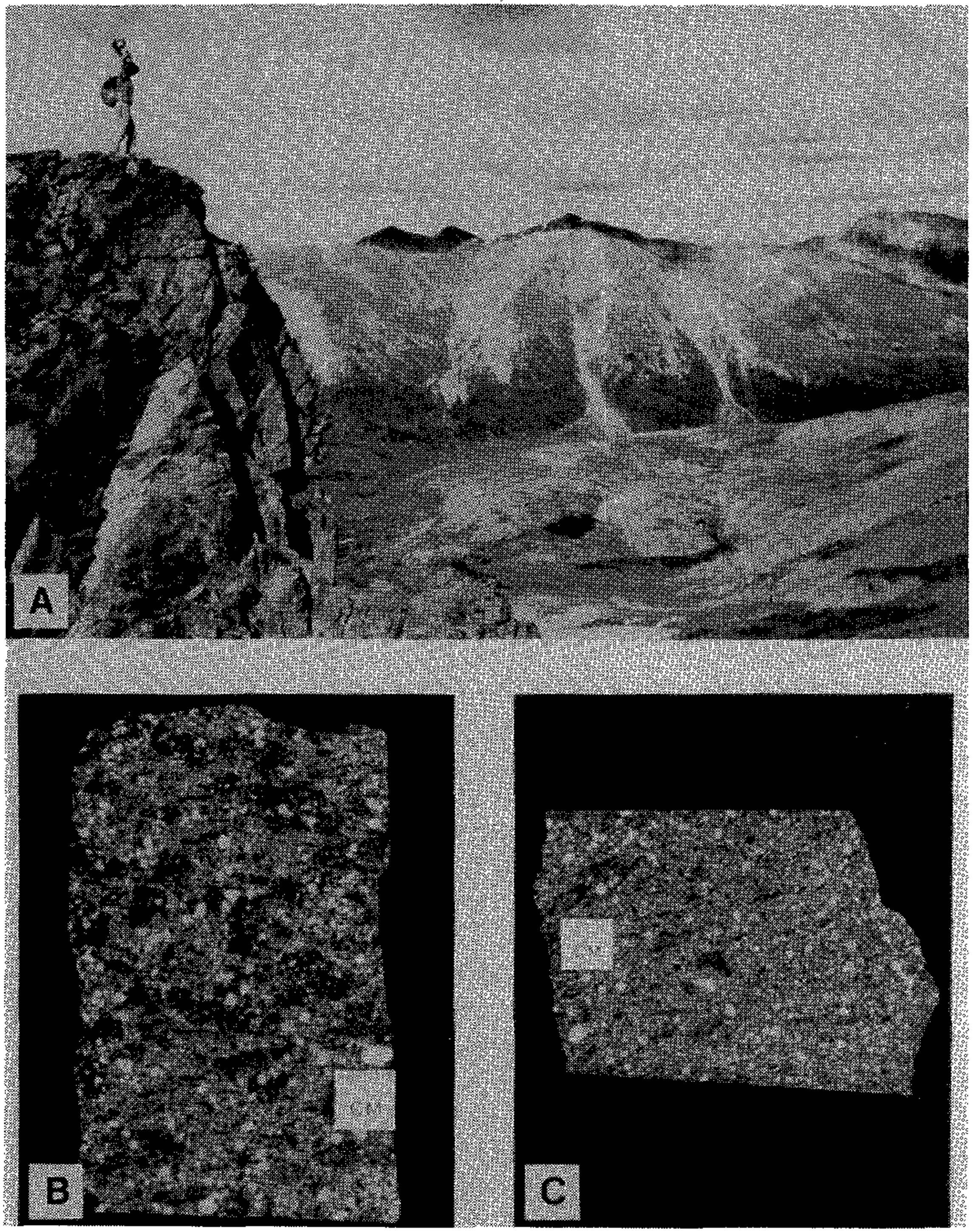


Plate 7. Saunders Member. A. Resistant dacite ash-flow tuff of the Saunders Member in the foreground, looking northwest across valley underlain by recessive, dacitic pyroclastic rocks and tuffite of the Attycelley Member, 1 kilometre northeast of Tiger Notch Pass. B, C. Typical incipient to partly welded dacite ash-flow tuffs of the Saunders Member. Note the diagnostic spatter-like cognate lithic fragments (dark grey) and the large concentration of broken crystals. Phenocrysts are typically supported by a grey-green, ash-rich matrix.

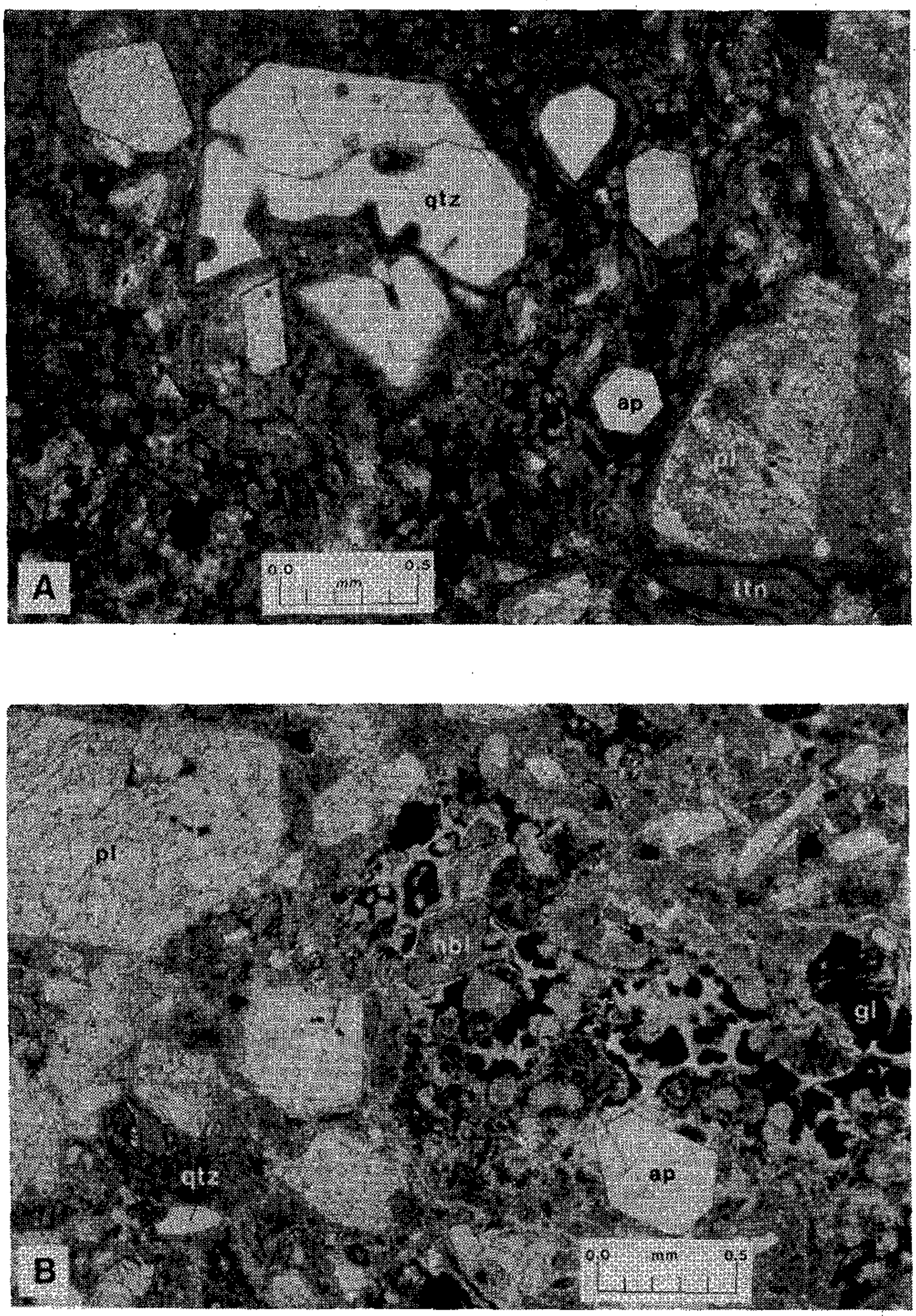


Plate 8. *Saunders Member. A. Photomicrograph (ppl) of an incipiently welded, dacite ash-flow* tuff. Randomly oriented fragments of plagioclase (pl), resorbed quartz (qtz), apatite (ap) and titanite (ttn) are in a fine-grained, devitrified groundmass. B. Photomicrograph (ppl) of partly welded ash-flow tuff containing semi-oriented crystals of patchy zoned plagioclase (pl), unaltered hornblende (hbl), quartz (qtz) and apatite (ap). The groundmass is fine grained with relics of glass (gl) that are partly devitrified to spherulites.

Limy and tuffaceous siltstone and sandstone are poorly exposed in the vicinity of the east tributary of Adoogacho Creek (H.W. Tipper, written communication, 1985). According to Dr. Tipper, these rocks occur as a number of large blocks that are believed to be *in situ*. They apparently represent erosional remnants of strata that may originally have been more widespread. Ammonites, coarse-shelled pelecypods and belemnites in these rocks were initially identified as Bajocian fauna by Hans Frebold of the Geological Survey of Canada. The ammonites from this collection have been re-examined and at present they are thought to be of middle to late Toarcian age (H.W. Tipper, written communication 1989; Appendix C).

Greyish black tuffaceous siltstone containing concretions and disseminated pyrite unconformably overlies well-layered tuffs and lahar of the Adoogacho Member about 16 kilometres northwest of Tuff Peak. These sediments, less than 10 metres thick, crop out over a 1 square kilometre area. The fine-grained character and presence of sulphide minerals in these rocks suggests a relatively deep water, oxygen deficient depositional environment. Although their age is unknown, based on general lithologic features, they may be time equivalent with deep-marine deposits of the Pliensbachian to Toarcian Wolf Den Formation of the Spatsizi Group (Thomson, 1985).

MAJOR ELEMENT ABUNDANCES

Major element abundances and CIPW norms were determined for 59 samples of variably altered volcanic rocks from the Toodoggone Formation (Appendix A; Map 2, back pocket). The 31 least-altered samples, in which carbon dioxide is less than 1 weight per cent and water less than 3 weight per cent, are used to determine the composition of the volcanic succession. This selected suite consists of 15 ash-flow tuff samples from both the Adoogacho and Saunders members, 14 lava flow samples from the Metsantan Member, and two crystal tuff samples from the Attycelley Member. Bivariate and trivariate discriminant diagrams are used to classify the suite according to magma series and to designate rock names. Within-suite chemical differences for individual analyses from Appendix A are shown on Figure 7; the average composition of rocks from the stratigraphic members are compared in Table 2 and on Figure 8.

The average compositions of ash flows from the Saunders and Adoogacho members are remarkably similiar and are only slightly different from flows of the Metsantan Member. The Attycelley Member has compositional affinity with both the Saunders and Adoogacho members. Silica varies from 64.3 per cent to 54.5 per cent with an average of 59.7 per cent for the entire volcanic suite. Average silica is from 61.6 per cent to 61.4 per cent in the Adoogacho and Saunders members respectively, and 58.2 per cent in the Metsantan Member. A decrease in average K_2O from 3.5 per cent in the Adoogacho and Saunders members to 3.3 per cent in the Metsantan Member corresponds with the silica trend, and alkalis gradually decrease about 1.5 per cent between the stratigraphic lowest to highest members, 8.7 per cent and 7.1 per cent respectively. Alumina is relatively constant between 15.5 per cent and 17.8 per cent with a mean of 16.5 per cent. Titania decreases as silica increases; individual analyses are consistantly greater and average 0.67 per cent in the Metsantan Member compared with the uniform average of 0.53 per cent in volcanic strata of bounding members. Similarly total iron, expressed as FeO*, is approximately 1 per cent greater in the Metsantan Member, 5.9 per cent; but, the Metsantan FeO*/MgO ratio of 2.2 per cent is slightly less than in either the Adoogacho Member, 2.8 per cent, or the Saunders Member, 2.3 per cent.

From member to member, major element variability reflects the greater abundance and more varied phenocryst assemblage of the more silica-rich rocks. The Adoogacho and Saunders members have similar phenocrysts (Table 3), of sanidine, quartz, hornblende and titanite. Brown oxyhornblende is abundant only within the Adoogacho Member. By contrast, the less siliceous Metsantan Member has rare phenocysts of orthoclase and quartz, and light green augite is the dominant mafic mineral. The representative suite is oversaturated in silica, thus there is abundant normative quartz and quartz phenocrysts occur in the volcanic rocks. Although hypersthene is a prominent normative constituent in all analyses, it was not observed in the volcanic rocks of the study area. Normative orthoclase is uniformly abundant, and averages about 20 per cent in the three volcanic members. Most potassium is located in the groundmass, particularly within the Metsantan Member where alkali feldspar phenocrysts are rare. Normative hematite is prominent except in the Saunders Member. Its relative abundance in the norm corresponds with a relatively large Fe_2O_3/FeO ratio and reddish to maroon hue characteristic of volcanic rocks of the Adoogacho and Metsantan members. Lower oxidation state in the Saunders Member is indicated by its diagnostic grey-green color, and absence of oxyhornblende. Corundum, albeit minor, is present in most of the normative calculations. Corundum is common in high-potassium andesites (Gill, 1981).

The most significant feature of major element distribution is the large potassium content of volcanic rocks from the Toodoggone Formation, 3.1 per cent K_2O at 57.5 per cent SiO_2. Moreover, chemical consanguinity between the Adoogacho and Saunder members is consistent with their similar phenocrysts and uniqueness in composition in comparison to the Metsantan Member.

Lava flows of the Metsantan Member are mainly high-potassium andesite (Figure 9) or latite, the potassic analog of trachyandesite (Figure 10). The average composition of the Metsantan Member (Table 2) is similar, with the exception of less TiO_2, to an average trachyandesite (Table 4, No. 6). Ash-flow tuffs, characteristic of both the Adoogacho and Saunders members, have compositions which straddle the field boundary separating high-potassium andesite from high-potassium dacite in the K_2O-SiO_2 diagram. Saturated latite generally includes hornblende, biotite and a few augite phenocrysts in the mode (Williams *et al.*, 1954), whereas dacite of the high-potassium series has a diverse phenocryst assemblage characterized mainly by increased abundance of sanidine, quartz and the notable presence of accessory titanite (Ewart, 1979). The average composition of the Adoogacho and Saunders members

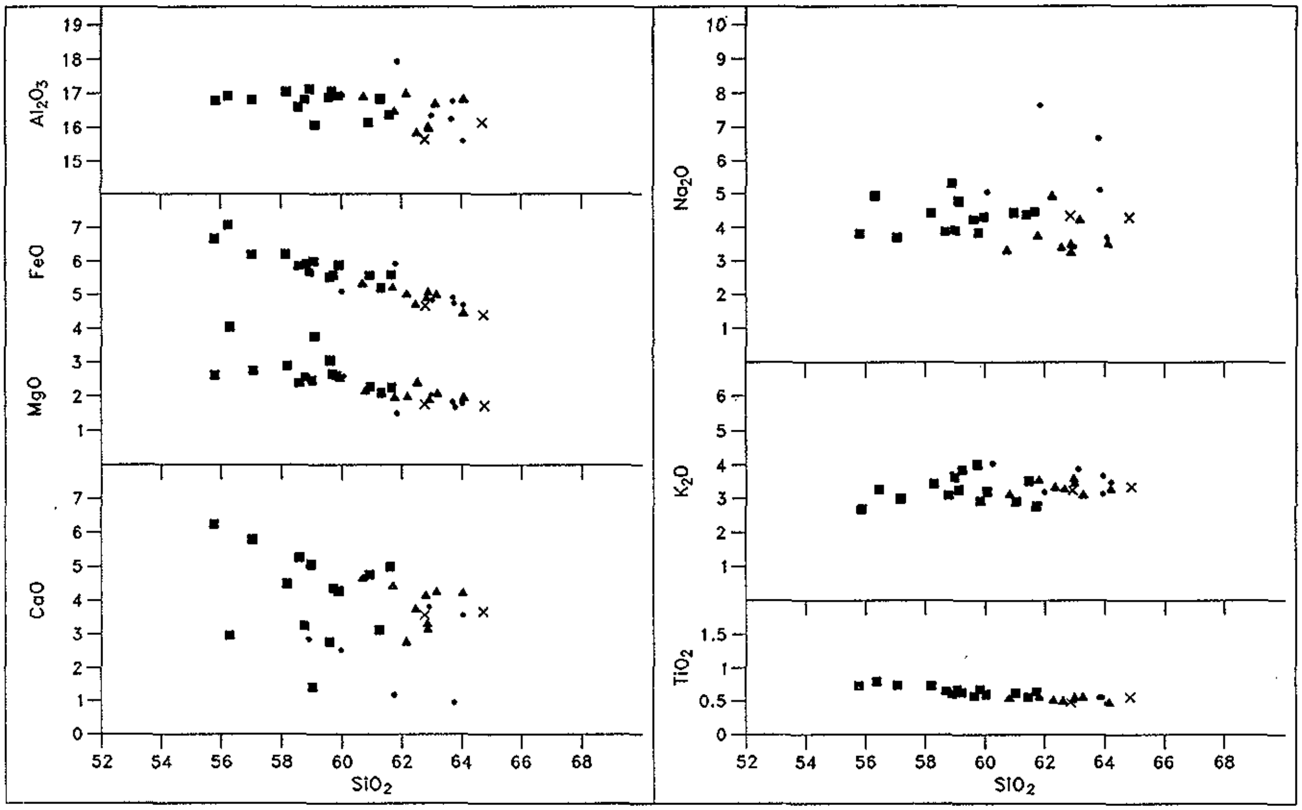


Figure 7. Harker diagram of oxide variation with silica for volcanic rocks of the Toodoggone Formation. Data points represent weight per cent oxide values as determined in Appendix A. (dot) Adoogacho Member, (square) Metsantan Member, (cross) Attycelley Member, (triangle) Saunders Member.

TABLE 2

COMPOSITION OF VOLCANIC ROCKS AND MEAN MAJOR ELEMENT ABUNDANCE OF MAJOR MAP UNITS, TOODOGGONE FORMATION

	Entire Suite[1]	Mean composition[2] of map units 1, 3, 5, 6	Map Unit: 1 Adoogacho member	3 Metsantan member	5 Attycelley member	6 Saunders member	Standard deviation	Range: Maximum	Minimum
SiO_2	59.71	60.04	61.55	58.21	62.45	61.36	2.13	63.30	53.37
TiO_2	0.58	0.59	0.53	0.67	0.53	0.53	0.08	0.80	0.49
Al_2O_3	16.20	16.48	16.54	16.64	15.83	16.35	0.50	17.82	15.53
Fe_2O_3	4.12	4.37	4.96	4.99	4.38	3.01	1.20	6.93	2.48
FeO	1.44	1.31	0.50	1.29	0.55	2.06	0.76	2.39	0.05
MnO	0.16	0.16	0.13	0.17	0.15	0.15	0.03	0.26	0.11
MgO	2.29	2.29	1.84	2.69	1.74	2.10	0.56	4.03	1.42
CaO	3.57	3.77	2.47	4.23	3.68	3.95	1.24	6.24	1.03
Na_2O	3.99	4.26	5.17	4.24	4.28	3.67	0.95	7.54	3.26
K_2O	3.77	3.37	3.51	3.27	3.30	3.45	0.38	4.33	2.71
P_2O_5	0.22	0.23	0.19	0.25	0.24	0.22	0.06	0.34	0.12
H_2O^+	1.78	1.46	1.22	1.62	1.88	1.28	0.73	2.72	
H_2O^-	0.62	0.51	0.70	0.52	0.40	0.37	0.28	1.04	
CO_2	1.02	0.59	0.52	0.48	1.04	0.72	0.48	2.00	
S	0.04	0.02	0.01	0.02	0.01	0.00	0.03	0.12	
Total	99.67	99.72	99.84	99.57	100.44	99.72	0.46	100.65	
No. of samples	55	31	6	14	2	9	31		

[1] Mean calculated on 55 samples; intensely altered samples 40, 41, 54 and 55 rejected from calculation; data from Appendix A.
[2] Mean calculated on 31 least-altered samples with $CO_2 < 1$ wt. % (except 23, 43, 50 and 57) and $H_2O_T < 3$ wt. %.

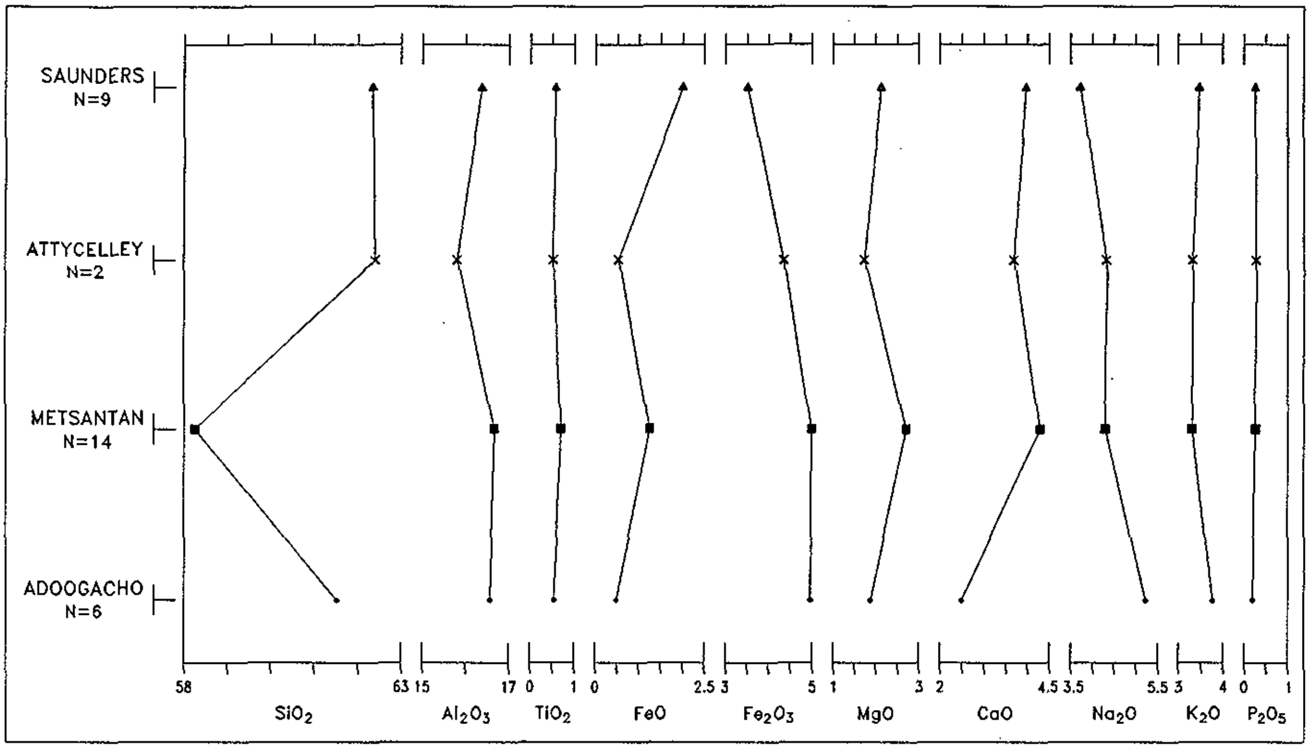


Figure 8. Comparison of average major element abundances for major volcanic members of the Toodoggone Formation. Data points represent the average of oxide values as determined in Table 2.

TABLE 3

PHENOCRYST ASSEMBLAGE AND THE MAIN FEATURES OF CIPW NORMS IN MAJOR STRATIGRAPHIC MEMBERS OF THE TOODOGGONE FORMATION

Stratigraphic member	Phenocryst Volume (%)	Phenocryst Assemblage (diagnostic minerals underlined)*	CIPW Norm
Saunders	35–55	Pl + Sa + Qtz ± rAug + Hbl + Bt + Ttn + Ap	Qtz, Hy, Or
Attycelley	—	Pl + Sa + Qtz ± rAug + Hbl + Bt + Ttn + Ap	Qtz, Hy, Or, Hm
Metsantan	20–30	Pl ± rOr ± rQtz + Aug + Hbl + Bt + Ap	Qtz, Hy, Or, Hm
Adoogacho	30–40	Pl + Sa + Qtz ± rAug + Hbl + Bt + Ttn + Ap	Qtz, Hy, Or, Hm

* Abbreviations: r=rare; Pl=plagioclase; Sa=sanidine; Or=orthoclase; Qtz=quartz; Aug=augite; Hy=hypersthene; Hbl=hornblende; Bt=biotite; Ttn=titanite; Ap=apatite; Hm=hematite.

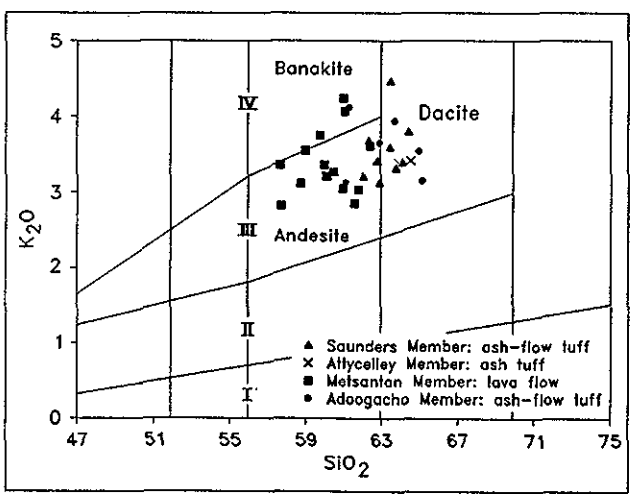


Figure 9. K_2O-SiO_2 diagram for volcanic rocks of the Toodoggone Formation. Field boundaries and nomenclature adopted from Peccerillo and Taylor (1976). Division lines of K_2O mark boundaries between: I. island-arc tholeiite series, II. calcalkaline series, III. high-K calcalkaline series and IV. shoshonite series (Fields I, II and III between 53 and 63 wt% SiO_2 correspond with low, medium and high-potassium fields for orogenic andesites of Gill (1981). Data points are anhydrous weight per cent oxide values.

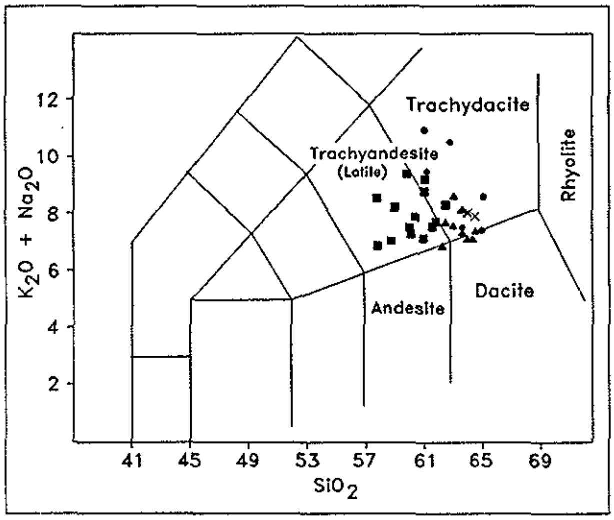


Figure 10. Total alkalis-silica (TAS) diagram for volcanic rocks of the Toodoggone Formation. Field boundaries and nomenclature adopted from LeBas et al. (1986). Data points are anhydrous weight per cent oxide values.

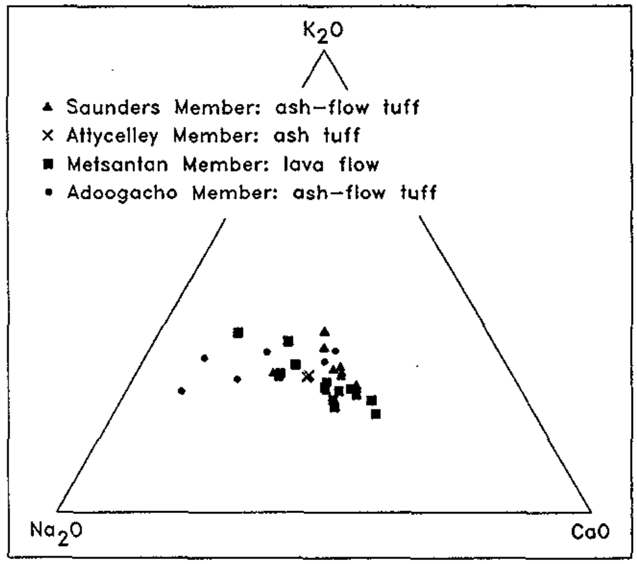


Figure 11. Na_2O-K_2O-CaO ternary diagram for volcanic rocks of the Toodoggone Formation.

TABLE 4

PUBLISHED AVERAGE COMPOSITIONS OF SELECTED VOLCANIC ROCKS

	Shoshonite	Andesite			Banakite	Trachy-andesite	Latite		Latite (Qtz-Banakite)	Dacite		Trachyte
	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	50-56.5	57.6	57.94	58.2	52-59	58.15	54.02	61.25	59-64	63.58	65.01	61.21
TiO_2		0.77	0.87	0.82		1.08	1.18	0.81		0.64	0.58	0.70
Al_2O_3	16-20	17.3	17.02	17.2	16.5-18.5	16.70	17.22	16.01	15.5-20	16.67	15.91	16.96
Fe_2O_3	7-9*	3.1	3.27	3.1	7-9*	3.26	3.83	3.28	3.75-6.5*	2.24	2.43	2.99
FeO		4.3	4.04	4.0		3.21	3.98	2.07		3.00	2.30	2.29
MnO		0.15	0.14	0.15		0.16	0.12	0.09		0.11	0.09	0.15
MgO	2.75-4	3.6	3.33	3.2	1.5-3.5	2.57	3.87	2.22	1-2.5	2.12	1.78	0.93
CaO	6-8	7.2	6.79	6.8	5-6.5	4.96	6.87	4.34	3.5-5.5	5.53	4.32	2.34
Na_2O	2.5-4	3.2	3.48	3.3	2.75-4	4.35	3.32	3.71	2.5-4.5	3.98	3.79	5.47
K_2O	2.5-4	1.5	1.62	1.7	4-6	3.21	4.43	3.87	4-6	1.40	2.17	4.98
P_2O_5		0.21	0.21	0.23		0.41	0.49	0.33		0.17	0.15	0.21
LOI		1.0	1.22	1.3		1.91	0.78	1.85		0.56	1.25	1.71
N	30	2500	2203	2177	19	223	42	146	16	50	578	483

* Total iron expressed as Fe_2O_3

1 Composition range of shoshonite, Table X; Joplin, 1968.
2 Average orogenic andesite, Table 1.1, No. 4; Gill, 1981.
3 Average andesite; Le Maitre, 1976.
4 Average andesite; Chayes, 1975.
5 Composition range of banakite, Table X; Joplin, 1968.
6 Average trachyandesite; Le Maitre, 1976.
7 Average latite; Nockolds, 1954.
8 Average latite; Le Maitre, 1976.
9 Composition range of latite (quartz banakite), Table X; Joplin, 1968.
10 Average dacite; Nockolds, 1954.
11 Average dacite; Le Maitre, 1976.
12 Average trachyte; Le Maitre, 1976.

(Table 2) is similar to average latite (Table 4, No. 8) but has marginally less TiO_2, CaO and K_2O. Similarly, they are within the range of oxide concentrations reported for latite or quartz banakite (Table 4, No. 9). However, K_2O content is significantly less and K_2O/Na_2O is less than 1, which sets them apart from the generally very potassic absarokite-shoshonite-banakite series described by Joplin (1968). Silica is greater, titania is equal and potash is significantly less than average dacite compositions (Table 4, No. 10 and No. 11). On a total alkalis versus silica plot (TAS), the Adoogacho and Saunders analyses cluster in the trachyte field close to the trachyte-trachydacite-dacite boundary. The variation of total alkalis in the Adoogacho Member is because of erratic soda concentration as shown in the Na_2O-

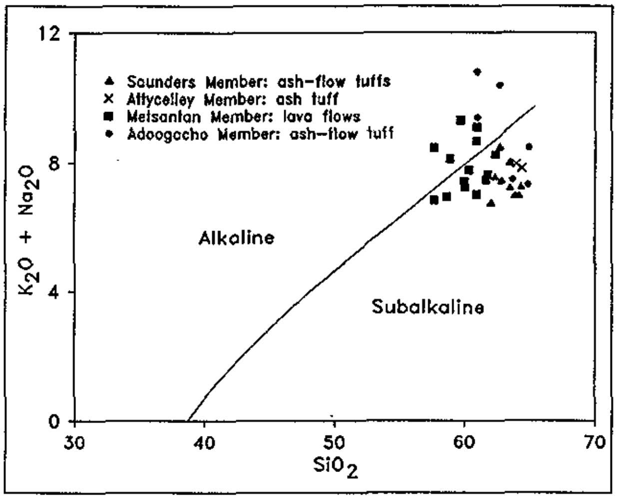


Figure 12. Total alkalis-silica diagram for volcanic rocks of the Toodoggone Formation. Solid line of Irvine and Baragar (1971) separates alkaline from subalkaline compositions. Data points are anhydrous weight per cent oxide values.

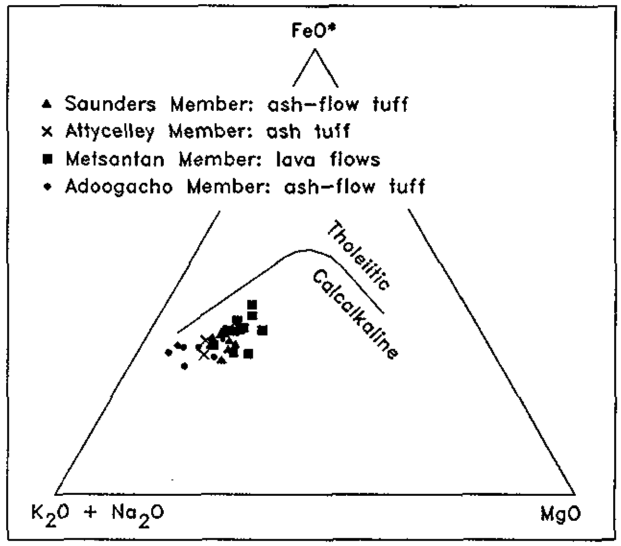


Figure 13. Na_2O+K_2O – $FeO+.8998Fe_2O_3$ – MgO (AFM) diagram for volcanic rocks of the Toodoggone Formation. Curved line separates tholeiitic series from calc-alkaline series compositions.

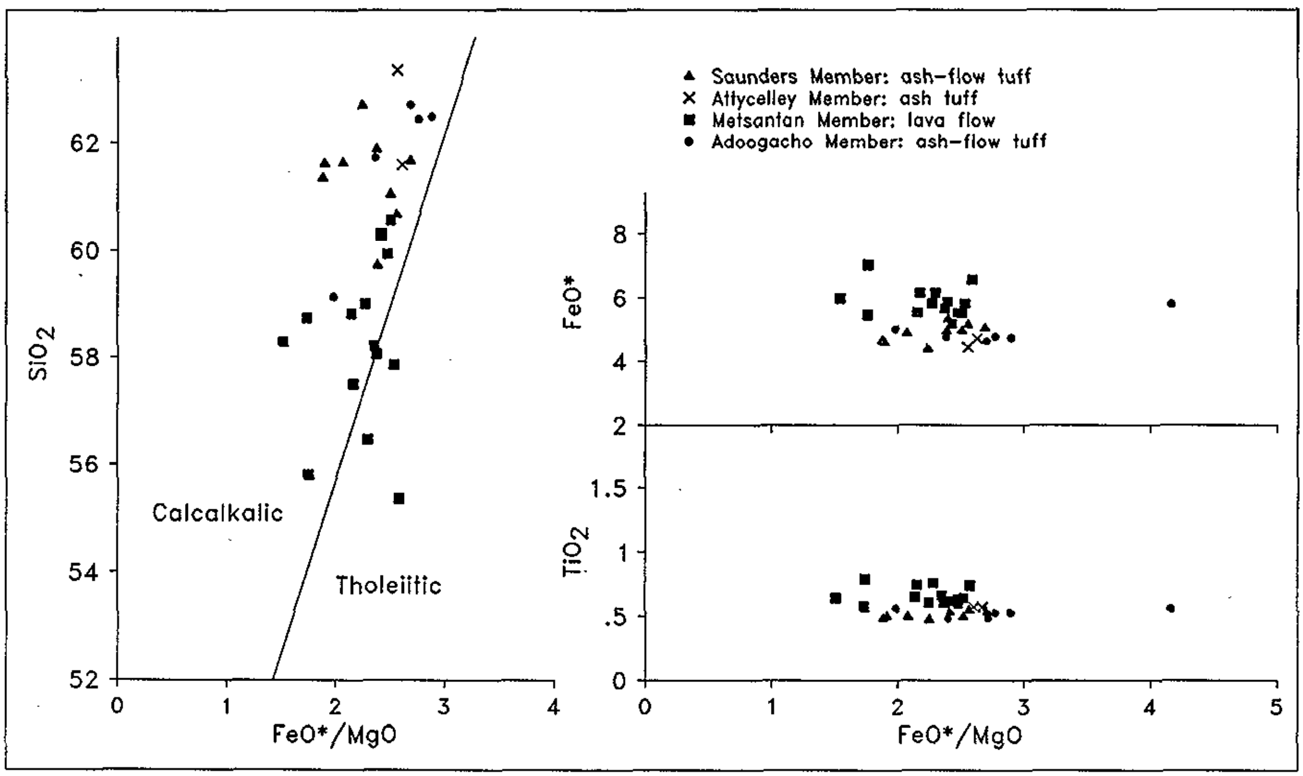


Figure 14. Variations in SiO_2, FeO* and TiO_2 concentrations with increasing FeO*/MgO for volcanic rocks of the Toodoggone Formation. Solid line separates tholeiitic series from calcalkaline series volcanic rocks (Miyashiro, 1974). Data points represent oxide values as determined in Appendix A.

K_2O-CaO ternary diagram (Figure 11). No volcanic rocks in the Toodoggone Formation classify as trachytes on the TAS diagram; the analyzed samples have significantly less potash than average trachyte (Table 4, No. 12), and they lack the large modal proportions of alkali feldspar and contain ubiquitous quartz phenocrysts which is atypical in trachytes (Ewart, 1979). When these data are plotted on a TAS diagram, ignoring the marginal increase in total alkalis and silica because of removing water and carbon dioxide from the analyses (Sabine *et al.*, 1985), only three of the analyzed samples from the Adoogacho Member are trachytes.

Latite to dacite volcanic rocks of the Toodoggone Formation are generally within the domain of subalkaline compositions (Figure 12). Analyses in the alkaline field reflect the slightly greater soda content of the Adoogacho and Metsantan samples relative to those from the Saunders (Figure 11). On an AFM diagram the analysed samples plot on a trend nearly perpendicular to the FeO*-MgO edge of the triangle (Figure 13). Their position indicates that they are well fractionated lavas in the calcalkaline series. Miyashiro (1974) noted that calcalkaline volcanoes have characteristic rapid increases in SiO_2 with small increases in FeO*/MgO ratios, where FeO*/MgO is a measure of fractional crystallization. Moreover, FeO* and TiO_2 decline steadily with increasing FeO*/MgO ratio or advancing fractional crystallization in the calcalkaline series. The position of analysed samples on variation diagrams of SiO_2, FeO* and TiO_2 plotted against FeO*/MgO (Figure 14) confirms a calcalkaline affinity for Toodoggone volcanic rocks. The rate of decrease in TiO_2 and FeO* content in the suite during crystallization is difficult to determine because of the narrow range of silica abundances, between 54.5 and 64.3 per cent, for representative samples of the Toodoggone Formation.

AGE DETERMINATIONS

The chronology of lithostratigraphic members in the Toodoggone Formation were originally constrained by nine K-Ar age determinations, spanning approximately 22 million years, and corroborated by geological field relationships. However, four recent $^{40}Ar/^{39}Ar$ age determinations on new and previously analyzed volcanic rock samples (Clark and Williams-Jones, 1991; Shepard, 1986) substantially reduce the duration of lower and upper cycle volcanism to roughly 7 million years or less.

Six K-Ar ages for this study were done by the Geochronology Laboratory at The University of British Columbia in conjunction with the Analytical Laboratory of the British Columbia Geological Survey Branch (Appendix B). The other three K-Ar ages are reported by Carter (1972) and Gabrielse *et al.* (1980) (Figure 15, Appendix B; sample locations on Map 2, back pocket).

Potassium-argon ages determined from biotite and hornblende in strata representative of the entire stratigraphic range of the Toodoggone Formation vary from 204 to 182 Ma. These ages contrast with $^{40}Ar/^{39}Ar$ dates that vary from 197.6 to 192.9 over the same stratigraphic range. A continuous progression of six K-Ar ages from rocks of the lower volcanic cycle vary from 204 to 197 Ma, whereas deposition of upper cycle volcanic rocks is less well constrained by three K-Ar ages ranging from 189 to 182 Ma. By comparison, the oldest $^{40}Ar/^{39}Ar$ age is concordant with K-Ar dates (late Sinemurian) determined for the lower volcanic cycle. Three $^{40}Ar/^{39}Ar$ dates from the upper volcanic cycle suggest that volcanic activity was relatively brief; it began after an intercycle hiatus and ceased during early Pliensbachian time.

The oldest K-Ar age of 204±7 Ma is on biotite from ash-flow tuff of the Adoogacho Member immediately south of Attycelley Creek (Panteleyev, 1983). The mineral separate that yielded this age was reanalyzed by the $^{40}Ar/^{39}Ar$ method and yielded an age of 197.6±0.5 Ma (Shepard, 1986). In the type area, near Adoogacho Creek, hornblende and biotite from a sample of moderately welded, flat-lying ash-flow tuff have yielded concordant ages of 200±7 and 199±7 Ma, respectively. Biotite from another sample of weakly welded ash-flow tuff west of Deedeeya Creek is

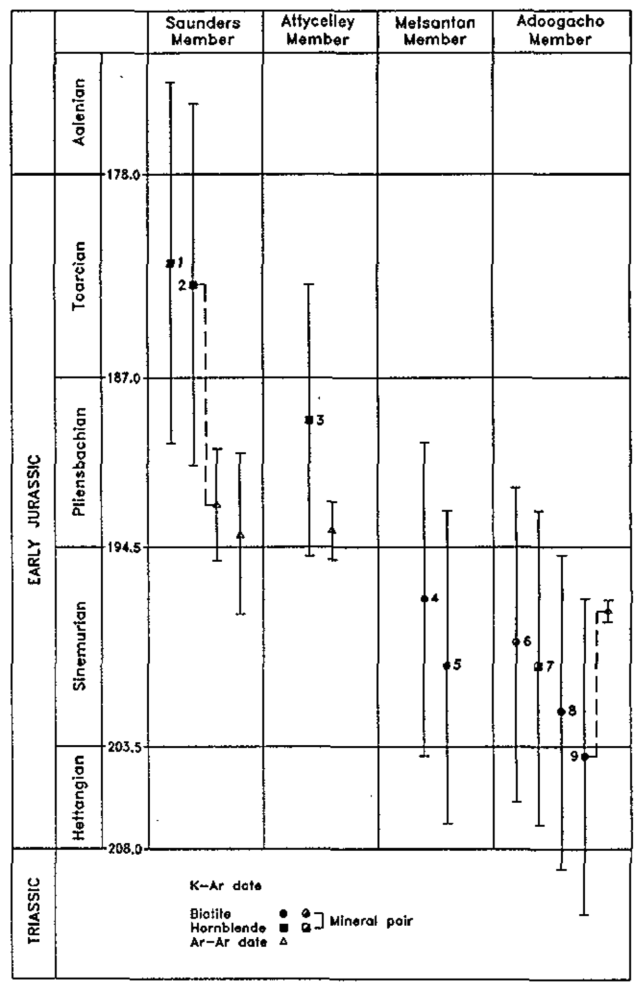


Figure 15. Comparison of K-Ar and Ar-Ar age determinations from biotite and hornblende in volcanic rocks of the Toodoggone Formation. Numerals correspond with location numbers from analyses in Appendix B. Stage boundaries are after Harland *et al.* (1990) and the Triassic-Jurassic boundary in British Columbia follows the time-scale calibration of Armstrong (1982).

202±7 Ma. Ages of the Adoogacho Member near Adoogacho Creek are believed to represent the inception of pyroclastic eruptions upon basement rocks of the Takla Group. Lava flows of the Metsantan Member have ages from biotite of 200±7 and 197±7 Ma. The apparently older date is thought to represent a relatively higher level in the succession of flows underlying the north slope of Metsantan Mountain, whereas the younger age is from flows occupying a block that has a faulted contact with rocks of the Adoogacho Member to the west of Moyez Creek.

A Rb-Sr whole-rock isochron age of 185±5 Ma is reported by Gabrielse *et al.* (1980) for strata near Oxide Peak. This area is underlain largely by the McClair Member, a heterogeneous succession of interlayered tuffs, flows and epiclastic rocks that are intruded and variably altered by pink porphyritic andesite dikes and subvolcanic plugs. Discordance of this Rb-Sr isochron age compared with significantly older K-Ar ages obtained for the Metsantan Member, which either underlies or in part interleaves the McClair Member, may reflect postdepositional mobility of radiogenic strontium associated with the emplacement of numerous hypabyssal intrusions that crop out in the vicinity of Oxide Peak.

The Attycelley Member has an age determined by the K-Ar method on hornblende of 189±6 Ma (Carter, 1972). This sample, collected several kilometres north of Attycelley Creek, is close to the conformable upper contact of a thick succession of recessive pyroclastic rocks that are overlain by ash-flow tuff of the Saunders Member. The Attycelley Member, near Jock Creek, is unconformable on rocks of the Takla Group. Hornblende-bearing tuff, supposedly near the top of the Attycelley Member in the Jock Creek section, has an $^{40}Ar/^{39}Ar$ age of 193.8±2.6 Ma (Clark and Williams-Jones, 1991). This date, which infers the minimum time of emplacement of the Attycelley Member, is conjectural as the location of the dated sample (Sample 8HM 11-14, Unit 9, p. 51; Marsden, 1990) is from an area that is demonstrably underlain by strata of the Saunders Member. Crystal-rich ash-flow tuff of the Saunders Member which is comformable on the Attycelley Member about 1 kilometre north of Carter's sample site has an age determined by K-Ar on hornblende of 183±8 Ma (Wanless *et al.*, 1978). A concordant K-Ar age on hornblende of 182±8 Ma is reported from compositionally identical rocks more than 20 kilometres to the north (Wanless *et al.*, 1979). These ages, derived from ash-flow horizons close to the base of the Saunders Member, are a minimum age for the highest stratigraphic rocks of the Toodoggone Formation. However, recently reported $^{40}Ar/^{39}Ar$ ages of 192.9±2.7 Ma at a new sample site and 194.2±3.6 Ma (Clark and Williams-Jones, 1991) from a sample near the base of the Saunders Member, previously dated by the K-Ar method, define a new minimum age for volcanism of the Toodoggone Formation.

The apparent time which separates deposits of the uppermost lower cycle (197 Ma) and lowermost upper cycle (189 Ma) volcanic rocks is within the 1σ error of the K-Ar method; therefore, this hiatus may not necessarily signify a long-lived pause in volcanism between eruptive cycles or it may be as long as 8 Ma. New $^{40}Ar/^{39}Ar$ ages also refute a protracted intervolcanic cycle hiatus. Except for conglomeratic deposits at the base of the Attycelley and Saunders members, which are found locally along the margin of the Black Lake stock, a regional unconformity that apparently separates the eruptive cycles is not widely recognized in the study area.

RELATIONSHIP OF TOODOGGONE FORMATION AND HAZELTON GROUP IN THE TOODOGGONE RIVER MAP AREA

Gabrielse *et al.* (1977) originally mapped strata east of the present study area as part of the Hazelton Group. Detailed mapping conducted in this study within a 15-kilometre square area south of Toodoggone Lake between Mount Graves and The Pillar (Map 1 and Chapter 2: Lower and Middle Jurassic Hazelton Group) suggests that these rocks are a facies of the Toodoggone Formation. A similar facies relationship probably exists for other rocks of the Hazelton Group found east of the study area; however, more detailed mapping is required.

The area south of Mount Graves is underlain by a west-dipping homocline of green and maroon hornblende, augite and plagioclase-phyric lava flows with rare quartz phenocrysts. These flows are the top and bottom of a heterogeneous sequence of interlayered tuffs, breccia and volcanic conglomerate; rare interbeds of limestone and thin flows of basalt and rhyolite are found in places. Based on the rock type and constituent minerals, the lava flows in particular correlate most closely with those of the Metsantan Member. Hornblende and pyroxene-porphyritic andesite flows sampled at Mount Graves (Forster, 1984) show little variation in major element abundances in comparison to latite flows of the Metsantan Member. A major lithologic difference is volcanic conglomerate and associated finer grained epiclastic beds, lapilli-block tuff and breccia are significantly more abundant in the Mount Graves area, whereas flows of the Metsantan Member greatly exceed the volume of epiclastic and volcaniclastic interbeds within the study area. Moreover, basalt and rhyolite extrusions occur as discrete layers in the Mount Graves area; but are absent, with the exception of relatively few dikes and sills cutting strata of the Toodoggone Formation.

The rocks in the Mount Graves area probably represent an eastward extension of the Toodoggone Formation and more specifically the Metsantan Member. Variations in rock type between the Mount Graves area and the closest rocks of the Metsantan Member, several kilometres to the west near Saunders Creek, are explicable in terms of the following alternatives:

1. they are coeval deposits erupted from a common volcanic centre and various facies are exposed at different structural levels by steeply dipping normal faults, or
2. they are coalescing deposits erupted simultaneously from separate, but nearby volcanic centres.

The first explanation is favoured because a fault apparently delimits an elongate granodiorite pluton that underlies the area between Mount Graves and Saunders Creek.

Although movement on this structure is unknown, it is presumed small because apparently similar rock sequences are traceable laterally between areas.

INTRUSIVE ROCKS

Volcanic strata of the Toodoggone Formation are spatially associated with stocks and subvolcanic porphyritic plutons, and cut by a variety of dikes. The largest and most significant plutons are barely unroofed stocks that have low relief in the west and central study area (Figure 16). In contrast, craggy mountains expose their uplifted counterparts near Geigerich Peak in the southeast part of the study area. These Early Jurassic granitoids, designated the Black Lake Plutonic Suite (Woodsworth *et al.*, 1988), form part of an arcuate belt of Late Triassic and Early to Middle Jurassic stocks and composite batholiths that are exposed intermittently along the east margin of the Bowser basin then swing westward to occupy the cores of the Stikine and Skeena arches (Figure 17). The spatial and temporal relationship of these intrusions with predominately calcalkaline Upper Triassic and Lower Jurassic volcanic successions suggests that they probably mark the locus of an extensive magmatic arc.

STOCKS

The Black Lake stock underlies 115 square kilometres centred on Black Lake. It is exposed from Castle Mountain southeast to the Finlay River and from west of Drybrough Peak to Sturdee River. The north-northeast contact is intrusive, steeply dipping and locally faulted; blocks of the Asitka Group and the Takla Group are uplifted and disrupted along the margin. No contact relationships with the Toodoggone Formation were observed.

The Black Lake stock is a pink granodiorite and quartz monzonite of coarse to medium-grained, hypidiomorphic-granular plagioclase, orthoclase, quartz, hornblende and biotite. Accessory minerals include apatite, zircon and magnetite. Partly chloritized brown biotite and green hornblende locally define a weak foliation near the pluton margin.

Similar plutons crop out near Spruce Hill, east of Saunders Creek and north to McClair Creek, and between Attycelley and Kemess creeks. They are commonly cut or associated with nearby pink porphyritic andesite dikes. Associated with the pluton near Kemess Creek is a porphyry copper-molybdenum occurrence within a pendant of intensely clay-altered rocks mapped as the Takla Group (Cann, 1976). Quartz veins cut the pluton and bordering volcanic rocks of the Takla Group northwest of Castle Mountain. Contact metamorphism of limestone to marble and locally skarn also occur at Castle Mountain and is common within screens of Asitka and Takla strata near Drybrough Peak.

POTASSIUM-ARGON AGE DETERMINATIONS

Potassium-argon ages are reported for the Black Lake stock (Gabrielse *et al.*, 1980) and compositionally similar granitic rocks adjacent to the Kemess porphyry copper-molybdenum occurrence (Cann and Godwin, 1980; Figure 18 and Appendix B, sample locations are on Map 2). Potassium-argon age determinations for hornblende-biotite granodiorite at Kemess are 207±7, 182±6 and 203±6 Ma. The oldest, 207 Ma on hornblende, and the youngest, 182 Ma on biotite, are from the same sample collected near the margin of the pluton. The other age on hornblende of 203 Ma, also from the pluton's margin at a nearby location, confirms an Early Jurassic or older emplacement. An age on whole rock of 182±6 Ma for intensely quartz-sericite-pyrite-altered volcanic rock, in a screen of the Takla Group at Kemess, is the same as the K-Ar age on biotite from nearby granodiorite. Cann and Godwin (1980) attribute this younger age to argon loss in biotite during a post-emplacement hydrothermal event which reset the K-Ar isotopic system in samples close to the present margin of the pluton. A Rb-Sr isochron age of the Kemess pluton is 190±4 Ma. The discrepancy in time with the average age

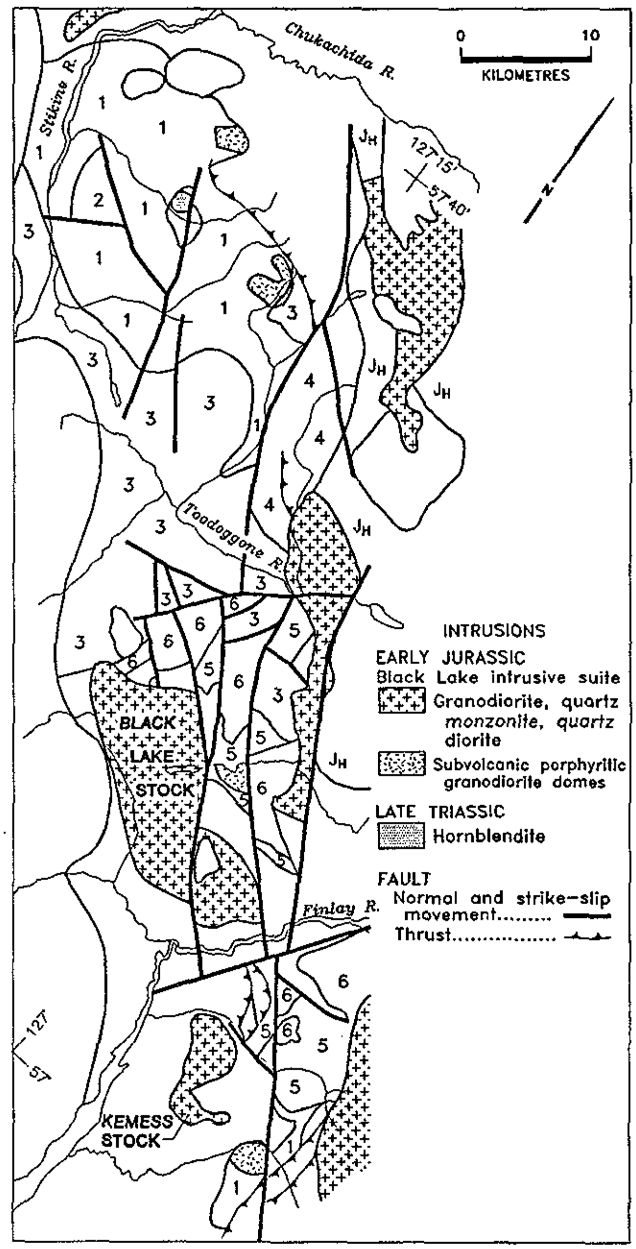


Figure 16. Distribution of the Early Jurassic Black Lake intrusions and subvolcanic porphyritic domes in the study area. Numerals correspond to lithostratigraphic units of the Toodoggone Formation.

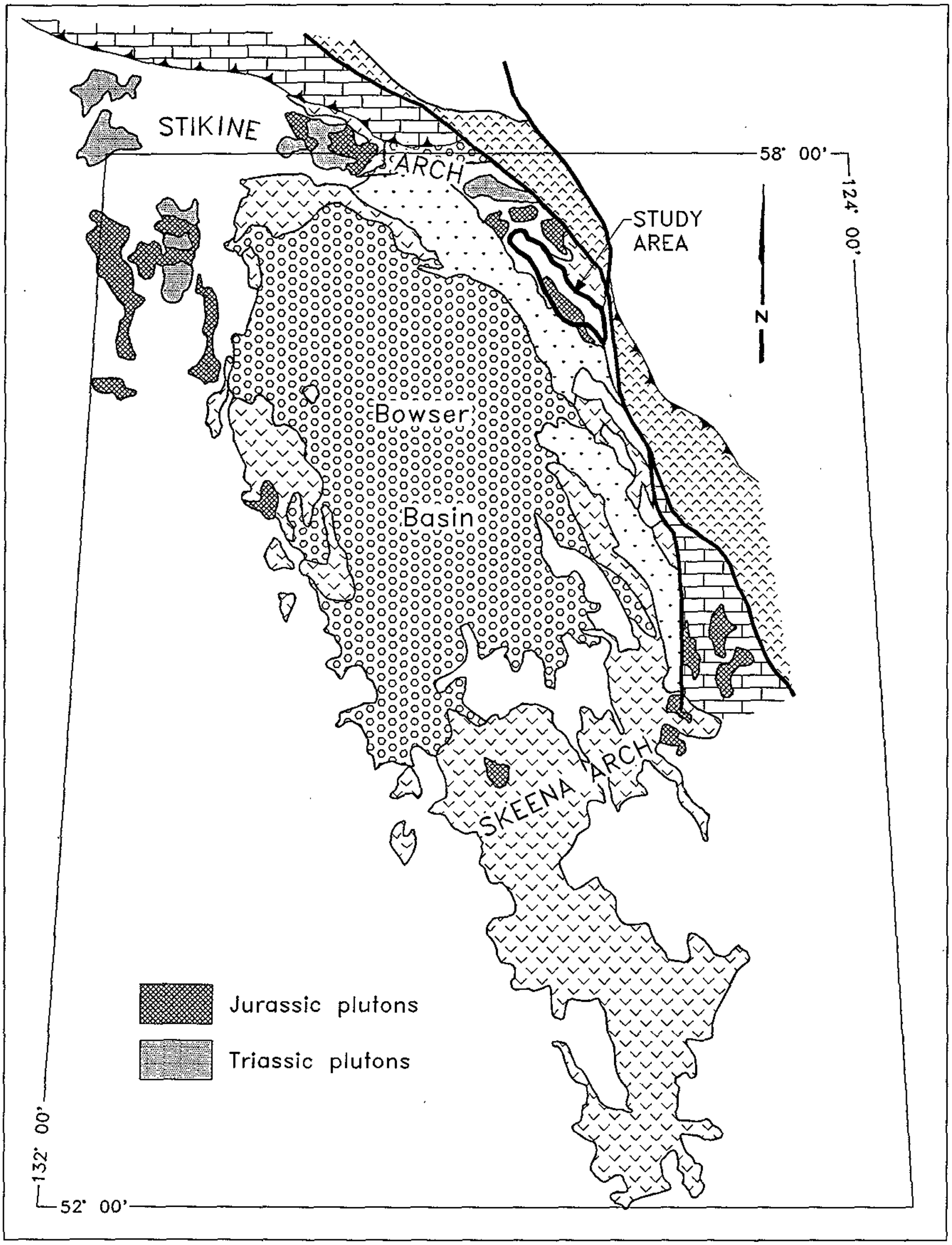


Figure 17. Distribution of Late Triassic and Early Jurassic plutons along the axes of the Stikine and Skeena arches.

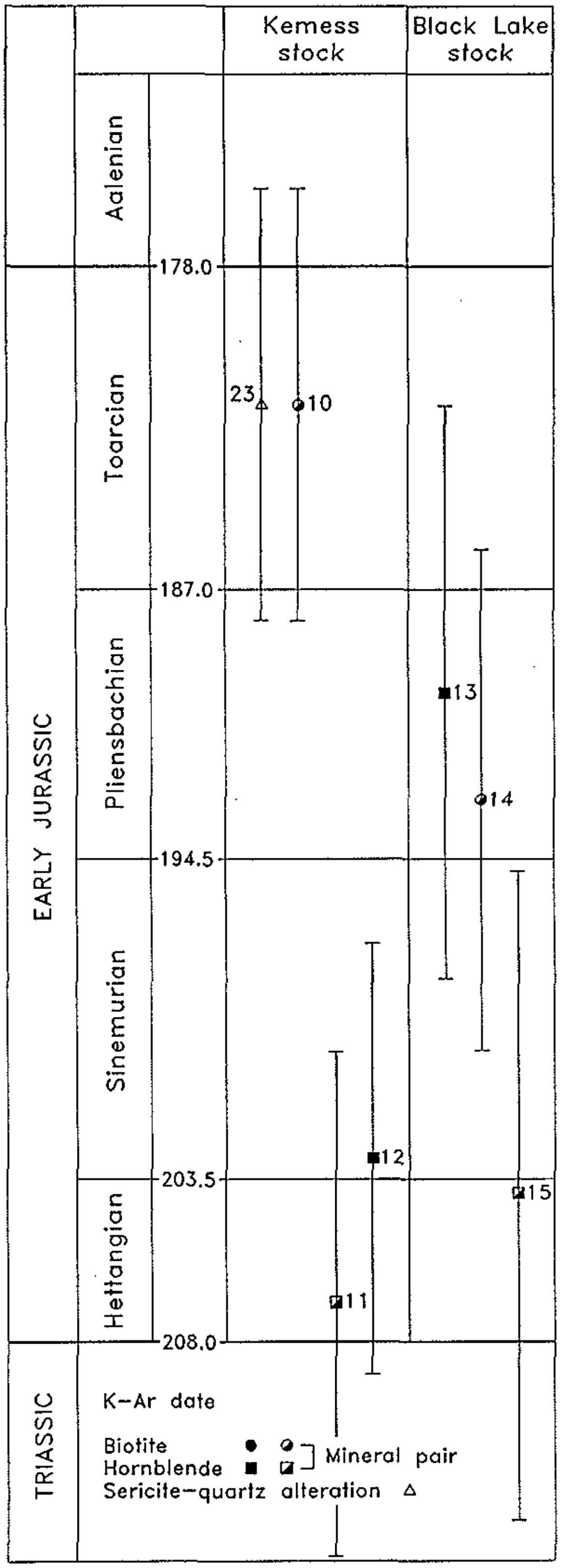


Figure 18. Published K-Ar age determinations on biotite and hornblende from intrusions in the study area. Numerals correspond to location numbers from analyses in Appendix B. Stage boundaries are after Harland *et al.* (1990) and the Triassic-Jurassic boundary in British Columbia follows the time-scale calibration of Armstrong (1982).

determinations on hornblende of 204±7 Ma is thought to represent cooling of the Kemess pluton (Cann and Godwin, 1980).

The Black Lake stock has ages of 204±9, 193±7 and 190±8 Ma. The age on hornblende of 204 Ma is identical to the average age of hornblende from Kemess. It is also concordant, within the error limits, with the age on biotite of 193 Ma from the same sample of granodiorite taken near the west margin of the pluton at Sturdee River. An age on hornblende of 190 Ma was determined from weakly foliated biotite-hornblende quartz monzonite near the geographic centre of the Black Lake stock at Black Lake.

The different ages for hornblende and biotite may indicate crystallization cooling of the pluton below the closure temperatures for these minerals (Table 4-1 in Harland *et al.*, 1990).

Subvolcanic Porphyritic Plutons

Subvolcanic porphyritic plutons similar in composition and mineral constituents to latite-dacite volcanic rocks of the Toodoggone Formation occur near the headwaters of Adoogacho and Deedeeya creeks in the north, immediately adjacent to Kemess Creek in the south, and at Jock Creek. The circular pluton dissected by Deedeeya Creek is the largest, encompassing roughly 5 square kilometres. Monolithic breccia, made up of poorly sorted blocks derived from the pluton, crops out in places along the east flank. Along part of the south contact a conglomerate bed has cobbles eroded from the pluton. It passes upward into well-layered, fine to coarse-grained epiclastic beds that contain abundant clasts of ash-flow tuff from the Adoogacho Member. The stratigraphic relationship of these epiclastic rocks with nearby flat-lying ash flows is uncertain; although the ash flows appear to locally onlap the intrusion and have not been altered by it. These features suggest that the pluton was uplifted and exhumed before deposition of the Adoogacho Member ceased.

Phenocrysts are as much as 50 volume per cent in these plutons. The dominant phenocryst is plagioclase. Remnants of amphibole and pyroxene, which make up 7 volume per cent of the rock, are pseudomorphed by variable combinations of granular opaques, carbonate and chlorite. Resorbed and bipyramidal quartz is up to 2 volume per cent and sanidine is rare. Carbonate, clay minerals and epidote of probable deuteric origin selectively replace plagioclase. Several per cent pyrite is ubiquitous in the domes at Kemess and Adoogacho creeks. Xenoliths are present throughout the rock and locally up to 10 per cent by volume within the intrusion at Kemess Creek; most are basalts from the Takla Group, and rare quartzite which might suggest the presence of metamorphic rocks at depth.

At Jock Creek, a dacitic flow-dome, characterized by phenocrysts of quartz, biotite, hornblende, and rare granitoid xenoliths, is reported to host precious metals at the Shasta property (Marsden, 1990). Epiclastic rocks, coarse breccia and variably welded pyroclastic flow and air-fall tuffs of the Attycelley Member comprise a crudely bedded apron on the periphery of this dome.

Dikes and Sills

North and northwest-trending dikes and few sills cut strata of the Toodoggone Formation. Although most dikes are widely spaced, solitary bodies, they form en echelon swarms in the general vicinity of the headwaters of McClair Creek to The Pillar. Individual dikes are traceable intermittently along strike for distances exceeding 1000 metres; some are of sufficient size to be portrayed on Map 1. The contacts are typically sharp and steeply dipping with almost no alteration minerals. Andesite dikes predominate, basalt is less common, and dacite to rhyolite dikes are rare.

ANDESITE

Andesite dikes are most prominent within volcanic rocks of the lower cycle of the Toodoggone Formation from the headwaters of McClair Creek to the Finlay River; there is a spatial and possible genetic association with granodiorite and quartz monzonite plutons. Unaltered dikes cut broad areas of pervasively altered quartz-clay rocks at Silver Pond, at Alberts Hump and at the Kemess mineral prospect. Typically, the dikes are resistant in relief, sometimes forming ridges. They average 10 to 15 metres in width but are up to 55 metres wide. The contacts are generally sharp; epidote alteration of country rocks occurs only rarely.

The dikes have a diagnostic pink to red colour and a medium to coarse porphyritic texture which is imparted by plagioclase phenocrysts (Plates 9A and B). Quartz phenocrysts, where present, are resorbed grains less than 1 millimetre in diameter. Pyroxene, amphibole and biotite are typically replaced by epidote, chlorite and opaque granules. Potassium feldspar phenocrysts, present as rare orthoclase megacrysts, occur in a plug near the headwaters of McClair Creek.

BASALT

Basalt dikes crosscut andesite dikes and also the youngest strata of the Toodoggone Formation. They are spatially associated with sills or lava flows(?) that appear to have conformable contacts in areas east and west of Saunders Creek. A sill, estimated to be at least 75 metres thick, is exposed on the road crossing the east-facing slope below the Lawyers AGB zone. Solitary dikes occur throughout the study area, although they are particularly widespread in the area east of Saunders Creek. Swarms of basalt dikes trend northwest between Mount Graves and The Pillar. They always weather recessively and average about 1 metre wide, but locally can be 30 metres wide.

Basalt dikes typically have several per cent amygdules in a fine-grained, dark green groundmass (Plate 9C). In contrast, the sills are porphyritic with augite phenocrysts or crowded felty plagioclase set in a purple or dark-coloured groundmass. Both the dikes and sills have plagioclase, augite and rarely hornblende in a pilotaxitic groundmass of plagioclase microlites (Plate 10A). Plagioclase laths, averaging 1 millimetre long, are partly replaced by sericite, epidote and carbonate. The composition of plagioclase varies between andesine and labradorite. Light green augite forms equant solitary crystals and cumulophyric clusters between 1.5 and 3 millimetres in diameter, respectively; it is also present with opaque granules and intergrown epidote and chlorite in interstices between groundmass plagioclase. Apatite prisms are ubiquitous in trace amounts. The amygdules in dikes are generally calcite and less commonly a mixture of the zeolites: thomsonite, analcime, natrolite and minor heulandite.

DACITE AND RHYOLITE

West-northwest-trending dacite dikes cut the Saunders Member west of the Baker minesite and Saunders Creek. They contain sanidine and readily discernible quartz phenocrysts; features which distinguish them from texturally similar andesite dikes (Plate 9D). Dacite dikes are up to 30 metres wide; in places they have columnar joints.

Rhyolite dikes are grouped with the dacites, even though they only seem to cut strata as young as the Metsantan Member. The rhyolite dikes are relatively unaltered and have no extrusive equivalents preserved in the study area. They contain phenocrysts of sanidine, plagioclase, quartz, biotite and sparse titanite. Idiomorphic sanidine crystals and resorbed or bipyramidal quartz are the most abundant and diagnostic phenocrysts (Plate 10B). Locally potassium feldspar is intergrown with quartz, producing graphic texture. The groundmass of the rhyolites is a cream to pink, fine-grained, unidentifiable mineral aggregate.

METAMORPHISM

Volcanic strata of the Toodoggone Formation are typically non-schistose with original textures generally well preserved, and in places remnants of the vitric matrix in ash flows of the Adoogacho and Saunders members remain. Locally, primary hornblende and pyroxene phenocrysts lack replacement by secondary minerals.

Zeolite minerals are ubiquitous at all stratigraphic levels in the Toodoggone Formation in three principal forms:

1. pseudomorphing phenocrysts and pyroclasts, and infilling matrix voids
2. in veins and lining fractures
3. as primary infillings of amygdules in basalt dikes

In general, zeolites weakly replace phenocrysts and matrix of rocks, and they appear to be more common within permeable, less consolidated pyroclastic successions. A systematic study of stratigraphic position, bulk rock composition and permeability of volcanic rocks in relation to zeolitic zoning patterns in the Toodoggone Formation has not been done.

The most widespread zeolite minerals, confirmed by x-ray analysis, are laumontite and heulandite. Both zeolites coexist in the volcanic rocks with albitized plagioclase, quartz, and small amounts of calcite, chlorite, epidote and fine-grained illite-montmorillonite. Rarely, celadonite is found in volcaniclastic rocks of the Metsantan Member at Tuff Peak. Near Mount Graves, prehnite-pumpellyite mixed with epidote coat a fracture cutting volcanic rocks, which are presently mapped as the Hazelton Group, although they tentatively correlate with the Metsantan Member in this study. With the exception of this occurrence, prehnite and pumpellyite have not been recognized elsewhere in the Toodoggone Formation, but they commonly occur within the underlying mafic volcanic rocks of Takla Group.

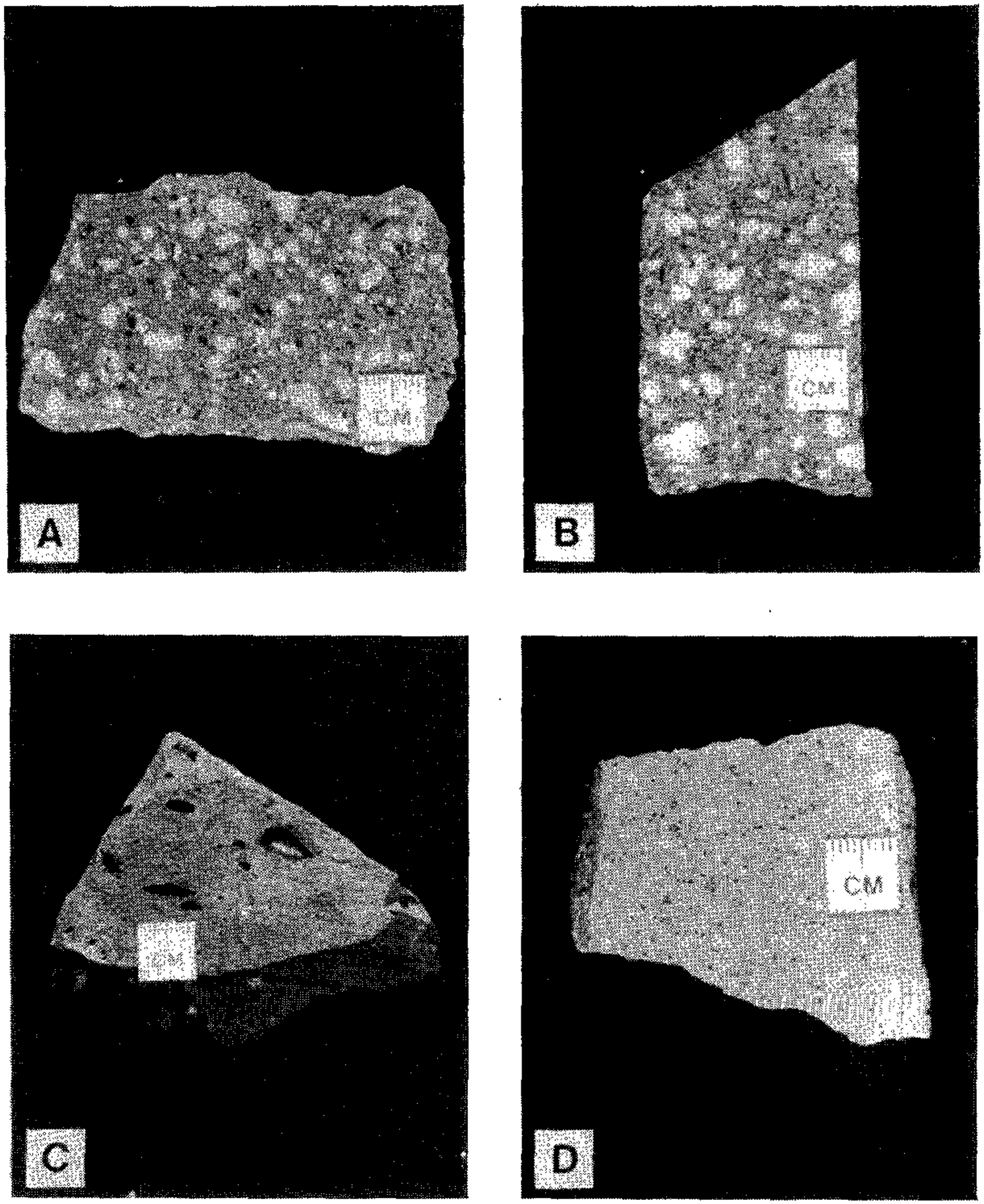
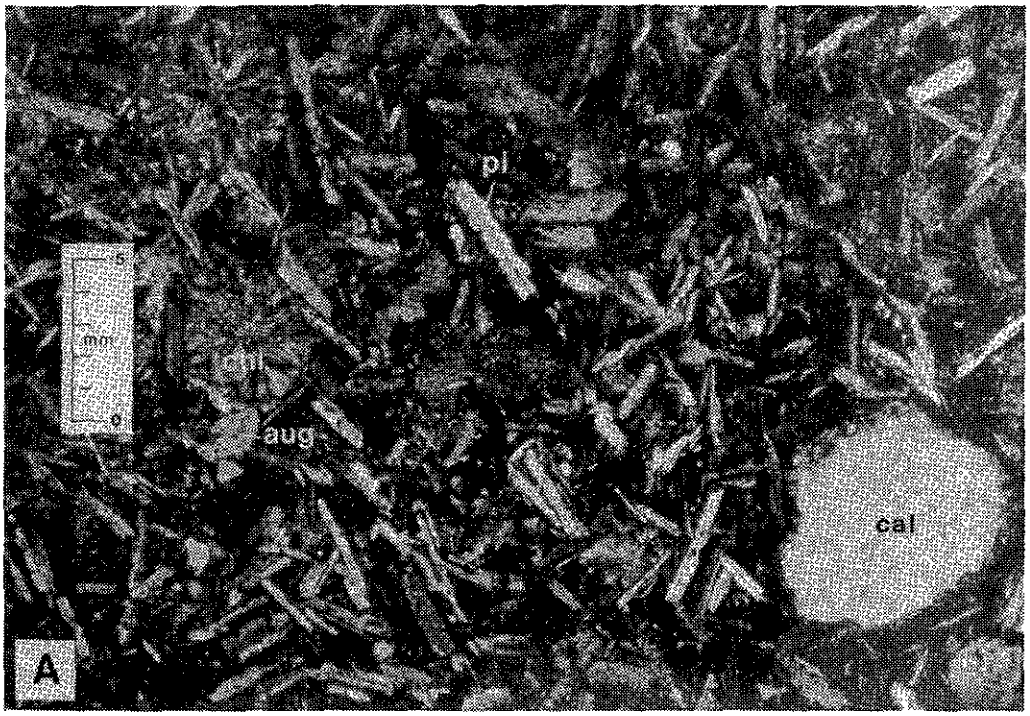


Plate 9. Dikes. A, B. Typical porphyritic andesite dikes with coarse, subhedral plagioclase and smaller mafic phenocrysts set within a pink to red-coloured matrix. Note the similar texture and phenocrysts with those in latite flows of the Metsantan Member in Plate 5. C. Basalt dike with fine-grained, aphyric texture and vugs infilled with calcite. D. Rare rhyolite dike containing quartz and sanidine phenocrysts in an aphanitic flesh-pink coloured matrix.



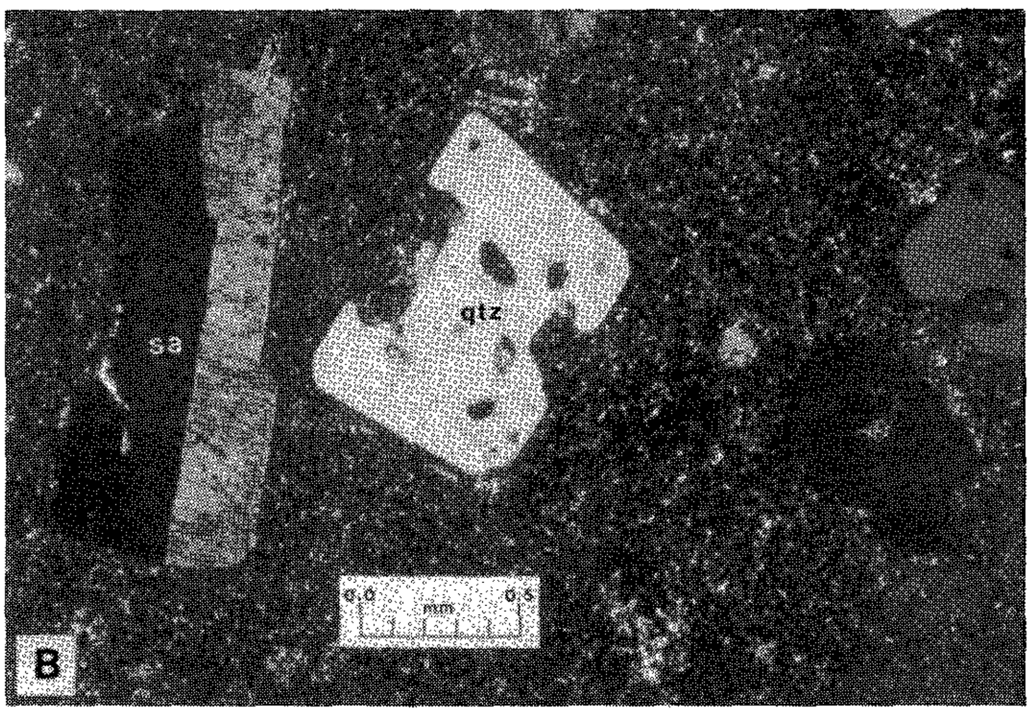


Plate 10. Dikes. A. Photomicrograph (ppl) of the basalt dike from Plate 9C. Plagioclase (pl) microlites with felty texture and augite (aug) phenocrysts in a groundmass of chlorite, epidote and opaque granules. Note the vugs filled with radiating aggregates of chlorite (chl) and calcite (cal). B. Photomicrograph (ppl) of rhyolite dike from Plate 9D with unaltered sanidine (sa) and resorbed quartz (qtz) phenocrysts in a fine-grained groundmass of quartz and alkali feldspar.

The laumontite-quartz assemblage in the volcanic strata is indicative of low pressure and low temperature conditions in the very low grade of regional metamorphism (Coombs *et al.*, 1959; Winkler, 1979). The transition to strata with prehnite or pumpellyite suggests slightly higher temperature conditions that may reflect a local increase in depth of burial (Zen, 1974).

Stilbite is restricted to veins with or without calcite and laumontite. Locally, these veins cut ash flows as young as the Saunders Member and, rarely, hydrothermally altered wallrocks of the Takla Group at the Baker mine. These veins may have a hydrothermal origin; their relationship with regionally distributed authigenic hydrated calcium-aluminum silicates is uncertain.

STRUCTURAL FEATURES

Rocks of the Toodoggone Formation are disrupted by numerous steeply dipping normal faults, and a few strike-slip and thrust faults that juxtapose successions of differing stratigraphic level. Composite layered sections of the Toodoggone Formation are undeformed, shallow-dipping beds which locally define gentle flexures. In contrast, younger and older volcanic and sedimentary rocks are locally folded. The major faults are shown on Figure 19 and Map 1; structural sections are included on Figure 20 and in the back pocket.

MAJOR FAULTS

The dominant structures are steeply dipping faults which define a prominent northwest-trending regional structural fabric. In turn, high-angle northeast-trending faults appear to truncate and displace northwest-trending faults. Collectively, these faults form a boundary for variably tilted and rotated blocks that are underlain by monoclinal strata.

The Toodoggone fault which intersects the Toodoggone River valley and the Cascadero fault that coincides with the Finlay River valley, divide the Toodoggone Formation into three segments. The northwest and southeast segments have basal rocks of the Toodoggone Formation resting unconformably on rocks of the Takla Group. Inclined bedding within these segments generally faces towards the central segment. The central segment is dissected by the prominent northwest-trending Castle, Drybrough and Saunders faults. Because of uplift along the perimeter of the Black Lake stock, older rocks of the Takla Group occupy much of the western and southern part of the central segment. These rocks are unconformably overlain by a north to northwest-facing homocline of interlayered pyroclastic and epiclastic rocks of the Attycelley Member which, in turn, are capped by ash-flow tuffs of the Saunders Member. These ash flows appear to be thickest within panels dropped between the Castle and Saunders faults and immediately south of the Toodoggone fault, suggesting that they may have been ponded within a structural depression named the central Toodoggone depression (cross-section C-F in Figure 20).

Feldspar-porphyritic andesite and a few basaltic dikes trend consistently north to northwest. Although solitary dikes are widespread, swarms of dikes are prevalent in the area between Saunders fault, Mount Graves and The Pillar and extend northwest to the headwaters of McClair Creek.

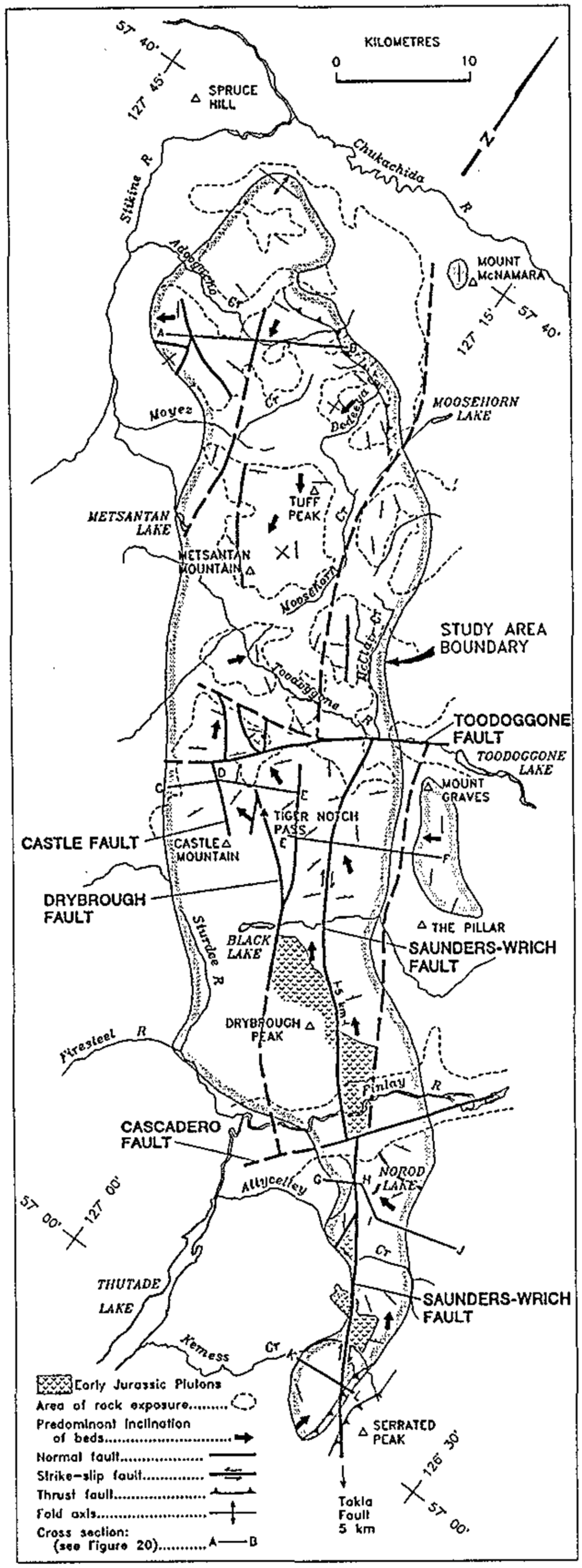


Figure 19. Major faults in the study area. The map shows the dominant northwest fabric of faults offset by northeast-trending structures. Dextral motion on the Saunders-Wrich fault is indicated by displacement of volcanic and plutonic rocks by as much as 5 kilometres.

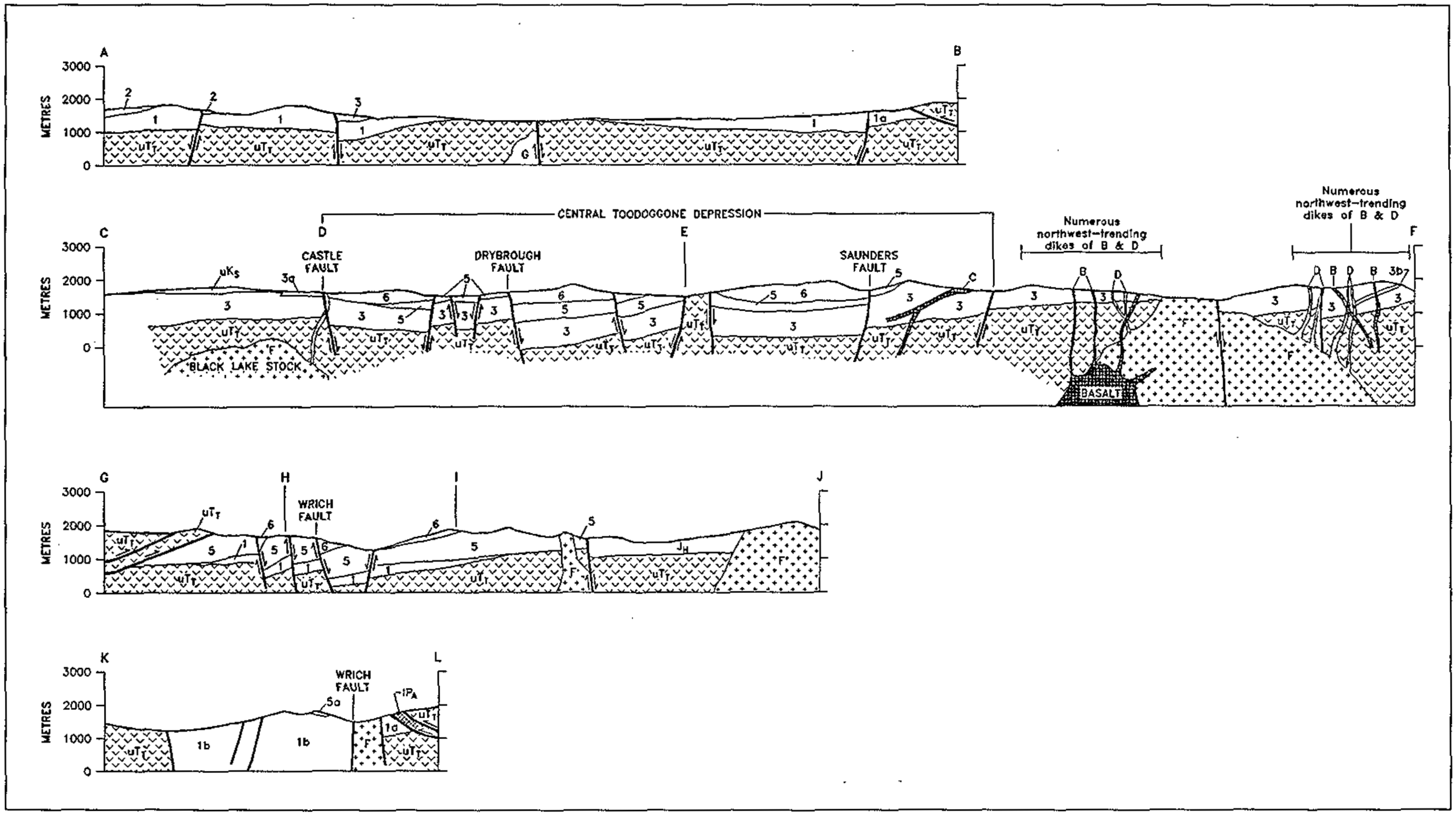


Figure 20. Stratigraphic cross-sections of the Toodoggone Formation.
Sections correspond with locations on Figure 19 and Map 1.

A northwest-elongated granodiorite pluton, also in this general area, appears to be delimited by steep faults that intersect the Toodoggone fault east of the Saunders fault.

West of Serrated Peak, several thrust faults imbricate north-trending slices of the Asitka Group and Takla Group (Gabrielse *et al.*, 1977). These faults dip east and override rocks of the Adoogacho Member to the west. About 10 kilometres northwest, a similar relationship is found where the Asitka Group and Takla Group are placed structurally above the Toodoggone Formation, although here, the thrust fault dips towards the west. Volcanic rocks of the Attycelley and Saunders members in the footwall of the thrust generally have west-inclined bedding, but are unfolded. Chert, argillite and tuffs in the hangingwall panel locally define tight, inclined folds that verge to the east and generally plunge gently north. Along a part of the north margin of the map area, low hills underlain by gently inclined ash flows of the Adoogacho Member rise abruptly above a sharp topographic break into an arcuate buttress of high-standing ridges underlain by volcanic rocks of the Takla Group. Although the contact is not exposed, it apparently is a north-dipping thrust fault as neither the distribution of rocks nor the change in topography are explicable in terms of an unconformity.

Conglomerate deposits are locally confined within blocks dropped by steeply dipping faults. North of the Toodoggone fault and about 1.5 kilometres southwest of the Lawyers AGB zone, fanglomerate derived from nearby flows of the Metsantan Member infill a graben. The displacement on the bounding faults is not known. Elsewhere, indirect evidence of local uplift and erosion is provided by conglomerate interlayered with tuffs resembling the Adoogacho Member, at the base of the Moyez Member. These deposits infill the subsided area adjacent to a steep fault that apparently preserves well-layered air-fall tuff and rare limestone beds within the downthrown block.

Relative motion on northwest and northeast-trending faults is difficult to determine because stratigraphic markers and easily recognized contacts are uncommon in the Toodoggone Formation. Despite this difficulty, the majority of faults appear to be extensional with normal and, rarely, strike-slip movement. The Toodoggone fault truncates important northwest-trending faults in the central segment. It has southwest-side-down normal displacement in which Saunders Member ash flows greater than 300 metres thick occupy the hangingwall block. Within the footwall block north of the Toodoggone River, ash flows are confined by high-angle structures in part of Kodah Creek, otherwise thick strata of the Metsantan Member crop out. Movement on the Toodoggone fault may be synchronous or postdate eruptions of the Saunders Member. The Saunders fault is a significant northwest-trending structure which marks a discrete discontinuity in the thickness and distribution of the Saunders Member. Northeast of Drybrough Peak, the Saunders fault has about 5 kilometres of right-lateral, strike-slip movement inferred from offset of the unconformity separating the Takla Group from the Attycelley Member. This structure apparently continues south of the Finlay River, as the Wrich fault, where it joins the Takla-Finlay fault system about 5 kilometres southeast of Serrated Peak. The Wrich fault also has about 5 kilometres of right-lateral offset indicated by displaced Takla Group and plutonic rocks.

Folds

With the exception of local broad warping, strata of the Toodoggone Formation are not folded. In general, the attitudes of monoclinal layered sections change from shallow to moderate dips within and between blocks separated by steeply dipping faults. In contrast, older and younger rocks are locally more deformed than the Toodoggone Formation. For example, the outlier of Sustut Group sedimentary rocks south of the Chukachida River forms an open, upright anticline-syncline pair. These large-scale folds have axial traces which trend easterly. Elsewhere, outcrop-scale recumbent and inclined plunging folds are mapped in rocks of the Asitka and Takla groups near Attycelley Creek and at Castle Mountain, where they are related to compressional faults.

Comparison of Local and Regional Structure

In order to better understand relationships of internal structure in the study area, it is essential to make comparisons with structural trends in adjoining map areas. Comprehensive studies embracing the stratigraphy and structure of sedimentary rocks underlying the Bowser and Sustut basins document several phases of deformation (Eisbacher, 1974; Moffat and Bustin, 1984; Thomson, 1985; Evenchick, 1986). In general, an early phase of north-northeast-trending fold axes is superposed by a later phase of very prominent northwest-trending thrust faults and folds which verge northeast. They result in significant regional northeast-southwest tectonic shortening (Evenchick, 1986, 1989, 1991). The thrust faults, for the most part, imbricate slices of Middle Jurassic through Upper Cretaceous sedimentary strata. However, Evenchick (1987) has mapped one such fault which detaches Lower Jurassic Cold Fish volcanics, and places them above Upper Cretaceous sediments. These structures in turn are disrupted by few, northwest, and more common northeast-trending high-angle faults that in places juxtapose strata of Early Jurassic to Late Cretaceous age (Evenchick, 1987, 1989).

Southwest-directed thrust faults have not been mapped in the north Bowser basin, Spatsizi map area, although north and east of the Hotailuh batholith, in the Cry Lake map area, they place Upper Triassic strata structurally above undeformed Toarcian strata (Tipper, 1978; Anderson, 1983). The timing of southwest-directed thrust movement is bracketed by K-Ar ages on intrusions; an upper limit of 147±5 Ma on the Snowdrift Creek pluton (Stevens *et al.*, 1982; p. 11), and a lower limit of approximately 173±4 Ma from granodiorite at Tachilta Lake (Stevens *et al.*, 1981; p. 16). These intrusions cut deformed rocks of the Cache Creek Group or truncate structures that are related to compressional deformation of the King Salmon fault (Monger and Thorstad, 1978). In the McConnell Creek map area

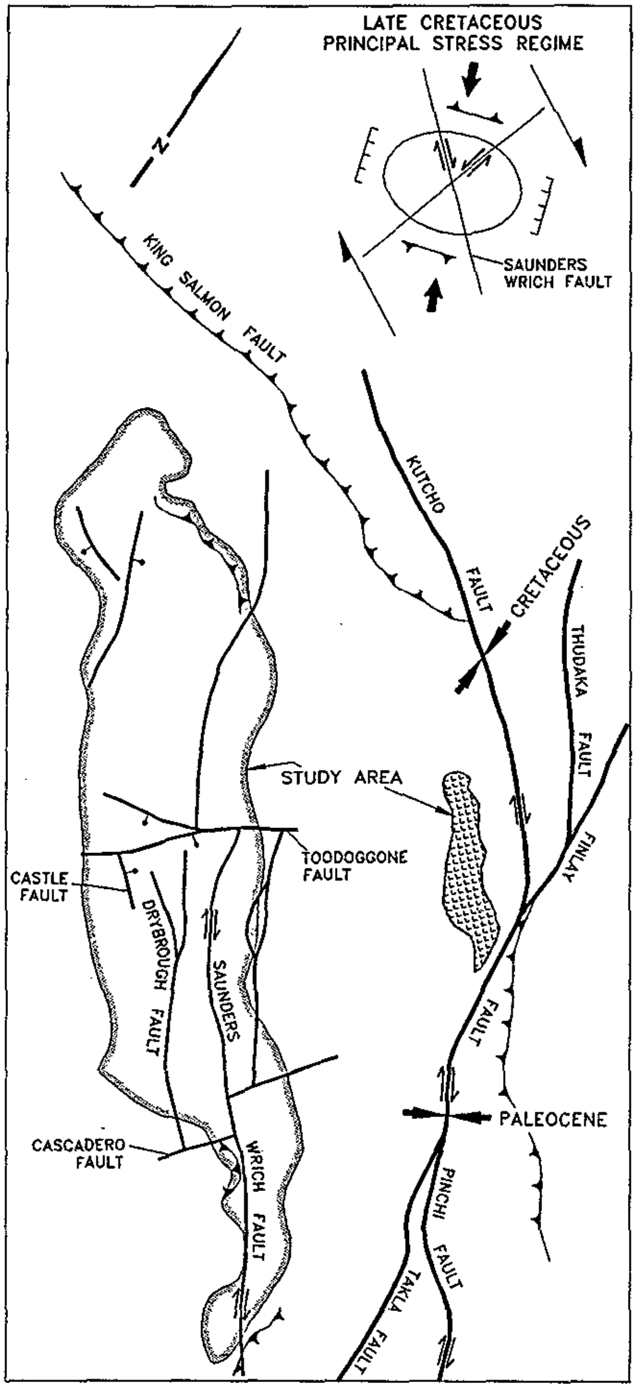


Figure 21. Major transcurrent faults in the Omineca and Cassiar mountains (modified after Wheeler and McFeely, 1987) and their relationship with structural features in the study area. The strain ellipse (modified after Wilcox *et al.*, 1973) shows predicted structures compatible with approximate regional north-south stress during Late Cretaceous time in north-central British Columbia (Gabrielse, 1985).

south-southwest-directed thrust faults involve rocks as young as the Callovian Ashman Formation (T. A. Richards, written communication, 1991).

The Kutcho and Finlay faults are major structures, 5 to 15 kilometres east-northeast of the study area (Figure 21). They coalesce to form part of a network of north-northwest-trending transcurrent faults which mark the major tectonic boundary between the Intermontane and Omineca belts. Gabrielse (1985), in a synthesis of these faults and regional fold patterns between faults in the Cassiar and Omineca mountains, proposes several major stages of fault movement in order to restore displaced mid-Cretaceous plutons and upper Paleozoic to Lower Jurassic volcano-sedimentary successions. In general, an early northwest fault trend, exemplified by the Kutcho and King Salmon faults, has been truncated and dextrally offset along a more northerly trend by the Finlay and Thudaka faults. This present pattern is thought to reflect regional principal stress directed north-south and northeast-southwest, mainly during Late Cretaceous and Early Tertiary time, respectively; although, northeast stress apparently affected the King Salmon fault and some northwest transcurrent faults as far back as Middle Jurassic time (Gabrielse, 1985).

Geometry of faults in the study area generally complies with the model of Late Cretaceous compressional stress (*see* inset, Figure 21). Regional compressive stresses have caused large-scale folds in Upper Cretaceous sedimentary rocks, and east and west-southwest-directed thrust faults that imbricate Triassic and Permian strata. The Toodoggone Formation, which is bound by regional unconformities between these successions, is little deformed, suggesting that the volcanic assemblage acted as a homogeneous, rigid unit that was largely unaffected by stress. Instead, steeply dipping faults dissect strata of the Toodoggone Formation. Evidence that supports tectonic disruption contemporaneous with eruptions of volcanic rocks is indicated by local conglomerate beds preserved within subsided blocks, and by ponding of ash-flow tuff. The magnitude of the faults is unclear, however, the elongate shape of plutons and the local presence of dike swarms may suggest some are deeply seated crustal fractures. Reactivation of early faults, in a stress regime predicted for nearby Late Cretaceous to Tertiary movement on transcurrent faults to the east, is inferred by dextral strike-slip displacement on the Saunders-Wrich fault. This structure is thought to be the dominant control localizing eruptions of the Saunders Member and contemporaneously preserves them by asymmetric subsidence. In general, dilation along strike-slip faults may be a mechanism for extension and subsidence which coincided with eruption and deposition of the Toodoggone Formation. Evidence is lacking for Early Jurassic deformation related to transcurrent structures that perhaps bound the study area in the west.

CHAPTER 4: DEPOSITIONAL ENVIRONMENT

GENERAL STATEMENT

The Toodoggone Formation is a succession, at least 2200 metres thick, comprised roughly of 55 per cent pyroclastic rocks, 30 per cent lava flows and 15 per cent epiclastic rocks. According to K-Ar and new $^{40}Ar/^{39}Ar$ dates the formation evolved during essentially two major eruptive cycles which span roughly 7 million years of late Sinemurian to early Pliensbachian time. The cycles, in turn, are subdivided into six discrete members which represent compositional facies (Fisher and Schmincke, 1984). Except for rare marine sedimentary rocks, deposited sometime after the major volcanism had waned, the Toodoggone Formation records prolonged and sequential volcanic activity exclusively in a subaerial environment.

Because regional metamorphism and deformation are slight to absent, the original texture and structure in stratigraphic members is well preserved. In addition, apart from block faults which tilt and juxtapose various levels of the stratigraphic section, the preserved remnants and geometry of members is thought to closely reflect the distribution of primary eruptive products during differing processes of transportation and deposition.

DEPOSITION OF THE LOWER VOLCANIC CYCLE

Rocks of the Adoogacho Member, which are the base of the Toodoggone Formation, are products of volcanic activity that spans as much as 3 million years of Sinemurian time. They rest immediately upon intermediate to mafic volcanic rocks of the Takla Group. The duration of time represented by this sub-Toodoggone hiatus is unknown; however, the gentle angular discordance of this contact implies relative tectonic quiescence. It shows no evidence of significant relief or epiclastic deposits with clasts of Triassic and older rocks, that would require significant regional uplift and erosion. The subdued paleotopography of this surface is further evidenced by the gentle inclination of the overlying Adoogacho Member.

The Adoogacho Member is a compositionally homogeneous assemblage of andesite and dacite, crystal-rich pyroclastic flows and associated air-fall tuffs with minor lava flows, and epiclastic debris containing clasts of local volcanic provenance. In general these strata intertongue and have rapid lateral and vertical variations. Such features are common in subaerial stratovolcanoes where pyroclastic and epiclastic processes take place concurrently to make complexly layered successions with limited lateral continuity (Nakamura, 1964). The reddish hue and the presence of basaltic hornblende in many tuffs indicate that oxidizing conditions persisted throughout deposition.

The preponderance of fragmental deposits with abundant crystals but devoid of vesiculated juvenile pyroclasts suggests fragmentation occurred during moderately high energy eruptive phases in which partly crystallized, volatile-poor magma was vented. In general, the unwelded to incipient welded state, and the absence of vapour phase crystallization in most ash-flow tuffs implies relatively low eruption temperatures, perhaps resulting from a low rate of discharge that caused latent heat to dissipate rapidly. Partial welding is widespread but discontinuous within flat-lying ash flows that extend for a distance of 12 kilometres near Adoogacho Creek. Buried topography can profoundly affect the thickness and continuity of welded zones in cooling units (Smith, 1960). It is possible that partial welding in the Adoogacho area was caused by successive ash flows emplaced quickly into a shallow topographic depression, where the temperature and lithostatic pressure were sufficient to promote local welding. No evidence has been found to associate the ash flows with caldera collapse; they may simply represent valley-ponded deposits. Rare lava flows are volumetrically insignificant products; they probably signify a transition toward declining discharge in an eruptive phase.

Epiclastic beds with reworked pyroclasts separate pyroclastic deposits; they suggest erosion of poorly lithified volcanic rocks during repose periods. Lithic clasts and crystals derived from loosely consolidated underlying pyroclastic beds were transported as low-volume, grain-dominated debris flows which were dispersed as laterally tapering layers. They generally lack internal stratification and traction bedforms. Shallow-water ponds established on the flat top of the ash-flow succession trapped clay and sand-sized clastics. Except for fern growth around these ponds, the landscape was apparently arid and devoid of vegetation.

Vents for the Adoogacho Member have not been recognized. Subvolcanic plutons with porphyritic texture, which suggests crystallization at a shallow crustal level, contain fragments of pre-Jurassic basement, however, nowhere has an intrusive contact been observed with surrounding rocks of the Adoogacho Member. These intrusions are thought to be temporally associated with parts of the Adoogacho Member; a genetic relationship is yet to be proven.

The Moyez Member is laterally persistent, and has parallel-layered and graded tuffs that resemble fallout deposits produced during explosive volcanism (Fisher and Schmincke, 1984). Within the reference section a basal unconformity marked by channel-fill conglomerate, that is derived and resting upon ash-flow tuff of the Adoogacho Member, signifies local tectonic instability.

Because unwelded tuffs generally have low potential for preservation in a subaerial environment, it is thought that tuffs of the Moyez Member accumulated within a broad topographic depression. The paleoslope was relatively flat as indicated by a slightly inclined unconformity, and the broad extent of uniform tuff beds. The absence of marine fauna in deposits of interlaminated marlstone and chert is interpreted as the result of deposition in temperate freshwater lakes (Reading, 1978). The sporadic distribution, and thin, lenticular morphology of these deposits suggests that lacustrine deposition was probably intermittent and short-lived during periods of volcanic quiescence.

Mineralogic similarity in tuffs of the Moyez Member with those of the Adoogacho Member implies they are perhaps contemporaneous and the former probably represents a distant-source facies. Because of the local provenance of clasts in basal conglomerate beds, the erosional unconformity which separates these members may not imply a significant lapse of time. Neither evidence for this unconformity nor tuffs resembling the Moyez Member have been mapped regionally. Therefore, the limited areal distribution of thick air-fall tuffs is believed to reflect subsidence and preservation within a local, perhaps, structurally controlled basin. Elsewhere, correlative tuffs laid down on high-standing areas were likely removed during erosion and reworked into non-distinct epiclastic deposits.

Deposition of the Metsantan Member began at least 197 million years ago and overlaps strata of the Moyez and Adoogacho members in space and time. The Metsantan Member west of Moosehorn Creek and south of Toodoggone River is an extensive build up of thick, compositionally homogeneous lava flows. Epiclastic volcaniclastic, lahar and some tuff and breccia deposits occur in erratic thicknesses between the flows. As a whole, physical characteristics of these deposits and their mutual association in gently inclined successions represent the bevelled flanks of large stratovolcanoes.

Typically the lava flows appear as thick successions with few separations suggesting prolonged episodes of passive eruption. Incision of flow surfaces during intermittent erosional episodes made channels, which were subsequently infilled with intraformational conglomerate. Finer epiclastic rocks, winnowed and transported by streams, were deposited in small lakes producing laterally restricted redbed deposits of coarse sandstone grading upward into alternating siltstone-mudstone beds. Planar crossbedding and ripple laminations suggest traction flow, whereas the thinly laminated and graded clastic rocks represent settling of suspended load in calmer water. Desiccation cracks and rainprints in red mudstone indicate dry spells which periodically exposed the bottoms of lakes. Except for sporadic growth of ferns around some of these lakes, this volcanic terrain, like that of the Adoogacho, was apparently a sparsely vegetated semi-arid region.

Alluvial fans mark breaks in the topographic paleoslope. These successions are characterized by as much as several hundred metres of crudely bedded and laterally overlapping pulses of graded rudite detritus. In several places, particularly south of Lawyers Amethyst Gold Breccia zone, a thick wedge of epiclastic rocks apparently prograded from an escarpment which appears to have formed during a local stage of graben development contemporaneous with Metsantan volcanic eruptions. Lahars, most abundant east of Deedeeya Creek, are interlayered with thin latite flows. They probably formed by gravity sliding of volcanic debris off the over-steepened flank of a volcanic cone.

Stratigraphy east of the study area near Mount Graves is thought to be correlative with the Metsantan Member. Here, a large proportion of well-layered epiclastic and pyroclastic rocks that change laterally along strike into thickly layered flows and pyroclastic rocks suggests a transition from a volcaniclastic apron to dominantly flows in a lower slope setting of a large stratovolcano. The lateral change from predominantly pyroclastic and epiclastic facies near Mount Graves to flow-dominated facies to the west is thought to indicate coalescing deposits from separate point sources or a facies gradation; a major fault has subsequently juxtaposed slightly different stratigraphy.

The partly coeval relationship of the Adoogacho and Metsantan members corresponds with a transition from early explosive to partly synchronous, and younger passive volcanism. This change in eruption style with time is accompanied by a gradual change toward slightly more mafic compositions in the Metsantan Member. Evolutionary trends such as these are common in volcanic fields where volcanoes of intermediate to silicic composition are above large, homogeneous batholiths (Lipman *et al.*, 1978). Gradients in chemical composition and phenocryst content in products of an eruptive cycle are inherited from compositional zoning established as high-level magmas differentiate and crystallize (Smith, 1979; Hildreth, 1979). The small decrease in silica and phenocrysts between the early erupted Adoogacho Member and later erupted Metsantan Member suggests progressive tapping of a deeper, more mafic and less crystallized part of a zoned magma chamber.

Plutons like the Black Lake stock have composition and cooling ages identical to nearby strata of the Adoogacho and Metsantan members. They undoubtly represent the exhumed roots of near-surface magma chambers that were the source for lower volcanic cycle eruptions. Dikes of porphyritic andesite are abundant in the Metsantan and McClair members. They contain the same phenocrysts as the enclosing volcanic rocks, which may suggest a cogenetic relationship.

The McClair Member east of Moosehorn River is a complex mixture of pyroclastic rocks, subordinate flows of intermediate composition, and minor sedimentary rocks. Because these deposits locally interfinger with those of the Metsantan Member they are interpreted as a lateral facies, possibly in a nearer to source setting. They formed by a similar mode of eruption that built stratovolcanoes in a extensional setting during Metsantan time.

DEPOSITION OF THE UPPER VOLCANIC CYCLE

The upper volcanic cycle differs from its older counterpart in that it has two members composed almost exclusively of dacitic pyroclastic rocks. The Attycelley Member is dominantly bedded crystal-rich tuffs with subordinate breccia, and few interspersed ash flows and lava flows that mark a resurgence in explosive volcanism.

Explosive eruptions built up a complex mixture of tuffs in which individual depositional units show rapid lateral changes in thickness. Much of this variability is related to deposition of the Attycelley Member upon pre-existing topography developed on the older successions. Some of this relief, at least locally, can be attributed to passive uplift of plutons and denudation during an intervolcanic cycle hiatus. This is particularly evident northeast of Drybrough Peak where uplift and erosion of the Black Lake stock and Takla Group are indicated by an unconformable contact relationship; in places it is marked by conglomerate containing clasts of granitic rock and volcanic rocks of the Takla Group. The common occurrence of tuffs with interspersed epiclastic rocks is perhaps further evidence for frequent episodes of erosion of poorly lithified pyroclastic deposits from topographically elevated areas. Local lenses of limestone, devoid of marine fauna, attest to pauses in volcanism and deposition in shallow lakes.

The upper volcanic cycle climaxed about 193 million years ago when more than 9 cubic kilometres of dacite ash-flow tuff of the Saunders Member apparently erupted along a regional fracture system thought to coincide closely with the Saunders-Wrich fault. The greatest volume of ash flows is within the central Toodoggone depression; a broad area of asymmetric subsidence which resembles a normal-faulted downsag caldera (Walker, 1984). The thickest successions correspond with maximum subsidence south of Toodoggone River and adjacent to Saunders Creek. The ash flows tail out toward the west where pre-depositional uplift of the Black Lake stock is indicated by an erosional unconformity with uplifted strata of the Takla Group. This contact, in conjunction with the Attycelley Member resting unconformably on similar basement strata nearby, suggests the Black Lake stock was uplifted and eroded before volcanic activity of the upper cycle began.

The lack of depositional features in the Saunders Member resembling pumiceous ignimbrite ash-flow units (Sparks *et al.*, 1973; Wright *et al.*, 1981) generated by column collapse (Sparks and Wilson, 1976) during violent eruptions (Wilson and Walker, 1981) associated with caldera subsidence, suggests a different mechanism of formation. The ash-flow succession is typified by incipient to partial welding, and the absence of significant compositional or textural zonation. Like ash flows of the Adoogacho Member, these deposits are crystal rich and while cognate vitric pyroclasts are both diagnostic and widespread, they lack vesiculated fragments. These features indicate a common, homogeneous source and fragmentation of a partly crystallized magma with low volatile content.

Low initial volatile content combined with high crystallinity increase viscosity, which can prevent magma from disrupting explosively (Cas and Wright, 1987; Marsh, 1981). If the assumption that viscosity was high and volatiles low is correct, then fallout and surge deposits and conspicuous textural variation in welded ash flows produced by collapse of the eruption column may either be poorly developed or absent. Because the Saunders Member lacks either of the former deposit types, it is believed that moderately violent eruptions were driven by low gas volumes which resulted in low, steady state, fountaining columns of plastic, cognate vitroclasts. The mechanism of formation may resemble fallout of spatter, which produces deposits called agglutinates or tufolavas; they are thought to represent a transition in the mode of eruption of lava and hot pyroclastic flows (Cook, 1966).

The presence of glassy dacitic fragments indicates relatively hot eruption temperatures; however, uniform partial welding, even in the thickest single preserved section of about 300 metres, suggests that latent heat rapidly dissipated and load pressure was inadequate to cause discrete zones of welding. This feature is perhaps explicable in terms of rapid cooling during periodic discharge of relatively low volumes of magma.

Vents for the Saunders Member are unrecognized. However, because thick ash-flow successions appear to coincide spatially with the Saunders-Wrich fault, this structure may represent the locus of spaced fissure eruptions. It is conceivable that a fissure vent was choked and buried beneath the thickest succession of ash-flows within the area of maximum subsidence, near the east margin of the central Toodoggone depression. The rate of subsidence and discharge of magma were apparently uniform through time. This is suggested by flat-lying ash-flows lacking coarse landslide deposits, that could be derived by partial collapse of a topographic rim bordering the depression.

POSTVOLCANIC MARINE DEPOSITS

The lower volcanic cycle is overlain by areally restricted marine deposits containing ammonites of middle to late Toarcian age (H.W. Tipper, written communication, 1989). Tuffaceous siltstone enclosing these fossils occurs only as scattered blocks restricted to an area underlain by ash-flow tuff of the Adoogacho Member near Adoogacho Creek.

These deposits have local and regional significance as they represent the only demonstrable remnant of marine sedimentary rocks within the study area. In addition, if the lower contact with Sinemurian strata is correct, they also indicate a significant hiatus that was marked perhaps by uplift and erosion prior to a marine transgression. Evidence for widespread erosion during this time interval has not been recognized in the Toodoggone Formation. Also, on a broader scale, the very limited lateral extent of marine deposits diminishes the likelihood that marine conditions prevailed throughout the entire study area. Instead, local subsidence of the volcanic plain to near sea level, and inundation of the subsided area during a marine transgressive event is envisaged.

Marine deposition in the study area occurred sometime after volcanism of the Toodoggone Formation had waned in early Pliensbachian time. Eustatic curves for the late Pliensbachian and early Toarcian suggest a gradual sea level rise during a widespread transgressive event (Hallam, 1981). In Cry Lake map area this deepening event in the marine sequence is manifest as shale deposits, which in turn are overlain by silt and sand that represent a shallowing event in middle to late Toarcian time (Thomson *et al.*, 1986). In the Toodoggone River map area, an analog for early deepening conditions cannot be confidently inferred from pyritic fine-grained sediments northwest of Tuff Peak as the age of these strata is unknown. However, shoaling may be inferred from fine-grained sedimentary rocks near Adoogacho Creek which contain abundant large and coarse-shelled fauna indicative of a shallow-water, high-energy environment of deposition.

TECTONIC SETTING OF THE TOODOGGONE FORMATION

Volcanic activity in different tectonic environments is generally characterized by specific physical features and chemical compositions. These reflect tectonic controls that influence the depositional patterns of volcanic rocks and the style of eruptions. They are also fundamental criteria used to interpret the tectonic setting of ancient volcanic successions (Cas and Wright, 1987).

Several stratigraphic and structural features, if considered together, indicate that heightened volcanic activity of the Toodoggone Formation occurred in an extensional stress regime. A longitudinal section of the distribution of the Toodoggone volcanic rocks apparently defines a symmetric, northwest-elongated down-warp (Figure 22). Older rocks are only exposed at the edges of the depression; stratigraphically younger rocks crop out only towards the centre. Subsidence along the length of the volcanic depression was apparently uniform because ash-flow tuffs and flows are almost flat lying. They built up a broad volcanic plateau, in which abrupt thickening of some ash-flow units is attributed to local collapse along penecontemporaneous faults. These smaller structural depressions are apparently nested within the broader depression and locally preserve much of the youngest phase of ash-flow volcanism.

Granitoid stocks have a close spatial and temporal relationship with the volcanic rocks of the Toodoggone Formation. The Black Lake stock, some smaller satellitic bodies, and several generations of dikes are either elongated or preferentially oriented northwestward, parallel to the regional structural fabric. This may suggest that the ascent of magma to subvolcanic levels was probably facilitated by extensional structures.

High-potassium, calcalkaline volcanic rocks characterize the Toodoggone Formation. Except for some late dikes and sills, basalt and rhyolite are notably absent from the succession. The calcalkaline magma series is typically associated with modern subduction-related magmatic arcs (Gill, 1981). In general, high-potassium volcanic activity occurs during an advanced stage of arc evolution.

Compositions of arc volcanic rocks are influenced by the nature and thickness of underlying crust (Coulon and Thorpe, 1981). The Toodoggone Formation is superimposed upon a basement composed of two older arc successions. It is conceivable that they formed a continent-like substrate, thus affecting the evolution of magma and style of volcanic activity in the Early Jurassic arc. Significant volumes of ash-flow tuff and flows of latite and dacite composition with phenocrysts of hornblende, biotite, quartz and sanidine are most common in tectonic environments in which a thick continental crust is developed (Ewart, 1979, 1982; Coulon and Thorpe, 1981); these features characterize the Toodoggone Formation.

Physical and chemical aspects of the Toodoggone Formation are uniform throughout the 7 million year history of Early Jurassic arc construction. This suggests the causative processes relating to dynamics of the subducted plate and internal arc structure remained constant through time. Along the east margin of Stikinia, an Early Jurassic arc system, the Hazelton island archipelago, may have been characterized by steep west-southwestward subduction which induced a regime of intra-arc extension.

A system of fractures and rifts apparently channelled parental magmas through the thick continent-like crust underlying the Toodoggone segment of the Hazelton island arc. Primary melts fractionated to high-potassium calcalkaline compositions as they ascended to magma chambers perched high in the basement. These hydrous and oxidized melts periodically segregated in the roof of the chamber causing minor mineralogic and compositional gradients in the rocks erupted. Eruptions, perhaps initiated by fault movements on basement structures, may have triggered the two cycles of volcanic activity. Steeply dipping faults controlled both the distribution and style of eruptions and emplacement of subvolcanic plutons. They also acted as important conduits for heated meteoric solutions to ascend and subsequently precipitate economic concentrations of precious metals in discordant quartz veins of epithermal character in advanced argillic alteration zones.

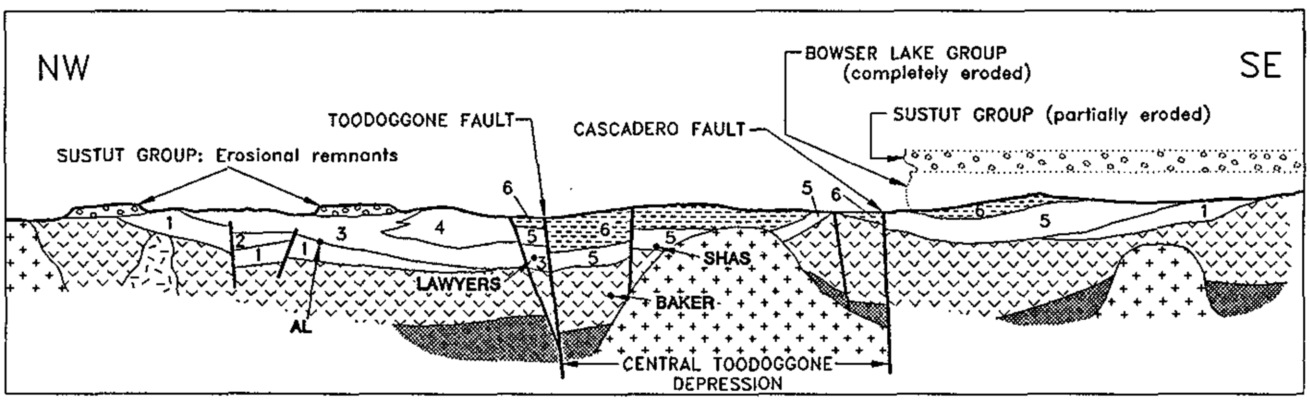


Figure 22. Diagrammatic northwest-southeast section of Permian to Cretaceous stratigraphy in the Toodoggone map area. Volcanic rocks of the Toodoggone Formation (Units 1 to 6) occupy a northwest-elongated structural depression underlain by pre-Jurassic basement successions of the Asitka and Takla groups. The central Toodoggone depression, a collapse feature, developed synchronously with ash-flow eruptions that mark the terminal eruptive episode of the Toodoggone Formation. Important epithermal precious metal deposits occur in fracture systems within or proximal to the main area of subsidence. Younger sedimentary successions of the Bowser Lake (?) and Sustut groups once formed an extensive cover that protected strata of the Toodoggone Formation and their associated epithermal deposits from erosion. This protective cover is largely eroded; at present, it consists of a few remnants of the Sustut rocks overlying older volcanic successions.

CHAPTER 5: MINERAL DEPOSITS

EXPLORATION AND MINING HISTORY

The discovery of gold in the Toodoggone mining district is attributed to Charles McLair. In 1925 and 1926 he reportedly recovered gold from placer workings in McClair Creek, previously called McLaren Creek (Lay, 1935). Production was short lived, however, as he and his partner went missing on return to the area in 1927. In 1933 an Edmonton syndicate, encouraged by gold values from a program which tested the old workings on McClair Creek and local gravel deposits, staked a number of placer mining leases that covered much of the Toodoggone River valley west of Toodoggone Lake, McClair Creek and the lower part of Moosehorn Creek and prompted the formation of a new company – the Two Brothers Valley Gold Mines Limited (Western Securities Limited, unpublished prospectus, 1934). Work on the leases, including a sluicing operation and some drilling on McClair Creek, ceased in 1935. Recorded production from 1931 to 1935 totalled 3270 grams (Holland, 1950). In 1961, 320 metres drilled in fifteen holes near the mouth of McClair Creek and throughout the Toodoggone River valley, where consistently good gold values were indicated by drilling during the 1930s, returned poor results (C.H.E. Stewart, unpublished report, 1961).

The Consolidated Mining and Smelting Company prospected for base metals in the Toodoggone area in the early 1930s. Discoveries resulting from this work include skarn at Castle Mountain, presently covered by four Crown-granted mineral claims, lead in quartz-barite veins immmediately east of Deedeeya Creek, and lead-zinc-silver in quartz veins hosted by limestone in the Thutade Lake area.

A regional geochemical reconnaissance survey carried out by Kennco Explorations (Western) Limited in 1966 heralded the beginning of exploration for porphyry copper deposits in the Toodoggone area, and subsequently led to the discovery of lode gold at the Chappelle and Lawyers deposits. Anomalous stream geochemistry from this survey resulted in staking at Kemess in 1967. During 1968, 1969 and 1971, Kennco conducted geochemical surveys, geologic mapping and diamond drilling at Kemess. Getty Mines Limited optioned the property in 1975, extending work into 1976. Since 1988, exploration at Kemess has attempted to evaluate the property's potential for disseminated and fracture controlled porphyry copper-gold mineralization.

The overall potential of the Toodoggone area as a precious metal mining camp was not recognized until relatively recently, mainly because of inaccessibility of the area. Between 1981 and 1986 most of the known gold-silver occurrences in the area were discovered by several major mining companies (*see* Map 2, back pocket). Since the early 1970s, over 55 new mineral prospects have been identified. At least nine deposits have an identified mineral inventory estimated to be in excess of 12 400 kilograms of gold and 236 400 kilograms of silver.

In 1968 Gordon Davies, exploring on behalf of Kennco Explorations (Western) Limited, discovered quartz float which contained fine-grained electrum and acanthite at the Chappelle property. During 1970 and 1972 exploration revealed six quartz veins of which Vein A contained the most significant precious metal concentrations (Barr, 1978). Underground development on Vein A by Conwest Exploration Company Limited was begun in 1973. The following year, under a new option agreement, Du Pont of Canada Exploration Limited embarked on a program of surface and underground development. In April, 1981, the Baker mine began production, milling ore from Vein A at a rate of 100 tonnes per day (Barr *et al.*, 1986). Production ceased in November, 1983 with a total output of 77 500 tonnes of ore yielding 1168 kilograms of gold and 23 085 kilograms of silver. In 1991, underground mining of Vein B by Multinational Resources Inc. produced 26.5 kilograms of gold and 773 kilograms of silver from 9990 tonnes of ore.

Kennco discovered the Amethyst Gold Breccia zone of the Lawyers deposit in 1973. Kennco recognized that features of the veins and associated mineralization resembled a high-level vein system and subsequently embarked on an exploration program of trenching and drilling in 1974 and 1975. In 1978, Kennco optioned the property to Semco Mining Corporation. In 1979, Serem Ltd. obtained an assignment of agreement and commenced trenching, followed later by surface and underground drilling which together defined reserves at the Amethyst Gold Breccia (AGB) zone and delineated two new mineralized zones – the Duke's Ridge zone and the Cliff Creek zone. In January, 1989, Cheni Gold Mines Inc., formerly Serem, began production on the Amethyst Gold Breccia zone with a drill-indicated reserve of 452 502 tonnes grading 8.33 grams per tonne gold and 263.65 grams per tonne silver. Ore in the Amethyst Gold Breccia zone was projected to be exhausted and a transition to mining underground at the Cliff Creek zone made by early 1992. In August, 1991, during this transition period, 48 000 tonnes of ore stockpiled from an open-pit operation at the BV zone of the Al deposit was intended to compensate reduced mill feed from the Amethyst Gold Breccia zone.

The Shasta deposit began limited production by open cutting in 1989 on the Creek and JM zones. Since 1989, 106 300 tonnes of ore from underground and open pits have yielded 482 kilograms of gold and 26 575 kilograms of silver.

Historically in the Toodoggone area, centres of intense acid-sulphate alteration have proven to be difficult targets to evaluate for precious metals mainly because erratic internal zoning is superimposed on complex fracture systems. At Silver Pond, St. Joe Canada Inc. conducted a program involving drilling and backhoe trenching, having limited success delineating mineralized rocks. Throughout the 1980s a similar, but more intensive, program at the Al property was undertaken by Kidd Creek Mines Limited and later by Energex Minerals Limited. During the period 1984-1987, a drill-indicated reserve of 340 000 tonnes

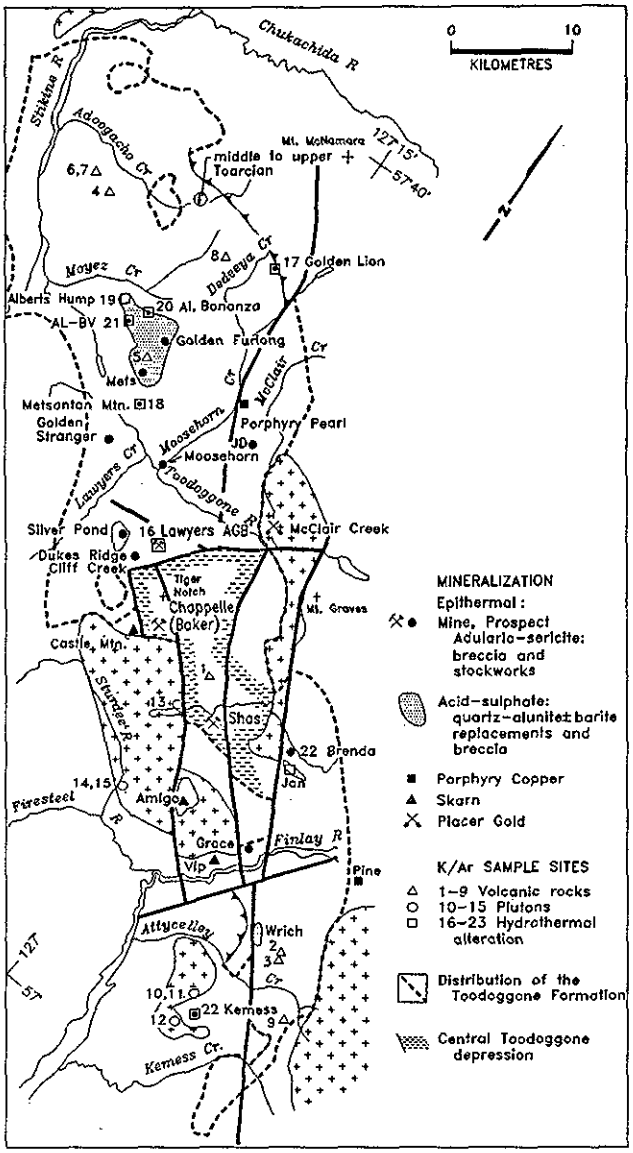


Figure 23. Mineral deposit types and the distribution of mines, major prospects, acid-sulphate and advanced argillic altered rocks in relation to the central Toodoggone depression and major faults in the study area. Numbered K-Ar age determinations correspond with data in Appendix B.

grading 9.6 grams per tonne gold was identified in three zones on the Al property. In 1986 a pilot mill produced 12 kilograms of gold.

GENERAL STATEMENT

The study area contains several ore deposits and a variety of metal concentrations that can be broadly categorized according to the nature of their occurrence and mode of origin as volcanic-hosted epithermal gold-silver, porphyry copper-molybdenum, skarn and placer gold occurrences (Figure 23 and Map 2, Table 5).

EPITHERMAL GOLD-SILVER DEPOSITS

Epithermal gold-silver mineralization is the major economic attraction in the Toodoggone district; it was initially recognized by Kennco at Marmot Lake then at the Lawyers deposit in the early 1970s. The Early Jurassic age of epithermal precious metal deposits and their genetic relationship with the Toodoggone Formation was first interpreted as a result of an age determination reported by Schroeter (1982).

Volcanic-hosted epithermal deposits are classified on the basis of their ore and alteration mineralogies into two widely utilized types described by Hayba *et al.* (1985) and Heald *et al.* (1987). Most Toodoggone deposits and prospects belong to the adularia-sericite type; a number of nearby related deposits and their alteration zones resemble the acid-sulphate type. The terminology for secondary mineral assemblages used in this report is slightly modified after that of Meyer and Hemley (1967). The dominant alteration assemblages recognized include:

- Silicic – microcrystalline quartz is added to other minerals in altered rocks
- Potassic – fine-grained potassium feldspar as adularia, with or without sericite
- Argillic – kaolinite and montmorillonite minerals
- Advanced argillic – dickite or kaolinite, sericite, quartz, and commonly alunite
- Propylitic – epidote, chlorite, carbonate, albite and pyrite.

Identification of secondary minerals from metal concentrations in the study area was by x-ray diffraction at the Analytical Laboratory, British Columbia Geological Survey Branch, Victoria.

ADULARIA-SERICITE TYPE

Gold and silver-bearing quartz veins bound by wallrocks enriched in adularia and sericite are diagnostic of the adularia-sericite type. Two of the deposits mined to date (Lawyers and Shas), and most of the major prospects, occur in either latite lava flows of the Metsantan Member or dacitic tuffs of the Attycelley Member. The Chappelle deposit at Baker mine is in basaltic to andesitic flows of the underlying Late Triassic Takla Group. The deposits are emplaced along prominent fracture systems and faults that define or occur near the margin of the central Toodoggone depression (Figure 22). The ore deposits and many of the mineral prospects are spaced evenly over a distance of about 30 kilometres along northwest-trending block faults that coincide roughly with the central, down-dropped axis of the thickest volcanic accumulations. The following descriptions briefly review key examples of the adularia-sericite type deposits.

LAWYERS DEPOSIT (CHENI MINE)

Gold-silver quartz vein, stockwork and breccia deposits at the Lawyers property include the Amethyst Gold Breccia (AGB), Cliff Creek and Duke's Ridge zones (Figure 24). They are within an 8 square kilometre area, about 4 kilometres south of the Toodoggone River. All are located along northwest-trending, steeply west-southwest-dipping fractures that cut conformable stratigraphic contacts. Hostrocks

TABLE 5

COMPARATIVE FEATURES OF MAJOR MINERAL DEPOSIT TYPES IN THE STUDY AREA

Deposit type	Host rock	Structure	Metallic minerals	Gangue minerals	Deposit morphology	Deposit name (located in Map 2)	Dimensions Length (m)	Width (m)	Depth (m)	Production	Reserves (as of Jan. 1/92) (t and g/t)
EPITHERMAL Adularia-sericite	Dacite and latite volcanic rocks of the Adoogacho, Metsantan, and Attycelley members (Units 1, 3, and 5); locally basalt and andesite of the Late Triassic Takla Group at Baker mine	Steeply dipping anastomosing fractures and fault systems in a northwest-trending regional extensional zone	Electrum, argentite-acanthite, native gold and silver with minor pyrite, chalcopyrite, sphalerite and galena; trace *polybasite*, stromeyerite and bornite	Quartz, amethyst, chalcedony, adularia, sericite and calcite with minor hematite, barite, kaolinite, illite, *montmorillonite* and chlorite, trace fluorite	Veins and stockwork veinlets with banded, vuggy and comb textures; breccia with massive microcrystalline quartz as matrix supporting earlier quartz and wallrock fragments	Lawyers				1989/91: 499 889 t yielded 4408 kg Au and 95 043 kg *Ag from Amethyst* Gold Breccia zone	
						Amethyst Gold Breccia zone (AGB)	500	60–75	150		139 710 @ 6.8 Au and 197 Ag
						Cliff Creek Breccia zone	1500	9–30	400		139 678 @ 6.8 Au and 199 Ag
						Duke's Ridge zone	480	2	100		21 770 @ 8.0 Au and 217 Ag
						Chappelle (Baker mine)				1980–1983: 77 500 t yielded 1168 kg Au and 23 085 kg Ag "B" 1991: 9990 t yielded 26.5 kg Au, 773 kg Ag and 37 346 kg Cu	
						A vein	435	0.5–9	150		
						B vein	150	2.4–7.1	120		"B" 7256
						Shasta (Shas)				1989–1991: 106 300 kg yielded 482 kg Au and 26 575 kg Ag from Creek and JM zones	
						Creek zone	350	2–23	100		
						JM zone (plus O, East Rainier, and *Jack zones*)	500	3–45	100		
						JD					
						Vein zone	600	1–4.6	50		27 000 @ 5.5Au
						Gasp zone	150	20	?		
						Gumbo zones	400	10	?		
						Other prospects — Metsantan, Golden Lion, Golden Stranger, Moosehorn, Brenda, Beaver Dam					2 054 355 @ 0.96 Au
Acid-sulphate	Mainly latite flows of Metsantan member (Unit 3); but locally dacite pyroclastic rocks of the Attycelley and Saunders members (Units 5 and 6)	Fracture systems, possibly localized above high-level plutons on flank of stratovolcanoes	Native gold, electrum, argentite-acanthite, pyrite with minor tetrahedrite-tennantite and chalcopyrite; trace sphalerite, galena, bornite and covellite	Quartz, kaolinite, dickite, nacrite, barite, alunite, gypsum, calcite with minor *montmorillonite*, hematite, sericite, rutile	Vuggy siliceous rocks, locally massive chalcedony replacements; gold and other ore minerals occur with crystalline barite in vugs, breccia, and veinlets within intensely silicified zones	AJ				1986: 6 tonne per day pilot mill ~12 kg gold "BV" 1991: 48 000 yielded ~643 kg Au	Total=340 000 @ 9.6 Au (open pittable)
						Thesis III zone	200	5–30	75		
						BV zone	500	5	50		
						Bonanza-Ridge zone	350	3–5	60		
						Mets					
						A zone	150	6–10	75		144 000 @ 11.3 Au
						Silver Pond					
						West zone	475	100–130	200		63 500 @ 5.83 Au
						Cloud Creek Zone	300	2	160		
						Amethyst zone	190	2–3	250		
						Jan	500	200	?		
						Wrich					
PORPHYRY	Early Jurassic granodiorite and quartz monzonite intruding Hazelton and Takla group volcanic rocks	Steeply dipping fractures and veinlet stockworks in volcanic and plutonic rocks	Pyrite, chalcopyrite, molybdenite, galena, sphalerite, magnetite, ± gold and silver	Broad propylitic *zones with local* quartz, sericite and clay minerals	Disseminations and *quartz veinlet* stockworks within intrusive host and volcanic rocks near pluton margins	Porphyry Pearl					
						Pine (Fin)					
						Kemess (North)					70 000 000 @ 0.66 Au and 0.18% Cu
						Kemess (South)	1402	610	240		206 796 000 @ 0.65 Au and 0.23% Cu
SKARN	Permian limestone of the Asitka Group *near intrusive* contacts with the Black Lake stock	Steep intrusive contacts or in screens of carbonate rocks on the Black Lake stock	Pyrite, magnetite, sphalerite, galena, bornite, chalcopyrite, ± gold and silver	Marble, epidote, and actinolite	Irregular pods replacing carbonate rocks	Castle Mtn.					
						Amigo					Small high-grade zones
						Perry Mason (Pau)					

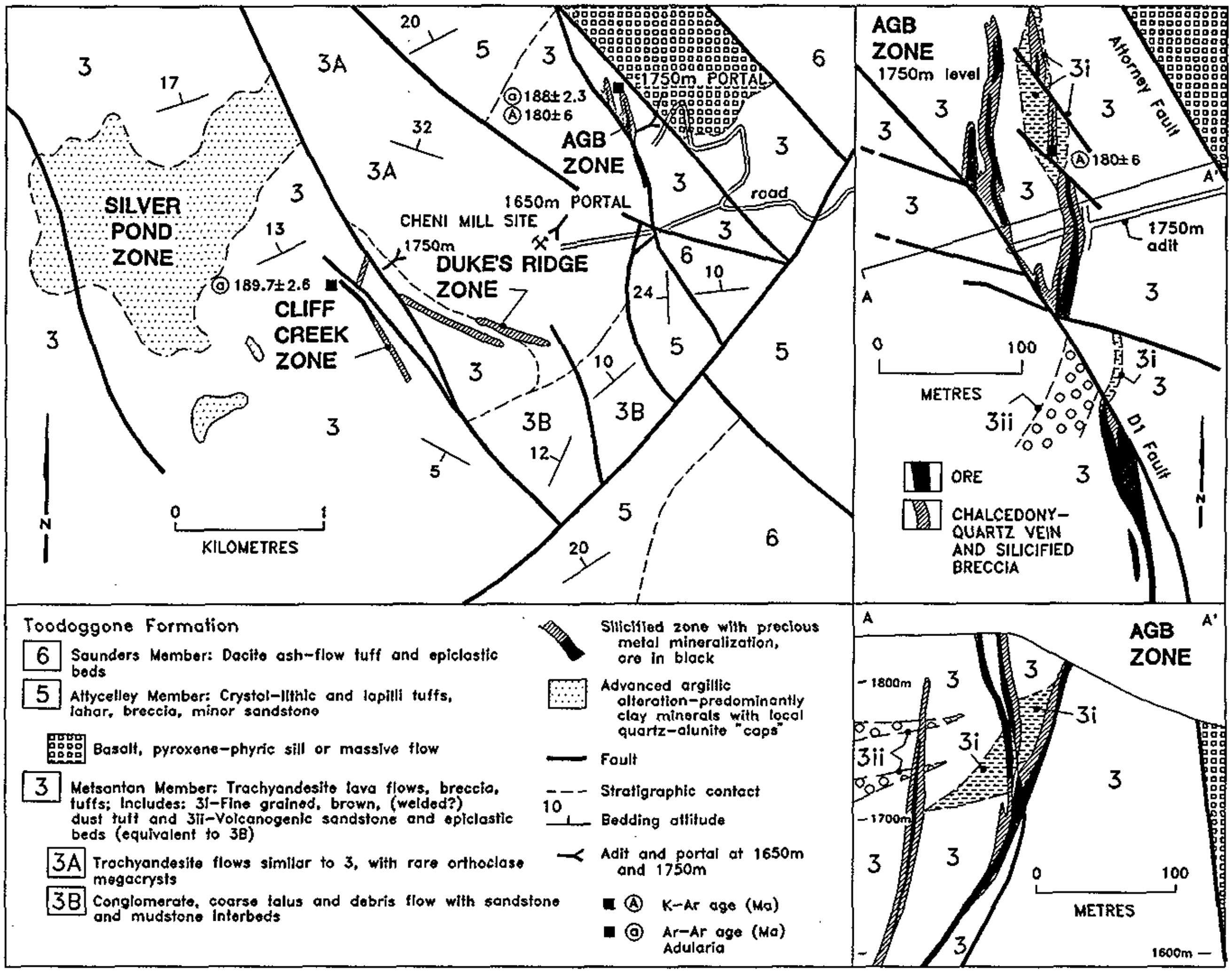


Figure 24. Geology of the Lawyers deposit and main mineralized zones – Amethyst Gold Breccia (AGB), Cliff Creek and Duke's Ridge; modified after Vulimiri *et al.* (1986). Location of the K-Ar age determination on adularia from the margin of quartz veins in the 0+75N crosscut on the 1750-metre level of the AGB zone is indicate by "A" (data in Appendix B). $^{40}Ar/^{39}Ar$ dates, "a", from Clark and Williams-Jones, 1991.

at the Amethyst Gold Breccia zone consist of basal quartz-bearing dacitic tuff with variably welded ash-tuff lenses mapped as part of the Adoogacho Member, and overlying latite flows and interspersed volcaniclastic deposits of the Metsantan Member.

The Amethyst Gold Breccia zone is spatially and probably temporally related to a graben margin in which block faults step down incrementally toward the west (Vulimiri *et al.*, 1986). Early graben faults trend north-northwest and project southward to the east end of Duke's Ridge, where subsidence is indicated by a structural break between flows of the Metsantan Member and contemporaneous epiclastic rocks preserved in an alluvial fan in the downthrown block. Younger faults with northwest trends and left-lateral movements, in part, parallel the postulated graben structures; they subsequently offset stratigraphy and metal concentrations in the Amethyst Gold Breccia zone. Post-ore basalt dikes are intruded along some of the late faults.

The Amethyst Gold Breccia deposit consists of fracture-controlled breccia zones and stockwork veins. In section, the deposit is a near-vertical zone that bifurcates about 100 metres from surface into two discrete zones. Principal ore minerals include fine-grained electrum, argentite, native gold, native silver with minor chalcopyrite, sphalerite and galena. Pyrite is uncommon, rarely in excess of 1 per cent by volume. Principal gangue minerals are chalcedony, crystalline quartz, amethyst, calcite, hematite and minor barite. Silver to gold ratio averages 20:1, but variable trends occur both horizontally and vertically along the ore zone. The highest ore grades are associated with chalcedony and hematite which form the matrix in breccia zones. Individual veins exhibit multistage depositional textures including thin alternating bands of chalcedony and hematite. The inner part of veins is commonly white, comb-textured and amethystine quartz. Sparry calcite with or without barite occurs locally in elongate discontinuous cavities at the centre of veins. In places clasts in breccia are remnants of earlier vein chalcedony, amethystine quartz and calcite, and potassic-altered wallrock fragments.

Pronounced potash enrichment and soda depletion are evident near the ore zone when compared to the compositions of unaltered hostrock samples (*see* analyses 40 and 41 in Appendix A and compare to average compositions for the Adoogacho and Metsantan members in Table 2). Adularia commonly forms millimetre-thick pink boundaries on vein margins, and outward of veins it pseudomorphs plagioclase phenocrysts and replaces groundmass silicate minerals, which partly obscure the primary porphyritic texture in the wallrocks; sericite is rare. This potassic alteration passes outwards to an assemblage of epidote-carbonate-chlorite-pyrite (propylite) in the peripheral volcanic rocks.

In contrast to the Amethyst Gold Breccia zone, the Cliff Creek quartz veins have minor silicified breccia ore. Adularia is present adjacent to metal-bearing veins; it has a diffuse sericitic outer boundary flanked by an assemblage of kaolinite with minor illite. Argillic alteration is extensively developed around the veins as symmetrical envelopes, some up to 20 metres in width. Pyrite is ubiquitous in the argillic rocks together with abundant chlorite. Weathered argillic zones are predominently stained by limonite minerals and manganese oxides. Propylitic alteration dominates in country rocks outward beyond the argillic zone.

CHAPPELLE DEPOSIT (BAKER MINE)

The Baker mine is approximately 7 kilometres southeast of the Lawyers mine. At least six precious metal bearing quartz veins have been discovered; two have been mined (Barr, 1978). They occur within an uplifted fault block of brightly iron-stained basalt and andesite flows of the Late Triassic Takla Group in intrusive contact with the Early Jurassic Black Lake stock (Figure 25). Several small apophyses of the Black Lake stock and feldspar-porphyritic dikes, which may represent feeders for lithologically similar volcanic rocks of the Toodoggone Formation, are adjacent to veins that generally strike northeast. A few relatively unaltered basaltic dikes, about 1 metre wide, strike northwest and locally cut propylitically altered wallrock near a southern segment of Vein A.

Most production at the Baker mine was from Vein A; a system of two or more closely spaced, subparallel veins trending northeast and steeply inclined to the northwest. The vein system varies in width from 10 to 70 metres, and individual veins are between 0.5 and 10 metres wide, through a vertical range of 150 metres. Although the vein system is segmented by numerous northwest-trending cross-faults, the offsets are minor.

Veins consist mainly of milky white quartz and are typically strongly fractured and brecciated; less common are vugs and banding imparted by thin layers of chlorite and pyrite. Principal ore minerals include fine-grained electrum and argentite, which occur with disseminated pyrite in concentrations of 3 to greater than 15 per cent, chalcopyrite, sphalerite and minor galena in a quartz and lesser carbonate gangue. Adjacent to the quartz veins is a narrow zone of sericite and clay minerals flanked by an extensive zone of propylitized country rocks containing pyrite, epidote, tremolite, chlorite and calcite (Peter, 1983). Veins of laumontite-calcite-quartz, with and without stilbite, cut altered wallrocks near Vein A; they are apparently postmineral and perhaps associated with regional metamorphism.

SHAS DEPOSIT

The Shas deposit (Figure 26) consists of anastomosing quartz-calcite stockwork-breccia systems that define narrow (<1 m) planar zones. They pinch and swell within wider (>10 m) sections of variable vein intensity and alteration over strike lengths of up to 500 metres (Thiersch and Williams-Jones, 1990). Hostrocks on the Creek and JM zones consist of interlayered pyroclastic and epiclastic rocks of the Attycelley Member which unconformably overlie basalt flows and breccias of the Takla Group (Marsden, 1990). The deposit occurs in a rotated fault block dominated by north to northwest-trending normal and/or dextral faults (Marsden, 1990). Native gold and silver, electrum and argentite occur with sparse, finely disseminated pyrite, sphalerite, galena and traces of chalcopyrite. Adularia in wallrocks adjacent to the quartz stockworks is associated with early, pervasively silicified zones up to tens of metres in width. Minor sericite and clay minerals occur locally. Chlorite is associated primarily with late calcite veins. Thiersch and Williams-Jones (1990) suggest that the precious metals precipitated in dilatant fractures in response to episodic boiling.

OTHER VEIN OCCURRENCES

Polymetallic quartz veins and veinlets with up to 3 per cent galena, sphalerite, chalcopyrite, with or without bornite and pyrite, commonly occur near the margins of larger granitoid intrusions. Sparse copper sulphide and oxide minerals associated with quartz-epidote-calcite veins are particularily widespread, and diagnostic of occurrences in mafic and intermediate volcanic rocks of the Takla Group.

Veins and stockwork veinlets on the Golden Lion prospect, 8 kilometres north of Tuff Peak, differ from other polymetallic occurrences in the study area. This vein system, traceable intermittantly for more than 700 metres along a northwest trend, transects a porphyritic andesite hypabyssal intrusion of probable Late Triassic age, and continues in adjacent volcanic rocks of the Metsantan Member. The intrusion appears to occupy a hangingwall panel that is structurally above a footwall panel occupied by lahar and latite flows of the Metsantan Member.

Galena, sphalerite and minor chalcopyrite occur in a quartz-calcite-pyrite gangue and commonly are accompanied by disseminated argentite and rarely stromeyerite in the matrix of narrow breccia zones. Rarely, linarite is associated with barite. Individual veinlets generally vary from 1 millimetre to 2 centimetres wide. Adularia commonly forms a selvage or pervasive envelope up to several centimetres thick on the margin of some quartz veins. The intensity of alteration decreases in wallrocks between veins; it is commonly manifest as greenish illite and minor montmorillonite pseudomorphous after plagioclase phenocrysts, and disseminated pyrite. Hematite is limited to envelopes surrounding fractures; it is superimposed on vein-related alteration.

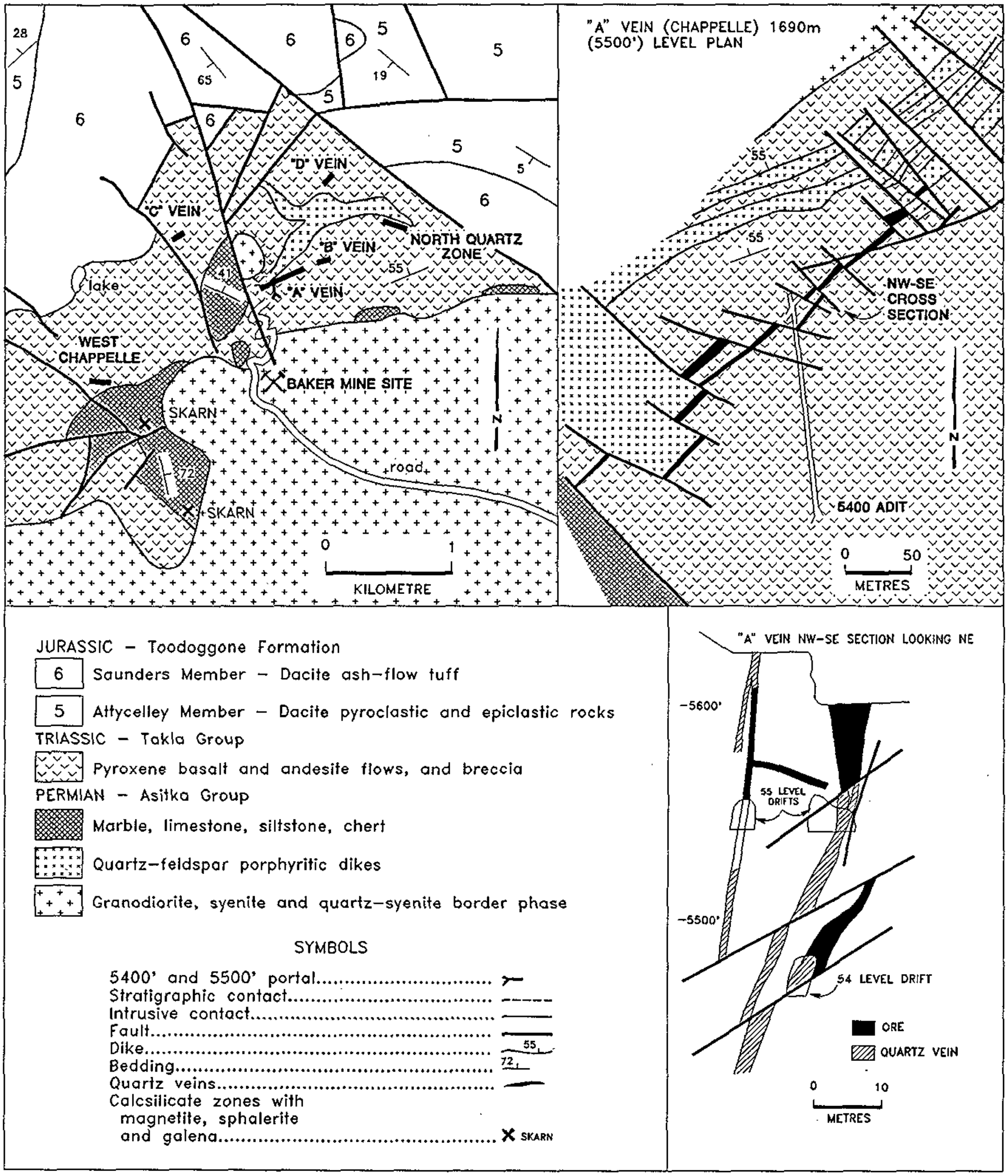


Figure 25. Geology of the Chappelle deposit showing the distribution of mineralized quartz veins and skarn in Upper Triassic volcanic rocks that are intruded by Early Jurassic granodiorite (modified from Barr, 1978; Barr *et al.*, 1986). Precious metal production at Baker mine has been mainly from the "A" vein. This vein was mined on surface from a small open pit and underground from the 5400′ and 5500′ levels.

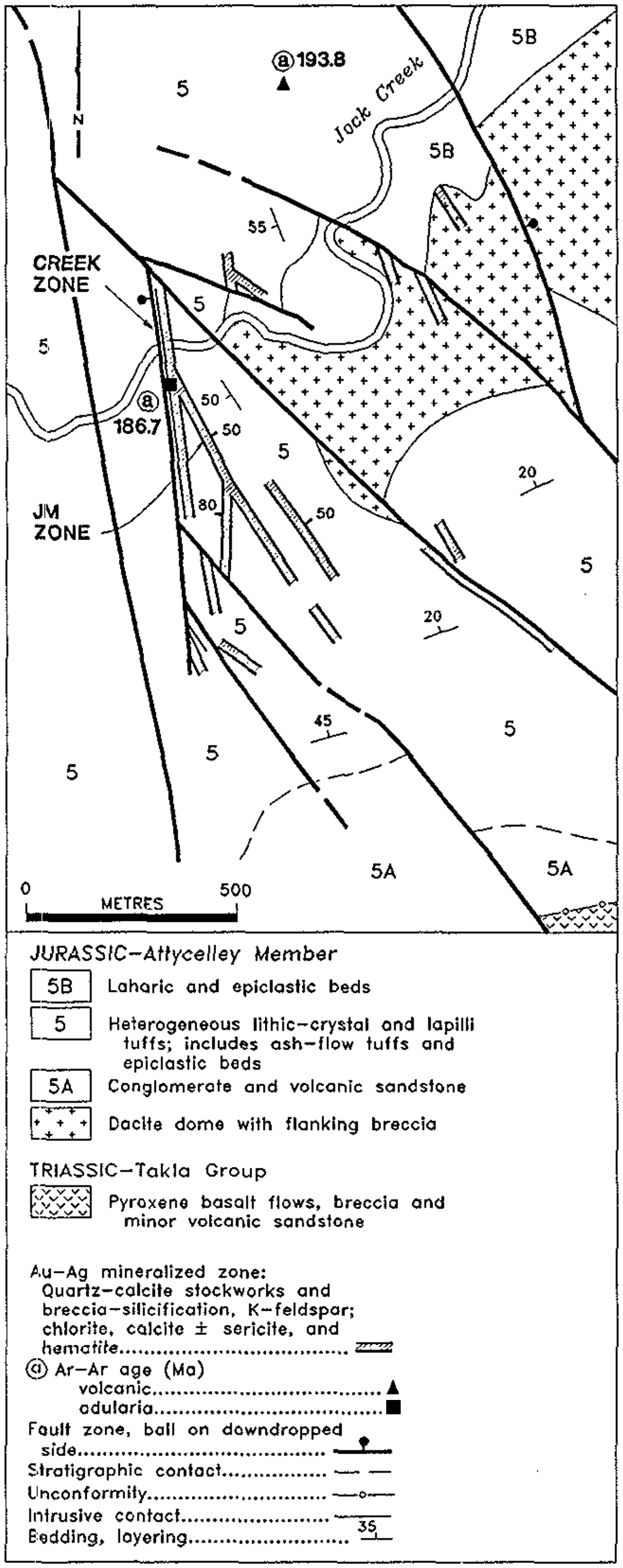


Figure 26. Geology of the Shas deposit (modified after Marsden, 1990). Mineralized quartz stockworks occur along extensional conjugate faults which disrupt bedded pyroclastic rocks of the Attycelley Member and a nearby cogenetic dacitic dome. $^{40}Ar/^{39}Ar$ dates, "a", from Clark and William-Jones, 1991.

Acid-Sulphate (Alunite-Kaolinite) Type

Acid-sulphate type precious metal bearing deposits have a highly sulphidized mineral assemblage of enargite with pyrite±covellite associated with advanced argillic alteration zones which contain kaolinite and alunite that formed contemporaneously with the deposit (Heald *et al.*, 1987).

ALBERTS HUMP AND SILVER POND ZONES

Numerous zones of intensive and extensive clay and quartz, some of which host gold and silver mineralization, occur in a 10 square kilometre area that is roughly bounded by Alberts Hump, Tuff Peak and Metsantan Mountain (Figure 22). Similarly at Silver Pond, 1 to 2 kilometres west of the Cliff Creek zone of the Lawyers deposit, clay-silica-altered rocks are well exposed in a circular area about 1.5 kilometres in diameter (Diakow, 1983; Figure 27 and Plate 11). In these areas the altered assemblages are most prevalent in flows of the Metsantan Member; they transcend the contact and extend into underlying ash-flow tuffs of the Adoogacho Member near Alberts Hump. Although primary porosity related to bedding contacts and textural inhomogeneity of volcanic and related epiclastic interbeds locally enhance alteration intensity, in general, the intensity and areal distribution of the altered mineral assemblages appear to be independent of rock type, fabric or primary igneous texture. All the altered zones are related to and centred on faults. Limited drilling, however, suggests that some laterally extensive zones of quartz and clay minerals are underlain at depth by less altered rocks. Hydrothermal fluids appear to have flared outward from the fault structures near the paleosurface, to produce zones of altered rocks that are generally concordant with the flat to gently dipping volcanic hostrocks.

The alteration mineral assemblages developed are typically zoned outward from a central core in which the original rock texture and rock-forming minerals are completely obliterated by microcrystalline silica, minor clay minerals and alunite, with or without pyrite, and trace anatase. Irregular cavities and narrow open fractures that commonly are lined by drusy quartz and interlocking tabular barite crystals occur in the massive zones of microcrystalline quartz. These zones of silica weather as low-lying mounds that vary from several metres to tens of metres across. The transition outward from silicified zones is gradational into an annular zone of predominantly dickite, nacrite, quartz and sodium-rich alunite, throughout the matrix and as discrete pseudomorphs after plagioclase. These argillically altered rocks are less resistant, and the primary volcanic textures better preserved as distance from the silicified core increases. The argillic zone grades outward, in turn, to a broad peripheral propylitic zone with chlorite, epidote and carbonate, in part replacing plagioclase, mafic phenocrysts and the rock matrix. Pyrite is widespread in concentrations of up to 5 per cent. Minor illite mixed with montmorillonite locally occurs in the transition from advanced argillic to propylitic alteration, however, for the most part distribution is poorly defined.

In both areas dikes of pink, porphyritic andesite transect country rocks replaced by pervasive quartz-clay-alunite minerals, but they themselves are relatively unaltered.

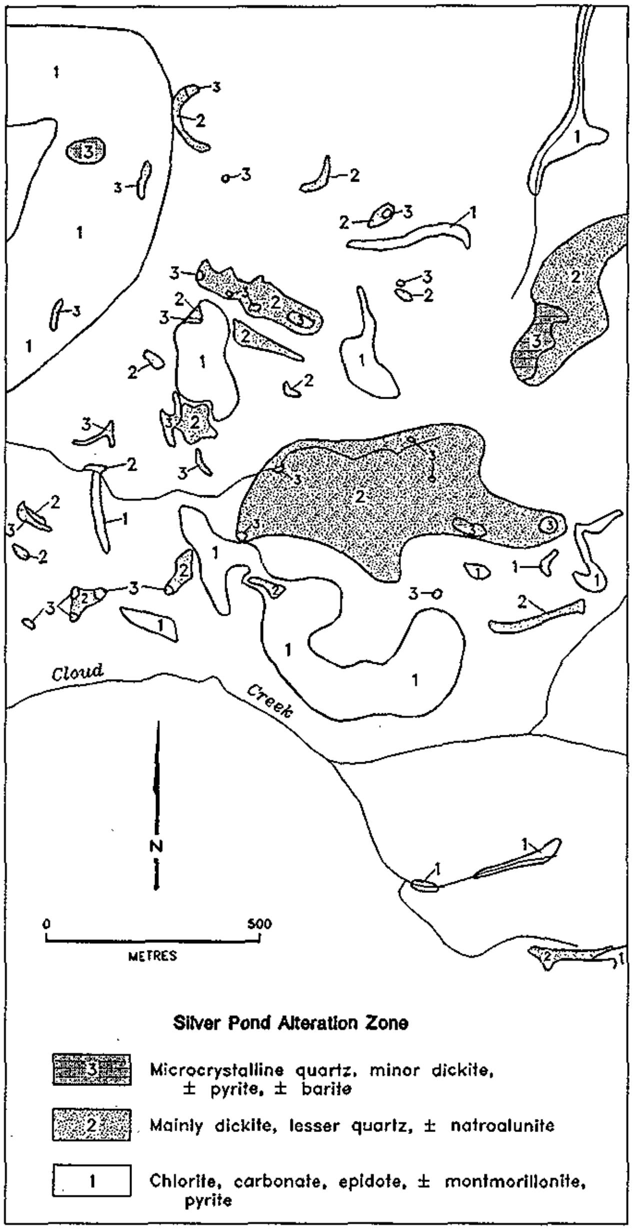


Figure 27. Surface distribution of secondary mineral assemblages at Silver Pond.

AL DEPOSIT

At present, the most significant precious metal bearing acid-sulphate type deposit is found at the Bonanza, BV and Thesis zones of the Al deposit within a radius of 3 kilometres east of Alberts Hump (Figure 28, Table 5). Three northerly trending fault systems, with little evident movement, transect a gently south to southwest-dipping sequence of dacitic ash flows and interspersed volcanogenic epiclastic beds of the Adoogacho Member. The gold-bearing zones are crudely elliptical and discontinuous along linear, mainly north and northwesterly trends. In places, breccia ore occurs within the complex fracture-fault system. The ore consists of native gold with minor amounts of pyrite, electrum, tetrahedrite, argentite, chalcopyrite, galena and sphalerite, associated with barite in open-space cavities within a silica-clay core. The silicified zone is flanked by quartz-natroalunite-dickite, and an outer quartz-illite-hematite assemblage (Clark and Williams-Jones, 1986), representative of a zoned, advanced argillic to argillic alteration suite. The silicified rock is characteristically porous, the result of leaching of clay-altered plagioclase and mafic phenocrysts. Brecciated zones with silicified clasts in a barite and crushed silica matrix contain the higher gold values. The BV zone also has a gold-barite association, but differs from the Bonanza zone in that ore occurs in discrete barite-quartz-pyrite veins. Also, sericite is abundant and an advanced argillic mineral assemblage is notably absent (Clark and Williams-Jones, 1989).

OTHER ACID-SULPHATE OCCURRENCES

Metal-bearing zones east-southeast of Alberts Hump are discontinous along faults within a complex northwest-trending fracture system. This fracture system coincides with a regional northwestly structural trend in which major precious metal deposits and prospects are aligned to the southeast of Alberts Hump. Along this corridor of metal deposits, particularly in the vicinity of Tiger Notch Pass, several elongate zones of pervasive silicic and advanced argillic alteration are localized on splay faults projecting from the Drybrough fault (Mihalynuk, 1983). Farther south at the Wrich prospect, 5 kilometres south of the Finlay River, a zone of silicic and advanced argillic alteration is enclosed by a zone of propylitized rocks along a segment of the Saunders-Wrich fault (Diakow, 1983). These altered zones have no significant reported metal concentrations, but they are important in that they demonstrate the spatial relationship of zones of advanced argillic alteration with major faults. Moreover, the secondary mineral assemblage in zones adjacent to these structures is identical to those at Silver Pond and Alberts Hump; however, they are in younger pyroclastic rocks of the Attycelley and Saunders members.

AGE CONSTRAINTS OF ALTERED AND MINERALIZED OCCURRENCES

Ages of potassium-bearing minerals from a number of mineralized veins and volcanic rocks of the Toodoggone Formation were analyzed by the K-Ar method at the University of British Columbia (Appendix B). Potassium-argon dates from this study are integrated with previously published dates as well as new step-heating $^{40}Ar/^{39}Ar$ data published by Clark and Williams-Jones (1991), in order to establish the timing of mineralizing and magmatic events in the Toodoggone area.

Three samples of adularia from vein selvages were collected from the Lawyers Amethyst Gold Breccia zone, Golden Lion and Metsantan occurrences (Figure 22, Appendix B, Samples 16, 17 and 18, respectively). The K-Ar dates provide a minimum age for ore deposition. The oldest K-Ar age on adularia is 180±6 Ma from the 0+75N crosscut on the 1750-metre level in the Lawyers AGB zone. This adularia forms discrete envelopes up to 3 millimetres wide on stockwork veinlets of amethystine quartz and calcite that cut the footwall of the ore zone. Vulimiri *et al.* (1986)

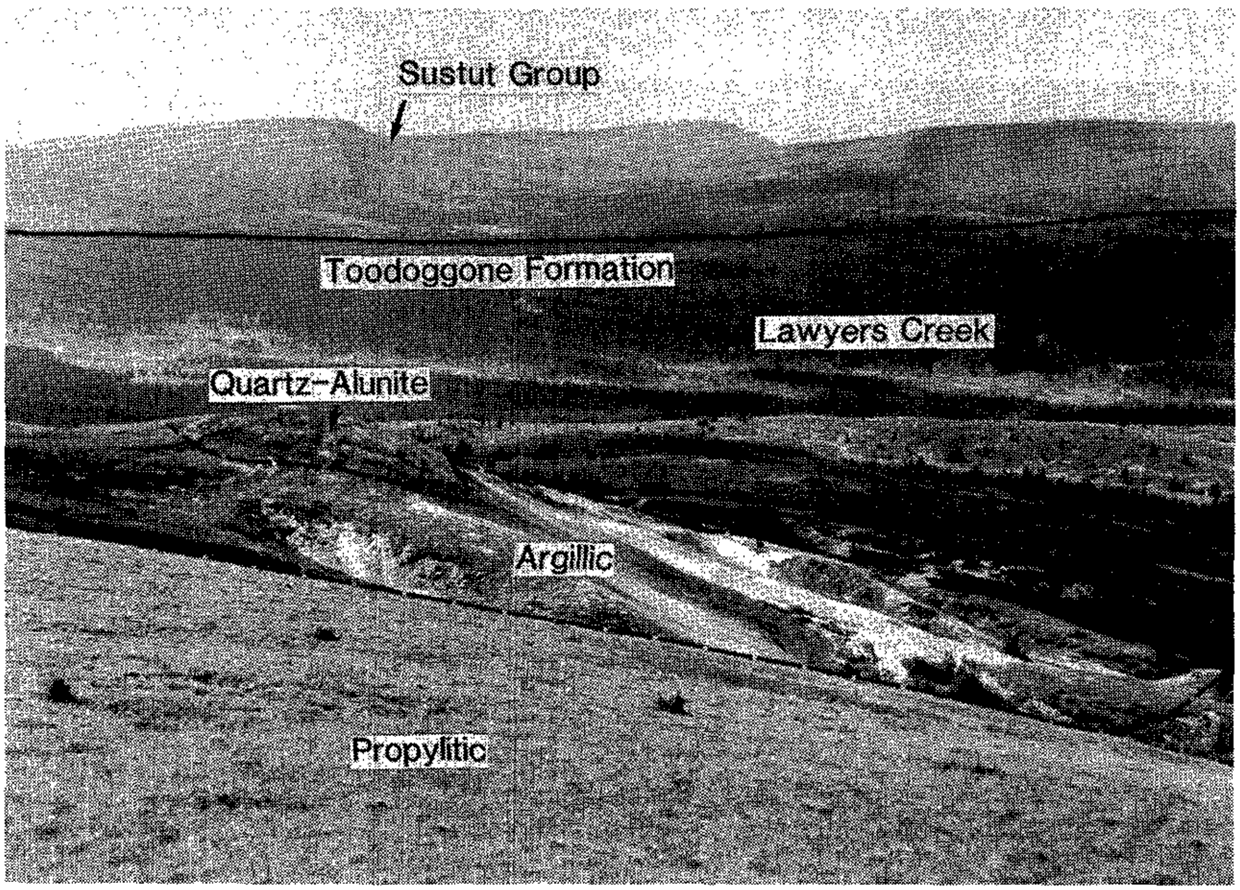


Plate 11. High-level, acid-sulphate advanced argillic altered rocks at Silver Pond, approximately 3 kilometres west of precious metal bearing quartz-adularia-calcite veins at the AGB zone, Lawyers deposit. At Silver Pond, resistant nodes of quartz-dickite-alunite altered rocks pass laterally outward to clay-rich argillic then propylitically altered volcanic rocks. Bedded rocks of the Sustut Group crop out extensively 6 kilometres west of Silver Pond. They form a thick cover of Late Cretaceous clastic sediments that have protected Toodoggone rocks and their associated epithermal deposits from erosion.

interpret this amethystine quartz - adularia gangue assemblage as a late, post-ore stage in the evolution of the mineralized veins and breccias. Adularia from the Golden Lion occurrence, with an age of 176±6 Ma, is associated with base metal bearing quartz veinlets that locally contain large amounts of argentite. Adularia from selvages on quartz-calcite-epidote veinlets at Metsantan is 168±6 Ma. This adularia is not from a metal-bearing vein but is nonetheless typical of other similar veinlets with comb-textured quartz that contain disseminated pyrite, chalcopyrite, galena, sphalerite and traces of polybasite. The broad range of ages in similar vein occurrences might suggest loss of radiogenic argon from adularia during later metamorphism and magmatic or hydrothermal activity. The $^{40}Ar/^{39}Ar$ dates from the previously sampled Lawyers AGB zone, and the similar Cliff Creek and Shasta deposits range from 187 to 190 Ma (Clark and Williams-Jones, 1991).

A sample of alunite from Alberts Hump, a resistant node of alunite and microcrystalline quartz that grades outward to a broad area of more recessive quartz-dickite altered rock, has a K-Ar age of 190±8 Ma (Appendix B, Sample 19). Although no significant precious metals are known to be directly associated with these altered rocks, the alunite is inferred to be a product of the same hydrothermal activity as that in the nearby, precious metal bearing Bonanza and BV zones of the Al deposit. However, K-Ar age determinations on sericite from these deposits are 171±6 Ma and 152±5 Ma, respectively (Appendix B, Samples 20 and 21; Clark and Williams-Jones, 1989). An $^{40}Ar/^{39}Ar$ date on sericite from the Bonanza deposit reported by Clark and Williams-Jones (1991) gives an age of 206.8±2.3 Ma. According to Clark and Williams-Jones the gas release pattern of this sample is complicated and their interpreted age for this mineralization is the minimum model age of 196 Ma. Another zone of quartz-alunite-dickite at the Jan prospect, 9 kilometres east of the Shas deposit, has a K-Ar age on alunite of 193±7 Ma (Appendix B, Sample 22; Clark and Williams-Jones, 1989), concordant with alunite in pervasively altered rocks at Alberts Hump. Near Alberts Hump, as well as at Silver Pond, slightly altered dikes of pink, porphyritic andesite cut zones of clay-altered rocks. These dikes have textures and composition similar to dikes cutting the Black Lake stock. They possibly represent a phase of the Black Lake stock that is synchronous or post-dates the youngest K-Ar cooling ages for the intrusion of 193 and 190 Ma (Gabrielse *et al.*, 1980).

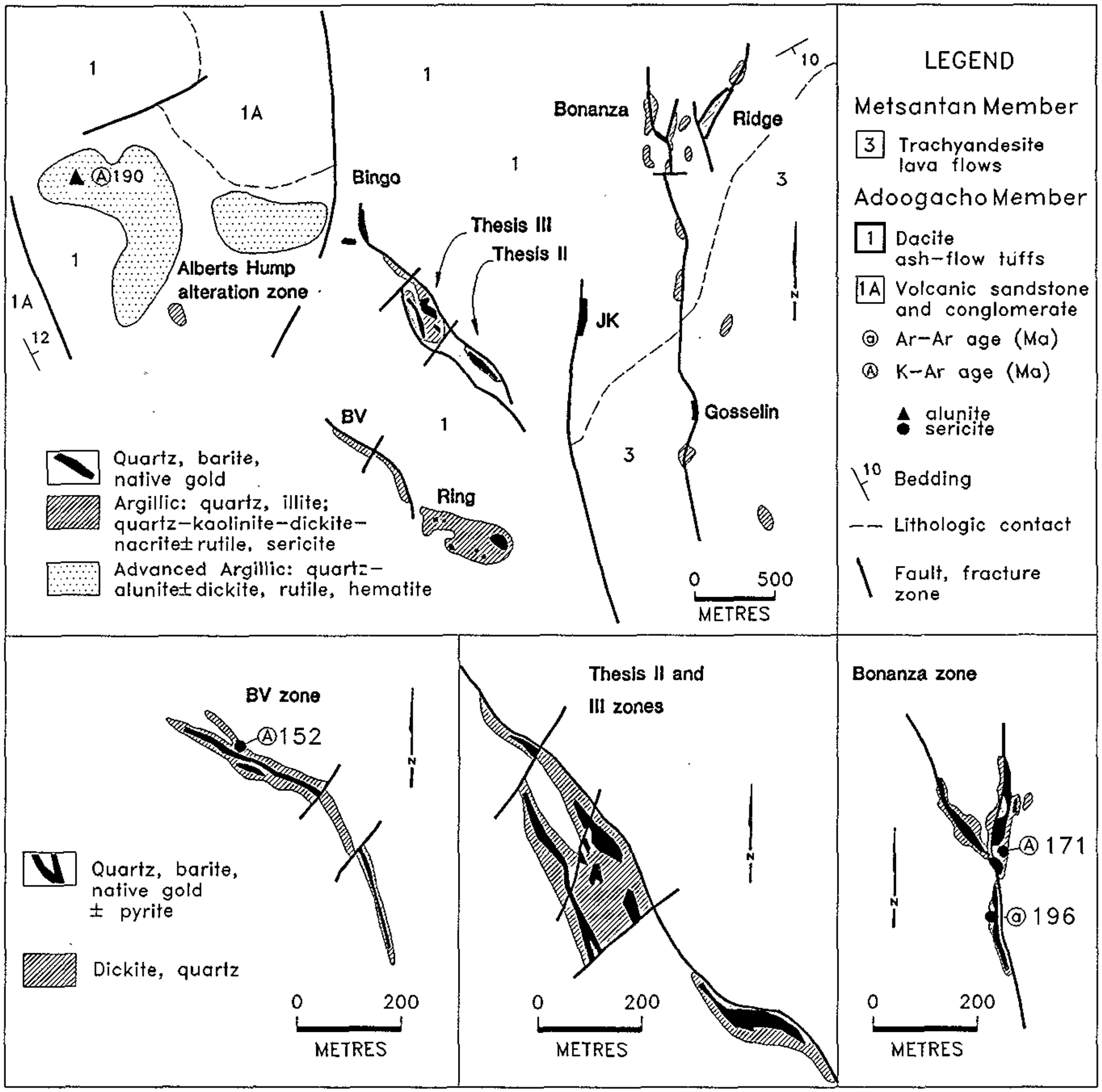


Figure 28. Barite-gold concentrations at the Al deposit, north of the Toodoggone River. Data from Energex Minerals Limited company reports (1986, 1987), and Clark and William-Jones (1986). Data for K-Ar dates (A) on altered rocks in Appendix B. $^{40}Ar/^{39}Ar$ date (a) from Clark and Williams-Jones, 1991.

Fluid Inclusion Studies

SAMPLE AND DATA SELECTION

Fluid inclusions in quartz, calcite and barite from a number of Toodoggone deposits have been examined, but only three studies have been conducted rigorously and provide thermometric data of acceptable quality. The quantitative results of the studies by Reynolds (1983), Forster (1984), and Clark and Williams-Jones (1986) are summarized in Table 6. Fluid inclusions, mainly in quartz, were described, categorized and subjected to microthermometric heating and freezing experiments as outlined by Roedder (1981). Primary and secondary inclusions were classified according to their morphology, distributions in quartz and, to a lesser extent, their liquid-vapour relationships. Primary inclusions used occur in crystal growth zones and tend to be rounded, equant in form with cuspate or faceted 'negative crystal cavity' shapes (Roedder, 1981). Secondary inclusions are generally smaller, more elongate to irregular in shape and occur in clusters that define planar structures within the host crystals. Standard microthermometric heating to determine liquid-vapour homogenization (filling) temperatures and freezing studies to determine freezing point depressions (salinity), were conducted using USGS-type gas-flow

TABLE 6

FLUID INCLUSION HEATING AND FREEZING DATA FOR VARIOUS MINERAL PROSPECTS AND DEPOSITS IN THE STUDY AREA

Sample location	Description of inclusions	Homogenization temperature (°C) no. of determinations in parentheses	Salinity Wt % NaCl equiv.	$T_{h_{total}}$ (°C)	$T_{m_{CO_2}}$ (°C)	$T_{m_{clathrate}}$ (°C)	$T_{h_{CO_2}}$ (°C)	Source[1]
Baker mine ore								
1. 5245m level, 814e 5,625′ elevation	Quartz — secondary, two or three phases liquid-rich H_2O inclusions	422, >600 (3)	31 31, 32, 38					1
	Quartz — secondary, vapour-rich H_2O inclusions	294 401, 410, 440 509	16.3 5.3, 5.9, −18.6					
	Quartz — secondary H_2O + CO_2 inclusions			244 to liquid decrepitated 360 to vapour 365 to vapour	−56.6 −56.7	7.7 7.9 6.4 2.5	20 19	
	Quartz — leaked primary, dendritic in growth zones; freezing only		0.7–2.4 (11) mean = 2.1					
Baker mine								
2. Late, narrow vein in syenite	Quartz — secondary, liquid-rich H_2O inclusions	311–351 (9)	1.4–2.1					1
Lawyers deposit								
3. Late vein in trachyandesite	Quartz — banded vein, primary inclusions	97–177 (21) mean 147±24	0.9–2.7 (5)					1
Moosehorn prospect								
4. Amethystine quartz with calcite intergrowths from quartz stockworks and breccia, drill-core specimens	Quartz (amethyst) — primary, two-phase with 5–20% vapour, homogenizes to liquid	212–251 (38) mean 232	1.0–6.3 (30) mean 3.3					
	Quartz (amethyst) — secondary, two-phase with consistent 5–10% vapour	160–185 (19) mean 170	0.4–5.1 (15) mean 2.8					
	Calcite — intergrowths between quartz crystals	116–146 (6) mean 131	0.4–2.6 (3)					
Mount Graves prospect								
5. Amethystine quartz from vein stockworks and breccia matrix	Quartz — primary, two phase, H_2O vapour variable from 5–45%, homogenizes to liquid	246–296 (20) mean 267	3.6–7.8 (18) mean 6.5					2
	Quartz — secondary, H_2O vapour consistent 5–10%	199–266 (11) mean 210	3.2–5.1 (9) mean 3.8					2
Al deposit (Verrenass zone)								
6. Quartz - barite - native gold veins	Barite — from quartz-barite veins in faults central to small argillic alteration zones	180–200	3					3

[1] Information sources: (1) Reynolds (1983); (2) Forster (1984); (3) Clark and Williams-Jones (1986).

heating-freezing microthermometric systems (Reynolds; Clark and Williams-Jones) or a Chaixmeca system (Forster).

FLUID COMPOSITIONS

Hydrothermal fluids in quartz described by Forster (1984) and Clark and Williams-Jones (1986) are low-temperature, low-salinity solutions typical of epithermal deposits. Homogenization temperatures range from 212 to 296°C in inclusions classed as primary and 160 to 226°C for inclusions considered to be secondary. Mean salinity is 3.3 and 2.8 equivalent weight per cent NaCl for primary and secondary inclusions in the Moosehorn prospect, but is 6.5 and 3.8 equivalent weight per cent NaCl for the Mount Graves prospect. The somewhat greater salinity in the Mount Graves mineralization might well account for the presence of significant amounts of base metal sulphides with the precious metals. A temperature range of 180 to 200°C and salinity of about 3 equivalent weight per cent NaCl is reported by Clark and Williams-Jones (1986) for the quartz - barite - native gold veins in the argillic and advanced argillic altered rocks at the Al deposit. This appears to be part of a high-level, possibly vapour-dominated, acid-sulphate type mineralization that is distinct from the adularia-sericite type alteration predominant in the district.

More complicated relationships of hydrothermal fluids and crystal growth histories are evident in the samples from Baker mine and the Lawyers deposit studied by Reynolds (1983). In all Baker mine samples and one of the two Lawyers samples examined, he documents the presence of secondary high-temperature (>300°C), high-salinity inclusions in addition to older, leaked, lower salinity primary inclusions. Some of the Lawyers quartz, however, displays only primary, low-temperature inclusions (T_h <180°C and salinity 0.9 to 2.7 equivalent weight per cent NaCl). In summary, Reynolds postulates that three hydrothermal fluids were present – an early, low-temperature, low-salinity, mineralizing fluid dominated by meteoric water; a secondary high-temperature, high-salinity, vapour-rich and CO_2-bearing fluid of probable magmatic origin; and possibly a late, dilute fluid in fracture-controlled, convective meteoric water flow systems driven by cooling of the nearby Early Jurassic intrusive bodies.

DISCUSSION

Much of the comb quartz and amethystine quartz with intergranular calcite overgrowths associated with precious metals was deposited in open, fault-controlled structures as vein filling, vein stockworks and breccia matrix. Inclusions considered to be primary on the basis of their morphology and distribution in the quartz crystals exhibit low homogenization temperatures (<200 to 300°C) and low salinity compatible with meteoric sources, typical of precious metal and base metal bearing epithermal fluids. These hydrothermal solutions can be regarded as relatively simple epithermal hydrothermal systems. On the other hand, at Baker mine, higher temperature (>300°C), high-salinity fluids, commonly with considerable CO_2 content, appear to overprint the older epithermal mineralization. This is consistent with the observed geological relationships that suggest that magmatically produced fluids derived from the nearby, weakly mineralized, Early Jurassic plutons circulated through reactivated structures. The presence of high-temperature secondary inclusions similar to those at Baker mine in at least some samples from Lawyers deposit suggests that unexposed intrusive bodies might be present in that area (Reynolds, 1983). Additional definitive fluid inclusion studies are required in order to adequately understand the apparently complex histories of some of the precious metal vein deposits in the Toodoggone district.

LIGHT STABLE ISOTOPE STUDIES

ISOTOPIC COMPOSITIONS

Light stable isotope compositions of hydrothermal quartz, clay, calcite and variably altered volcanic rocks, as well as a few biotite and hornblende age determination separates, were determined in the manner described by Zhang *et al.* (1989); results are listed in Table 7. Measured values in the rocks and minerals range predominantly from +5 to +17‰ ^{18}O, −4 to −10‰ $^{13}C_{PDB}$ and about −130 ±3 and −50‰ D. All the ^{18}O compositions are greater than the commonly reported −5 to +5‰ in hydrothermal quartz and altered volcanic hostrocks from typical Tertiary volcanic-hosted epithermal deposits in British Columbia, Nevada and elsewhere (Nesbitt *et al.*, 1986; Field and Fifarek, 1985). Values of ^{13}C and D indicated by a few analyses are in the normal expected range for hydrothermal deposits or magmatic products. Little distinction is statistically evident in ^{18}O between suites of the least altered, zeolite-grade regionally metamorphosed volcanic rocks (+5.4 to 11.4‰), hydrothermally altered volcanic rocks (+5.6 to 11.1‰), and mineralized vein quartz (+5.9 to 9.2‰); the mean ^{18}O value for 31 samples is +8.4‰ with a standard deviation of 1.7. In contrast, chalcedonic quartz from advanced argillic altered rocks has ^{18}O values of +12.3 to 15.6‰. Analyzed quartz-calcite pairs appear to be in isotopic equilibrium at a relatively high (epithermal) temperature in Samples 32 and 44, and 35 and 45 (Table 7), but display greater ^{18}O enrichment in calcite from a calcite-laumontite vein in Sample 11, consistent with a late-stage vein origin at a lower temperature during regional metamorphism. Biotite and hornblende have normal magmatic values of +5.6 to 6.4‰ ^{18}O. Heaviest ^{18}O compositions (up to +16.1‰) are revealed by a barren quartz vein (Sample 43), cryptocrystalline silica from silica-clay-alunite cappings in the advanced argillic altered zones (Samples 26-30) and a sample of perlitic rhyolite (Sample 10).

HYDROTHERMAL FLUID COMPOSITIONS

Variations in fluid isotopic composition (Field and Fifarek, 1985) are due to differences in fluid source or origin, temperature and water-rock ratio. The observed isotopic complexion of rocks in the Toodoggone area with high ^{18}O indicates that evolved hydrothermal fluids were involved in mineralization throughout the district. Multiple generations of fluids are inferred from banded, re-opened, and brecciated veins with crosscutting relationships; this observation is corroborated by the fluid inclusion studies. The compositions of all the successive fluids involved in mineral deposition are expressed by the whole-rock and

TABLE 7

LIGHT STABLE ISOTOPE COMPOSITIONS OF VOLCANIC ROCKS AND MINERAL SEPARATES IN THE STUDY AREA

Location No.	Sample No.	*Location-site*	Map unit	Material analyzed	$\delta^{18}O$	δD	$\delta^{13}C_{PDB}$	Source
Volcanic hostrocks — regional zeolite facies burial metamorphism								
1	82LD-251	Moosehorn Creek; ash flow, moderately altered	1	Whole rock	9.0, 10.7		–4.9	1
2	83LD-264-3C	Northern Adoogacho Creek; ash flow, weakly altered	1	Whole rock	9.8			1
3	83LD-266-5	South Adoogacho Creek; ash flow, weakly altered	1	Whole rock	11.4			1
4	83LD-277-1	Moyez Creek; ash flow, moderately altered	1	Whole rock	9.4			1
5	84LD-310-2	West Deedeeya Creek; ash flow, moderately altered	1	Whole rock	10.7			1
6	83LD-292-1	North Metsantan Mountain; flow, moderately altered	3	Whole rock	9.7		–7.4	1
7	82AP-T27	Northwest Tiger Notch Pass; ash flow, weakly altered	6	Whole rock	8.4			1
8	81LD-15-2	Saunders Creek; ash flow, weakly altered	6	Whole rock	6.1			1
9	83LD-293-3	Northwest Castle Mountain; ash flow, moderately altered	6	Whole rock	5.4			1
10	84LD-313-2A	Regional (late?) alteration; Mt. McNamara, rhyolite flow	9	Perlite	16.1			1
11	82AP-15A	Regional (late?) alteration; Tiger Notch Pass calcite-zeolite vein cutting ash flows of Unit 6	Vein	Calcite	17.2		–9.3	1
Volcanic hostrocks — radiometric age determination samples								
12	83LD-266-5	South Adoogacho Creek; ash flow, weakly altered	1 (K-Ar site 6)	Hornblende	6.4	–50		1
13	83LD-266-5	South Adoogacho Creek; ash flow, weakly altered	1 (K-Ar site 7)	Biotite	6.1			1
14	83LD-274-4	West Deedeeya Creek; crystal ash tuff, moderately altered	1 (K-Ar site 8)	Biotite	6.4	–134		1
15	83LD-292-1	North Metsantan Mountain; flow, moderately altered	3 (K-Ar site 5)	Biotite	5.6	–127		1
Volcanic hostrocks — hydrothermally altered								
16	82LD-A15	Silver Pond	3	Dickite ≫quartz[1]	7.1			1
17	82LD-Z1-5M	Silver Pond	3	Dickite ≫quartz[1]	10.2			1
18	82LD-Z2-24M	Silver Pond	3	Dickite ≫quartz[1]	11.1			1
19	82LD-A43A	Silver Pond	3	Dickite ≫quartz[1]	9.7			1
20	82LD-A77	Silver Pond	3	Dickite ≫quartz[1]	8.5			1
21	82LD-A94	Silver Pond	3	Dickite ≫quartz[1]	9.3			1
22	83LD-290-8B	North Metsantan Mountain	3	Dickite ≫quartz[1]	5.6			1
23	82LD-201D	East Tiger Notch Pass	6	Dickite	6.7	–129		1
24	82LD-7-4	West Tiger Notch Pass; ash flow, argillic alteration	6	Quartz ≫dickite	9.0			1
25	82LD-7-14	West Tiger Notch Pass; ash flow, propylitic alteration	6	Whole rock[1]	5.9			1
Silicification, advanced argillic alteration								
26	82LD-229A	Alberts Hump summit	1	Quartz-clay	15.7			1
27	82LD-215G	Golden Furlong	3	Chalcedony-quartz	15.6			1
28	82LD-215C	Golden Furlong	3	Chalcedony-quartz	13.0			2
29	TGS10	Golden Furlong	3	Chalcedony-quartz	12.3			2
30	TGS9	Al, Thesis III zone	3	Silica cap	14.6			2
Vein quartz and calcite								
31	82LD-827	Lawyers AGB zone; mineralized quartz vein, 0 + 30N, 1760 m level	Vein	Chalcedony	9.0			1
32	82LD-828	Lawyers AGB zone; mineralized quartz vein, 0 + 30N, 1760 m level	Vein	Amethyst	8.0			1
33	82LD-829	Lawyers AGB zone; mineralized quartz vein, 1 + 65N, 1760 m level	Vein	Amethyst	7.9			1
34	82AP-107A	Lawyers AGB zone; mineralized quartz vein, 0 + 75N, 1760 m level	Vein (K-Ar site 16)	Amethyst	8.7			2
35	82AP-107B	Lawyers AGB zone; mineralized quartz vein, 7 Dwarfs trench	Vein	Amethyst	9.2			2
36	82AP-196A	Cliff Creek zone; mineralized quartz stockworks	Vein	Quartz	8.6			2
37	82AP-198B	Cliff Creek zone; mineralized quartz stockworks	Vein	Quartz	8.1			2
38	81AP-76	Baker mine; mineralized quartz vein, vein A, 5550 level south	Vein	Quartz	8.6			2
39	81AP-76A	Baker mine; mineralized quartz vein, vein A, 5550 level north	Vein	Quartz	8.4			2
40	82AP-105A	Baker mine; mineralized quartz vein, vein A, 5450 sublevel	Vein	Quartz	6.1			2
41	83AP-11A	Shasta; mineralized quartz stockworks, Creek zone	Vein	Quartz	7.4			2
42	TGS11	Golden Stranger, mineralized quartz vein	Vein	Quartz	5.9			2
43	82LD-157	Awesome; barren quartz vein	Vein	Quartz	12.6			2
44	82LD-377	Lawyers AGB zone; calcite in mineralized quartz vein, 1 + 65N, 1760 m level	Vein	Calcite	8.0		–10.1	1
45	82AP-107B	Lawyers AGB zone; calcite in mineralized quartz vein, 7 Dwarfs trench	Vein	Calcite	8.1		–8.3	2
46	84LD-312-1	Metsantan Mountain; calcite in mineralized quartz vein	Vein	Calcite	4.5		–4.1	1
47	82DL-WR5	Silver Pond, calcite in propylitic alteration zone	3	Calcite	7.2		–4.0	1

[1] Clay-rich concentrates of mainly dickite with minor quartz are from advanced argillic altered volcanic rocks.

Sources of analysis: 1. L.J. Diakow, M.R. Wilson, and T.K. Kyser, University of Saskatchewan, 1984; 2. K. Muehlenbachs and B. Nesbitt, University of Alberta, 1986.

mineral analyses. Thus, if 275°C is used as an overall temperature for the dominant epithermal mineralization, as indicated by the fluid inclusion studies, an ^{18}O water composition of 0‰ is calculated using isotope fractionation factors and the method described by Matsuhisa *et al.* (1979). This value represents a composite hydrothermal fluid composition from which the main mineralized vein quartz was deposited. A composition of +1‰ and −1‰ ^{18}O can be calculated for a fluid depositing quartz at temperatures of 300°C and 250°C, respectively. In contrast, biotite with an average mineral composition of +6‰ ^{18}O would be in equilibrium with magmatic water with +9‰ ^{18}O using the fractionation factors of Bottinga and Javoy (1973) as summarized by Kyser (1987).

The samples strongly enriched in ^{18}O from the barren vein quartz at the Awesome prospect and a late laumontite-calcite vein may simply reflect lower temperatures of formation and resulting greater isotopic fractionation. The Awesome vein quartz (Sample 43 with +12.6‰ ^{18}O) has a calculated water composition of +1‰ at 200°C; calcite from the zeolite-bearing veinlet (Sample 11 with +17.2‰ ^{18}O) would have been in equilibrium with water of +0.5‰ at 100°C.

Causes of the high ^{18}O values in cryptocrystalline quartz from zones of advanced argillic alteration (Samples 26 to 30 with 12.3 to 15.7‰ ^{18}O) are equivocal. The analyzed samples consist largely of fine-grained mixtures of mainly quartz and dickite. If temperatures of the argillic alteration were on the order of 180°C to 200°C, as inferred from fluid inclusions in quartz-barite veins near the core of a number of these altered zones, the following hydrothermal fluid isotopic compositions can be calculated using fractionation factors of Clayton *et al.* (1972): crystalline quartz, +2.6‰, amorphous silica, −1‰, and kaolinite (A), +5.9‰ or kaolinite (B), +8.9‰ ^{18}O. Kaolinite A and B refer to kaolinite-water fractionation factors of Land and Dutton (1978), and Kulla and Anderson (1978), respectively. Because much of the hydrothermal quartz in the acid-sulphate argillic zones is chalcedonic or opaline, the isotopic compositions probably span a range of values dependent on the state of quartz mineral crystallinity. The ^{18}O of water from which quartz precipitated in isotopic equilibrium is similar in the acid-sulphate zones and mineralized quartz veins. In contrast, ^{18}O of water in equilibrium with kaolinite in the argillically altered rocks shows a distinctly greater ^{18}O enrichment. This can be interpreted to indicate that there was more magmatic input in the hydrothermal clay minerals or more extensive isotopic exchange took place between the country rocks and fluids that produced the (advanced) argillic mineral assemblage.

GENETIC IMPLICATIONS

A typical hydrothermal fluid that formed argillically altered rocks in the Toodoggone area is assumed to have been near 200°C with an isotopic water composition of about 0‰ ^{18}O. The limited deuterium data of −130 ±3‰ D in dickite and biotite or −50‰ D in hornblende (Table 7) do not permit further interpretation. The marked isotopic shift with heavy, ^{18}O-enriched water sets apart the isotopically distinct Jurassic Toodoggone deposits from volcanic-hosted epithermal precious metal deposits in the southwestern U.S.A. (Figure 29). However, the waters are comparable to some large geothermal-hydrothermal reservoirs, 'Carlin-type' sediment-hosted precious metal deposits, the genetically complex silver and base metal deposits in Creede, Colorado and the magmatically influenced Andean deposits discussed by Field and Fifarek (1985), Ohmoto (1986) and Kerrich (1990).

Interpretation of the observed ^{18}O enrichment in the Toodoggone epithermal deposits suggests, first that the Toodoggone mineralizing fluids are complex, extensively isotopically exchanged mixtures of meteoric and magmatic fluids. We cannot dismiss the possibility that metamorphic water may also have been involved. The large volume of plutonic rock coeval and comagmatic with volcanic rocks in the Toodoggone area and many stocks with genetically related disseminated copper, skarn and veins carrying base metal sulphides, virtually dictates that some magmatic fluid was present during the Early Jurassic epithermal mineralizing episode. The amount of meteoric-magmatic and other fluid mixing in the mineralizing hydrothermal solutions may have been considerable. In addition, the measured heavier ^{18}O water compositions could be a consequence of low water/rock mass ratios (Field and Fifarek, 1985) but the effects of this ratio have not been evaluated. Second, the long-term effects and consequences on the isotopic compositions of hydrothermal minerals during multiple hydrothermal events and a long crustal residence time in an accreted, tectonically active and extensively intruded island-arc terrain are undetermined. The isotopic compositions of similar epithermal deposits older than Tertiary need to be examined and compared.

PORPHYRY COPPER-GOLD OCCURRENCES

Copper-gold and/or molybdenum mineralization with minor sphalerite and galena is found in quartz veinlets or as disseminations within volcanic flows and tuffs intruded by Early Jurassic calcalkaline plutons of granodiorite to quartz monzonite composition. Since 1988, such prospects in the Toodoggone area have been aggressively explored for their bulk-tonnage, low-grade copper-gold potential.

The Kemess property, located 11 kilometres southeast of the Finlay River, is the most intensely explored prospect of this type in the study area. Four zones of porphyry copper-gold mineralization have been identified. The Kemess North and West zones, formerly the Kemess and Rat properties, respectively, were initially explored in the late 1960s and the early 1970s; the Kemess South zone is a significant new discovery.

At Kemess North, pyrite, chalcopyrite and minor molybdenite occur in quartz and potassium feldspar stockworks and as disseminations apparently associated with monzonite and quartz monzonite dikes(?) in an area of intense propylitic and argillic alteration in volcanic rocks of the Upper Triassic Takla Group. In 1991, drill-indicated reserves were estimated at 70 million tonnes grading 0.18 per cent copper and 0.66 gram per tonne gold.

The altered rocks are strongly oxidized and comprise jarosite, hematite and minor kaolinite, epidote, chlorite and

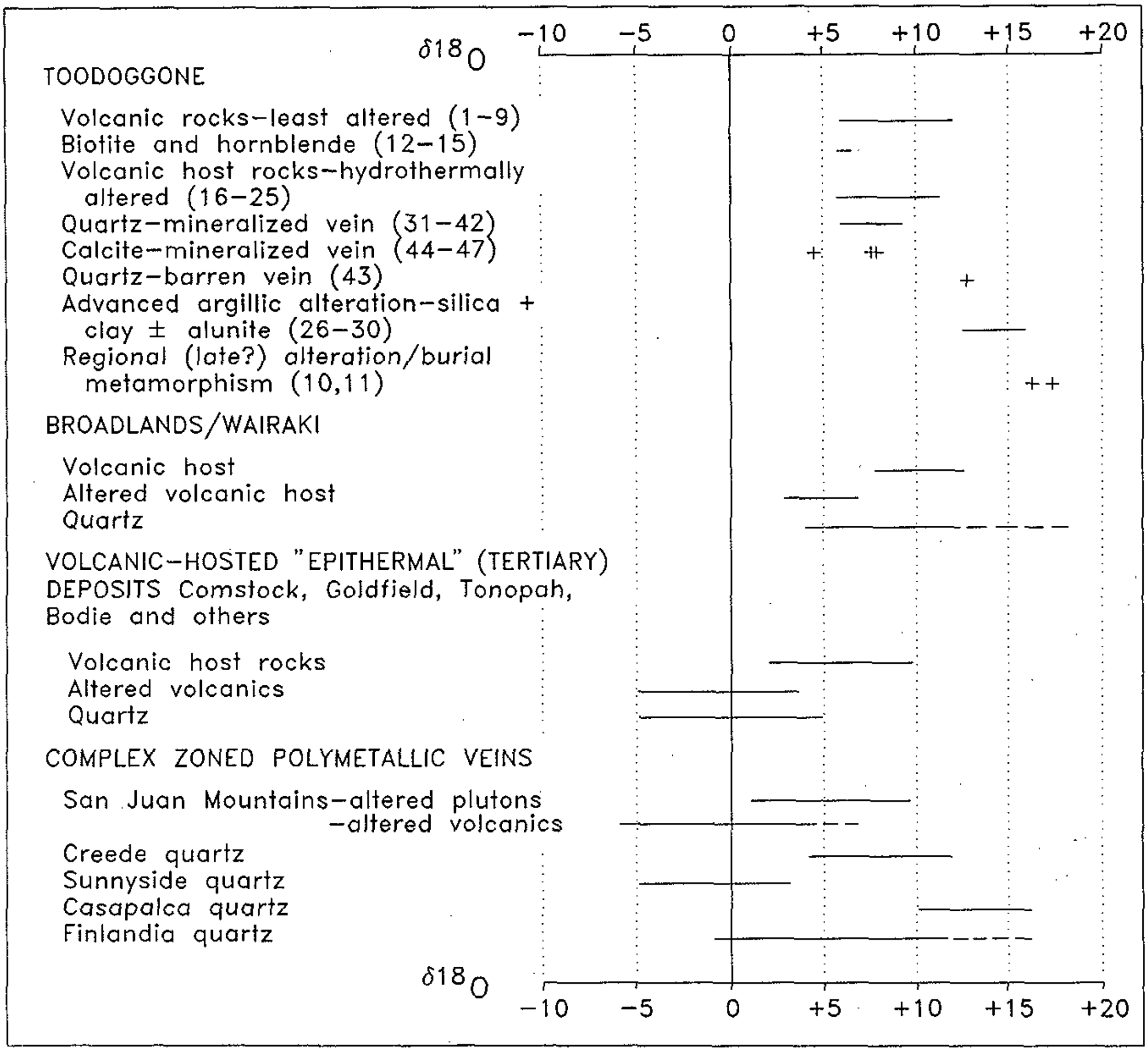


Figure 29. Distribution of whole-rock and quartz ^{18}O in Toodoggone and other epithermal deposits. Numerals in brackets correspond with samples described in Table 7. Comparative data from Field and Fifarek (1985).

calcite. Notable concentrations of anhydrite are locally encountered in boreholes. In general, the pattern of altered minerals grades from a core zone of intensive, quartz - sericite - potassium feldspar - pyrite alteration, outward into argillically altered rocks. At Kemess North, a K-Ar whole-rock date of 182±6 Ma from quartz-sericite-pyrite-altered volcanic rocks is interpreted as representing a period of hydrothermal activity related to mineralization (Cann and Godwin, 1980). This date is similar to the ages of epithermal alteration and mineralization at the Shasta and Lawyers deposits; 25 and 40 kilometres, respectively, northwest of the Kemess property.

At Kemess South, copper and gold are associated with a gently dipping, tabular body of monzonite which is in fault contact with footwall volcanic rocks of the Takla Group. Primary mineralization within the monzonite consists of chalcopyrite, pyrite, magnetite and minor molybdenite as disseminated grains and in stockwork veinlets. Within the upper part of the sill, the hypogene ore grades into an enriched supergene zone, up to 25 metres thick, containing chalcocite, native copper, cuprite and malachite. In places the supergene zone passes upwards into a leached zone of clay minerals and hematite up to 2 metres thick. Elsewhere, the leached zone may be absent and a quartz-bearing fragmental rock, presumably from the Toodoggone Formation, mantles the zone of supergene enrichment. Copper and gold assays are highest within the supergene zone. They decrease in comparatively less altered monzonite where the gold is apparently concentrated in quartz-hematite stockworks. In 1991, an average grade of 0.23 per cent copper and 0.48 gram per tonne gold was calculated from drilling within a 900 by 600 metre blanket-like deposit.

Several other porphyry prospects, including the Porphyry Pearl, Pine (Fin), Riga and Mex, occur northwest of the Kemess property. Some of these have exposed granitic plutons, others have copper mineralization and zoned alteration assemblages indicative of a buried porphyry system.

SKARN OCCURRENCES

Skarn is developed in Permian carbonate rocks in contact with the Black Lake stock near Castle Mountain and in pendants of similar rocks near Drybrough Peak. The skarn at Castle Mountain occurs in sporadically distributed pods which are rarely more than 1 or 2 metres long. They are chalcopyrite-sphalerite-galena-magnetite with green amphibole, garnet, epidote and pyrite within marble. At the Amigo prospect approximately 2 kilometres west-southwest of Drybrough Peak, native gold is reportedly associated with massive magnetite over a width of 10 metres at the contact between limestone and granodiorite (T.G. Schroeter, unpublished report, 1987).

PLACER DEPOSITS

The lower part of McClair Creek is a gossanous zone along an intrusive contact between granodiorite and rocks of the Toodoggone Formation. As early as the mid-1920s, prospectors worked a small-scale sluicing operation near the mouth of McClair Creek from which gold worth several thousand dollars is reported to have been recovered (Lay, 1935). Subsequent exploration in the valley of the Toodoggone River and McClair Creek in the early 1930s resulted in the production of 3265 grams of gold (Holland, 1950).

SYNTHESIS

Geological and mineralogical data for the various mineral deposit types in the Toodoggone area were considered by Panteleyev (1986) within a broader depth-zoning context and formulated into an epithermal model for British Columbia. The model proposes a continuum of mineralized environments in the Toodoggone area that ranges from porphyry deposits and skarn associated with granitoid intrusions at depth, to precious metal bearing quartz veins at shallower levels that pass upwards into near-surface, acid-sulphate altered zones (Figure 30).

Volcanic-hosted gold and silver deposits in the Toodoggone area have characteristics of the epithermal type based upon ore and gangue mineralogy, vein textures and interpreted relationships to the paleosurface (Heald *et al.*, 1987; Buchanan, 1981). These deposits are: (1) quartzose veins, stockworks and breccia containing argentite, electrum with lesser native gold and minor base metal sulphides; these have secondary adularia, calcite and sericite in the wallrocks, and (2) precious metals with barite in fractures cutting broad zones of pervasive quartz-alunite-dickite alteration. Both types of precious metal bearing deposits formed in fractured and faulted volcanic rocks of Late Triassic to Early Jurassic age.

Studies of fluid inclusions in quartz from the vein deposits indicate that ore minerals were deposited by low-temperature (<200 to 296°C) and low-salinity (<1 to 6.5 equivalent weight per cent NaCl) fluids (Forster, 1984). Barite associated with gold in acid-sulphate alteration at the Al deposit near Alberts Hump was also generated by cool (180 to 200°C) and dilute (3 equivalent weight per cent NaCl) solutions (Clark and Williams-Jones, 1986). These fluids resemble geothermal fluids and those of deeper epithermal deposits in which the hydrologic regimes are dominated by meteoric water. Veins with comb textures, banded structure and central open cavities suggest that cymoid dilations, extensional fractures and faults were pathways for multiple pulses of hydrothermal fluids. At the Lawyers deposit and Mount Graves prospect, veins with silica-rimmed breccia fragments are healed by multiple layers of microcrystalline quartz. This might suggest that rupture or hydraulic fracturing has occurred during episodic hydrostatic boiling. Although we have no direct evidence for boiling, it can, in addition to mixing of hydrothermal and meteoric fluids, provide an effective mechanism for deposition of precious metals in epithermal systems (Drummond and Ohmoto, 1985; Henley, 1985, Spycher and Reed, 1989).

Radiometric ages from the hydrothermal minerals suggest that episodes of circulating fluids both accompanied and followed emplacement of Toodoggone volcanic and plutonic rocks. However, some younger K-Ar dates from adularia and sericite compared to alunite dates, demonstrate the difficulty in relating the alteration and associated mineralization to any specific magmatic-hydrothermal event. Despite this uncertainty, two main ore-forming events are proposed, based on the radiometric ages of potassium-bearing secondary minerals, contrasting types of metal and altered rock assemblages and their stratigraphic position.

The earliest hydrothermal mineralization evident is the barite-gold veining associated with advanced argillic alteration at the Bonanza and BV zones of the Al deposit near Alberts Hump. This is believed to be part of one large hydrothermal system that was active by 190 Ma or earlier, based on dated alunite, and the interpreted 196 Ma age from sericite (Clark and Williams-Jones, 1991). Apparently younger hydrothermal mineralization is represented by the metalliferous quartz veins with adularia-sericite at the Anethyst Gold Breccia zone of the Lawyers deposit as well as the genetically related zone of acid-sulphate altered rocks at Silver Pond, 1 to 2 kilometres to the west. Mineralized zones at the Lawyers deposit and Silver Pond are considered here to represent different structural levels and stages of the same hydrothermal system, that are juxtaposed by block faults. The later timing of metal deposition at the Lawyers AGB and the other adularia-sericite epithermal deposits is supported by the 180 to 168 Ma K-Ar dates from adularia vein selvages from the AGB deposit and the similar Golden Lion and Metsantan occurrences in the north as well as the 187 to 190 Ma $^{40}Ar/^{39}Ar$ dates reported by Clark and Williams-Jones (1991). The range of dates from adularia and sericite suggests that variable loss of radiogenic argon has occurred, possibly during regional low-grade metamorphism or intrusion of dikes.

Because there is a striking resemblance in alteration mineral assemblages at Alberts Hump and Silver Pond, it is tempting to suggest that they formed at the same time, but independently, from two separate hydrothermal systems.

The precious metal bearing veins at Lawyers have very similar metallic and alteration mineral assemblages to the veins at the Shas deposit, which are confined to younger strata of the upper volcanic cycle. If the association of Lawyers with Shas based on physical similarities is valid, these deposits are part of a discrete, younger mineralizing event that is distinct from that in the older strata at Alberts Hump.

The spatial and temporal relationship between acid-sulphate precious metal bearing deposits, intrusive bodies, and related juvenile fluids appears to be a characteristic feature in a number of epithermal districts described by Heald *et al.* (1987). Sillitoe (1989) emphasizes the association between near-surface acid-sulphate and deeper adularia-sericite gold deposits, intrusions and stratovolcanoes in volcano-plutonic island arcs in the western Pacific. Interestingly, the acid-sulphate altered zones at Alberts Hump and in the Jan area have K-Ar ages from alunite that are identical to K-Ar cooling dates of 190 Ma and 193 Ma for the Black Lake stock. Although there is no evidence for large intrusions closer than 6 kilometres from Silver Pond and 12 kilometres from Alberts Hump, these deposits have relatively unaltered dikes cutting the advanced argillic altered rocks. The dikes may be derived from larger granitoid intrusions at depth.

Whether intrusions are involved in ore formation, either directly as a specific source of mineralizing fluids or indirectly as heat sources for convecting metalliferous meteoric water has long been debated. Sillitoe (1989) advocates a two-stage model for intrusion-related epithermal gold deposits. During the initial stage magmatic volatiles ascend and, in the presence of oxygenated water, form low pH condensates that cause extreme leaching of country rock and resultant advanced argillic alteration. Precious metals are precipitated from these early magmatic fluids and vapours, commonly together with base metal sulphides. As

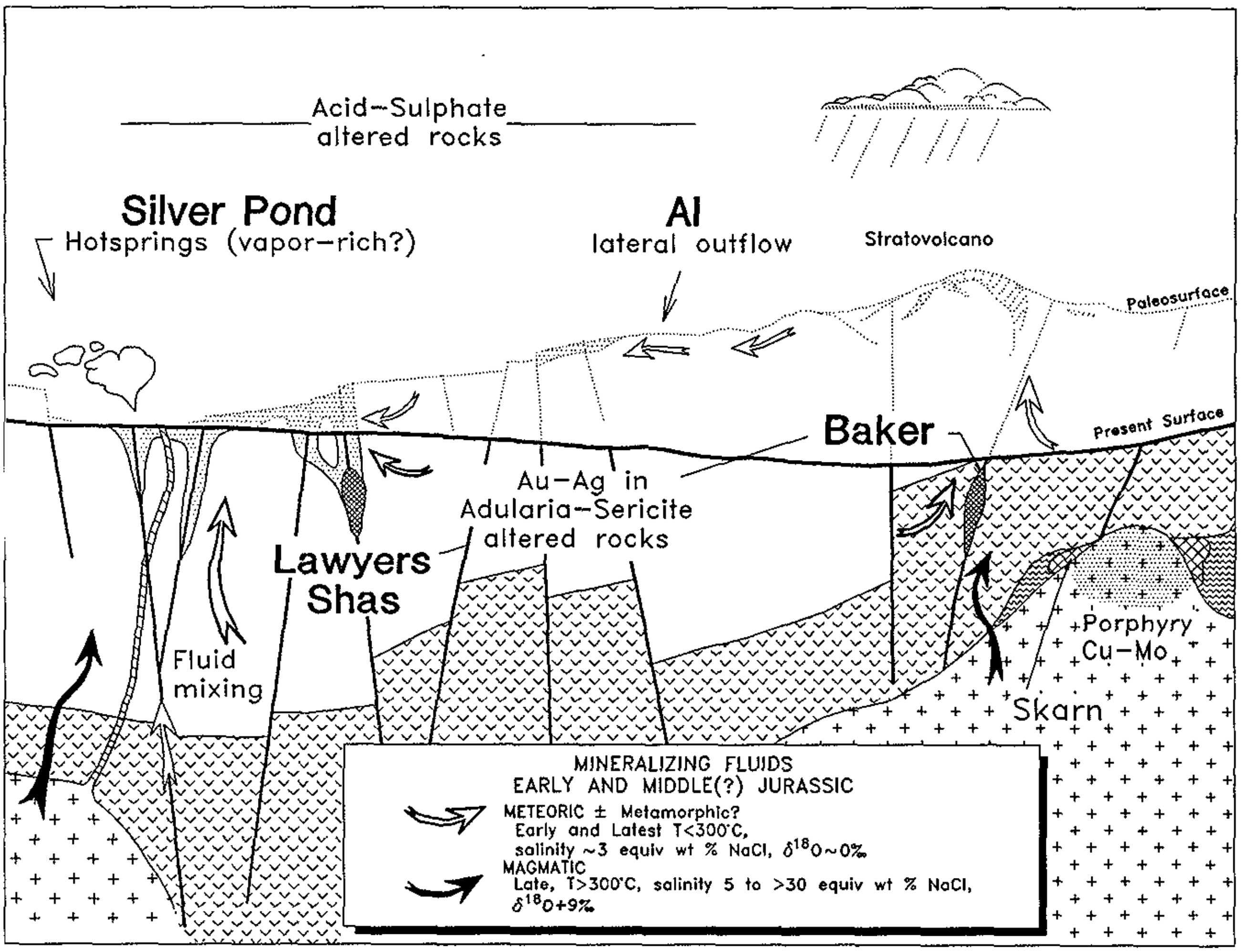


Figure 30. Conceptual model of Early Jurassic metallogenic relationships in the Toodoggone River map area. Gold-silver deposits are found mainly in the Toodoggone Formation and rarely in basement strata of the Takla Group. Typical epithermal mineralization occurs as either: (1) quartz veins, stockworks and breccias in extensional fault-fracture systems with associated adularia and lesser sericite and calcite or (2) silicification in pervasive, argillically and advanced argillically altered rocks containing vuggy quartz-barite zones with native gold. Mineralizing fluids are predominantly low-temperature, dilute meteoric or mixed meteoric-magmatic waters. Overprinting by higher temperature, saline magmatic fluids is evident at the Chappelle and Lawyers deposits. The late magmatic fluids are derived from coeval Early Jurassic plutons exhibiting weak concentrations of base metals.

the magmatic activity wanes this early fluid regime is overprinted by fluids dominated by meteoric water. Mixing of the different source fluids and boiling induce precious metals to precipitate in deeper and more peripheral adularia-sericite veins, whereas, the metals deposited earlier can be reworked and redeposited in the nearer surface acid sulphate deposits (Stoffregren, 1987). Present knowledge of the source and evolution of fluids involved in acid-sulphate and adularia-sericite epithermal deposits in the study area is limited. This could be the basis for future research emphasizing stable isotope characteristics and physiochemical constraints of ore and alteration assemblages on deposit models.

In summary, the oldest dated epithermal mineralization in the Toodoggone area is associated with acid-sulphate alteration. Adularia-sericite type mineralization appears to postdate the acid-sulphate type, but this may be a consequence of argon loss from the dated hydrothermal minerals rather than a real time difference. Either mineral deposit type may be associated with hydrothermal systems closely related in time to cooling of Early Jurassic granitoid stocks and related subvolcanic intrusions. The younger ore deposition is related to structural events initiated near the end of volcanic activity that produced the upper volcanic cycle of the Toodoggone Formation. This style of ore deposition is in accord with magmatic events described in many Tertiary epithermal precious metal districts in the southwest United States (Silberman, 1985; Heald *et al.*, 1987) and elsewhere. In these Tertiary systems ore is deposited episodically during short-lived local events within longer periods of hydrothermal activity. Most commonly, mineralization occurs during the waning stages of volcanism or post-dates the termination of volcanism by a million years or more.

Precious metal deposits in the Toodoggone mining district, including the Lawyers mine, Baker mine, Al and Shas, all lie within a northwesterly trending corridor. Elongation of the Black Lake stock, other smaller plutons and dike swarms also follow this northwesterly trend. This structural grain outlines or reflects an extensional tectonic regime that has regulated structural and magmatic development of the Toodoggone Formation. The resulting depositional site was a shallow, northwest-elongated volcanic depression occupying the medial part of an island arc. Extension facilitated ascent of magma to shallow reservoirs, where the heat of crystallization initiated and sustained plumes of relatively cool and dilute hydrothermal waters. Steeply dipping fracture and fault systems host all significant precious metal deposits in the study area. In particular, the vein systems at the Lawyers, Shas, and Baker mines formed at or near the margin of the central Toodoggone depression. This demonstrable spatial and temporal relationship of ore-bearing veins near the perimeter of this subsidence feature suggests that mineralizing fluids were repeatedly channelled along faults and fractures during and after subsidence.

The probability of preserving any of the Jurassic high-level mineralization and its contemporaneous host strata, in light of the subsequent Middle Jurassic and younger tectonic terrane interactions (Monger, 1984; Gabrielse, 1985), is very slight without some unusual mechanism of preservation. The Early Jurassic volcanic strata of the Toodoggone Formation erupted concurrently with the development of deeply rooted faults that both focused magmatism and regulated the subsidence of a volcanic depression. Younger molasse sedimentary rocks of the Bowser Lake Group probably blanketed the volcanic depression as early as Middle Jurassic time. However, these sediments presumably were completely eroded and then supplanted by yet another sedimentary succession, the Sustut Group, in Late Cretaceous time. These overlapping sedimentary successions are believed to be a critical factor that minimized erosion in the Toodoggone map area. The consequence is the remarkable state of preservation of some of the more delicate subaerial components of the Toodoggone Formation, the associated epithermal deposits and their related, readily eroded hydrothermal alteration zones.

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APPENDIX A

MAJOR ELEMENT ANALYTICAL PROCEDURE

Major element analyses were carried out by the Analytical Sciences Section of the Ministry of Energy, Mines and Petroleum Resources in Victoria. Samples to be analysed were crushed to a fine powder, fused in $LiBO_2$ and dissolved in dilute HNO_3 and HF with CsCl added as an ionization buffer. Major element concentrations of the samples, duplicates and international standard, CCMRP Syenite SY-2, were measured on a Perkin Elmer Model 107 atomic absorption flame spectrophotometer.

Total iron was measured as Fe_2O_3*, ferrous iron was determined by titration with $KMnO_4$ after H_2SO_4 and HF dissolution. Ferric iron was then calculated by:

$$Fe_2O_3 = Fe_2O_3^* - 1.113\ FeO$$

Determination of CO_2 was by KOH absorption with volumetric gas measurement in a Leco induction furnace. Determination of H_2O^- was by drying two grams of sample powder at 110°C overnight then weighing the cooled sample for weight loss. Determination of H_2O^+ was by a gravimetric method described by Johnson and Sheppard (1978); it involves "fusion of the sample in a test tube with a litharge flux. The water which is released is swept into a tared U-tube containing a desiccant. The water absorbed by the desiccant is measured by weighing the tared U-tube".

Raw data of replicate readings for all standards and samples was processed by computer using a program which monitors and corrects for instrument drift. Precision of analyses is about 0.3 per cent relative standard deviation (RSD) with accuracy, estimated from runs of international standards, of 0.5 per cent RSD.

Major oxide compositions and CIPW normative minerals for 70 analyzed samples are listed in the following section. Total oxide values, with volatiles added, range from 98.20 to 101.55 per cent, most are within the range of 99 to 100 per cent. The composition of volcanic rocks from the Toodoggone Formation is represented by 31 least-altered samples. Representative samples were selected based on the low relative abundance of secondary minerals replacing primary minerals in thin section, and total volatile concentrations less than 4 weight per cent.

MAJOR ELEMENT ANALYSES AND CIPW NORMS
ADOOGACHO MEMBER (MAP UNIT 1)

Sample+	1* D266-5	2* D274-4	3* D311-9	4* D316-1	5* AP-40	6* AP-57	7 D310-2	8 D310-10	9 D311-6	10 AP-27	11 AP-28
Oxides as Determined											
SiO_2	62.42	62.47	62.72	61.74	59.18	60.74	57.95	59.16	61.69	62.93	57.52
TiO_2	0.53	0.53	0.49	0.50	0.58	0.56	0.50	0.53	0.48	0.52	0.50
Al_2O_3	16.16	16.66	15.53	16.24	16.83	17.82	15.95	15.31	15.24	16.77	15.38
Fe_2O_3	4.48	5.17	4.62	3.96	5.42	6.14	4.38	4.10	4.56	4.58	1.69
FeO	0.80	0.05	0.47	1.18	0.16	0.34	0.53	0.70	0.43	0.20	2.93
MnO	0.12	0.12	0.14	0.15	0.11	0.16	0.16	0.12	0.09	0.13	0.37
MgO	1.75	1.64	1.72	2.00	2.54	1.42	1.00	1.58	2.64	1.46	2.26
CaO	2.52	1.03	3.61	3.83	2.58	1.26	7.42	5.25	1.26	0.77	5.02
Na_2O	6.61	5.03	3.56	3.31	4.97	7.54	2.99	2.75	3.58	4.41	3.82
K_2O	3.65	3.04	3.42	3.83	3.99	3.10	1.37	2.81	5.64	6.74	2.97
P_2O_5	0.21	0.19	0.20	0.15	0.20	0.17	0.19	0.37	0.21	0.32	0.20
H_2O^+	0.46	1.37	1.63	1.64	2.20	0.71	4.81	4.12	1.66	0.96	1.94
H_2O^-	0.33	0.91	0.65	1.00	0.30	0.33	0.92	1.25	0.65	0.58	2.23
CO_2	0.40	0.81	0.61	0.14	0.99	0.15	1.77	1.22	0.68	0.15	2.11
S	0.01	0.01	0.01	0.02	0.01	0.01	—	0.01	0.01	0.01	0.01
Total	100.45	99.03	99.38	99.69	100.06	100.45	99.94	99.28	98.82	100.53	98.96
FeO*	4.83	4.70	4.63	4.74	5.04	5.86	4.47	4.39	4.53	4.32	4.45
FeO*/MgO	2.76	2.87	2.69	2.37	1.98	4.13	4.47	2.78	1.72	2.96	1.97
K_2O/Na_2O	0.55	0.60	0.96	1.16	0.80	0.41	0.46	1.02	1.58	1.53	0.78
CIPW Normative Minerals (anhydrous)											
q	4.27	*18.24*	*19.99*	*17.65*	*6.51*	*0.73*	*21.62*	*22.03*	*13.85*	*8.70*	*11.10*
c	—	3.84	—	0.05	0.13	0.19	—	—	1.53	1.61	—
or	21.73	18.73	20.95	23.36	24.42	18.46	8.76	17.92	34.78	40.30	18.94
ab	56.34	44.35	31.21	28.90	43.54	64.26	27.36	25.10	31.60	37.75	34.87
an	*3.69*	*4.03*	*16.90*	*18.60*	*11.90*	*5.18*	*28.20*	*22.81*	*5.09*	*1.75*	*17.33*
di	5.86	—	0.24	—	—	—	8.00	2.09	—	—	6.65
hy	1.68	4.26	4.33	5.14	6.55	3.56	1.02	3.28	6.86	3.68	6.97
mt	1.44	—	0.57	2.93	—	—	0.85	1.20	0.30	—	2.64
il	*1.01*	*0.38*	*0.96*	*0.98*	*0.59*	*1.07*	*1.03*	*1.09*	*0.95*	*0.71*	*1.02*
hm	3.52	5.39	4.39	2.06	5.61	6.19	4.15	3.60	4.55	4.63	—
ru	—	0.35	—	—	0.29	—	—	—	—	0.15	—
ap	0.49	0.46	0.48	0.36	0.48	0.40	0.48	0.93	0.51	0.75	0.50
AN%	*6.15*	*8.33*	*35.13*	*39.16*	*21.47*	*7.46*	*50.75*	*47.62*	*13.88*	*4.43*	*33.20*

* Least altered sample plotted on geochemical discrimination diagrams.

+ Sample locations are in Map 3. Specimen number prefix indicates collector: AP=A. Panteleyev, D=L. Diakow, MM=M. Mihalynuk, TS=T. Schroeter.

METSANTAN MEMBER (MAP UNITS 3, 3a)

Sample+	12* D3	13* D28	14* D40	15* D118	16* D268-3a	17* D283-2a	18* D291-3	19* D292-1	20* D294-1	21* D300-2a
Oxides as Determined										
SiO_2	58.83	58.20	57.49	56.47	58.06	55.37	55.82	58.32	60.55	59.92
TiO_2	0.66	0.67	0.74	0.76	0.62	0.74	0.80	0.65	0.64	0.62
Al_2O_3	16.93	17.02	16.88	16.71	16.69	16.71	16.79	16.00	16.30	16.05
Fe_2O_3	3.44	3.89	4.80	5.08	5.72	6.02	6.93	5.91	5.01	3.94
FeO	2.39	2.11	1.83	1.58	0.71	1.14	0.80	0.36	0.91	1.79
MnO	0.21	0.15	0.16	0.15	0.18	0.21	0.15	0.21	0.13	0.13
MgO	2.57	2.40	2.86	2.70	2.48	2.56	4.03	3.73	2.18	2.17
CaO	4.42	5.09	4.51	5.84	3.30	6.24	2.99	1.48	5.00	4.82
Na_2O	3.75	3.83	4.36	3.61	5.26	3.73	4.83	4.68	4.42	4.36
K_2O	2.93	3.26	3.45	2.99	3.65	2.71	3.25	3.89	2.80	2.94
P_2O_5	0.25	0.34	0.28	0.25	0.29	0.33	0.22	0.19	0.21	0.18
H_2O^+	1.69	1.87	1.21	2.04	1.10	2.72	1.61	2.13	1.49	2.13
H_2O^-	0.88	0.69	0.47	0.79	0.77	0.44	0.48	0.71	0.54	0.35
CO_2	0.21	0.35	0.42	0.28	0.62	0.14	0.91	0.84	0.15	0.10
S	0.12	0.01	0.02	0.01	0.01	—	—	0.02	0.02	0.02
Total	99.28	99.88	99.47	99.26	99.46	99.06	99.61	99.12	100.35	99.50
FeO*	5.49	5.61	6.15	6.15	5.86	6.56	7.04	5.95	5.52	5.51
FeO*/MgO	2.13	2.34	2.15	2.28	2.36	2.56	1.75	1.52	2.49	2.46
K_2O/Na_2O	0.78	0.85	0.79	0.83	0.69	0.73	0.67	0.83	0.63	0.67
CIPW Normative Minerals (anhydrous)										
q	13.34	11.02	6.92	10.08	4.43	9.18	3.65	8.44	12.54	12.21
c	0.16	—	—	—	—	—	0.44	1.95	—	—
or	17.96	19.87	20.94	18.38	22.25	16.72	19.88	24.09	16.86	17.93
ab	32.91	33.41	37.88	31.76	45.89	32.95	42.29	41.49	38.09	38.05
an	21.06	20.25	16.76	21.40	11.52	21.79	13.87	6.39	16.69	16.05
di	—	2.73	3.38	5.48	2.66	6.45	—	—	5.59	5.77
hy	7.52	4.90	5.75	4.45	5.14	3.67	10.39	9.73	2.94	2.90
mt	—	5.52	4.39	3.51	1.11	2.31	0.78	—	1.53	4.54
il	5.17	1.31	1.44	1.50	1.21	1.47	1.57	1.27	1.24	1.21
hm	1.30	0.21	1.90	2.86	5.13	4.69	6.64	6.19	4.05	0.94
ru	—	—	—	—	—	—	—	0.01	—	—
ap	0.60	0.82	0.67	0.61	0.70	0.80	0.53	0.46	0.50	0.43
AN%	39.02	37.74	30.67	40.25	20.06	39.80	24.69	13.35	30.47	29.66

METSANTAN MEMBER (MAP UNITS 3, 3a)

Sample+	22* D314-1	23* D314-2	24* AP-115	25* TS-277a	26 D9b	27 D2	28 D16	29 D26b	30 D68	31 D10
Oxides as Determined										
SiO_2	58.73	57.86	60.29	59.03	57.51	57.47	56.76	61.34	61.01	54.47
TiO_2	0.59	0.65	0.56	0.62	0.59	0.64	0.68	0.51	0.52	0.76
Al_2O_3	16.77	16.52	16.74	16.83	16.08	16.26	16.56	15.49	15.15	16.27
Fe_2O_3	5.28	5.53	3.02	5.29	3.73	2.63	2.06	2.06	1.68	5.12
FeO	0.47	0.81	2.28	0.92	2.23	3.21	3.18	2.44	2.69	1.96
MnO	0.16	0.19	0.19	0.16	0.22	0.19	0.18	0.11	0.14	0.21
MgO	3.01	2.30	2.08	2.52	2.42	2.84	2.17	1.68	1.81	2.64
CaO	2.77	5.28	3.18	4.34	3.66	3.38	3.73	3.17	3.29	4.35
Na_2O	4.18	3.77	4.31	4.27	4.17	4.31	3.62	3.18	3.54	4.99
K_2O	4.07	3.09	3.51	3.20	3.38	3.87	3.71	5.16	4.49	3.07
P_2O_5	0.21	0.18	0.29	0.23	0.21	0.26	0.14	0.08	0.18	0.34
H_2O^+	1.87	1.41	1.95	1.13	2.42	2.09	2.75	1.61	2.23	1.99
H_2O^-	0.41	0.38	0.15	0.69	1.03	0.41	1.07	0.39	0.46	0.58
CO_2	0.02	2.00	0.99	0.62	1.99	2.08	2.57	2.24	2.04	2.65
S	—	0.01	0.01	0.01	0.01	0.13	0.10	0.01	0.26	—
Total	98.54	99.98	99.55	99.86	99.64	99.64	99.18	99.46	99.49	99.40
FeO*	5.43	5.79	5.18	5.83	5.59	5.58	5.03	4.29	4.20	6.57
FeO*/MgO	1.74	2.52	2.40	2.25	2.31	1.96	2.32	2.56	2.32	2.49
K_2O/Na_2O	0.98	0.82	0.81	0.75	0.81	0.90	1.02	1.62	1.27	0.62
CIPW Normative Minerals (anhydrous)										
q	9.40	11.64	12.66	10.43	10.23	6.12	9.89	14.29	14.10	2.99
c	1.00	—	0.80	—	—	—	0.16	—	—	—
or	24.99	18.99	21.51	19.41	21.20	24.06	23.63	32.02	28.08	19.26
ab	36.74	33.16	37.80	37.08	37.45	38.35	33.00	28.25	31.69	44.82
an	12.85	19.80	14.39	17.78	16.13	14.31	18.96	13.41	12.91	13.74
di	—	4.84	—	2.16	1.33	1.24	—	2.07	2.54	5.30
hy	7.79	3.71	6.53	5.44	6.25	10.02	9.43	5.64	6.65	4.52
mt	0.34	1.40	4.54	1.74	5.74	4.01	3.22	3.14	2.58	5.10
il	1.16	1.28	1.10	1.21	1.19	1.28	1.39	1.02	1.05	1.53
hm	5.25	4.78	—	4.23	—	—	—	—	—	1.92
ru	—	—	—	—	—	—	—	—	—	—
ap	0.51	0.44	0.70	0.55	0.52	0.64	0.35	0.20	0.44	0.84
AN%	25.92	37.39	27.58	32.41	30.10	27.18	36.49	32.18	28.95	23.47

METSANTAN MEMBER (MAP UNIT 3, 3a)

Sample+	32 D291-2	33 D309-2	34 D312-1	35 D312-2	36 D319-5	37 AP-49	38 AP-197	39 MM-3	40 LAW.AGB F.W.	41 LAW.AGB H.W.
Oxides as Determined										
SiO_2	56.06	58.41	59.16	58.58	58.83	57.75	59.30	61.62	68.24	60.24
TiO_2	0.70	0.61	0.61	0.64	0.63	0.60	0.64	0.48	0.40	0.50
Al_2O_3	15.61	15.66	15.44	16.34	16.49	15.84	15.39	15.58	12.92	15.22
Fe_2O_3	4.40	6.00	4.78	5.40	5.31	3.57	5.03	4.75	4.73	5.30
FeO	2.25	0.10	1.04	0.60	0.91	2.14	0.94	0.03	—	—
MnO	0.22	0.16	0.16	0.15	0.16	0.13	0.13	0.13	0.09	0.13
MgO	3.08	2.13	2.34	3.01	2.58	2.05	2.54	1.89	0.34	3.04
CaO	2.87	3.59	2.87	2.82	2.55	4.57	2.70	2.41	1.48	0.49
Na_2O	3.43	4.69	3.57	3.98	4.10	4.19	4.09	4.63	1.05	0.55
K_2O	6.15	2.48	5.71	4.07	5.06	3.27	5.30	4.29	7.79	9.31
P_2O_5	0.25	0.21	0.23	0.15	0.37	0.17	0.23	0.09	0.18	0.20
H_2O^+	1.61	2.48	1.34	1.86	1.62	2.00	2.31	1.75	0.91	1.07
H_2O^-	0.24	0.47	0.25	0.34	0.31	0.26	0.13	0.62	0.18	0.36
CO_2	2.04	2.45	1.70	1.60	1.36	2.93	1.25	1.34	1.50	3.67
S	0.01	—	0.01	—	0.01	0.01	0.01	0.01	0.01	0.20
Total	98.92	99.44	99.21	99.54	100.29	99.48	99.99	99.61	99.82	100.28
FeO*	6.21	5.50	5.34	5.46	5.69	5.35	5.47	4.30	—	—
FeO*/MgO	2.02	2.58	2.28	1.81	2.20	2.61	2.15	2.28	—	—
K_2O/Na_2O	1.79	0.53	1.60	1.02	1.23	0.78	1.30	0.93	7.41	16.93
CIPW Normative Minerals (anhydrous)										
q	3.51	12.60	8.69	10.22	7.61	10.49	7.46	11.55	—	—
c	—	—	—	0.65	0.54	—	—	—	—	—
or	38.25	15.58	35.18	25.12	30.83	20.50	32.53	26.43	—	—
ab	30.53	42.19	31.49	35.16	35.76	37.59	35.93	40.84	—	—
an	9.52	15.28	9.65	13.59	1.55	15.67	8.30	9.46	—	—
di	2.91	0.80	2.83	—	—	5.63	3.15	1.01	—	—
hy	6.72	5.27	4.77	7.83	6.62	3.03	5.11	4.44	—	—
mt	6.25	—	2.20	0.59	1.68	5.49	1.66	—	—	—
il	1.40	0.59	1.21	1.27	1.23	1.21	1.26	0.36	—	—
hm	0.32	6.38	3.47	5.23	4.32	—	4.08	4.95	—	—
ru	—	—	—	—	—	—	—	—	—	—
ap	0.61	0.52	0.56	0.37	0.89	0.42	0.56	0.22	—	—
AN%	23.77	26.59	23.46	27.87	22.78	29.41	18.77	18.81	—	—

SAUNDERS MEMBER (MAP UNIT 6)

Sample+	42* D162	43* D195	44* AP-5	45* AP-18	46* AP-27	47* AP-153	48* TS-4	49* TS-68	50* MM-4
Oxides as Determined									
SiO_2	61.63	59.74	61.64	60.64	61.88	61.67	61.03	62.71	61.34
TiO_2	0.52	0.56	0.52	0.58	0.56	0.56	0.52	0.49	0.50
$Al_{2O}3$	15.89	16.81	15.98	16.41	16.66	15.96	16.92	16.76	15.75
Fe_2O_3	2.82	3.30	2.99	3.01	2.88	3.26	3.62	2.48	2.77
FeO	1.85	2.10	2.04	2.31	2.28	2.14	1.72	2.12	1.95
MnO	0.26	0.13	0.11	0.14	0.12	0.16	0.15	0.14	0.13
MgO	2.32	2.12	2.28	1.97	2.05	1.89	1.99	1.95	2.37
CaO	3.30	4.74	4.20	4.53	4.34	3.43	2.85	4.30	3.84
Na_2O	3.26	3.32	3.45	3.69	4.18	3.36	4.84	3.52	3.37
K_2O	3.62	3.09	3.50	3.59	3.06	4.33	3.32	3.26	3.25
P_2O_5	0.12	0.18	0.30	0.23	0.27	0.21	0.13	0.28	0.23
H_2O^+	1.97	1.69	1.79	1.34	0.93	0.80	1.30	1.85	1.95
H_2O^-	0.61	0.57	0.50	0.44	0.11	0.48	0.53	0.37	0.67
CO_2	0.83	1.46	0.70	0.55	0.15	0.70	0.99	0.08	1.01
S	0.10	0.01	0.11	0.01	0.01	0.01	0.01	0.01	0.01
Total	99.10	99.81	100.01	100.00	99.48	98.97	99.92	100.32	99.13
FeO*	4.59	5.28	4.87	5.17	4.96	5.07	4.98	4.35	4.65
FeO*/MgO	1.89	2.39	2.06	2.55	2.37	2.68	2.50	2.23	1.87
K_2O/Na_2O	1.11	0.93	1.01	0.97	0.73	1.29	0.69	0.93	0.96
CIPW Normative Minerals (anhydrous)									
q	19.19	16.37	17.12	14.13	14.49	16.23	11.85	18.24	18.74
c	0.94	—	—	—	—	0.02	0.51	0.30	0.27
or	22.38	19.00	21.32	21.85	18.40	26.39	20.21	19.66	20.11
ab	28.85	29.23	30.08	32.15	35.98	29.31	42.17	30.38	29.85
an	16.31	22.74	18.34	18.15	17.98	16.13	13.69	19.90	18.37
di	—	0.40	0.88	2.74	1.69	—	—	—	—
hy	6.77	5.77	6.08	4.84	5.52	5.48	5.10	6.28	6.92
mt	4.28	4.98	4.47	4.49	4.25	4.87	4.66	3.67	4.21
il	1.03	1.11	1.02	1.13	1.08	1.10	1.02	0.95	0.99
hm	—	—	—	—	—	—	0.51	—	—
ru	—	—	—	—	—	—	—	—	—
ap	0.29	0.44	0.72	0.55	0.64	0.50	0.31	0.67	0.56
AN%	36.11	43.76	37.88	36.09	33.33	35.50	24.51	39.58	38.10

Sample+	SAUNDERS MEMBER (MAP UNIT 6)					ATTYCELLEY MEMBER (MAP UNIT 5)			
	51 D163	52 D197	53 D200	54 D201	55 MM-1	56* D198	57* AP-7	58 D300-3	59 AP-15
Oxides as Determined									
SiO_2	60.62	58.88	64.26	68.21	69.03	63.30	61.59	57.98	63.47
TiO_2	0.51	0.51	0.56	0.56	0.45	0.57	0.49	0.59	0.48
Al_2O_3	15.75	15.45	16.14	22.23	19.47	16.06	15.60	17.09	14.82
Fe_2O_3	2.63	2.33	2.72	0.00	1.61	4.11	4.64	4.09	3.58
FeO	2.24	2.69	1.79	0.06	0.10	0.66	0.44	1.90	1.20
MnO	0.13	0.20	0.34	0.00	0.01	0.15	0.14	0.13	0.15
MgO	3.12	2.14	1.62	0.01	0.01	1.71	1.77	3.43	2.61
CaO	2.63	3.80	2.41	0.02	0.04	3.73	3.63	1.59	3.05
Na_2O	2.53	2.19	2.24	0.00	0.02	4.26	4.29	3.85	2.74
K_2O	4.79	4.92	5.62	0.02	0.03	3.34	3.26	4.02	3.95
P_2O_5	0.18	0.24	0.26	0.42	0.00	0.18	0.30	0.20	0.26
H_2O^+	2.17	2.35	1.83	7.80	6.95	1.23	2.52	2.42	3.17
H_2O^-	1.52	2.18	0.66	0.28	0.43	0.37	0.43	0.89	0.27
CO_2	0.76	1.46	0.28	0.41	0.18	0.55	1.54	0.77	0.15
S	0.07	0.01	0.82	0.18	1.50	0.01	0.01	0.02	0.01
Total	99.65	99.35	101.55	100.20	99.71	100.22	100.65	98.95	99.91
FeO*	4.61	4.79	4.24	—	—	4.36	4.62	5.58	4.42
FeO*/MgO	1.48	2.24	2.62	—	—	2.55	2.61	1.63	1.69
K_2O/Na_2O	1.89	2.25	2.51	—	—	0.78	0.76	1.04	1.44
CIPW Normative Minerals (anhydrous)									
q	18.10	16.63	23.04	—	—	16.60	15.74	12.94	23.63
c	2.16	0.21	2.67	—	—	—	—	4.21	1.16
or	29.75	31.15	33.90	—	—	20.13	20.04	25.04	24.24
ab	22.50	19.84	19.34	—	—	36.74	37.74	34.33	24.07
an	12.48	18.52	10.47	—	—	15.14	14.24	6.94	13.95
di	—	—	—	—	—	1.97	1.90	—	—
hy	9.58	8.43	4.88	—	—	3.43	3.70	9.00	6.75
mt	4.01	3.62	4.03	—	—	0.98	0.47	5.10	3.08
il	1.02	1.04	1.09	—	—	1.10	0.97	1.18	0.95
hm	—	—	—	—	—	3.51	4.50	0.79	1.59
ru	—	—	—	—	—	—	—	—	—
ap	0.44	0.60	0.62	—	—	0.43	0.73	0.49	0.63
AN%	35.68	48.27	35.12	—	—	29.18	27.40	16.81	36.69

Sample+	SUBVOLCANIC DOMES (MAP UNIT E)					DIKES, SILLS AND SMALL PLUTONS (MAP UNIT)					
						(D)	(D)	(A)	(C)	(B)	(B)
	60 D310-1	61 D310-4	62 D317-5	63 D298-4	64 AP-51a	65 D72	66 D288-1	67 D296-2	68 AP-55	69 TS-7	70 TS-5
Oxides as Determined											
SiO_2	54.85	58.63	55.36	61.78	61.06	56.43	60.05	65.01	50.88	49.76	46.03
TiO_2	0.76	0.62	0.64	0.50	0.51	0.69	0.58	0.45	1.13	1.04	1.15
Al_2O_3	17.04	16.23	17.55	16.52	16.86	16.81	16.13	14.80	17.95	17.43	16.68
Fe_2O_3	5.72	3.03	5.11	2.33	2.92	3.26	2.69	2.08	8.49	8.04	6.60
FeO	0.19	2.02	0.27	1.75	2.51	3.12	2.56	1.85	1.33	2.08	2.71
MnO	0.20	0.13	0.19	0.17	0.16	0.24	0.18	0.11	0.16	0.18	0.26
MgO	0.90	1.29	0.92	0.77	2.58	3.33	1.82	1.45	3.66	3.93	5.91
CaO	7.71	5.86	6.75	3.37	3.09	4.80	3.03	3.54	8.31	7.87	2.30
Na_2O	3.88	3.77	4.24	4.98	4.99	3.25	5.56	3.21	3.68	3.03	4.53
K_2O	2.10	2.88	2.82	2.30	2.35	3.41	2.97	4.11	2.28	3.69	2.04
P_2O_5	0.25	0.28	0.37	0.14	0.23	0.25	0.23	0.17	0.28	0.30	0.13
H_2O^+	2.41	0.85	1.70	1.67	1.23	1.79	1.11	1.29	1.15	0.86	1.47
H_2O^-	0.59	0.43	1.15	0.44	0.61	0.53	0.19	0.17	0.23	0.73	1.84
CO_2	2.99	2.92	2.95	2.05	0.37	1.19	1.09	1.43	0.15	0.10	7.37
S	0.01	0.10	—	—	0.01	0.15	0.01	0.01	0.01	0.01	0.01
Total	99.60	99.04	100.02	98.77	99.86	99.25	98.20	99.68	99.85	99.05	99.03
FeO*	5.34	4.75	4.87	3.85	5.14	6.05	4.98	3.72	8.97	9.31	8.65
FeO*/MgO	5.93	3.68	5.29	5.00	1.99	1.82	2.74	2.57	2.45	2.37	1.46
K_2O/Na_2O	0.54	0.76	0.67	0.46	0.47	1.05	0.53	1.28	0.62	1.22	0.45
CIPW Normative Minerals (anhydrous)											
q	9.30	14.39	7.02	16.61	12.86	9.52	8.01	22.13	1.28	—	—
c	—	—	—	0.05	1.08	—	—	—	—	—	3.57
or	13.26	17.96	17.69	14.37	14.28	21.08	18.32	25.10	13.73	22.40	13.65
ab	35.06	33.66	38.07	44.52	43.40	28.76	49.09	28.06	31.72	26.33	43.38
an	24.46	19.92	21.80	16.70	14.22	22.20	10.75	14.31	26.23	23.70	11.95
di	10.48	6.97	8.34	—	—	0.80	2.71	2.15	10.83	11.20	—
hy	—	0.56	—	2.85	8.30	10.74	5.36	3.88	4.26	2.08	11.11
ol	—	—	—	—	—	—	—	—	—	1.94	3.89
mt	—	4.64	—	3.57	4.35	4.94	4.07	3.12	1.56	4.39	7.07
il	0.89	1.24	1.04	1.00	1.00	1.37	1.15	0.88	2.19	2.03	2.47
hm	6.11	—	5.42	—	—	—	—	—	7.57	5.23	2.59
ru	—	—	—	—	—	—	—	—	—	—	—
ap	0.62	0.69	0.92	0.34	0.55	0.61	0.56	0.41	0.66	0.72	0.34
AN%	41.09	37.18	36.42	27.28	24.67	43.56	17.97	33.78	45.26	47.38	21.61

APPENDIX B

POTASSIUM-ARGON ANALYTICAL PROCEDURE

Preparation and potassium analyses of samples for K-Ar dating were carried out by the Analytical Sciences Section of the Ministry of Energy, Mines and Petroleum Resources in Victoria. Age determinations were on mineral concentrates prepared by heavy liquid, electromagnetic and hand-picking techniques.

Mineral concentrates weighed to 0.2 gram were fused in 2 grams of $LiBO_2$ at 1050°C. The glass was dissolved in 4 per cent HNO_3 and stabilized with 3 millilitres of 50 per cent HF; a small amount of CsCl was added as an ionization buffer. Potassium abundance in the sample was measured on a Perkin Elmer Model 107 modified single-beam atomic absorption flame spectrophotometer.

Argon analyses were conducted by Joe Harakal of the Department of Geological Sciences, The University of British Columbia. Mineral concentrates were fused using a Phillips radio frequency generator and an induction coil which encircles the fusion jar. A spike of high purity ^{38}Ar is introduced during the fusion stage. Impurities from the gas mixture are removed by passing over titanium furnaces. Argon isotopic ratios were measured in an Associated Electrical Industries MS-10 mass spectrometer that is modified with a Carey Model 31 vibrating reed electrometer.

The precision of the data, reported as ± values, is the estimated analytical uncertainty at one standard deviation. The decay constants used for ^{40}K are those adopted by the International Union of Geological Sciences Subcommission on Geochronology (Steiger and Jäger, 1977).

POTASSIUM-ARGON AGE DETERMINATIONS FOR VOLCANIC AND PLUTONIC ROCKS, AND ALTERED ROCKS ASSOCIATED WITH PRECIOUS METAL DEPOSITS

Location[1]	Sample No.[2]	Latitude	Longitude	Rock unit, type, or occurrence	Mineral	% K	$^{40}Ar^o$ 10^{-6}cc/g	$^{40}Ar^o$	Age (Ma)[3]	Reference[4]
Volcanic Rocks										
1.	GSC78-24	57°16′26.2″	127°00′54.8″	Saunders	hornblende	0.787	5.858	56.9	182±8	1
2.	GSC76-77	57°08′24.1″	126°42′42.3″	Saunders	hornblende	0.864	6.466	75.5	183±8	2
3.	NC71-1	57°07′54.5″	126°42′32.5″	Attycelley	hornblende	0.873	6.763	91.3	189±6	3
4.	83LD-268-3A	57°31′37.6″	127°30′11.9″	Metsantan	biotite	5.57	45.022	95.6	197±7	4
5.	83LD-292-1	57°26′53.1″	127°20′11.3″	Metsantan	biotite	6.19	51.005	93.6	200±7	4
6.	83LD-266-5	57°32′25.6″	127°32′24.0″	Adoogacho	biotite	6.34	51.738	94.4	199±7	4
7.	83LD-266-5	57°32′25.6″	127°32′24.0″	Adoogacho	hornblende	0.806	6.645	65.7	200±7	4
8.	83LD-274-4	57°32′45.2″	127°20′22.6″	Adoogacho	biotite	6.83	56.768	96.6	202±7	4
9.	81AP-T28	57°05′40.6″	126°38′34.0″	Adoogacho	biotite	6.87	57.69	97.5	204±7	5
Intrusive Rocks										
10.	G76-CS112	57°03′50.5″	126°46′26.4″	granodiorite	biotite	5.27	39.25	95.4	182±6	6
11.	G76-CS112	57°03′50.5″	126°46′26.4″	granodiorite	hornblende	0.439	3.759	77.3	207±7	6
12.	G76-CS113	57°02′50.0″	126°46′17.7″	granodiorite	hornblende	0.670	5.587	85.6	203±6	6
13.	GSC76-74	57°14′30.6″	127°01′49.5″	quartz monzonite	hornblende	0.447	3.486	78.8	190±8	2,7
14.	GSC76-75	57°09′53.3″	127°01′45.9″	granodiorite	biotite	6.40	50.679	94.6	193±7	2,7
15.	GSC76-76	57°09′53.3″	127°01′45.9″	granodiorite	hornblende	0.459	3.856	83.8	204±9	2,7
Altered Rocks										
16.	82AP-T107A	57°20′23.0″	127°10′48.0″	Lawyers-AGB	adularia	7.68	56.584	95.0	180±6	8
17.	84LD-LION	57°33′56.8″	127°17′18.2″	Golden Lion	adularia	10.38	74.377	97.9	176±6	8
18.	84LD-MET	57°25′14.5″	127°18′12.5″	Metsantan	adularia	8.09	55.277	96.4	168±6	8
19.	81TGS-191	57°28′32.9″	127°25′07.2″	Alberts Hump	alunite	2.79	21.755	95.2	190±7	9
20.	A84-4-19.5	57°28′45.3″	127°21′44.6″	AL-Bonanza	sericite	4.26	29.689	96.4	171±6	10
21.	A84-19-72.5	57°27′47.6″	127°23′11.7″	AL-BV	sericite	1.93	11.959	78.4	152±5	10
22.	JN-12	57°15′24.9″	127°51′18.4″	Brenda-Jan	alunite	3.28	25.959	95.1	193±7	10
23.	G76CS-7WR	57°03′49.5″	127°45′13.8″	Kemess	whole rock	1.27	9.438	38.8	182±6	6

[1] Sample locations are shown in Map 3.

[2] Except for mineral concentrates with the prefix "GSC", all samples were analyzed by Joe Harakal at the Geochronometry Laboratory, University of British Columbia, Vancouver.

[3] Decay constants used in age calculations $^{40}K_{\lambda_\epsilon}=0.581\times10^{-10}\ yr^{-1}$; $^{40}K_{\lambda\beta}=4.962\times10^{-10}\ yr^{-1}$; $^{40}K/K=0.01167$ atom per cent; errors are 1σ, except for samples with the prefix "GSC" which are 2σ.

[4] (1) Wanless *et al.* (1979); (2) Wanless *et al.* (1978); (3) Carter (1972); (4) Diakow (1985); (5) Panteleyev (1983); (6) Cann and Godwin (1980); (7) Gabrielse *et al.* (1980); (8) Diakow *in* Schroeter *et al.* (1986); (9) Schroeter (1982); (10) Clark and Williams-Jones (1989).

Ar^o = radiogenic argon.

APPENDIX C

FOSSIL IDENTIFICATIONS

Macrofossils

Fossils referred to in this report were originally studied in 1975 by Dr. H.W. Tipper of the Geological Survey of Canada; they were also examined by Dr. H. Frebold (GSC report J-1-1976-HF), and Dr. T. Poulton (GSC report J-15-1976-TPP). The original collection was re-examined by Dr. H.W. Tipper in 1989; Giselle Jacobs collaborated with him in confirming generic identification of some of the ammonites. Dr. Tipper's revised report (GSC report J2-1989-HWT) and previous written correspondence are as follows:

Field Number: F1-24TD75

G.S.C. Location Number: 93261

Location: 8.6 kilometres west of Claw Mountain at 57°34′24″ north latitude and 127°25′00″ west longitude

Hostrock: *In situ* blocks of limy tuffaceous sedimentary rocks that are restricted to a glacial meltwater channel.

Fauna:

- Ammonites
  - *Phylseogrammoceras* sp.
  - *Phymatoceras* sp.
  - *Haugia?* sp.
  - *hildoceratid ammonite?*
- Bivalves
  - *Myaphorella* sp.
  - *Pholadomya* sp.
  - *Oxytoma* sp.
  - *astartidae*
  - *gryphaeidae*
  - *ostreidae*
  - various other bivalves
- Coleoids
  - belemnites

Age and Correlation: The ammonites indicate a middle to late Toarcian age for the collection. Similar fauna occur in the Melisson Formation of the Spatsizi Group, Spatsizi map area. Strata of this age also occur in McConnell Creek map area, southeast of Mount Carruthers, and they are widespread in Iskut River area west of the Bowser basin. Similar ammonites are also found in the Phantom Creek Formation on Queen Charlotte Islands.

Comments: Strata of Toarcian age are widespread adjacent to the margin of the Bowser basin. In Spatsizi map area, early Toarcian time corresponds with a major marine transgressive event which is manifest as a deep-water shale sequence; this is succeeded by shoaling in late Toarcian time and deposits of siltstone and sandstone (Thomson *et al.*, 1986). Large, thick-shelled fauna in the Toodoggone area suggest a high-energy shallow-water environment.

Palynomorphs

Dr. G.E. Rouse of The University of British Columbia identified 11 species of spores from two samples collected by L. Diakow in 1984. This report cites these identifications and some interpretations by Dr. Rouse.

Field Numbers: 83LD-268-1 and 83LD-290-4

Location: Sample 83LD-268-1: 1750 metres elevation, 14.5 kilometres at 285° azimuth from Tuff Peak, 57°31′44″N and 127°31′54″W; sample 83LD-290-4: 1890 metres elevation, 7.0 kilometres at 205° azimuth from Tuff Peak, 57°26′08″N and 127°20′42″W.

Hostrocks: Sample 83LD-268-1 is a marlstone and chert in a well-bedded succession of siltstone and coarse sandstone from the Moyez Member. They unconformably rest on nearby ash-flow tuffs of the Adoogacho Member. Sample 83LD-290-4 comprises plant debris from maroon-coloured mudstone and fine-grained sandstone forming a lens 20 metres thick in porphyritic latite flows of the Metsantan Member.

Species of Spores:

- *Enzonalasporites vigens*
- *Thompsonisporites signatus*
- *T. punctus*
- *Simplicesporites virgatus*
- *Cuneatisporites radialis*
- *Apiculatisporites variabilis*
- *A. globosus*
- *Ovalipollis ovalis*
- *Vallasporites antonii*
- *Laevigatisporites toralis*
- *Duplicisporites granulatus*

Age: According to Dr. Rouse the species of spores correlate most closely with Upper Triassic assemblages from western North America and Europe.

Comments: The spores represent entirely nonmarine fern species and the absence of cycad or coniferous pollen indicates a landscape virtually devoid of trees. Redbeds suggest the environment was hot and dry, with local shallow-water lakes supporting fern growth along the margins. The spores are extremely carbonized (TAI of 5) which indicates heat generation during burial of at least 270°C.

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Ministry of Energy, Mines and Petroleum Resources

Geological Survey Branch

This map is to accompany

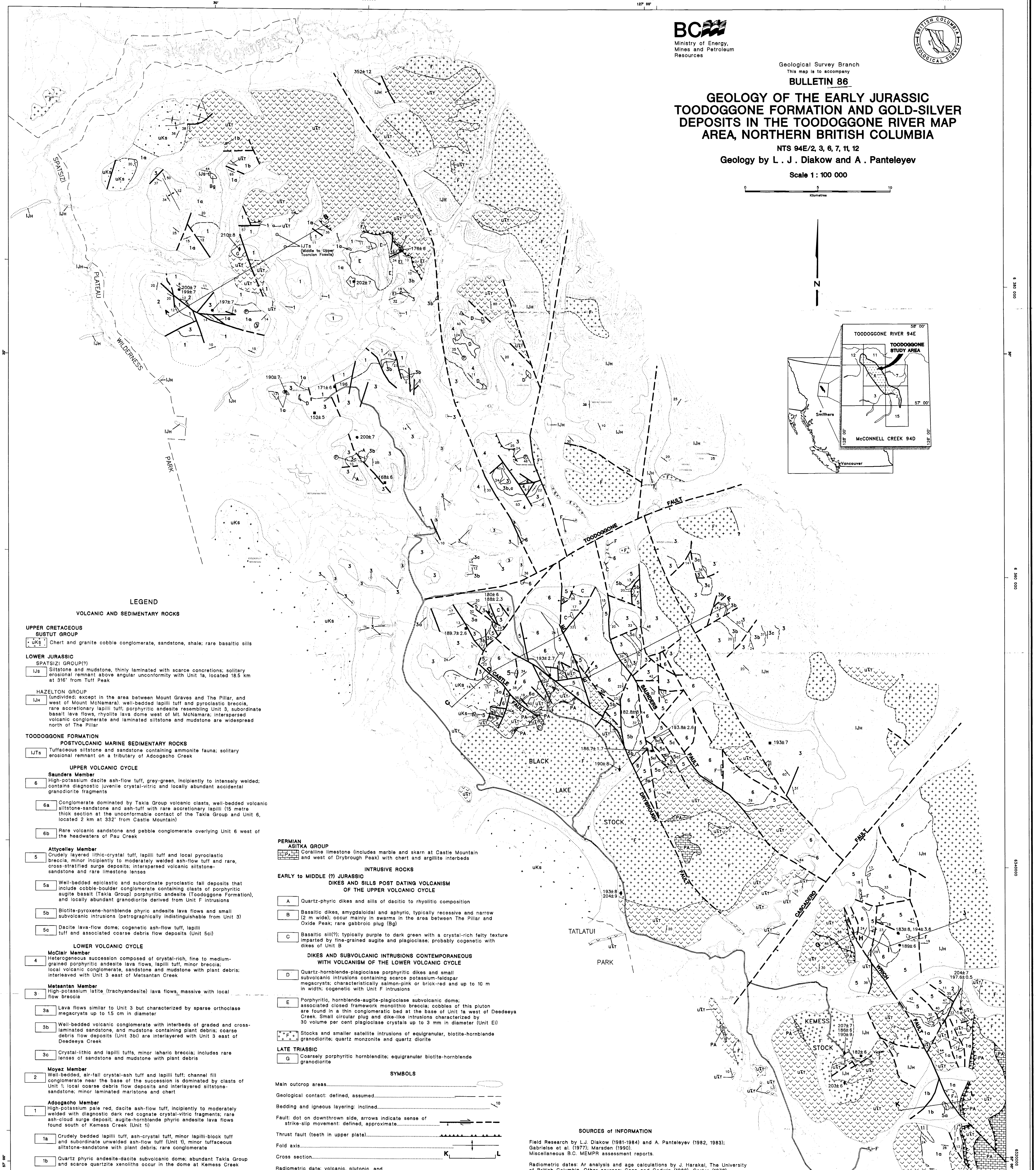
BULLETIN 86

GEOLOGY OF THE EARLY JURASSIC TOODOGGONE FORMATION AND GOLD-SILVER DEPOSITS IN THE TOODOGGONE RIVER MAP AREA, NORTHERN BRITISH COLUMBIA

NTS 94E/2, 3, 6, 7, 11, 12

Geology by L . J . Diakow and A . Panteleyev

Scale 1 : 100 000



LEGEND

VOLCANIC AND SEDIMENTARY ROCKS

UPPER CRETACEOUS

SUSTUT GROUP

uKs — Chert and granite cobble conglomerate, sandstone, shale; rare basaltic sills

LOWER JURASSIC

SPATSIZI GROUP(?)

lJs — Siltstone and mudstone, thinly laminated with scarce concretions; solitary erosional remnant above angular unconformity with Unit 1a, located 18.5 km at 316° from Tuff Peak

HAZELTON GROUP

lJH — (undivided; except in the area between Mount Graves and The Pillar, and west of Mount McNamara). well-bedded lapilli tuff and pyroclastic breccia, rare accretionary lapilli tuff; porphyritic andesite resembling Unit 3, subordinate basalt lava flows, rhyolite lava dome west of Mt. McNamara; interspersed volcanic conglomerate and laminated siltstone and mudstone are widespread north of The Pillar

TOODOGGONE FORMATION

POSTVOLCANIC MARINE SEDIMENTARY ROCKS

lJTs — Tuffaceous siltstone and sandstone containing ammonite fauna; solitary erosional remnant on a tributary of Adoogacho Creek

UPPER VOLCANIC CYCLE

Saunders Member

6 — High-potassium dacite ash-flow tuff, grey-green, incipiently to intensely welded; contains diagnostic juvenile crystal-vitric and locally abundant accidental granodiorite fragments

6a — Conglomerate dominated by Takla Group volcanic clasts, well-bedded volcanic siltstone-sandstone and ash-tuff with rare accretionary lapilli (15 metre thick section at the unconformable contact of the Takla Group and Unit 6, located 2 km at 332° from Castle Mountain)

6b — Rare volcanic sandstone and pebble conglomerate overlying Unit 6 west of the headwaters of Pau Creek

Attycelley Member

5 — Crudely layered lithic-crystal tuff, lapilli tuff and local pyroclastic breccia, minor incipiently to moderately welded ash-flow tuff and rare, cross-stratified surge deposits; interspersed volcanic siltstone-sandstone and rare limestone lenses

5a — Well-bedded epiclastic and subordinate pyroclastic fall deposits that include cobble-boulder conglomerate containing clasts of porphyritic augite basalt (Takla Group) porphyritic andesite (Toodoggone Formation), and locally abundant granodiorite derived from Unit F intrusions

5b — Biotite-pyroxene-hornblende phyric andesite lava flows and small subvolcanic intrusions (petrographically indistinguishable from Unit 3)

5c — Dacite lava-flow dome; cogenetic ash-flow tuff, lapilli tuff and associated coarse debris flow deposits (Unit 5ci)

LOWER VOLCANIC CYCLE

McClair Member

4 — Heterogeneous succession composed of crystal-rich, fine to medium-grained porphyritic andesite lava flows, lapilli tuff, minor breccia; local volcanic conglomerate, sandstone and mudstone with plant debris; interleaved with Unit 3 east of Metsantan Creek

Metsantan Member

3 — High-potassium latite (trachyandesite) lava flows, massive with local flow breccia

3a — Lava flows similar to Unit 3 but characterized by sparse orthoclase megacrysts up to 1.5 cm in diameter

3b — Well-bedded volcanic conglomerate with interbeds of graded and cross-laminated sandstone, and mudstone containing plant debris; coarse debris flow deposits (Unit 3bi) are interlayered with Unit 3 east of Deedeeya Creek

3c — Crystal-lithic and lapilli tuffs, minor laharic breccia; includes rare lenses of sandstone and mudstone with plant debris

Moyez Member

2 — Well-bedded, air-fall crystal-ash tuff and lapilli tuff; channel fill conglomerate near the base of the succession is dominated by clasts of Unit 1; local coarse debris flow deposits and interlayered siltstone-sandstone; minor laminated marlstone and chert

Adoogacho Member

1 — High-potassium pale red, dacite ash-flow tuff, incipiently to moderately welded with diagnostic dark red cognate crystal-vitric fragments; rare ash-cloud surge deposit; augite-hornblende phyric andesite lava flows found south of Kemess Creek (Unit 1i)

1a — Crudely bedded lapilli tuff, ash-crystal tuff, minor lapilli-block tuff and subordinate unwelded ash-flow tuff (Unit 1), minor tuffaceous siltstone-sandstone with plant debris; rare conglomerate

1b — Quartz phyric andesite-dacite subvolcanic dome; abundant Takla Group and scarce quartzite xenoliths occur in the dome at Kemess Creek

UPPER TRIASSIC

TAKLA GROUP

uTt — Coarse-grained augite phyric basalt and andesite lava flows, lesser amygdaloidal and coarse bladed plagioclase phyric flows, local pillow lava and hyaloclastite; interflow tuffaceous siltstone and fossil-bearing mudstone; limestone lenses

PERMIAN

ASITKA GROUP

PA — Coralline limestone (includes marble and skarn at Castle Mountain and west of Drybrough Peak) with chert and argillite interbeds

INTRUSIVE ROCKS

EARLY to MIDDLE (?) JURASSIC

DIKES AND SILLS POST DATING VOLCANISM OF THE UPPER VOLCANIC CYCLE

A — Quartz-phyric dikes and sills of dacitic to rhyolitic composition

B — Basaltic dikes, amygdaloidal and aphyric, typically recessive and narrow (2 m wide); occur mainly in swarms in the area between The Pillar and Oxide Peak; rare gabbroic plug (Bg)

C — Basaltic sill(?); typically purple to dark green with a crystal-rich felty texture imparted by fine-grained augite and plagioclase; probably cogenetic with dikes of Unit B

DIKES AND SUBVOLCANIC INTRUSIONS CONTEMPORANEOUS WITH VOLCANISM OF THE LOWER VOLCANIC CYCLE

D — Quartz-hornblende-plagioclase porphyritic dikes and small subvolcanic intrusions containing scarce potassium-feldspar megacrysts; characteristically salmon-pink or brick-red and up to 10 m in width; cogenetic with Unit F intrusions

E — Porphyritic, hornblende-augite-plagioclase subvolcanic dome; associated closed framework monolithic breccia; cobbles of this pluton are found in a thin conglomeratic bed at the base of Unit 1a west of Deedeeya Creek. Small circular plug and dike-like intrusions characterized by 30 volume per cent plagioclase crystals up to 3 mm in diameter (Unit Ei)

F — Stocks and smaller satellite intrusions of equigranular, biotite-hornblende granodiorite; quartz monzonite and quartz diorite

LATE TRIASSIC

G — Coarsely porphyritic hornblendite; equigranular biotite-hornblende granodiorite

SYMBOLS

Main outcrop areas

Geological contact: defined, assumed

Bedding and igneous layering: inclined

Fault: dot on downthrown side, arrows indicate sense of strike-slip movement: defined, approximate

Thrust fault (teeth in upper plate)

Fold axis

Cross section

Radiometric date: volcanic, plutonic, and alteration/mineralization; age in Ma

Fossil locality: macrofossil, plant debris

Mining Road

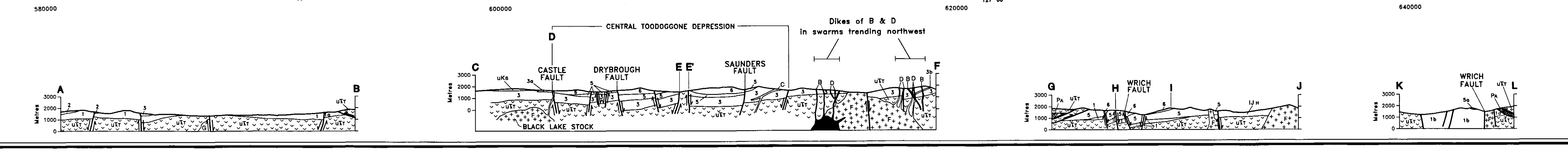
Provincial Park boundary

SOURCES of INFORMATION

Field Research by L.J. Diakow (1981-1984) and A. Panteleyev (1982, 1983); Gabrielse et al. (1977); Marsden (1990). Miscellaneous B.C. MEMPR assessment reports.

Radiometric dates: Ar analysis and age calculations by J. Harakal, The University of British Columbia. Other sources: Cann and Godwin (1980), Carter (1972), Clark and Williams-Jones (1989, 1991), Gabrielse et al. (1980), and Shepard (1986).

Dr. H.W. Tipper of the Geological Survey of Canada kindly provided unpublished information on macrofossils from the solitary outcrop of unit lJTs situated on a tributary of Adoogacho Creek. Dr. G. Rouse of The University of British Columbia identified palynomorphs.



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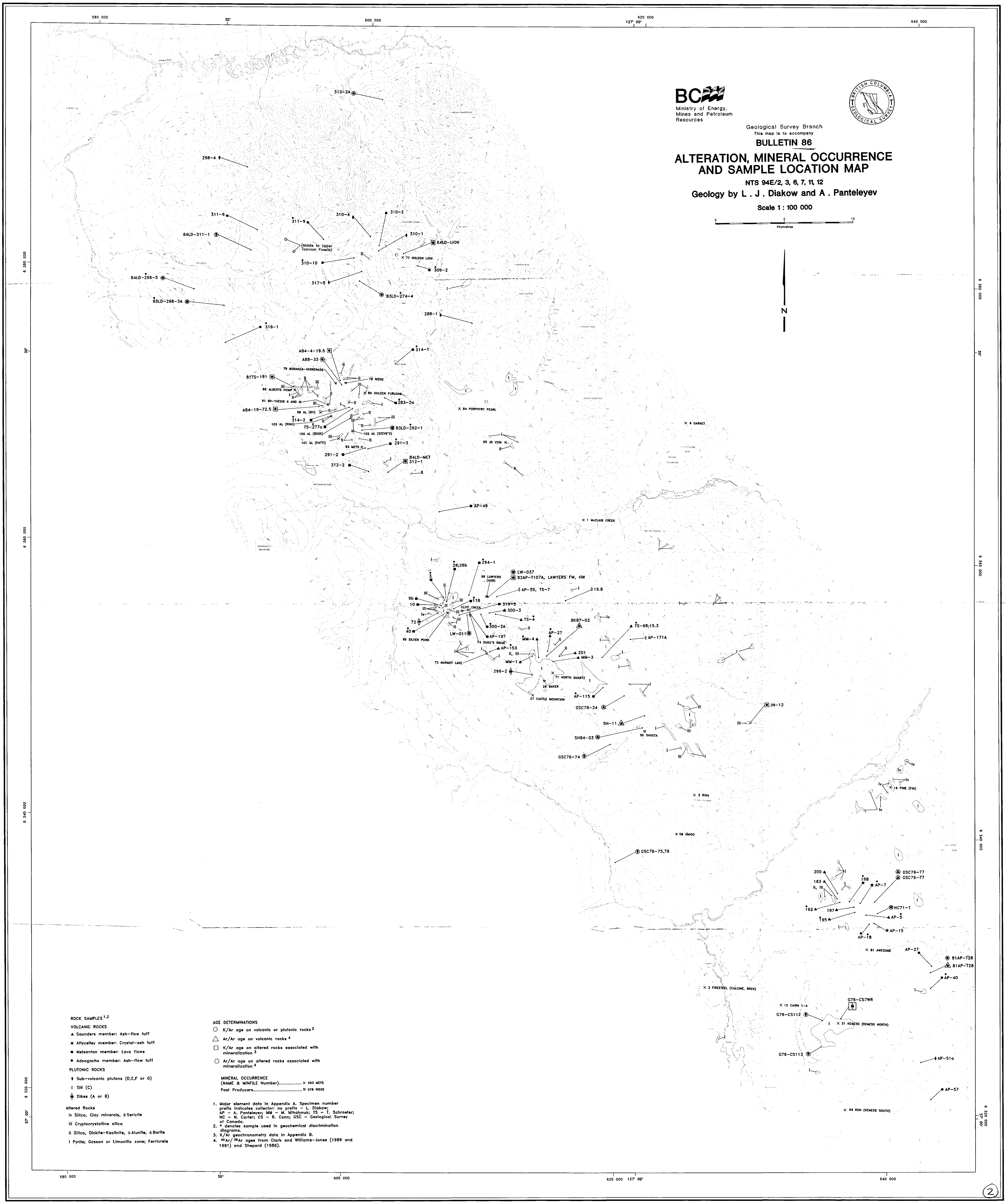

BC
Ministry of Energy, Mines and Petroleum Resources
BRITISH COLUMBIA GEOLOGICAL SURVEY
Geological Survey Branch
This map is to accompany
BULLETIN 86
ALTERATION, MINERAL OCCURRENCE AND SAMPLE LOCATION MAP
NTS 94E/2, 3, 6, 7, 11, 12
Geology by L . J . Diakow and A . Panteleyev
Scale 1 : 100 000
0
5
10
Kilometres
N
580 000
30'
600 000
620 000
127° 00'
640 000
6 360 000
6 340 000
6 320 000
57° 00'
313-2A
298-4
311-6
84LD-311-1
311-9
310-4
310-2
310-1
84LD-LION
(Middle to Upper Toarcian Fossils)
77 GOLDEN LION
310-10
309-2
84LD-266-5
317-5
83LD-274-4
83LD-268-3A
288-1
316-1
A84-4-19.5
314-1
A88-33
79 BONANZA-VERRENASS
78 RIDGE
81TS-191
85 ALBERTS HUMP
80 GOLDEN FURLONG
91 BV-THESIS II AND III
283-2a
A84-19-72.5
99 AL (BV)
84 PORPHYRY PEARL
314-2
103 AL (RING)
TS-277a
83LD-292-1
100 AL (BOSS)
102 AL (STEVE'S)
101 AL (PATTI)
93 METS
291-3
291-2
84LD-MET
312-1
312-2
6 GARNET
65 JD VEIN
AP-49
1 McCLAIR CREEK
28;26b
294-1
68 LAWYERS (AGB)
LW-037
82AP-T107A, LAWYERS FW, HW
AP-55, TS-7
19.8
9b
10
118
319-5
CLIFF CREEK
300-3
72
TS-4
BK87-03
TS-68;15.3
40
LW-011
300-2A
AP-27
AP-197
AP-171A
69 SILVER POND
74 DUKE'S RIDGE
MM-4
AP-153
201
MM-3
73 MARMOT LAKE
MM-1
296-2
71 NORTH QUARTZ
26 BAKER
27 CASTLE MOUNTAIN
AP-115
JN-12
GSC78-24
SH-11
50 SHASTA
SH84-03
GSC76-74
16 PINE (FIN)
3 RIGA
58 AMIGO
GSC76-75,76
200
GSC76-77
GSC76-77
163
198
AP-7
NC71-1
162
197
AP-5
195
AP-18
AP-15
81 AWESOME
AP-27
81AP-T28
81AP-T28
AP-40
2 FIRESTEEL (CALCINE, BREN)
12 CAIRN 1-a
G76-CS7WR
G76-CS112
21 KEMESS (KEMESS NORTH)
G76-CS113
AP-51a
AP-57
94 ROM (KEMESS SOUTH)
ROCK SAMPLES 1,2
VOLCANIC ROCKS
▲ Saunders member: Ash-flow tuff
★ Attycelley member: Crystal-ash tuff
■ Metsantan member: Lava flows
● Adoogacho member: Ash-flow tuff
PLUTONIC ROCKS
Sub-volcanic plutons (D,E,F or G)
◊ Sill (C)
Dikes (A or B)
Altered Rocks
iv Silica, Clay minerals, ±Sericite
iii Cryptocrystalline silica
ii Silica, Dickite-Kaolinite, ±Alunite, ±Barite
i Pyrite; Gossan or Limonitic zone; Ferricrete
AGE DETERMINATIONS
○ K/Ar age on volcanic or plutonic rocks 3
△ Ar/Ar age on volcanic rocks 4
□ K/Ar age on altered rocks associated with mineralization 3
⬡ Ar/Ar age on altered rocks associated with mineralization 4
MINERAL OCCURRENCE
(NAME & MINFILE Number)................ × 093 METS
Past Producers................................ 078 RIDGE
1. Major element data in Appendix A. Specimen number prefix indicates collector: no prefix – L. Diakow; AP – A. Panteleyev; MM – M. Mihalynuk; TS – T. Schroeter; NC – N. Carter; CS – R. Cann; GSC – Geological Survey of Canada.
2. * denotes sample used in geochemical discrimination diagrams.
3. K/Ar geochronometry data in Appendix B.
4. 40Ar/39Ar ages from Clark and Williams-Jones (1989 and 1991) and Shepard (1986).

(2)