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Volcanism And Evolution Of The Early And Middle Jurassic Toodoggone Formation, Toodoggone Mining District, British Columbia

Larry James Diakow

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I would like to thank T. Schroeter for informative discussions regarding the activity of mining companies in the study area. Drs. H.W. Tipper and H. Gabrielse of the Geological Survey of Canada, have been generous sources of first hand knowledge on various aspects of Mesozoic stratigraphy in north-central British Columbia.

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ABSTRACT

The Toodoggone Formation in Toodoggone River map area, north-central British Columbia, is an Early and Middle Jurassic time-stratigraphic Hazelton Group unit. Detailed mapping defined six subaerial lithostratigraphic members in the zeolite metamorphic facies. The High-K (3.1% K_2O at 57.5% SiO_2), calc alkaline latite and dacite volcanics are characterized by ± sanidine - quartz - biotite - hornblende phenocysts. Basalt and rhyolite occur only as late dykes. Toodoggone strata occupy an elongate volcanic depression; they unconformably overlie submarine, arc volcanic and sedimentary rocks of the Permian Asitka and Late Triassic Takla Groups, and are capped unconformably by continental, Late Cretaceous clastic rocks of the Sustut Group.

Potassium-argon dates from the four volcanic members show two discrete cycles of volcanism. Shallow marine clastic rocks with middle to upper Toarcian fossils were deposited locally during the lull between cycles. The lower cycle (204 Ma to 197 Ma) began with widespread plateau-forming eruptions of dacite ash-flows, which are in part synchronous and superseded by latite flows and lahars that built stratovolcanoes. Possible comagmatic granodiorite and quartz monozonite plutons were emplaced during this period. The upper cycle began by 189 Ma with mainly dacite air-fall deposits. It culminated at about 182 Ma with voluminous outpourings of ash-flow tuffs and accompanying asymmetric collapse that produced the Central Toodoggone Depression.

The Toodoggone Formation is interpreted to record island arc magmatism. This arc magmatism resembles modern continent margin arc successions both in style and composition, hence it is believed that a thick, continent-like substrate underlies the Toodoggone area. The Toodoggone arc segment may be east-facing and related to steep, oblique westward subduction with a protracted history of intra-arc

extension and shallow crustal subsidence. Extension and magmatism in Toodoggone map area is strikingly similar to large-scale extension and volcanic-sedimentary events in the McConnell Creek and Hazelton areas. This suggests consistent Jurassic tectonic evolution in these areas within a common, east-facing island arc developed along the east margin of the allocthonous Stikine terrane.

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CHAPTER 1

INTRODUCTION

1.1 Statement of Purpose

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 distinct e succession of quartz-bearing dacite and latite flows and pyroclastic rocks, called the Toodoggone Formation, are time-equivalent with strata of the Hazelton Group. The Toodoggone Formation and related intrusive rocks apparently occupy an elongate 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. However, one major precious metal-bearing lode is in volcanic rocks of the Takla Group.

Despite the economic importance of these mineralized rocks very little was known about their regional stratigraphic and tectonic setting. Consequently, a regional mapping project was initiated by the British Columbia Geological Survey in 1981 to study the Toodoggone Formation and the geologic setting of precious metal concentrations. This thesis is an integral part of this project, and it also incorporates the work of two colleagues in order to address the following objectives:

(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 and tectonic setting, and its significance in the evolution of an Early and Middle Jurassic magmatic arc in the eastern Stikine terrane of the Intermontane Belt.

(3) Describe the salient features, fundamental controls and relative time of ore deposition in quartz veins and zones of advanced argillic alteration.

1.2 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 townsite of Smithers, 300 kilometres south, is the principal centre of commerce and supplies for mining companies working within the study area.

Access is by fixed wing aircraft to a 1620 metre long gravel runway on the east bank of the Sturdee River. Float planes can land on Black, Metsantan, Moosehorn and Toodoggone Lakes. A gravel road 32 kilometres long connects the airstrip to the Baker minesite, and traverses Tiger Notch Pass to the Lawyers Mine, 4 kilometres south of the Toodoggone River. Extension of the Omineca Resource Road in 1987 presently provides restricted access from Moosevale Flats in the McConnell Creek map area (NTS 094D) to the Sturdee River airstrip about 70 kilometres northwest. Helicopter support is essential to reach most parts of the area beyond walking distance of the roads.

1.3 Physiography, Vegetation and Weather

The study area is in the northern Omineca Mountains where peaks rise on average more than 900 metres above valley elevations 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. A west-central area characterized by rounded mountains and shallow southwest sloping cuesta ridges of low relief form part of the Spatsizi Plateau (Figure 2).

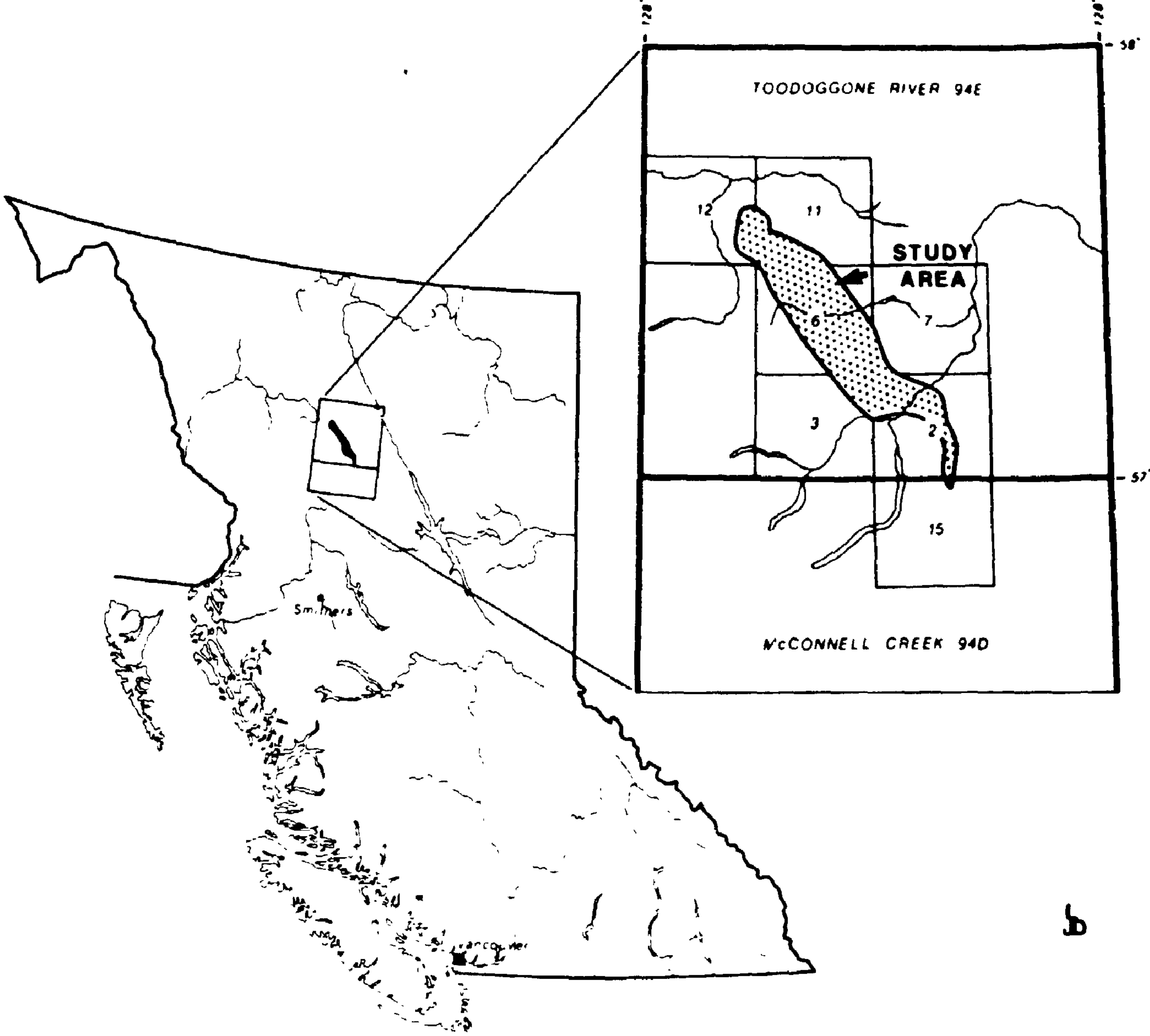
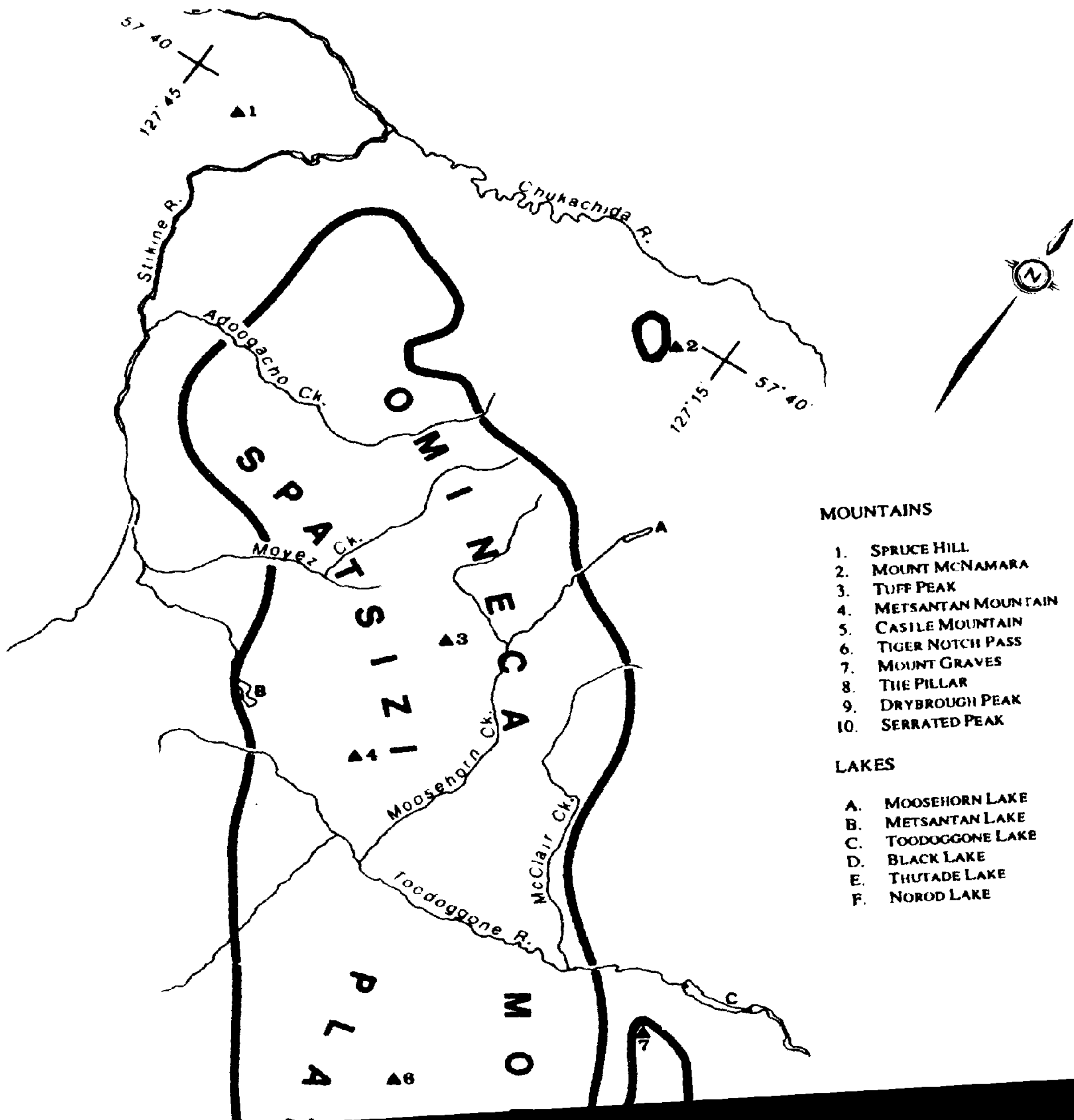


Figure 1. Location of study area within the Toodoggone River map sheet (NTS 094E), north-central British Columbia.



MOUNTAINS

1. Spruce Hill
2. Mount McNamara
3. Tuff Peak
4. Metsantan Mountain
5. Castle Mountain
6. Tiger Notch Pass
7. Mount Graves
8. The Pillar
9. Drybrough Peak
10. Serrated Peak

LAKES

A. Moosehorn Lake
B. Metsantan Lake
C. Toodoggone Lake
D. Black Lake
E. Thutade Lake
F. Norod Lake

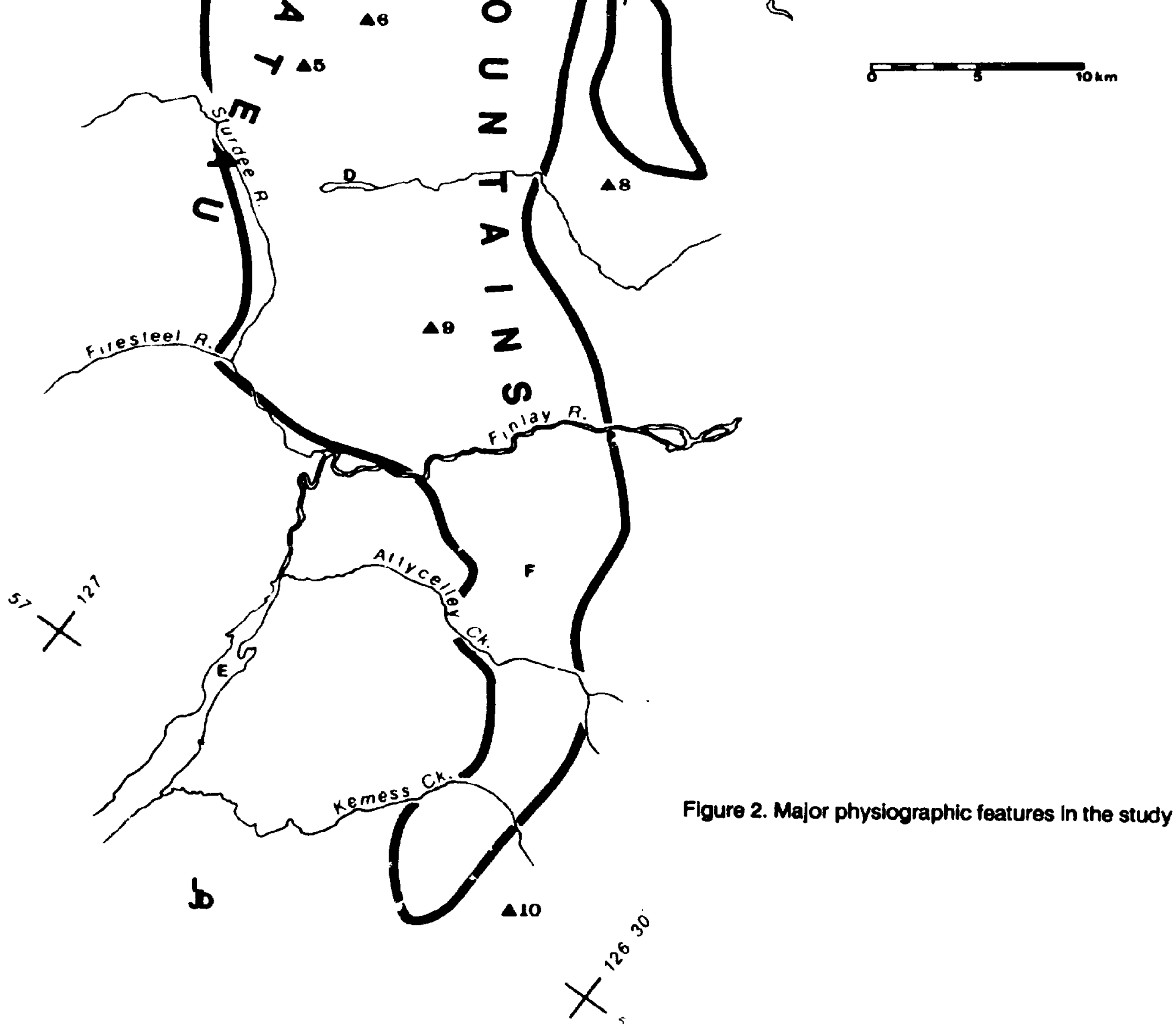


Figure 2. Major physiographic features in the study area.

The Stikine River and the Chukachida River form 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 constitute a trellice network of drainages at the headwaters of the Finlay River. Conifer forests and small pockets of deciduous trees are in 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 efficiently until the end of August. Precipitation varies considerably between field seasons, and it can form light snow at higher elevations 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.

1.4 Previous Mapping

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

1.5 Present Work

In 1980, with the onset 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 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 broad 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 and 1:63360 scale aerial photographs during 22 weeks of fieldwork by the writer between 1981 and 1984. This work was augmented by roughly 5 weeks of mapping by Ministry project geologist Dr. A. Panteleyev in 1982 and 1983. Mr. T. Schroeter, Ministry senior district geologist, documented mineral occurrences and exploration activity during numerous visits to the area from 1979 to 1985. The results of these field studies are available as two adjoining 1:50,000 scale preliminary maps, encompassing parts of map sheets NTS 094E/2, 3, 6, 7, 11 and 12 (Diakow, et al., 1985b).

CHAPTER 2

REGIONAL GEOLOGY

2.1 Tectonic Setting

The Toodoggone River map sheet (NTS 094E) spans two major geologic and physiographic divisions of the Canadian Cordillera; the Omineca Belt in the east and the Intermontane Belt in the west (Figure 3 inset). The Omineca Belt is a metamorphic-plutonic complex that is thought to have formed by the accretion of Insular and Intermontane superterranes to the ancestral continental margin of North America (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 local amphibolite grade (Mansy and Dodds, 1976; Gabrielse, et al., 1976; Evenchick, 1988) during orogenic events of roughly mid-Jurassic to mid-Cretaceous and Late Cretaceous to Eocene age (Gabrielse and Yorath, 1989). Quartz monzonite plutons of mid-Cretaceous age intrude the miogeoclinal succession of the Omineca Belt in the eastern Toodoggone map area; subsequently, they were dextrally displaced along a regional transcurrent fault system marked in part by the Finlay-Thudaka faults (Gabrielse, 1985).

By contrast, the Intermontane Belt is a composite of four tectono-stratigraphic terranes, each having internal structural-stratigraphic integrity and a complex history in terms of amalgamation, and subsequent accretion to North America (Coney, et al., 1980; Monger, et al., 1982). These terranes include the Slide Mountain and Cache Creek which are characterized by oceanic rocks ranging from mid-Paleozoic to Triassic in age. Stikinia and Quesnellia contain mainly island arc volcanic, plutonic and sedimentary rocks of Late Triassic to Middle Jurassic age. Stikinia is overlapped in north-central British Columbia by successor basins filled by molasse. This molasse was derived mainly from uplifted Cache Creek terrane and the Omineca Belt which were elevated and eroded during accretion of the Intermontane Superterrane to the North American margin.

Geology along the east-northeast margin of the Stikine Terrane in north-central British Columbia is dominated by successive volcano-plutonic arcs which were constructed from Permian, but mainly during Late Triassic to Early and Middle Jurassic time (Figure 3). The Toodoggone study area is situated along the trend of this extensive belt of Mesozoic arc magmatism which corresponds to the east trending Stikine Arch in the north and the east-northeast trending Skeena Arch in the south. The Stikine Arch is cored by Late Triassic and Early to Middle Jurassic plutons, and flanked by volcanic rocks of similar age and composition. These volcanic rocks are the Late Triassic Stuhini-Takla arc and the Early-Middle Jurassic Hazelton arc. Jurassic volcanics are most prevalent along the Skeena Arch where they are associated with the locus of Early Jurassic intrusions. Basement to these arcs is presumably Mississippian and Permian carbonate rocks and basalt to rhyolite flows and pyroclastics which crop out mainly southwest of the Stikine Arch.

Mesozoic arc volcanic rocks are unconformably overlain by Middle and Upper Jurassic sedimentary strata underlying the Bowser Basin. Early deposits of marine shale are succeeded by non-marine conglomeratic strata, dominated by chert clasts, derived mainly from uplifted Cache Creek terrane, north of the Stikine Arch (Eisbacher, 1981). The Skeena Arch provided a local influx of granitoid and volcanic clasts in the southern Bowser Basin. Middle to Late Cretaceous strata of the Sustut Basin overlap the east margin of the Bowser Basin. The Sustut Basin is underlain by continental clastic detritus derived initially from the Omineca Belt in the east, changing later to a west provenance in which conglomerates of the Bowser Lake Group and possibly the lower part of the Sustut Group were reworked along with clasts from uplifted parts of the Stikine Arch (Eisbacher, 1974; Evenchick, 1986).

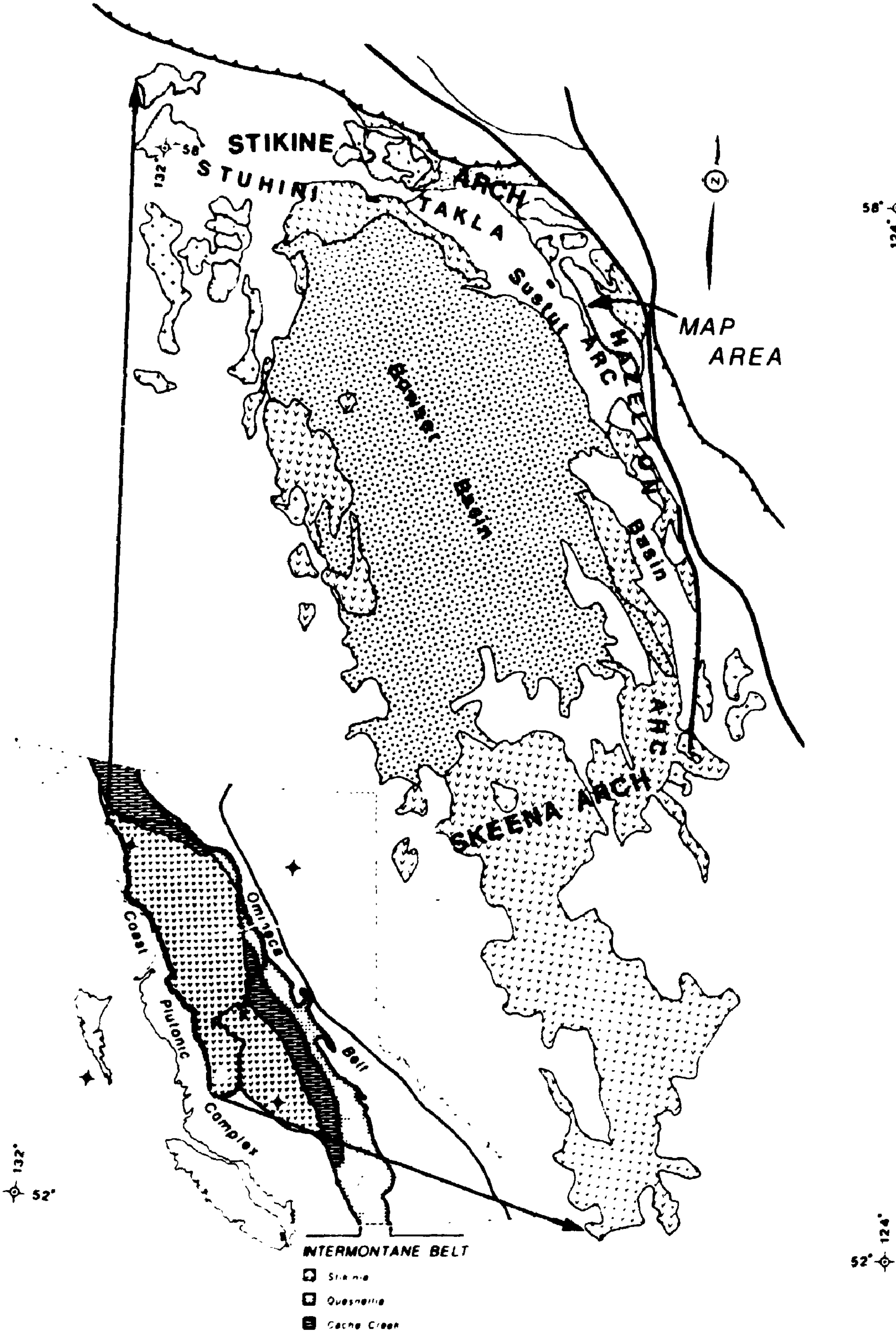


Figure 3. Physiographic belts of the Canadian Cordillera (inset) and major tectonic elements of Stikine allocthonous terrane in north-central British Columbia.

Strata in the Sustut Basin are tightly folded and thrust northeast along the basin's west margin, but 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, Hazelton Group and Toodoggone Formation, and the Sustut Group (Table 1; Figure 4). Sedimentary rocks of the Middle to Late Jurassic Bowser Lake Group are not exposed within the study area. The Toodoggone Formation, the subject of this thesis, is discussed in detail in Chapter 3. Granitic intrusive rocks mainly of Late Triassic to Early Jurassic age and cogenetic dykes crosscut the Mesozoic layered successions.

2.2 Stratigraphy

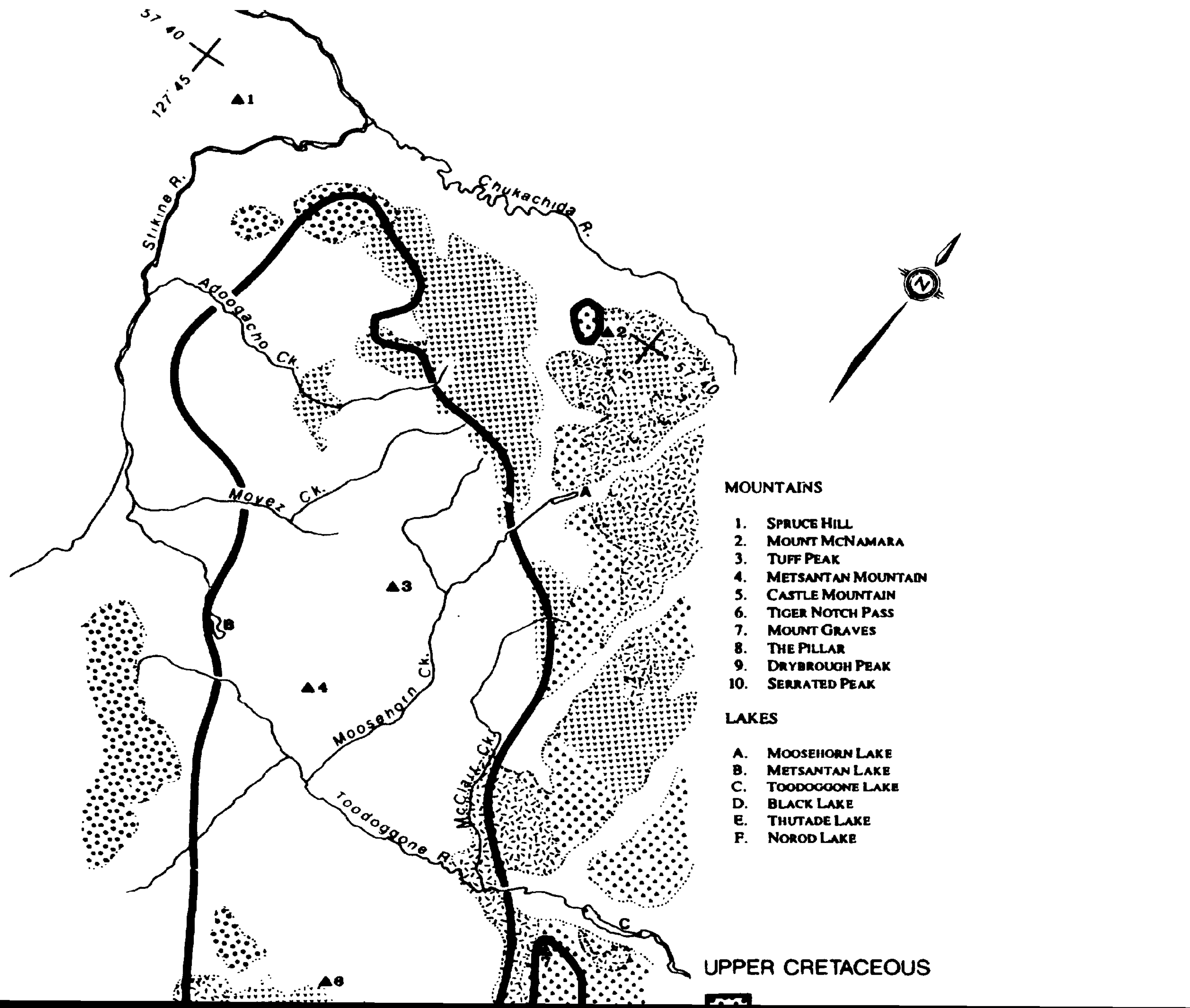
2.2.1 Lower Permian Asitka Group

The Asitka Group was assigned by Lord (1948) to marine sedimentary and volcanic rocks exposed in McConnell Creek map area (Figure 1). Near Dewar Peak, northern McConnell area, Monger (1977a) 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. Further 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 imbricate panels which are thrust from opposing directions toward a northwest trending central area underlain by volcanic strata of the Toodoggone Formation.

Table 1. Regional stratigraphy of the Toodoggone River map sheet (NTS 094E), north-central British Columbia. Compiled after Gabrielse et al. (1977).

Age	Stratigraphy	Rock Type
PALEOCENE(?) to late-EARLY CRETACEOUS	Sustut Group	Nonmarine conglomerate, siltstone shale, sandstone; minor ash tuff
	Cassiar intrusions	Quartz monzonite and granodiorite
UPPER and MIDDLE JURASSIC	Bowser Lake Group	Marine and nonmarine shale, siltstone and conglomerate
MIDDLE and LOWER JURASSIC	Hazelton Group and Toodoggone volcanics	Subaerial andesite flows and tuffs minor basalt and rhyolite flows, epiclastic sandstone to conglomerate, lahar
	Omineca intrusions	Granodiorite, quartz monzonite and quartz diorite
UPPER TRIASSIC	Takla Group	Submarine basalt to andesite flows and tuffs, minor limestone and argillite
LOWER PERMIAN	Asitka Group	Limestone, chert, argillite
CAMBRIAN and UPPER PROTEROZOIC		Siltstone, shale, sandstone, limestone; regionally metamorphosed to greenschist and amphibolite grade


57 40
127 45
Stikine R.
Chukachida R.
Adoogacho Ck.
Movez Ck.
Moosehorn Ck.
Toodoggone R.
McClair Ck.
57 40
MOUNTAINS
1. SPRUCE HILL
2. MOUNT MCNAMARA
3. TUFF PEAK
4. METSANTAN MOUNTAIN
5. CASTLE MOUNTAIN
6. TIGER NOTCH PASS
7. MOUNT GRAVES
8. THE PILLAR
9. DRYBROUGH PEAK
10. SERRATED PEAK
LAKES
A. MOOSEHORN LAKE
B. METSANTAN LAKE
C. TOODOGGONE LAKE
D. BLACK LAKE
E. THUTADE LAKE
F. NOROD LAKE
UPPER CRETACEOUS

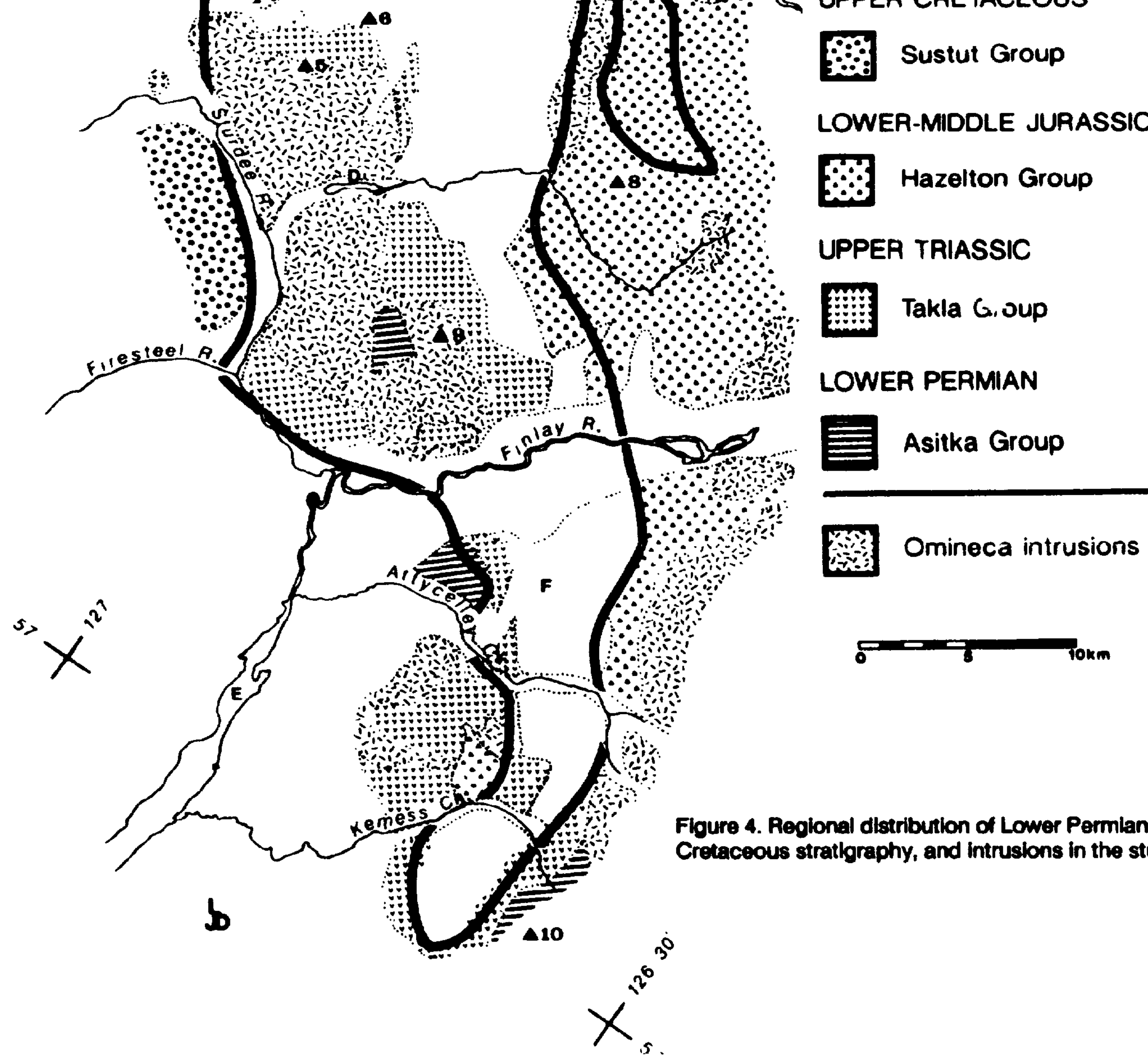


Figure 4. Regional distribution of Lower Permian to Upper Cretaceous stratigraphy, and intrusions in the study area.

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 indicates that it could be a low angle 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.

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 brachiopods occur in thinly laminated green tuffaceous carbonate rocks. Ages of these fossils are indeterminate, however the host rocks are tentatively correlated with Monger's (1977a) lower division of the Asitka Group on the basis of similar rock types.

2.2.2 Upper Triassic Takla Group

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 centered on Sustut Peak, McConnell Creek map area, is reviewed comprehensively by Monger and Church (1977). At the type locality 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 varicolored volcanic breccia interlayered with sandstone and mudstone near the base of the formation that is replaced upsection by reddish volcanic breccia a d 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 le 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 comprise broad gossans.

Rocks of the Takla Group are 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. 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 are present locally. About 6 kilometres southeast of the confluence of the Stikine and Chukachida rivers, limestone rests on basalt flows of the Takla Group but is separated by an angular unconformity from overlying bedded Cretaceous sedimentary rocks. 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.

Contacts of Takla Group volcanic rocks with Jurassic sequences are generally faulted, altnough unconformities are locally present. Southwest of Claw Mountain, a gentle 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 basaltic flow or subvolcanic intrusion of probable Triassic age, faulted against interbedded lahar and latite flows of Jurassic age. The contact is a reverse fault that dips steeply north-northeast and shallows 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 lower Paleozoic sediments of the Asitka Group.

In the type area Takla Group rocks yielded upper Karnian and lower Norian fossils (Monger, 1977a). On the basis of rock type, Takla Group rocks in the study area are similar to the massive flow rocks of the Savage Mountain Formation.

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 Creek and Moyez Creek. The hornblendite is a dark green rock with fresh prismatic hornblende up to 1.0 centimetre long which are zoned. Commonly, fine-grained granules of magnetite forms a diffuse rim on resorbed grain boundaries, and scarse secondary biotite patches partially replaces hornblende. The matrix consists of finely disseminated magnetite grains in a mesostatis 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 is a fault with Lower Jurassic volcanic rocks. 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 percent of the rock. It generally occupies angular interstices between plagioclase laths, imparting an intergranular texture. The plagioclase crystals range in composition from An43 to An58; 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 age of 210±8 Ma on hornblende from the hornblendite (Diakow, unpublished data).

2.2.3 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 sheets, is subdivided into three formations of non-marine 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 Telkwa Formation is further divided by Tipper and Richards (1976) into five depositional facies that are composed predominately of non-marine flows and pyroclastic deposits and less voluminous marine flows and interlayered epiclastic rocks. The upper two formations are dominantly shallow marine, fine-grained epiclastic and tuffaceous rocks. In the north McConnell Creek area, the Telkwa Formation includes the eastern Sikanni facies and the western Bear facies of Tipper and Richards (1976). The Sikanni facies is mainly composed of 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, rocks of the Hazelton Group extend for more than 80 kilometres from Attycelley Creek in the south to the Chukachida River in the north. The Hazelton Group 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 2 metre thick basalt flow, are infilled and overlain by one-half metre 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 overlie 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 not welded; 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 or less commonly green matrix. Sandstone beds derived by reworking of older volcanic rocks are grey-green. Mudstone in shades of maroon locally contain round accretionary lapilli less than 1 centimetre in diameter. The mudstone is interlayered with sandstone in graded and cross-laminated 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 deposits. Bedding averages from 10 to 15 centimetres thick; graded bedding and crossbedding are locally prominent. The overlying acidic flows are brown and green perlite glass 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 contain 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 in millimetre diameter, constitute 3 to 5 per cent of the rock by volume. Magnetite has 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 occurs with abundant chlorite in the matrix.

Dykes of dark green, fine-grained porphyritic basalt, that are seldomly more than 2 metres wide, intrude all rock types. In turn these are crosscut by porphyritic andesite dykes which weather to hues of pink or red and vary from 4 metres to more than 15 metres wide. The dykes form an en echelon pattern striking at 125 to 145 degrees Azimuth, a trend that is consistent with regional northwest faults. Individual dykes are continuous for more than 1000 metres along strike; contacts are sharp with little contact metamorphism.

Mafic dykes 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 dykes 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.

The age of the Hazelton Group in north-central British Columbia is bracketed by Late Sinemurian to Early Callovian fossil fauna (Tipper and Richards, 1976).

Sedimentary rocks are a very minor component of the Hazelton section exposed in the area near Mount Graves. The Hazelton Group is dominated by subaerial flows, pyroclastic and volcaniclastic rocks that are most similar to the Bear facies of the Telkwa Formation in the McConnell Creek area. A K-Ar age determination on brown rhyolite glass west of Mount McNamara is 352± 12 Ma (Diakow, unpublished data). This age, which is significantly older than expected, may be attributed to an excess abundance of initial argon in the melt prior to quenching.

Flows in the Hazelton Group in the Toodoggone River map area range from basalt to rhyolite; andesite predominates. The lavas have subordinate interlayers of volcanic breccias and tuffs that grade laterally into dominantly fine- to coarse-grained volcaniclastic rocks. The preponderance of finely dispersed hematite dust throughout most rocks suggests that deposition took place in a subaerial environment. Shallow subaqueous conditions persisted locally; in these areas impure limestone lenses are associated with dark green, unoxidized lava flows and cross-laminated intravolcanic sedimentary rocks. Widespread conglomerate beds with interdigitated tuffs attest to widespread reworking of older tephra, possibly on topography steepened by block faults.

2.2.4 **Middle and Upper Cretaceous Sustut Group**

The Sustut Group was named by Lord (1948), for well bedded continental sedimentary rocks outcropping near Sustut River, 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; pg.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 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 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 Sustut Group sedimentary rocks 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. Carbonaceous plant debris is in the underlying rocks. 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 Spatsizi map area (Evenchick, 1986). The overlying Brothers Peak Formation, has an Eocene age, as determined by K-Ar ages 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).

2.3 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 lake covered much of the subdued topography south of the Chukachida River, and at least as far south as the Toodoggone River.

CHAPTER 3

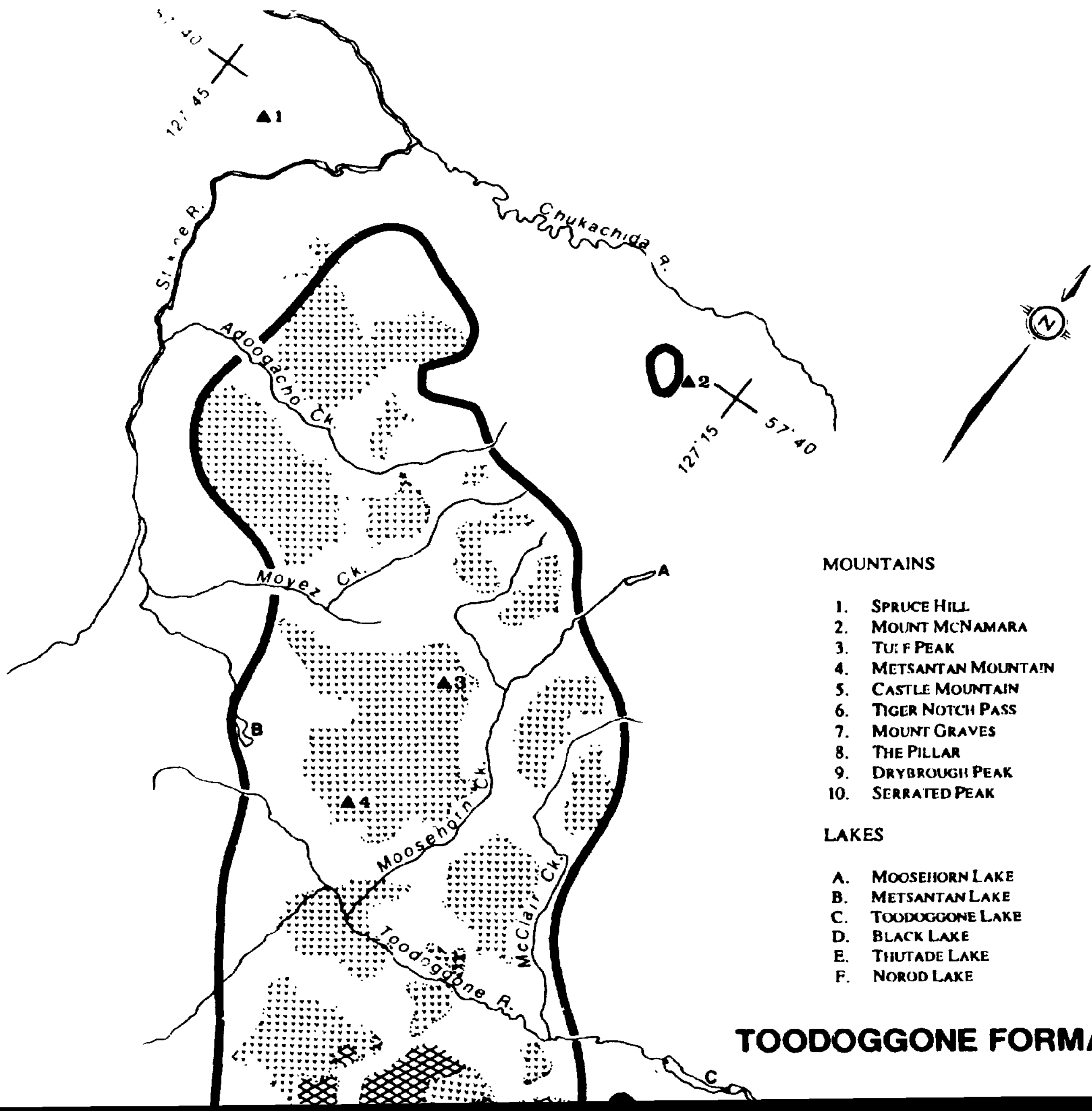
LOWER AND MIDDLE JURASSIC TOODOGGONE FORMATION AND ASSOCIATED INTRUSIVE ROCKS

3.1 Ger.. .. 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. It is described herein, in terms of distribution, contacts, rock type, major oxide abundances, potassium-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 Upper Cretaceous Sustut Group (Table 2). 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 both the north and south ends of the study area. Stratified rocks of the Toodoggone Formation are faulted against Early Jurassic Omineca intrusions and are cut by cogenetic northwest trending dykes.

The Toodoggone Formation is estimated to be more than 2200 metres thick, and consists dominantly of interstratified red and maroon pyroclastic and flow rocks. They are broadly divided into lower and upper volcanic cycles, that are further subdivided into six members. 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 or lava flows. In contrast, the Attycelley, McClair and



TOODOGGONE FORMATION

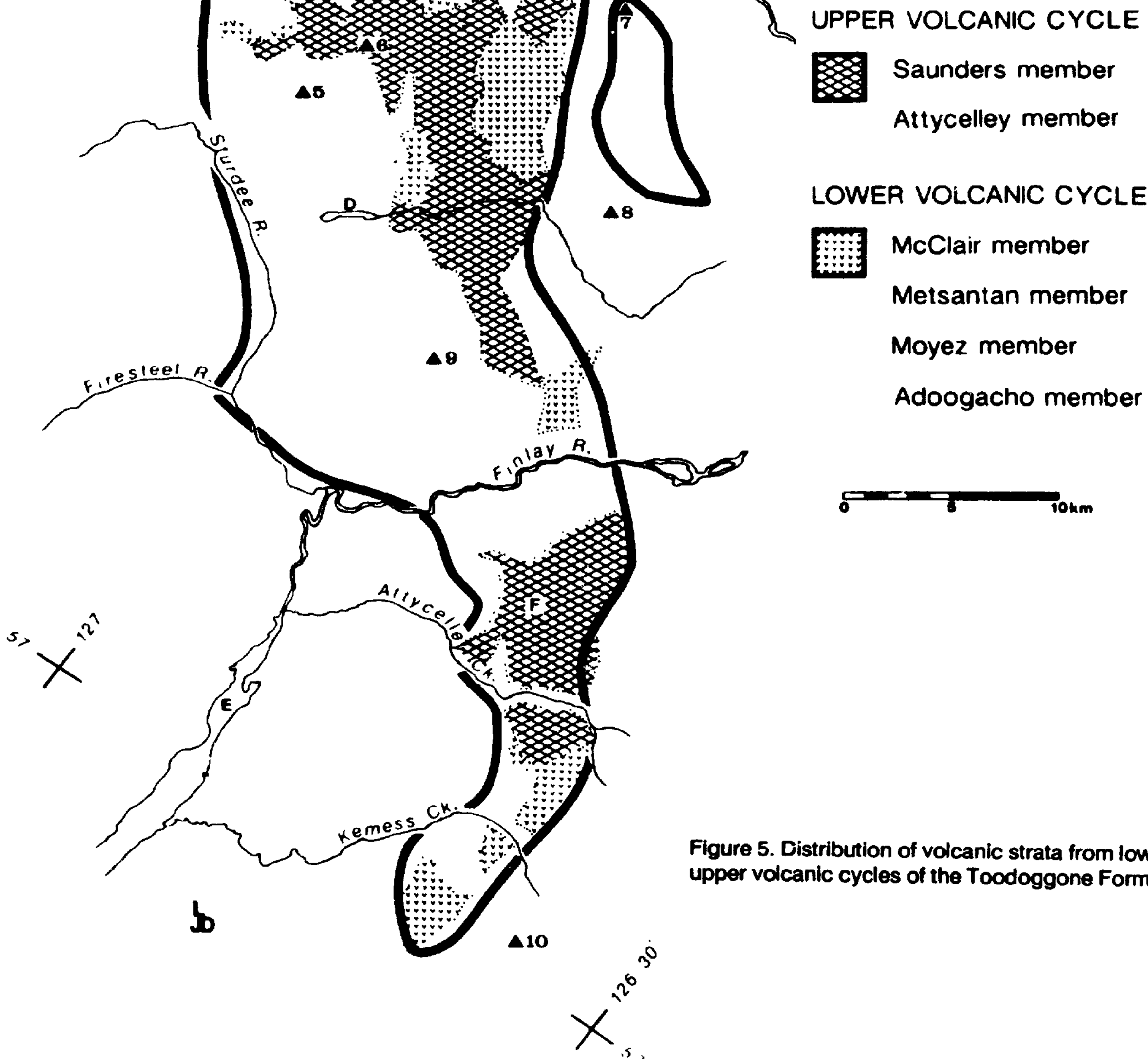


Figure 5. Distribution of volcanic strata from lower and upper volcanic cycles of the Toodoggone Formation.

Table 2. Major stratigraphic divisions of the study area.

Period and Epoch	Stratigraphic Division			Description
LOWER to UPPER CRETACEOUS	Sustut Group		Tango Creek Formation	chert pebble conglomerate, sandstone, carbonaceous mudstone, basaltic sills
	angular unconformity			
LOWER to MIDDLE JURASSIC	HAZELTON GROUP	TOODOGGONE FORMATION		Dykes: quartz-feldspar porphyritic dacite and rhyolite Dykes and sills: amygdaloidal and porphyritic basalt
			Saunders member	Dacite ash-flow tuff, volcanic sandstone and conglomerate at the base and top
			Attycelley member	Dacite lithic-crystal tuff, minor lapilli-block tuff, well layered volcanic sandstone to conglomerate, rare limestone
			unconformity	Erosional remnant of tuffaceous sandstone with middle to Late Toarcian fossil fauna
				Dykes: Pink, porphyritic andesite
			McClair member	"Crowded" porphyritic andesite flows, tuff to breccia, local sandstone to conglomerate
			Metsantan member	Latite lava flows, well layered epiclastic siltstone to conglomerate, minor lahar
			Moyez member	Well layered, crystal-ash tuff with conglomerate near the base, minor epiclastic sandstone and limestone
			gentle angular unconformity	
			Adoogacho member	Dacite ash-flow tuff, variably reworked tuff to breccia, rare porphyritic andesite lava flows
			fault and intrusive contacts	
			Omineca intrusions	Stocks and plugs: Equigranular and porphyrit.c granodiorite, quartz monzonite and quartz diorite
			fault and intrusive contact	
				Porphyritic andesite flows, lesser basalt to rhyolite flows; well bedded tuffs, volcanic conglomerate to mudstone
	gentle angular unconformity to paraconformable contact			
UPPER TRIASSIC	Takla Group			Augite porphyry basalt flows, fine-grained andesite, tuff, minor limestone and argillite
	fault contact			
LOWER PERMIAN	Asitka Group			Limestone, chert and argillite

Moyez members are mainly intercalated pyroclastic and epiclastic rocks that vary markedly in thickness but are mappable on a local scale.

Descriptions of pyroclastic rocks in the next section follows 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).

3.2 Lower Volcanic Cycle

The lower volcanic cycle has four stratigraphic divisions; namely, 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.

3.2.1 Adoogacho member

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 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 areas. Adjacent to Adoogacho Creek, an inlier of Takla Group augite bearing lava flows is unconformably overlain by Adoogacho lapilli-ash tuff. 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 are gently inclined layers in knolls separated by broad valleys (Plate 1A). Differential load compaction and post-depositional 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 colored matrix of crystals and ash (Plate 2B). Non-welded 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 percent, but range up to 15 percent 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 intergrown crystobalite 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 colored rims and bend plastically around crystal fragments in the matrix.

Broken crystals and a few intact phenocrysts constitute between 30 and 40 percent of the ash-flow tuffs (Plate 3A,B). The crystal assemblage is consistant

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 1

PLATE 2 - ADOOGACHO MEMBER

A. Compaction foliation defined by cognate lithic fragments in partly welded, dacite ash-flow tuff.

B. Handspecimen 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. Non welded ash-flow tuff with abundant crystals, and equidimentional cognate lithic fragments.

PLATE 2

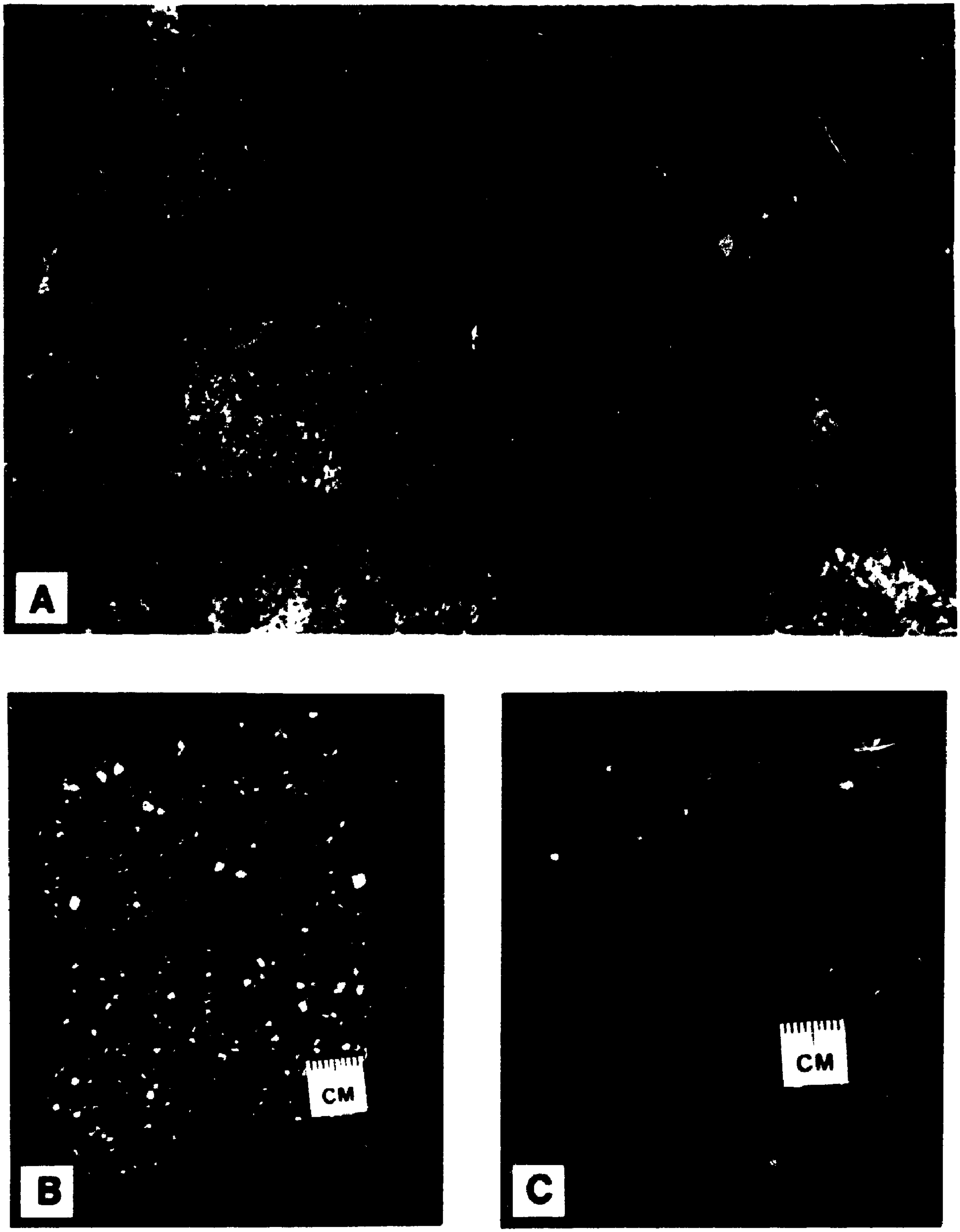


PLATE 3 - ADOOGACHO MEMBER

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 (t. ·) in a fine-grained matrix of interlocking quartz and alkali feldspar. Note the spherulites formed during devitrication of the glassy matrix.

B. Photomicrograph (ppl) of partly welded, dacite ash-flow tuff in which aligned subhedral crystal fragments occur in a cloudy anhredral matrix of silica and alkali feldspar. Deposition of hot pyroclasts is indicated by the deformed lithic fragment with a light colored rim, that is situated at the lower right side of the labelled quartz fragment (qtz).

PLATE 3

throughout the Adoogacho member, however relative mineral proportions vary. Plagioclase, ranges in composition from An24 to An55, it is typically turbid and very fractured. Albite twinning and scarce oscillatory zoning is commonly obscured by exsolution of irregular patches of unaltered alkali feldspar. A mixture of clay minerals, zeolites, sericite and clots of carbonate partly replace plagioclase. Sanidine and resorbed quartz crystals averaging 1 millimetre diameter are 1 to 3 percent of the rock, respectively. Green hornblende and dark red oxyhornblende, vary from 5 to 10 percent. 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 percent. Augite is usually absent; however, pale green unaltered crystal fragments less than one-half millimetre across are 1 percent 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 tuff 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 form 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-colored 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 3 metre thick section, south of Adoogacho Creek, contains well preserved plant imprints. Palynomorphs identified from this site are non marine fern species that correlate most closely with Upper Triassic assemblages (G.E. Rouse, written communication, 1984; Appendix C). Greyish-black pyritic siltstone containing concretions forms a cap less than 5 metres thick on well layered tuffs and lahar about 16 kilometres at 317 degrees azimuth from Tuff Peak. The age of the siltstone is uncertain; it may represent a small eroded remanent of the Lower Jurassic Spatsizi Group.

3.2.2 Moyez member

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. 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(Plate4B).

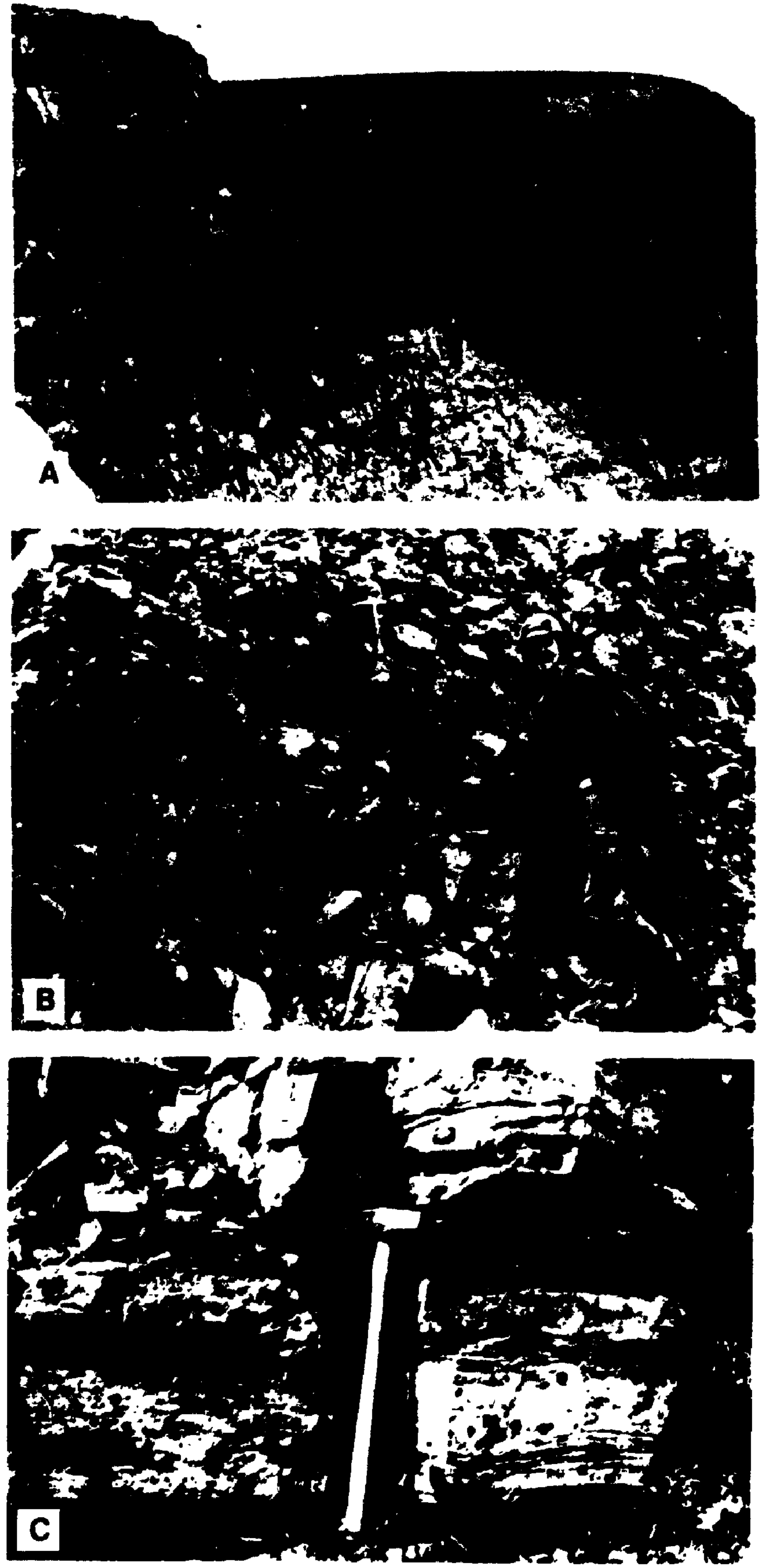
PLATE 4 - MOYEZ MEMBER

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.

PLATE 4



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 within a groundmass of green and brownish-red ash.

Phenocrysts consist of between 15 and 25 percent turbid plagioclase, and 1 to 2 volume percent each of quartz, green hornblende, magnetite and lesser apatite. Pale green augite, biotite and titanite are uncommon. Secondary epidote, chlorite, 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 none was found.

3.2.3 Metsantan member

The Metsantan member is mostly latite lava flows with interflow lahar, and mixed epiclastic and pyroclastic rocks. The Metsantan member has no type section, but is named for more than 600 metres of flows, interspersed layers of tuffs, 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 Mine. 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 percent 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 millimetres; 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 percent. Biotite plates less than 1.5 millimetres in diameter average about 1 volume percent. Quartz is scarce in the flows, rarely more than one or two visible grains per hand specimen. They are generally partly resorbed and vary from 0.5 to 1.0 millimetre 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 percent of the rock.

The rocks have a dull green or mauve-colored matrix enveloping feldspar and mafic phenocrysts. Turbid plagioclase is incipiently occupied by varying proportions

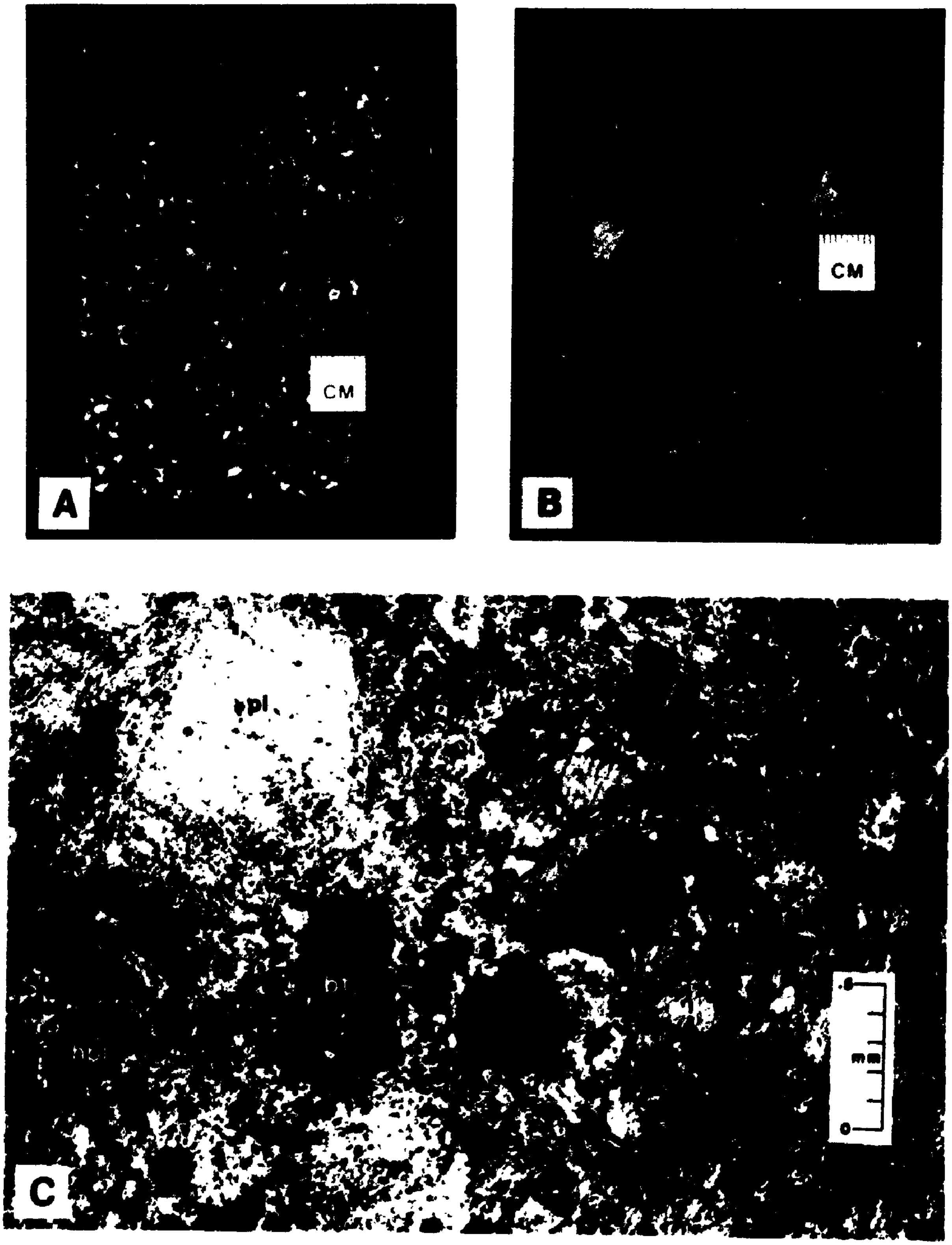
PLATE 5 - METSANTAN MEMBER

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.

PLATE 5



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 cross-laminated, 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, cross laminations, ripples, mud chip 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. Conglomerate layers with a clast supported framework dominated by subspherical clasts suggest reworking of these rocks. Other significant exposures of conglomeratic epiclastic rocks crop out on the south-facing slope above Cloud Creek, 3.5 kilometres southwest of the Lawyers AGB zone.

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.

3.2.4 McClair member

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 bound by McClair Creek in the east, by Moosehorn Creek in 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 have lapilli and block size fragments.

Crowded porphyritic textures, with 35 to 50 volume percent of phenocrysts averaging 2 millimetres diameter is 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 percent, 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 coalesced 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 5 to 10 centimetre thick beds of lapilli-ash tuff 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.

3.3 Intervolcanic Cycle Sedimentary Rocks

Fossiliferous sandstone forms a recessive weathering outcrop near the headwater of the east tributary of Adoogacho Creek (H.W. Tipper, written communication, 1985). The distribution and composition of these sedimentary rocks is not recorded; however, they are believed to be an erosional remanent which unconformably overlies volcanic rocks of the Adoogacho member.

Ammonites, coarse shelled pelecypods and belemnites in the sedimentary rocks were initially identified as Bajocian fauna by Hans Frebold of the Geological Survey of Canada. The ammonites from this collection are presently thought to be of Middle to Late Toarcian age (H.W. Tipper, written communication 1989; Appendix C).

3.4 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.

3.4.1 Attycelley member

The Attycelley member is mostly green, grey and mauve lapilli-ash tuff, subordinate lapilli-block tuff, a few interspersed ash-flows and lava flows, and lenses of epiclastic rocks and rare limestone lenticles. The volcanic rocks are similar in texture and mineral constituents to pyroclastic volcanic rocks of the Adoogacho member. Rocks of the Attycelley member are only distinguishable from the Adoogacho member by stratigraphic position relative to distinctive overlying strata of the Saunders member and the underlying Metsantan member.

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), and unconformable on Upper Triassic Takla Group rocks northeast of Drybrough Peak. The upper contact is inferred by a change in the general weathering resistance of outcrops; from recessive, generally crumbly and platy weathering rocks in the Attycelley member, to resistant, blocky weathering cliffs of the Saunders member. Between 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 predominantely non-welded, 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 outward from a recessed matrix. Layered tuff sections contain either a

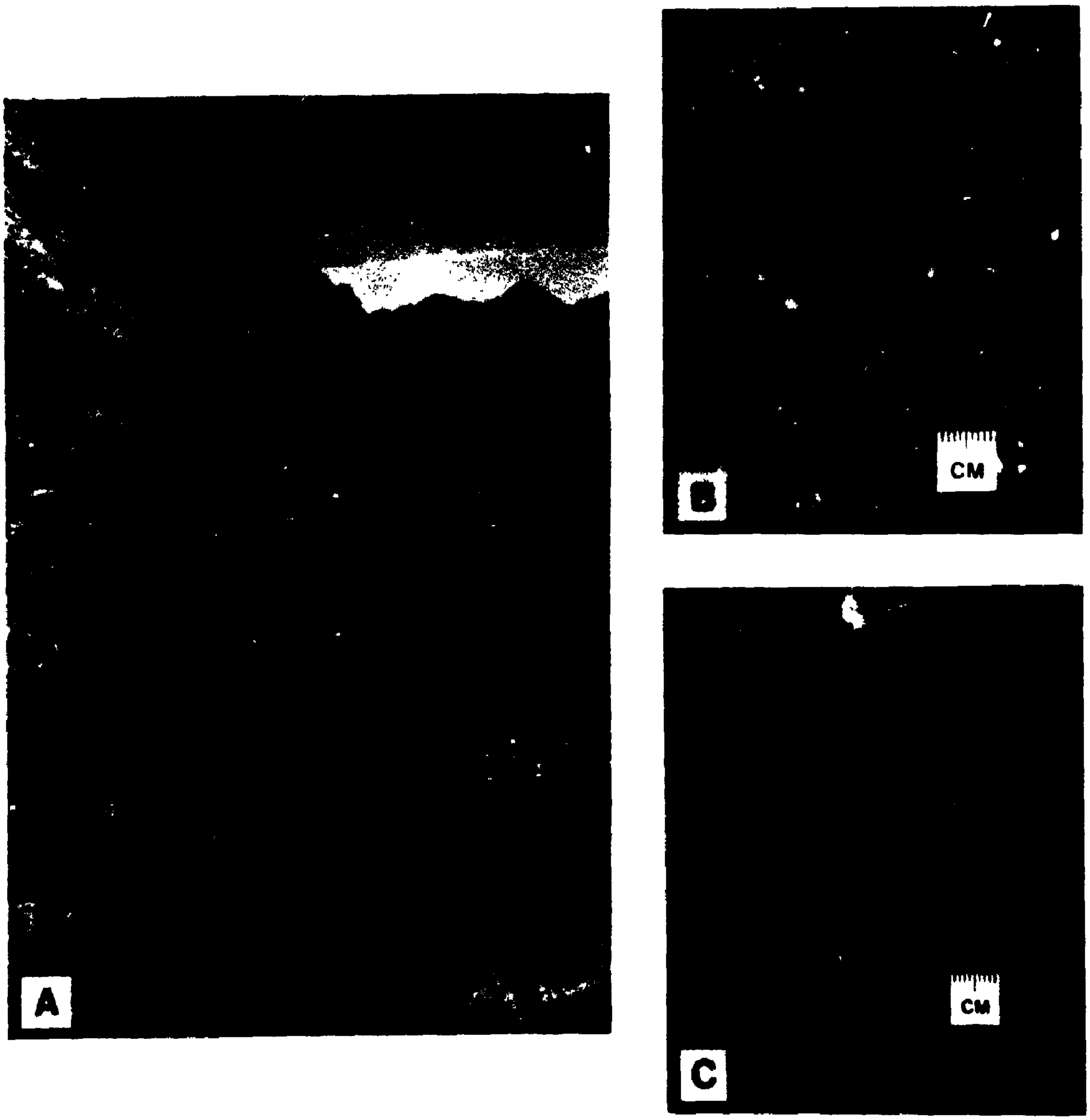
PLATE 6 - ATTYCELLEY MEMBER

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. Photo courtesy of A. Panteleyev.

B. Typical non-welded, 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.

PLATE 6



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 within the area between Drybrough Peak and 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 percent plagioclase phenocryst which impart a crowded seriate texture and several volume percent quartz phenocrysts. Elsewhere, andesitic flows 1.5 to 3.5 metres thick that resemble those of the Metsantan members are locally interspersed with typical pyroclastic deposits of the Attycelley member on the ridge immediately east of Saunders Creek.

Epiclastic beds of mainly volcanic sandstone, siltstone and conglomerate are interlayered with lapilli-ash tuffs to form differentially weathered distinctly bedded successions. These successions are locally prominent, particularily, 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. Panteleyev, written communication, 1986). 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 the same area documents conglomerate composed of Takla and granitic clasts occupying the basal part of a succession of thinly bedded fragmental and sedimentary rocks (Marsden and Moore, 1989). This conglomerate presumably is near the base of the Attycelley member, which in turn unconformably overlie flows, breccias and intraformational conglomerates of the Takla Group. South of Kemess Creek, an 80 metre thick section of layered and variably reworked fine-grained tuffs and intercalated tuffaceous sandstone have 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 4 centimetre thick several metre long lens 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 generally has a turbid appearance because of partial occupation by sericite, calcite and epidote. Sanidine crystals up to 1.5 millimetres in diameter are generally present in amounts of 1 volume percent 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 percent 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 percent of most rocks. Pyroxene, a rare constituent of these rocks, is pseudomorphed by carbonate. Biotite is generally occupied by chlorite and magnetite with or without muscovite, sphene and epidote. It accounts for between 1 and 2 volume percent of the tuffs. Microscopic prisms of apatite and less common titanite are present.

3.4.2 Saunders member

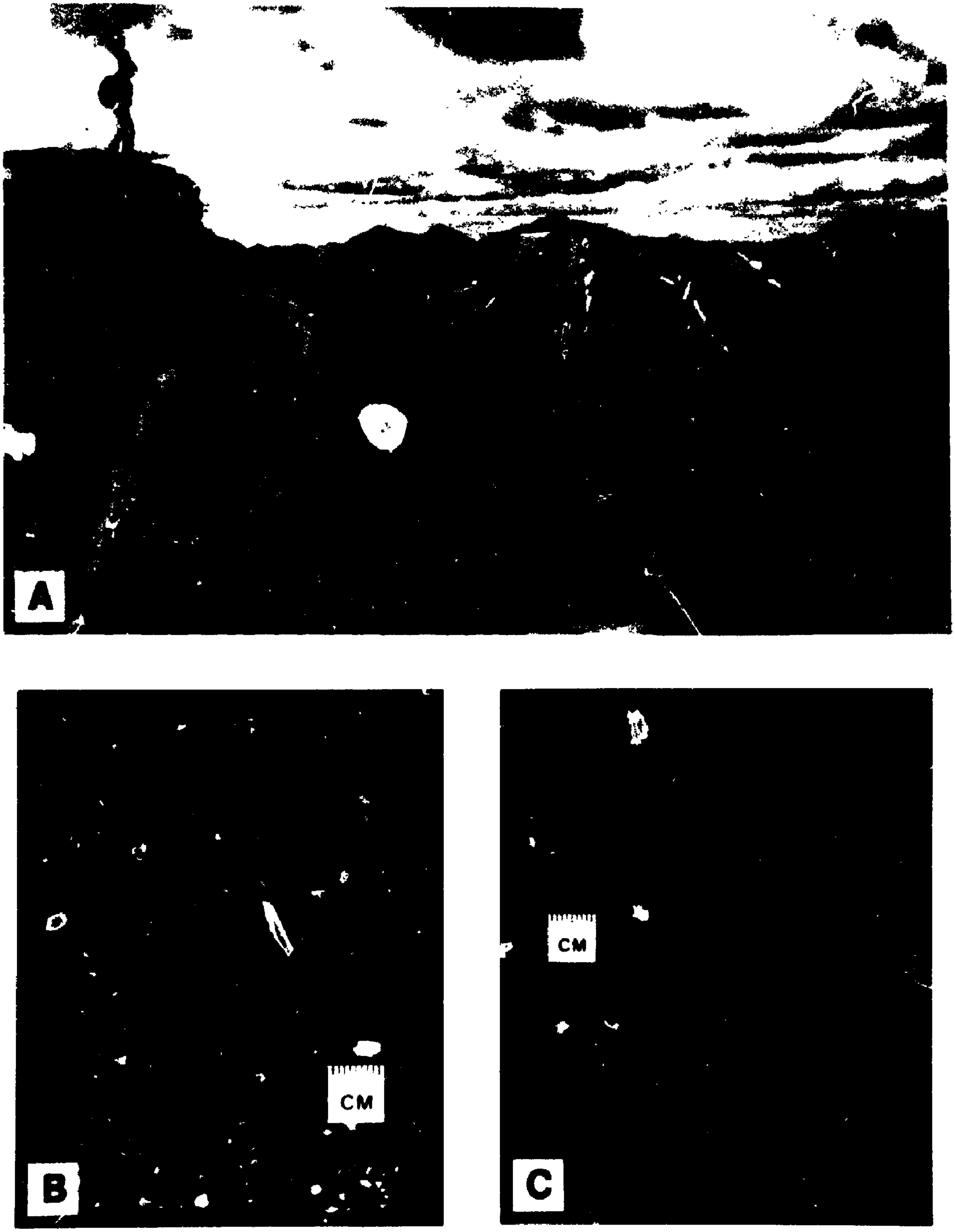
The Saunders member is the stratigraphically youngest rocks of the Toodoggone Formation, and is composed almost exclusively of partly welded, crystal-rich, dacitic ash-flow tuffs which typically form cliffs that weather to angular talus blocks (Plate 7A). In the type area, bounded to the east by the west tributary of Saunders Creek and an unnamed southeast trending tributary of Jock Creek, a

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. Photo courtesy of A. Panteleyev.

B,C. Typical incipient to partly welded dacite ash-flow tuffs ofthe 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 and matrix.

PLATE 7



succession of compositionally and texturally homogeneous ash-flow tuffs more than 250 metres thick cap 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 block-faulted section at Kodah Creek, immediately north of the Toodoggone River. At their southern extent identical strata more than 175 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 Saunders member strata are well exposed along the north flank 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 form 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 scarse quartz phenocrysts. The provenance of clasts is mainly Takla lava flows. The tuffaceous interbeds are reworked lapilli-ash tuffs in unsorted to graded beds between 4 and 10 centimetres thick. Rare accretionary lapilli are locally in discontinous layers several centimetres thick. The upper contact of the Saunders member is with fine grained sandstone to pebble conglomerate found locally west of Pau Creek. These discontinuous beds have abundant quartz grit, which is thought to be eroded from ash-flows of the Saunders member. Elsewhere, the top of the Saunders member is not exposed.

Ash-flow tuff that characterizes the Saunders member is typically grey-green with a large proportion of broken crystal, and non-vesiculated juvenile fragments with porphyritic texture (Plates 7B,C). These rocks have subtle variations in texture and relative mineral abundance but resemble a homogeneous, weak to moderately welded, single cooling unit in cliff sections. 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 percent crystals of plagioclase, hornblende, quartz, biotite, sanidine and scarse augite (Plate 8A). Plagioclase varies from 1 to 4 millimetres in diameter, is between 25 and 45 volume percent of the rock, and has a composition of An29 to An54. 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 percent. It is commonly occupied by incipient secondary clay minerals. Green hornblende, the dominant mafic mineral, accounts for between 3 and 10 volume percent 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 percent 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 percent, but may be 5 volume percent. 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.

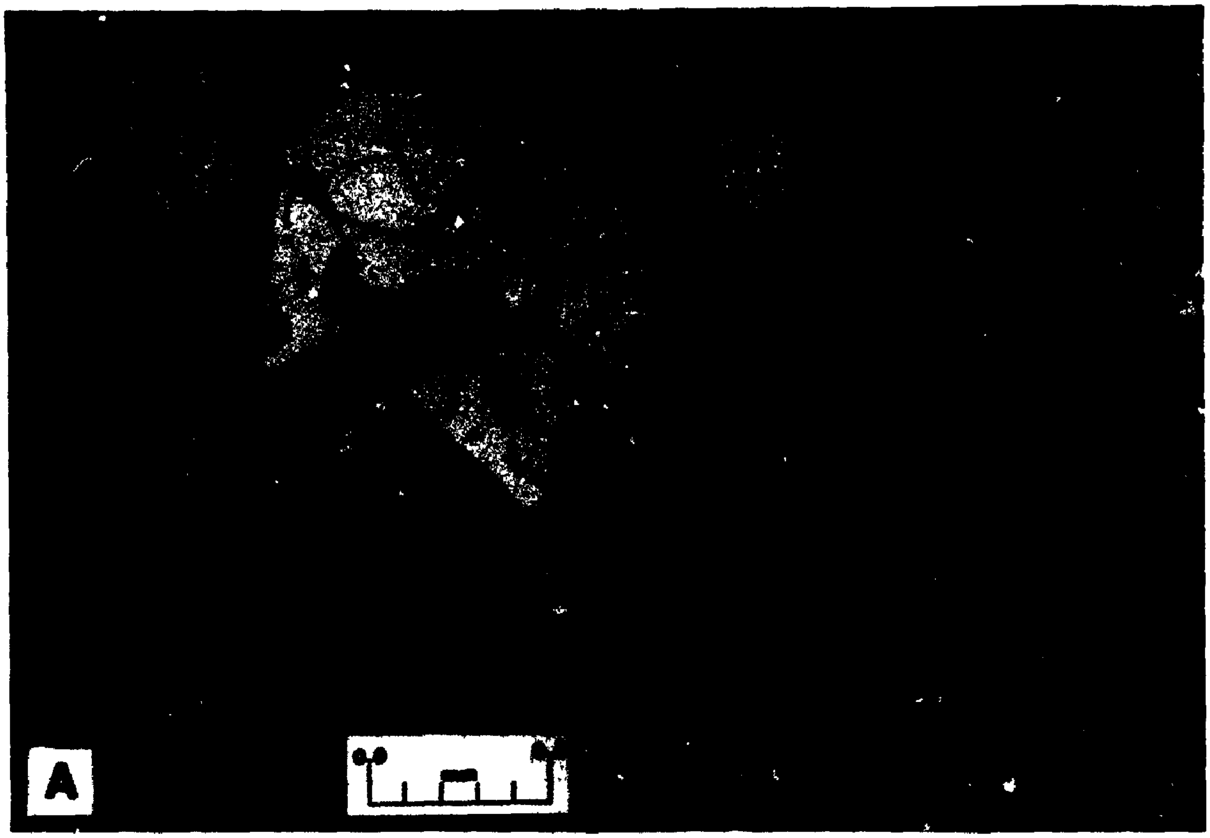
The tuffs have a glassy mesostasis which is devitrified to an aggregate of interlocking anhedral feldspar and quartz stippled with fine-grained opaque granules and less common crystallites. Rare vestiges of brown glass are preserved in the interstices between coalescing spherulites (Plate 8B). Faint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

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 matrix.

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 matrix is fine-grained with relics of glass (gl) that are partly devitrified to spherulites.

PLATE 8



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.

3.5 Major Element Abundances

Major element abundances and CIPW molecular norms were determined for 59 samples of variably altered volcanic rocks from the Toodoggone Formation (Appendix A; Map 2, back pocket). The thirty one least altered samples, in which carbon dioxide is less than 1 wt% and water less than 3 wt% 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 flows samples from the Metsantan member, and 2 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 in Figure 6; the average composition of rocks from the stratigraphic members are compared in Table 3 and Figure 7.

The average composition 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% to 54.5% with an average of 59.7% for the entire volcanic suite. Average silica is from 61.6% to 61.4% in the Adoogacho and Saunders members respectively, and 58.2% in the Metsantan member. A decrease in average K_2O from 3.5% in the Adoogacho and Saunders members to 3.3% in the Metsantan member corresponds with the silica

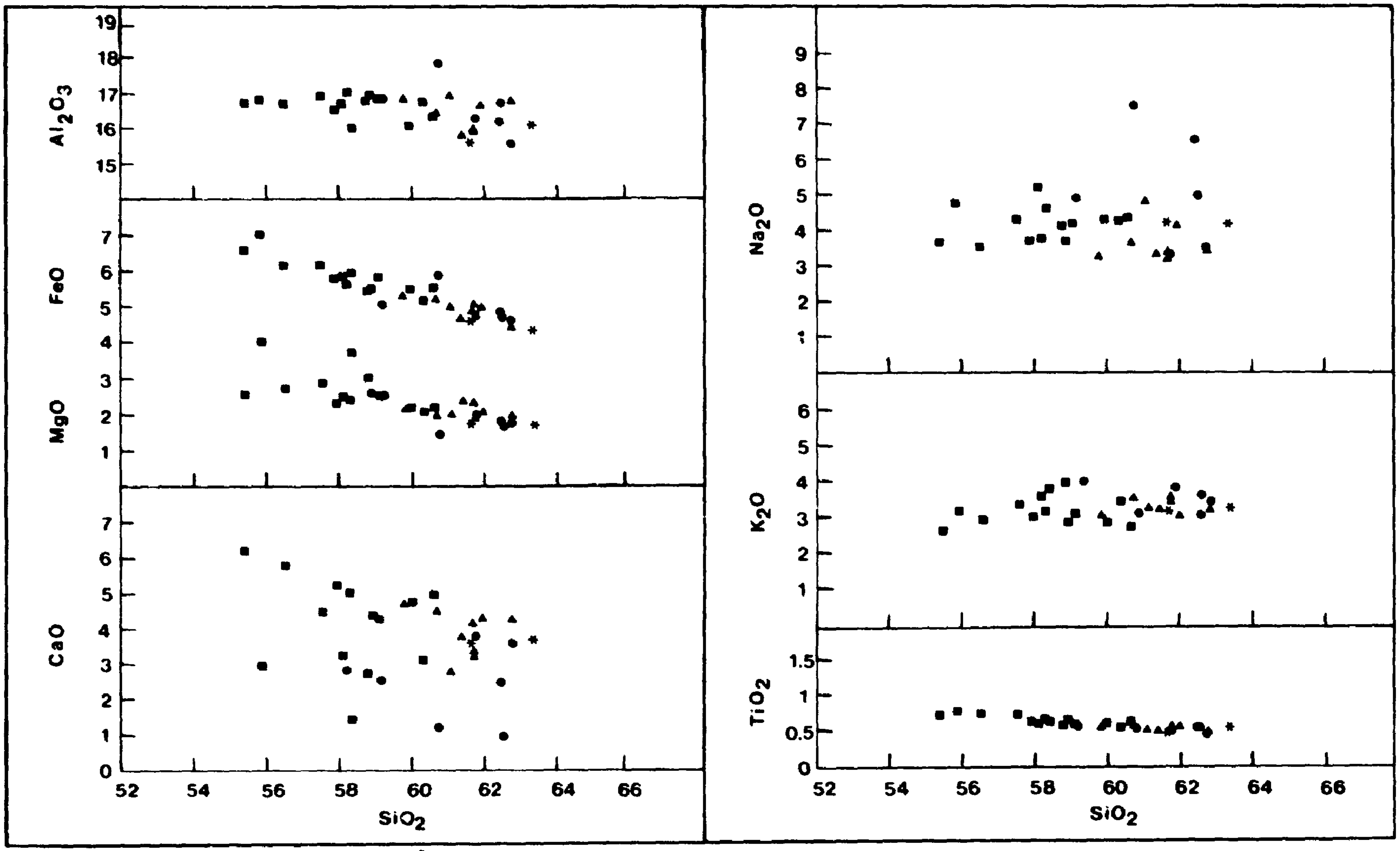


Figure 6. Harker diagram of oxide variation with silica for volcanic rocks of the Toodoggone Formation. Data points represent weight percent oxide values as determined in Appendix A. ● Adoogacho member, ■ Metsantan member, * Attycelley member, ▲ Saunders member.

Table 3. Composition and mean major element abundances of volcanic rocks from the Toodoggone Formation.

	Entire Suite[1]	Entire Suite (anhydrous)	Representative Suite[2]	Adoogacho member	Metsantan member	Attycelley member	Saunders member
SiO_2	59.71	62.10	60.04	61.55	58.21	62.45	61.36
TiO_2	0.58	0.61	0.59	0.53	0.67	0.53	0.53
Al_2O_3	16.20	16.81	16.46	16.54	16.64	15.83	16.35
Fe_2O_3	4.12	4.28	4.37	4.96	4.99	4.38	3.01
FeO	1.44	1.65	1.31	0.50	1.29	0.55	2.06
MnO	0.16	0.34	0.16	0.13	0.17	0.15	0.15
MgO	2.29	2.38	2.29	1.84	2.69	1.74	2.10
CaO	3.57	3.71	3.77	2.47	4.23	3.68	3.95
Na_2O	3.99	4.14	4.26	5.17	4.24	4.28	3.67
K_2O	3.77	3.92	3.37	3.51	3.27	3.30	3.45
P_2O_5	0.22	0.55	0.23	0.19	0.25	0.24	0.22
H_2O^+	1.76	-	1.46	1.22	1.62	1.88	1.28
H_2O^-	0.62	-	0.51	0.70	0.52	0.40	0.37
CO_2	1.02	-	0.59	0.52	0.48	1.04	0.72
S	0.04	-	0.02	0.01	0.02	0.01	0.03
Total	99.67	100.00	99.72	99.84	99.57	100.44	99.72
FeO*	5.18	-	5.32	4.97	5.86	4.49	4.88
FeO*/MgO	2.34	-	2.37	2.60	2.21	2.58	2.28
K_2O/Na_2O	1.01	-	0.82	0.75	0.77	0.77	0.96
n	55	55	31	6	14	2	9

[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 samples 23, 43, 50 and 57) and H_2O_T < 3 wt. %

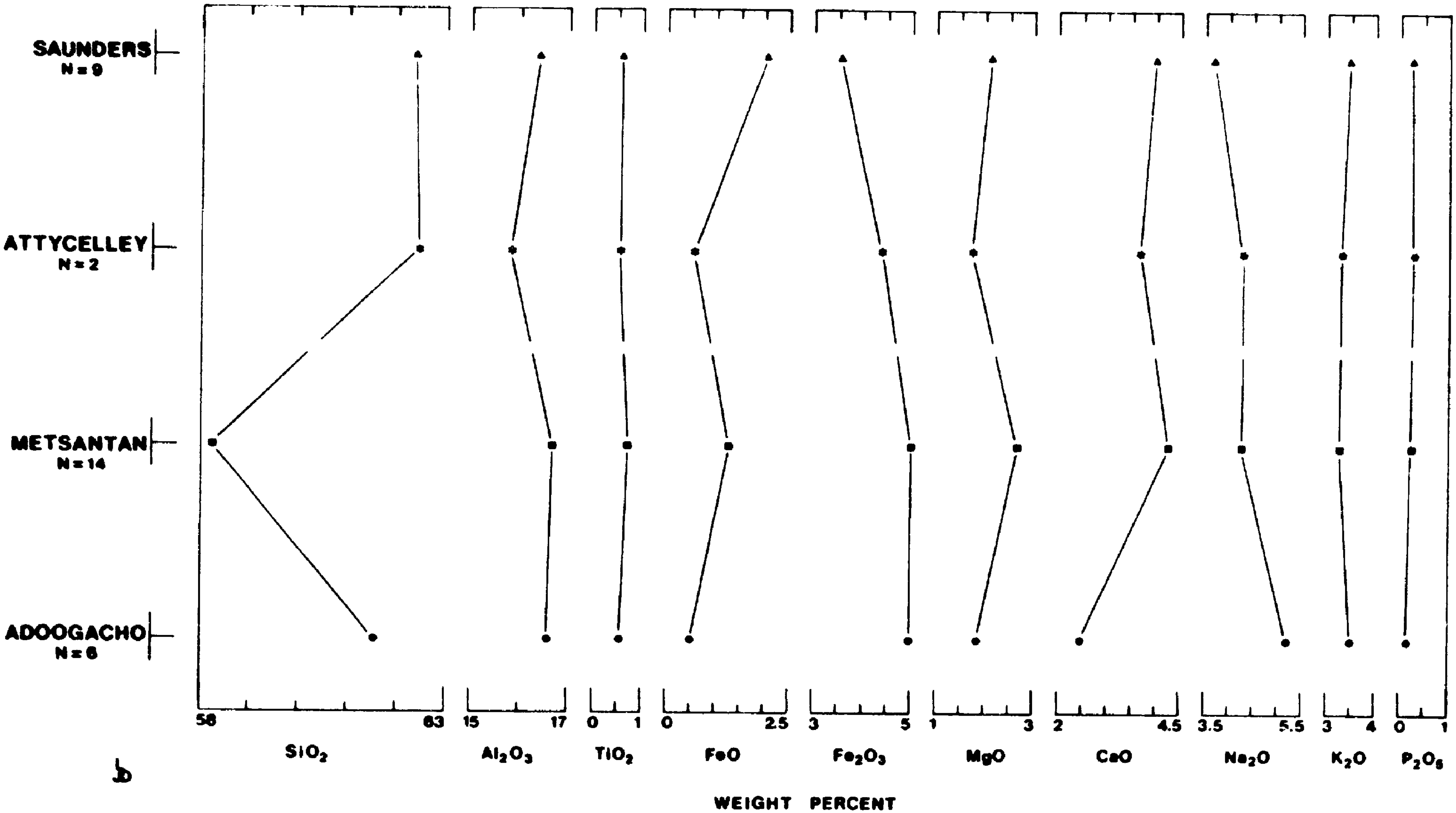


Figure 7. Comparison of major element abundances for volcanic rocks of the Toodoggone Formation. Data points represent the average of oxide values as determined in Table 3.

trend, and alkalis gradually decrease about 1.5% between the stratigraphic lowest to highest members, 8.7% and 7.1% respectively. Al_2O_3 is relatively constant between 15.5% and 17.8% with a mean of 16.5%. TiO_2 decreases as SiO_2 increases; individual analyses are consistantly greater and average 0.67% in the Metsantan member compared with the uniform average of 0.53% in volcanic strata of bounding members. Similarly total iron, expressed as FeO^*, is approximately 1% greater in the Metsantan member, 5.9%; but, the Metsantan FeO^*/MgO ratio of 2.2% is slightly less than in either the Adoogacho member, 2.8% or the Saunders member, 2.3%.

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 4), 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 hyperthene 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% in the three volcanic members. In most cases potassium is located in the groundmass, particularily 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 grey-green color and absence of oxyhornblende. Corundum, albeit minor, is present in most of the normative

Table 4. Phenocryst assemblage and the main features of CIPW molecular norms for volcanic rocks of the Toodoggone Formation.

Stratigraphic member	Volume (%)	Phenocrysts 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=hyperthene; Hbl=hornblende; Bt=biotite; Ttn=titanite; Ap=apatite; Hm=hematite

calculations. Corundum is common in high potassium andesites (Gill, 1981).

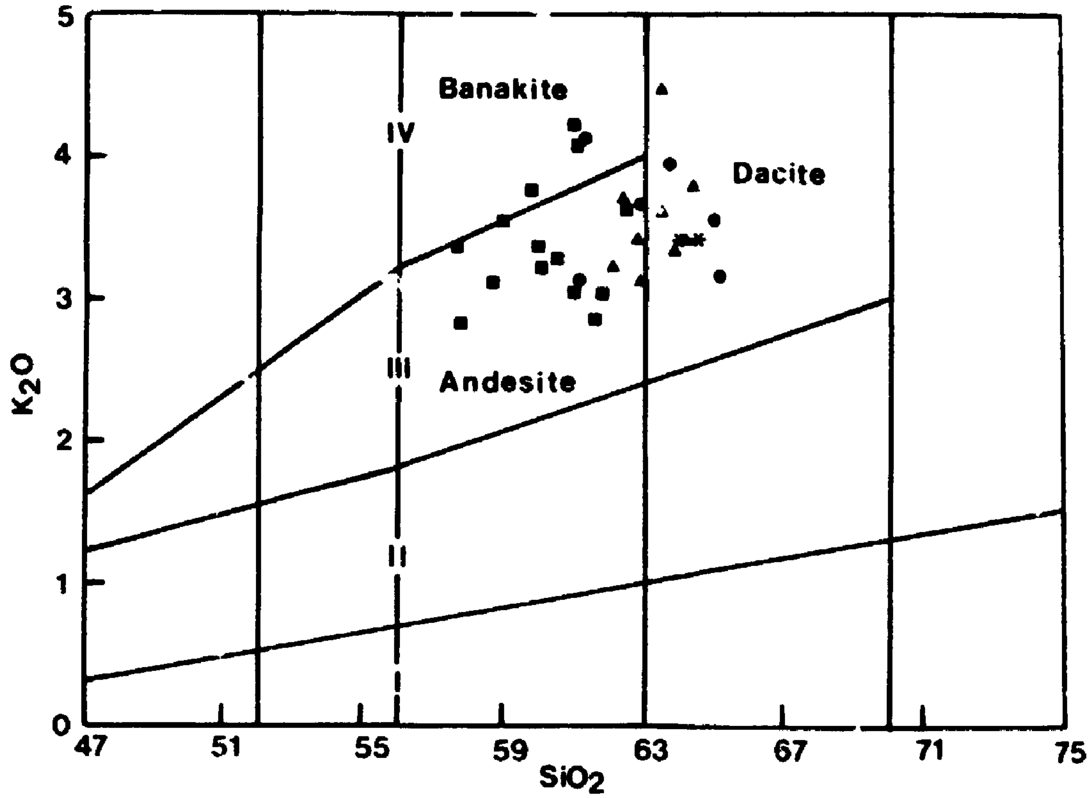
The most significant feature of major element distribution is the large potassium content of volcanic rocks from Toodoggone Formation, 3.1% K_2O at 57.5% SiO_2. Moreover, chemical consanguinity between the Adoogacho and Saunder members is consistent with their similar phenocrysts and uniqueness in composition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

Lava flows of the Metsantan member are mainly high-K andesite (Figure 8), or latite, the potassic analog of trachyandesite (Figure 9). The average composition of the Metsantan member (Table 3) is similar, with the exception of less TiO_2, to an average trachyandesite (Table 5, no.6). Ash-flow tuffs, characteristic of both the Adoogacho and Saunders members, have compositions which straddle the field boundary separating high-K andesite from high-K dacite in the K_2O-SiO_2 diagram. Saturated latite generally includes hornblende, biotite and a few augite phenocrysts in the mode (Williams, Turner and Gilbert, 1954), whereas dacite of the high-K 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 (Table 3) is similar to average latite (Table 5, 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 5, 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). Silicon dioxide is greater, TiO_2 is equal and K_2O is significantly less than average dacite compositions (Table 5, 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.

Figure 8. 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. calc-alkaline series, III. high-K calc-alkaline 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 percent oxide values.

▲ Saunders member: ash-flow tuffs
* Attycelley member: ash tuff
■ Metsantan member: lava flows
● Adoogacho member: ash-flow tuff

Figure 9. 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 percent oxide values.


Banakite
IV
Dacite
III
Andesite
II
K2O
SiO2
0
1
2
3
4
5
47
51
55
59
63
67
71
75

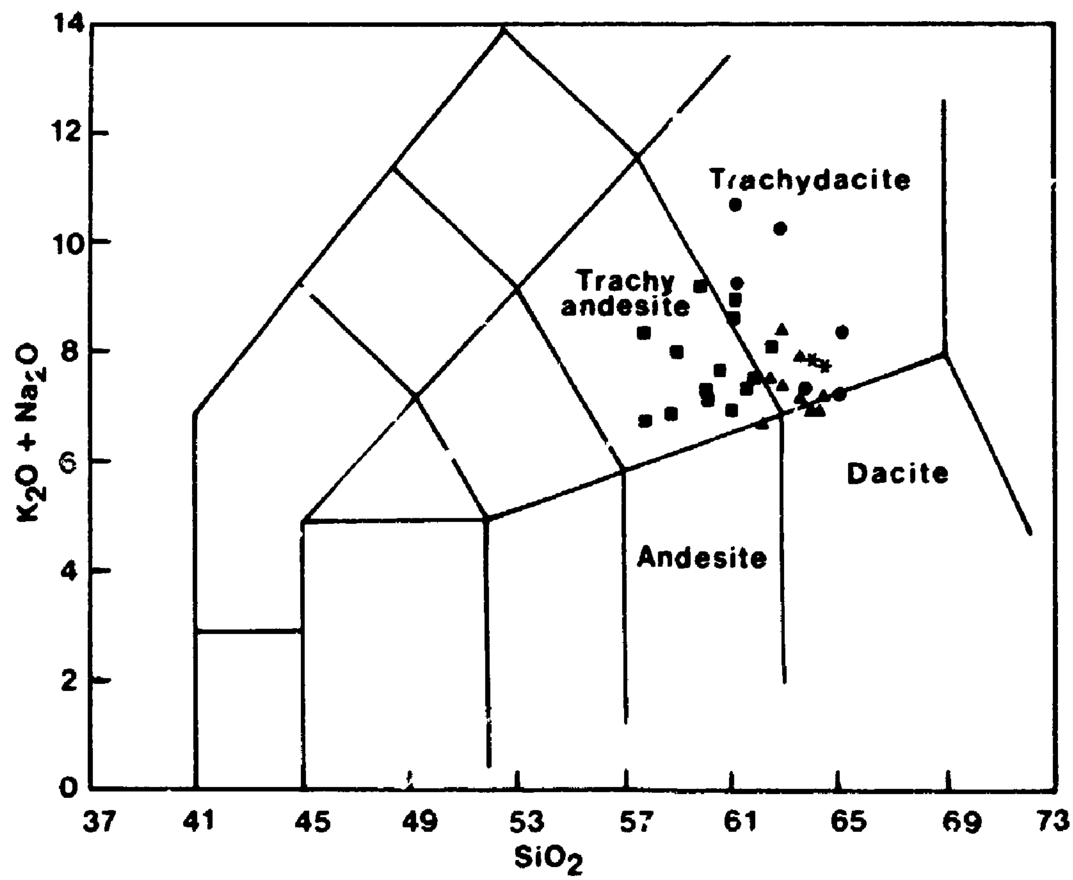

Trachydacite
Trachy andesite
Dacite
Andesite
K2O + Na2O
SiO2
0
2
4
6
8
10
12
14
37
41
45
49
53
57
61
65
69
73

Table 5. Published average compositions of selected volcanic rocks.

	Shoshonite 1	Andesite 2	Andesite 3	Andesite 4	Banakite 5	Trachy-Andesite 6	Latite 7	Latite 8	Latite (Qtz-Banakite) 9	Dacite 10	Dacite 11	Trachyte 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	1.19	0.81		0.64	0.58	0.70
Al_2O_3	16-20	17.3	17.02	17.2	16.5-16.5	16.70	17.22	16.01	15.5-20	16.67	15.91	16.96
Fe_2O_3	7-[illegible]	3.1	3.27	3.1	[illegible]*	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

The variation of total alkalis in the Adoogacho member is because of erratic Na_2O concentration as shown in the Na_2O-K_2O-CaO ternary diagram (Figure 10). No volcanic rocks in the Toodoggone Formation classify as trachytes on the TAS diagram; the analyzed samples have significantly less K_2O than average trachyte (Table 5, 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 TAS, ignoring the marginal increase in total alkalis and SiO_2 because of removing H_2O and CO_2 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 11). Analyses in the alkaline field reflect the slightly greater Na_2O content of the Adoogacho and Metsantan samples relative to those from the Saunders (Figure 10). On an AFM diagram the analysed samples plot on a trend nearly perpendicular to the FeO^*-MgO edge of the triangle (Figure 12). Their position within the AFM diagram indicates that they are well fractionated lavas in the calc-alkaline series. Miyashiro (1974) noted that calc-alkaline 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 calc-alkaline series. The position of analysed samples on variation diagrams of SiO_2, FeO^* and TiO_2 plotted against FeO^*/MgO (Figure 13) confirms a calc-alkaline 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%, for representative samples of the Toodoggone Formation.

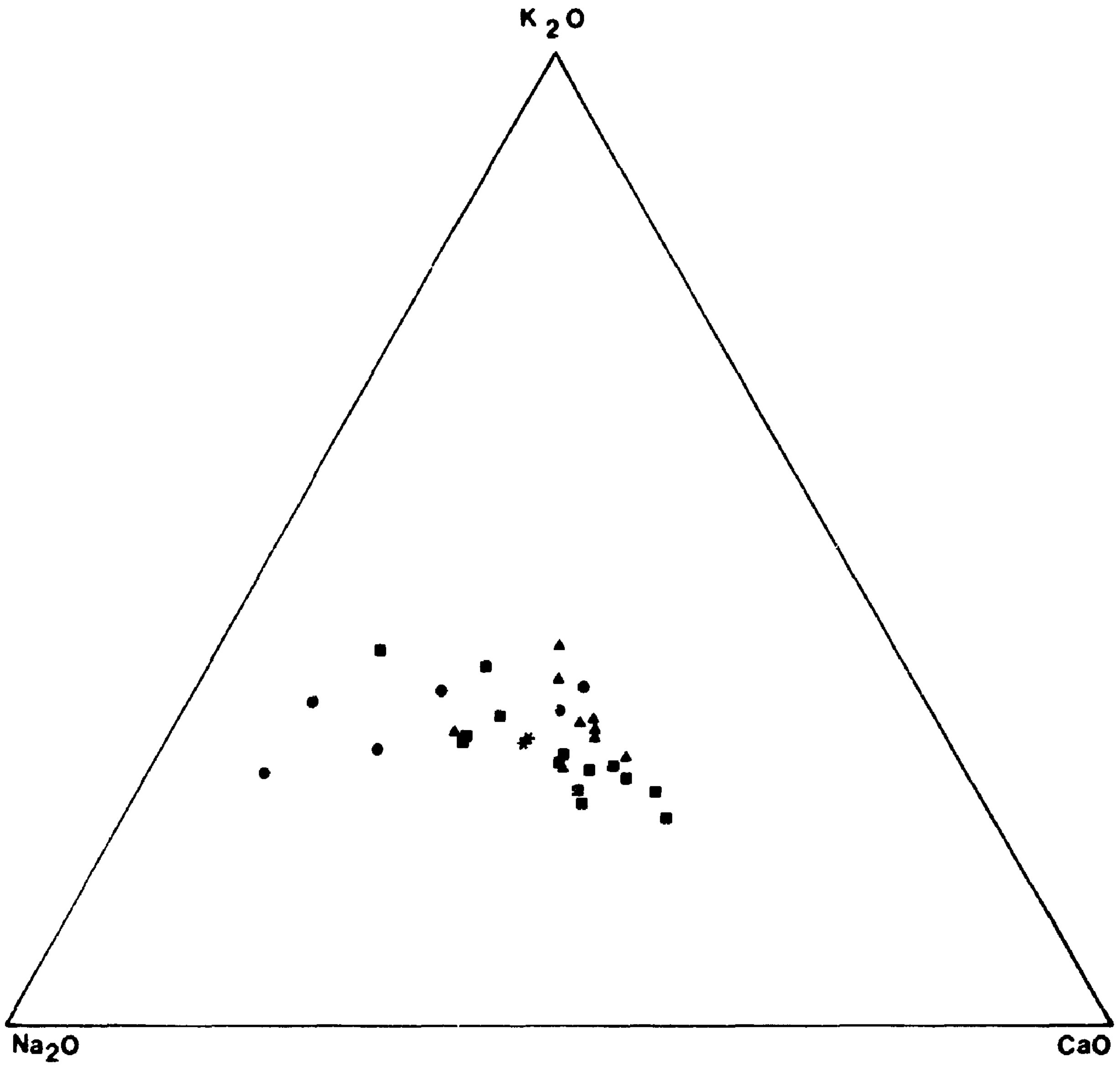


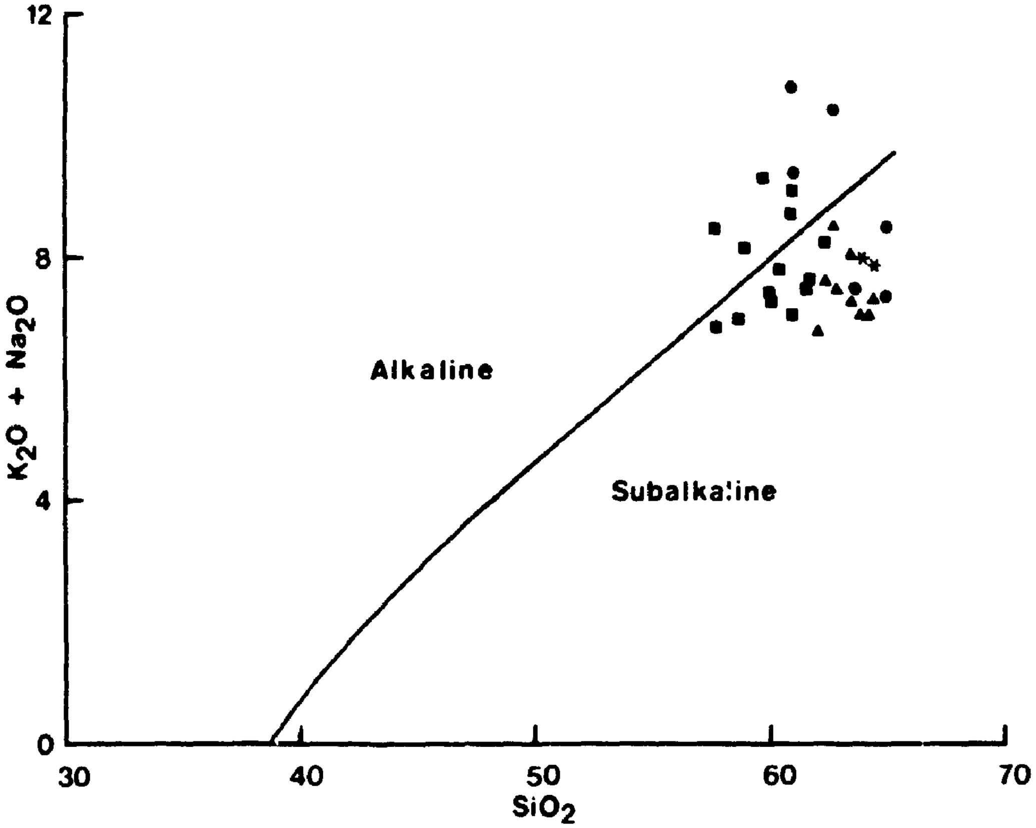
Figure 10. Na_2O-K_2O-CaO ternary diagram for volcan:c rocks of the Toodoggone Formation.

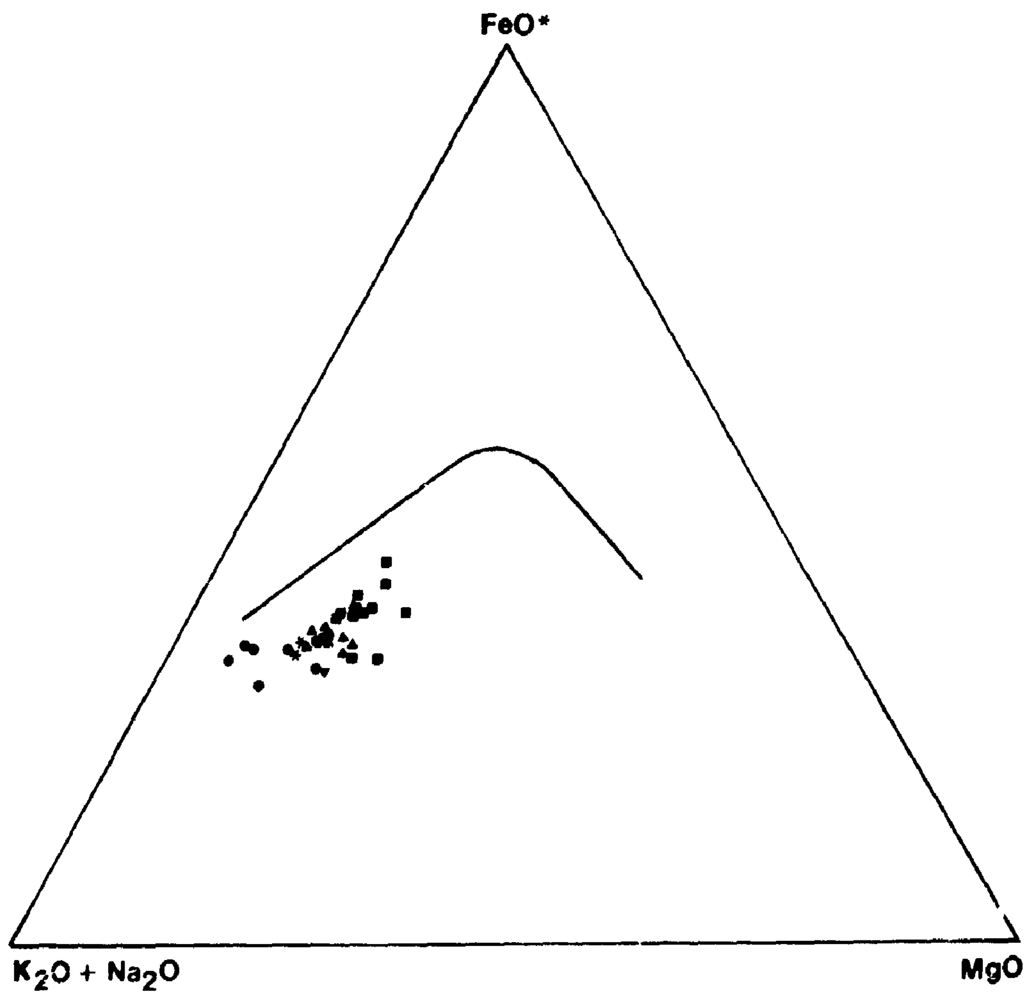
- ▲ Saunders member: ash-flow tuffs
- * Attycelley member: ash tuff
- ■ Metsantan member: lava flows
- ● Adoogacho member: ash-flow tuff

Figure 11. 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 percent oxide values.

- ▲ Saunders member: ash-flow tuffs
- * Attycelley member: ash tuff
- ■ Metsantan member: lava flows
- ● Adoogacho member: ash-flow tuff

Figure 12. $Na_2O + K_2O$ - $FeO + .8998Fe_2O_3$ - MgO (AFM) diagram for volcanic rocks of the Toodoggone Formation. Curved line separates tholeiitic series from calc-alkaline series compositions.


12
8
4
0
$K_2O + Na_2O$
Alkaline
Subalka:ine
30
40
50
60
70
SiO_2


FeO*
$K_2O + Na_2O$
MgO

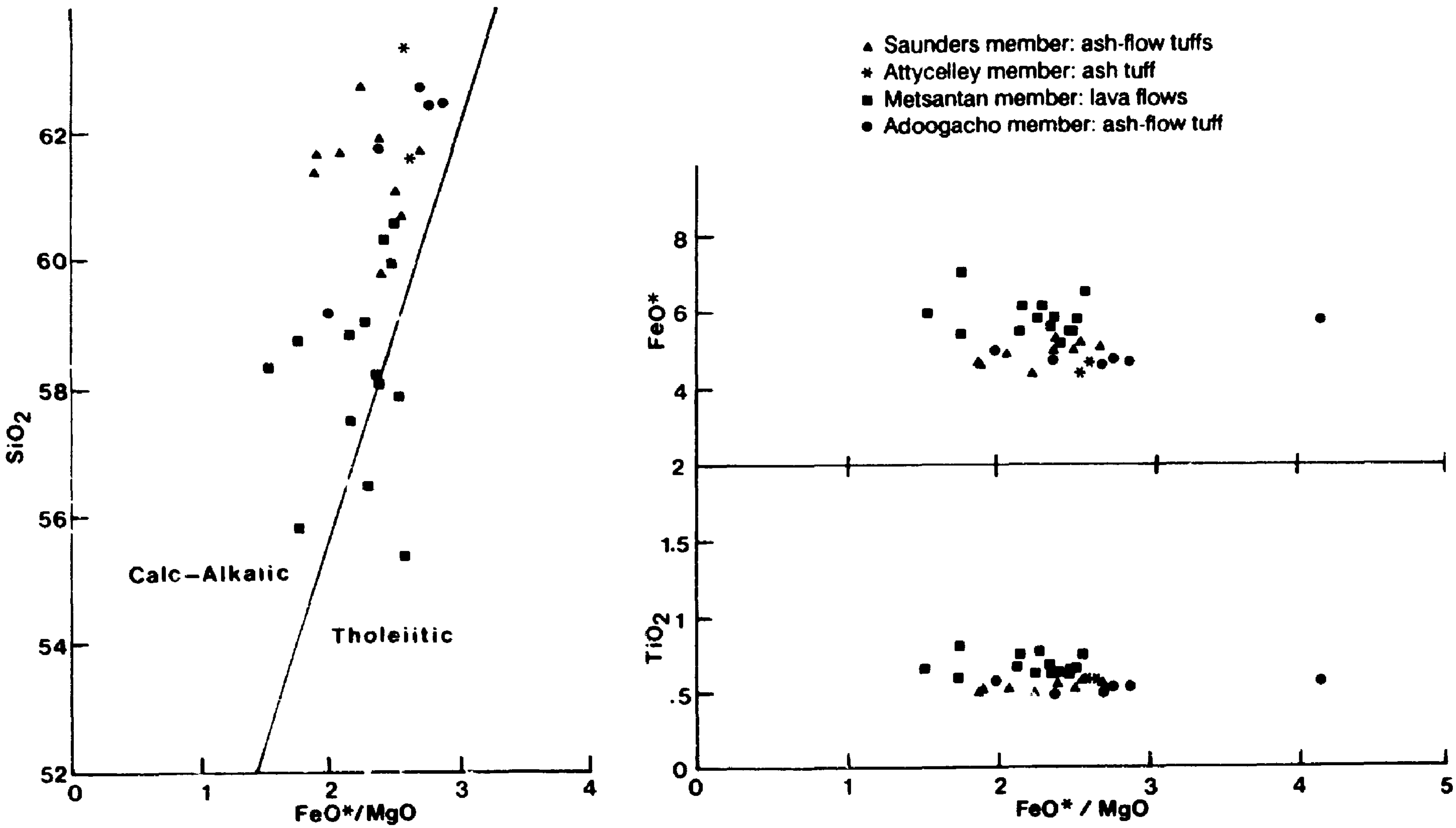


Figure 13. Variations in SiO_2, FeO^* and TiO_2 concentrations with increasing FeO^*/MgO for volcanic rocks of the Toodoggone Formation. Solid line separates tholeiitic series from calc-alkaline series volcanic rocks (Miyashiro, 1974). Data points represent oxide values as determined in Appendix A.

3.6 Potassium-Argon Age Determinations

The chronology of lithostratigraphic members in the Toodoggone Formation is based on nine potassium-argon age determinations corroborated by geological field relationships (Figure 14, Table 6; sample locations are in Map 2). Six numeric 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 ages are reported by Carter (1972) and Gabrielse and coworkers (1980).

Ages determined for biotite and hornblende from the Toodoggone Formation range from 204 to 182 Ma. A continuous progression of six 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 ages ranging from 189 to 182 Ma.

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). 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 Dedeeya Creek is 202±7 Ma. Metsantan member lava flows have ages from biotite of 200±7 and 197±7 Ma. The apparently older age 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 dykes and

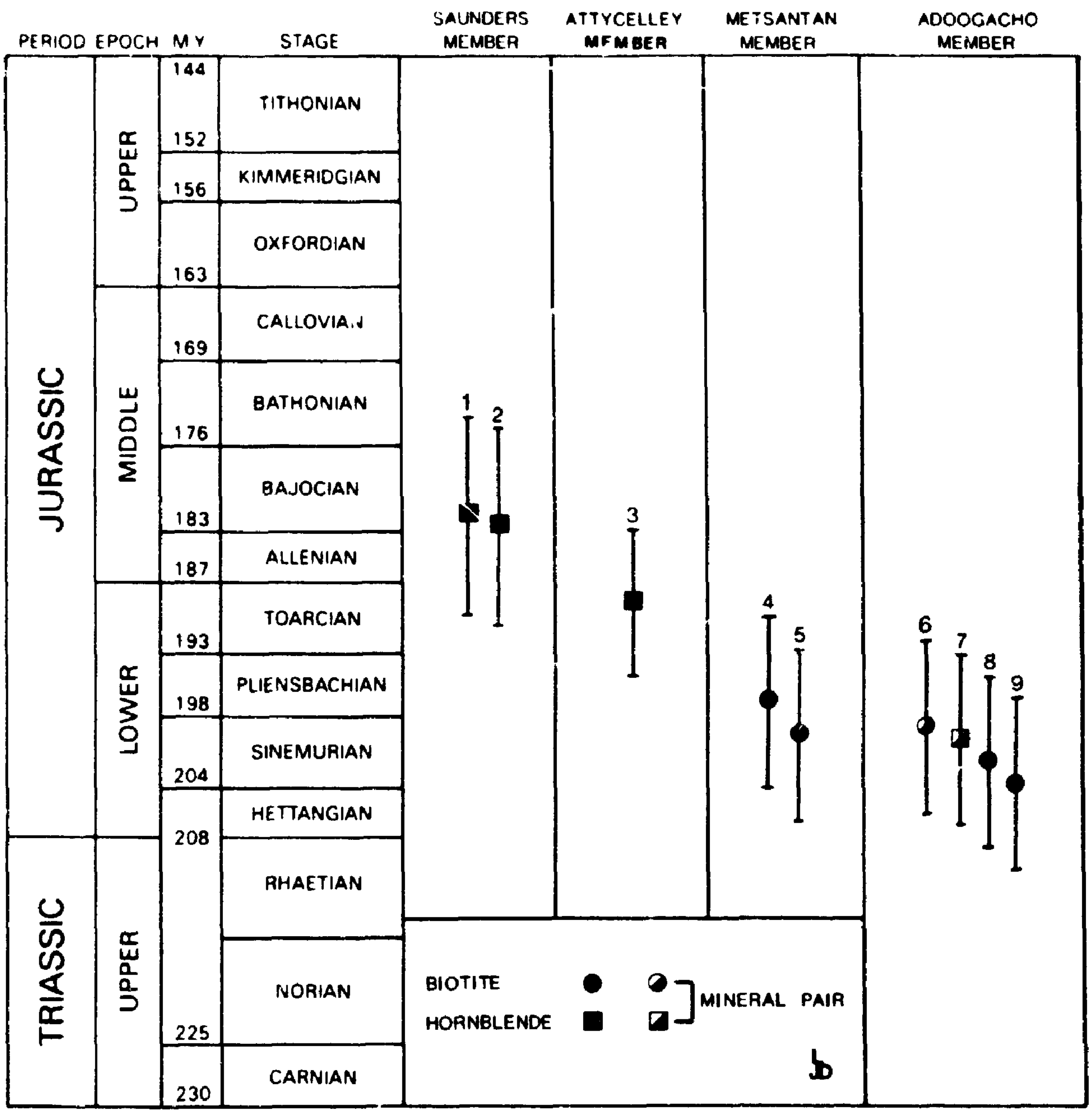


Figure 14. Potassium-argon age determinations from biotite and hornblende in volcanic rocks of the Toodoggone Formation. Numerals correspond with analytical data in Table 6. Stage boundaries are after the Geological Society of America Time Scale (Palmer, 1983). The Triassic-Jurassic boundary in British Columbia follows the time scale calibration of Armstrong (1982).

Table 6. Potassium-argon analytical data for volcanic rocks of the Toodoggone Formation.

Sample No.[1]	UTM-Zone 9 Easting	UTM-Zone 9 Northing	Mineral Analyzed	%K	^{40}Ar rad. 10^{-6}cc/gm	% ^{40}Ar rad. / ^{40}Ar total	Apparent[2,3] Age (Ma)	Reference
1. GSC76-24	619675	6349402	Hornblende	0.787	5.858	56.9	182 ± 8	Wanless et al., 1979
2. GSC76-77	638466	6335085	Hornblende	0.864	6.466	75.5	183 ± 8	Wanless et al., 1978
3. NC71-1	638770	6334184	Hornblende	0.873	6.763	91.3	189 ± 6	Carter, 1972
4. LD83-268-3A	589624	6376829	Biotite	5.57	45.022	95.6	197 ± 7	Diakow, 1985a
5. LD83-292-1	599863	6366315	Biotite	6.19	51.005	93.6	200 ± 7	"
6. LD83-266-5	587407	6378263	Biotite	6.34	51.738	94.4	199 ± 7	"
7. LD83-266.5	587407	6378263	Hornblende	0.806	6.645	65.7	200 ± 7	"
8. LD83-274-4	599360	6379139	Biotite	6.83	56.768	96.6	202 ± 7	"
9. AP81-T28	642843	6330177	Biotite	6.87	57.69	97.5	204 ± 7	Panteleyev, 1983

[1] Sample numbers with prefix "AP, LD, NC" analyzed for K at the Analytical Laboratory, Ministry of Energy, Mines and Petroleum Resources in Victoria, Ar analyzed at the Geochronology Laboratory, Department of Geological Sciences, University of British Columbia; "GSC" analyzed at the Geological Survey of Canada Laboratory in Ottawa.

[2] Constants used: $\lambda^{40}K_{\epsilon} = 0.581 \times 10^{-10} yr^{-1}$; $\lambda^{40}K_{\beta} = 4.962 \times 10^{-10} yr^{-1}$; $^{40}K/K = 1.167 \times 10^{-4}$ (Steiger and Jager, 1977).

[3] All errors shown are one standard deviation except for sample prefix "GSC" which are two standard deviations.

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 post-depositional 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 upper contact of a thick succession of recessive pyroclastic rocks that are overlain by ash-flow tuff of the Saunders member. Additional K-Ar age determinations of compositionally similar volcanic rocks that rest unconformably on strata of the Takla Group near Jock Creek are presently in progress as part of a MSc. thesis undertaken by H. Marsden at Carleton University, Ottawa. 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 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.

The apparent time which separates deposits of uppermost lower cycle (197 Ma) and lowermost upper cycle (189 Ma) volcanic rocks is within the error limits of the K-Ar method; therefore, this hiatus may not necessarily signify long-lived pause in volcanism between eruptive cycles. Except for an erosional remanent of sedimentary rocks with ammonites of Middle to Late Toarcian age which are spatially associated with probable Sinemurian ash-flows of the Adoogacho member near Adoogacho Creek, a regional unconformity that apparently separates the eruptive cycles is not recognized in the field.

3.7 Relationship of Toodoggone Formation and Hazelton Group in Toodoggone River Map Area

Gabrielse et al. (1977) originally mapped Hazelton Group strata east of the present study area. Hazelton Group rocks mapped in greater detail for this report are within a 15 kilometre square area south of Toodoggone Lake between Mt. Graves and The Pillar (Figure 4). The stratigraphy within this small area, described in Chapter 2, contains volcanic rocks that resemble strata of the Toodoggone Formation.

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 to 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 Mt. Graves (Forster, 1984) have little variation in major element abundances in comparison to latite flows of the Metsantan member. A major compositional difference is volcanic conglomerate and associated finer grained epiclastic beds, lapilli-block tuff and breccia are significantly more abundant in the Mt. 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 Mt. Graves area; but are absent, with the exception of relatively few dykes and sills cutting strata of the Toodoggone Formation.

The rocks in the Mt. Graves area likely represent an eastward extension of the Toodoggone Formation and more specifically the Metsantan member. Variations in rock type between the Mt. 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 models:

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

The first explanation is favoured because a complex fault apparently delimits an elongate granodiorite pluton that underlies the area between Mt. Graves and Saunders Creek. Movement along this structure is unknown, although it is presumed small, because similar rock sequences are traceable laterally between areas.

3.8 Regional Correlation

The Sinemurian to Bajocian Toodoggone Formation (K-Ar 204-182 Ma) is broadly correlated, mainly on the basis of age and regional contact relationships, with the Hazelton Group, Spatsizi Group and the informally named Cold Fish volcanics (Figure 15). These volcanic and sedimentary successions are widely distributed adjacent to the east to north margin of the Bowser and Sustut basins (Figure 16).

In the Smithers (93L), Hazelton (93M) and McConnell Creek (94D) map sheets Tipper and Richards (1976) divided the Hazelton Group into three formations; the Telkwa, the Nilkitkwa and the Smithers. Their respective ages, constrained by fossil fauna, are: Upper Sinemurian to lowest Pleinsbachian, Lower Pleinsbachian to Middle Toarcian, and Middle Toarcian to Lower Callovian. In the McConnell Creek map area, near Dewar Peak, about 30 kilometres south of the southernmost exposure of Toodoggone Formation strata, the Telkwa Formation is further divided into two dominantly non-marine facies; an eastern Sikanni facies and a western Bear Lake facies. The Sikanni facies is well-bedded epiclastic and pyroclastic rocks.

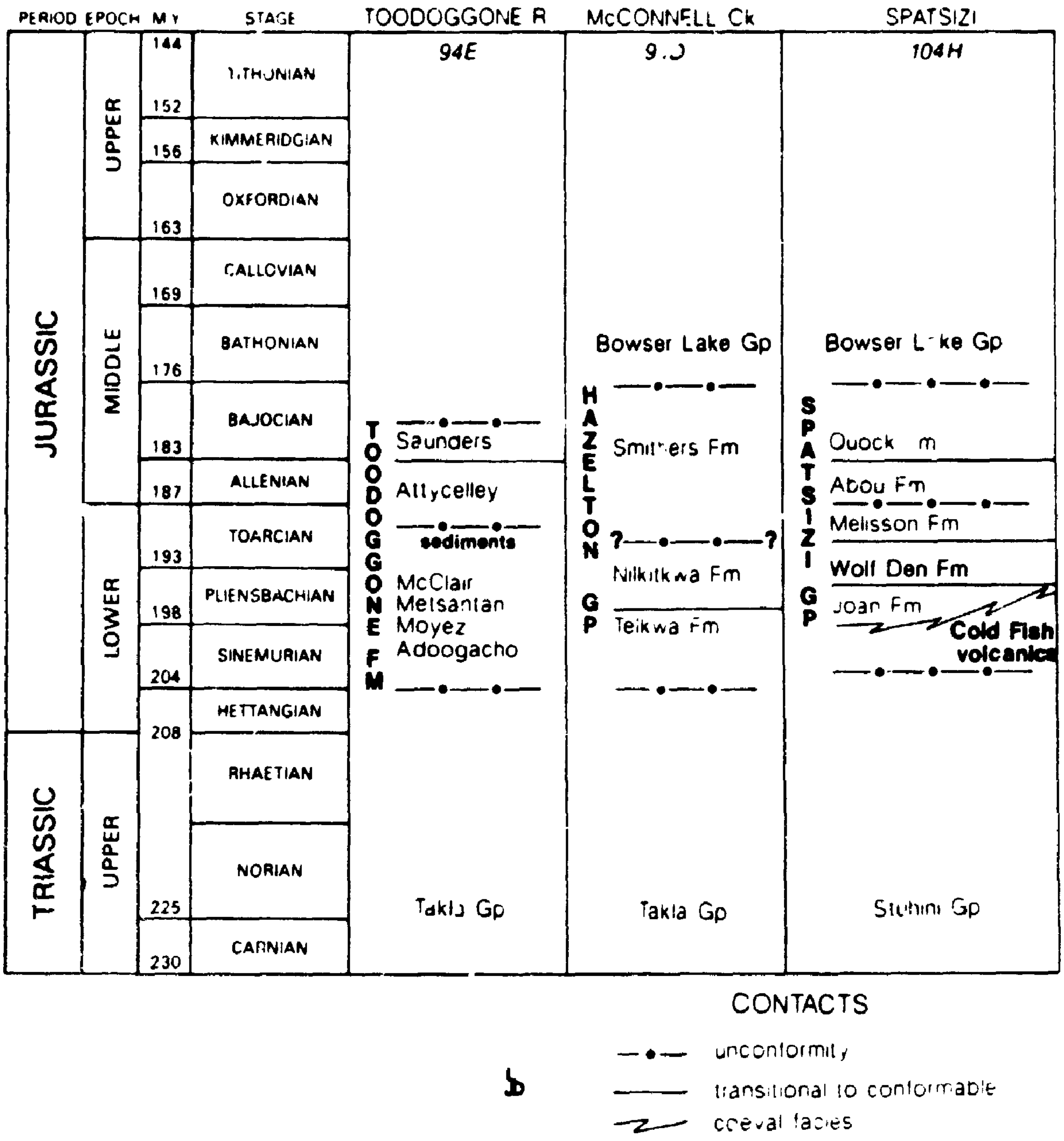


Figure 15. Regional correlation of Lower and Middle Jurassic rocks. The geographic locations of map areas are in Figure 16.

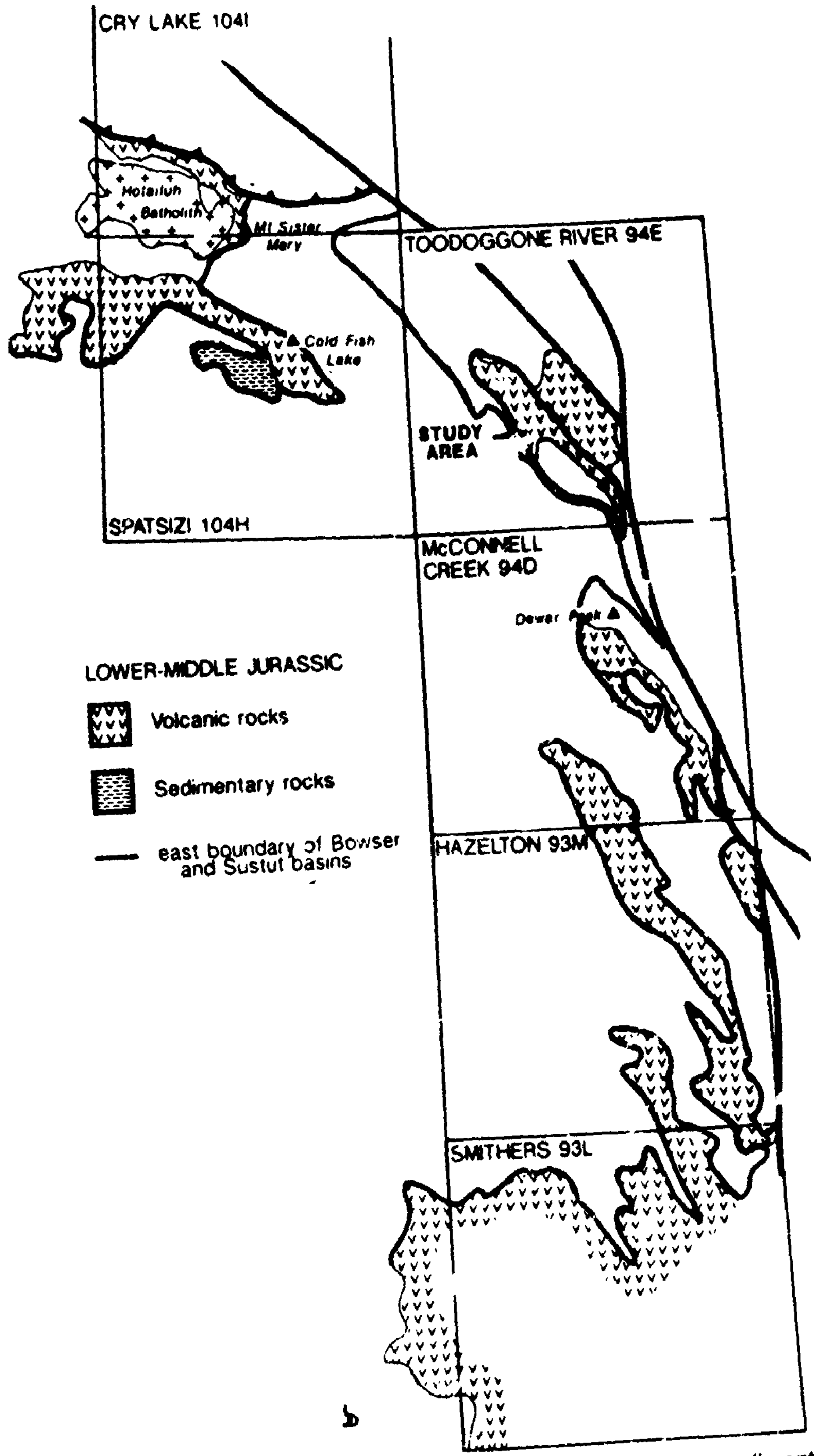


Figure 16. Di .bution of Lower and Middle Jurassic volcanic and sedimentary rocks adjacent to the east margin of the Bowser and Sustut basins, north-central British Columbia.

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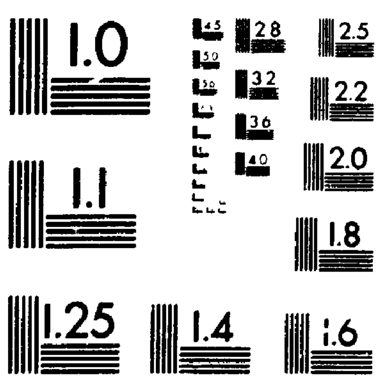


A distinctive polymictic conglomerate, which contains chert, limestone and granitic clasts derived from uplifted pre-Jurassic successions, is the base of the Sikanni facies and subsequently has been interpreted to represent an episode of regional uplift and erosion that marks initial deposits of the Hazelton Group (Tipper and Richards, 1976; Monger, 1977a). These rocks clearly occupy channels cut into the Lower Norian Moosevale Formation of the Takla Group near Dewar Peak (Monger and Church, 1977); a tentative Sinemurian age is suspected based on fossils in similar strata in Carrall Range, east of Takla Lake (Tipper and Richards, 1976; p.18). The overlying Bear facies is mainly reddish-brown tuffs and breccia, although ash-flow tuff and lava flows are also common. The volcanic rocks generally contain amphibole and subordinate augite. Phenocrysts of quartz are scarse in andesite, dacite and rhyolitic rocks in the area. Published chemical analyses of volcanic rocks from the Bear facies (Church, 1976; Tipper and Richards, 1976; Monger, 1977a) have a scattered pattern straddling the line between alkaline and subalkaline fields of Irving and Baragar (1971) on an alkali versus silica diagram. On an AFM diagram the analyses have a typical calc-alkaline trend for compositions listed in order of relative abundance: andesite, basalt and rhyolite.

Southwest of Dewar Peak, rocks of the Bear facies pass stratigraphically upward into marine tuffaceous siltstone and shale containing Lower to Upper Pleinsbachian fauna of the Nilkitkwa Formation; the contact is conformable. In turn, Lower Toarcian beds of the Nilkitkwa Formation locally are overlain by a conformable sequence of immature clastic rocks of the Smithers Formation. The westernmost exposure of Hazelton Group rocks in McConnell Creek map area are succeeded by an Upper Bajocian and younger sequence of shale and siltstone of the Ashman Formation of the Bowser Lake Group.

Monger and Thorstad (1978), and Anderson (1983) describe strata compositionally similar to the Telkwa Formation around the Hotailuh batholith in

Cry Lake and adjoining Spatsizi map areas. The absolute age of these strata is uncertain, hence they are broadly defined as Triassic to Jurassic. The rocks are grey to maroon flows, subordinate ash-flow tuff and interlayered air-fall pyroclastic and epiclastic rocks. According to Anderson (1983), a succession of massive and vesicular, plagioclase porphyritic lava northeast of the Hotailuh batholith is characteristic of flows in this area. They have phenocrysts of plagioclase and pseudomorphs of amphibole and clinopyroxene; some flows contain alkali feldspar, quartz and apatite phenocrysts. Four of ten analyzed samples from this succession are alkaline basaltic trachyandesite and trachyandesite which are sodic rather than potassic. The remaining, subalkaline samples are basaltic andesite, andesite and trachyte. On a FeO^*/MgO versus silica diagram the suite is clearly tholeiitic which contradicts the differentiated calc-alkaline trend indicated by the AFM diagram.

In north-central Spatsizi map area a dominantly volcanic succession with interspersed sediments containing Lower Pleinsbachian to Toarcian fossils (Smith et al., 1984) crop out between Spatsizi River and the confluence of Klappan and Stikine rivers (Gabrielse and Tipper, 1984); these strata have been given the informal name Cold Fish volcanics (Thomson et al., 1986). Erdman (1978) examined this succession within a small area about 13 kilometres west of the north end of Cold Fish Lake and obtained a Rb-Sr whole rock isochron age of 189 ± 13 Ma from flows of porphyritic andesite and rhyolite.

Evenchick (1986) and Thorkelson (1988) describe the Cold Fish volcanics, in the vicinity of Erdman's Rb-Sr age site, as a succession of mafic and felsic lava flows, tuff and ash-flow tuff interlayered with epiclastic and chemical sedimentary beds deposited in subaerial and shallow marine settings. The volcanic rocks are a bimodal basalt to rhyolite suite. The basalt commonly has amygdaloidal to porphyritic texture and contain tabular plagioclase megacrysts and serpentine pseudomorphous after olivine. The later feature has not been reported in Lower

Jurassic basaltic flows in adjoining areas, although they are common in basalts of the Upper Triassic Takla Group. The lava flows generally classify as alkaline basalt transitional to thoeiitic basalt and tholeiitic rhyolite (Thorkelson, 1988). Intermediate compositions include alkaline trachyandesite to trachyte, but these are volumetrically subordinate to the mafic and felsic rocks.

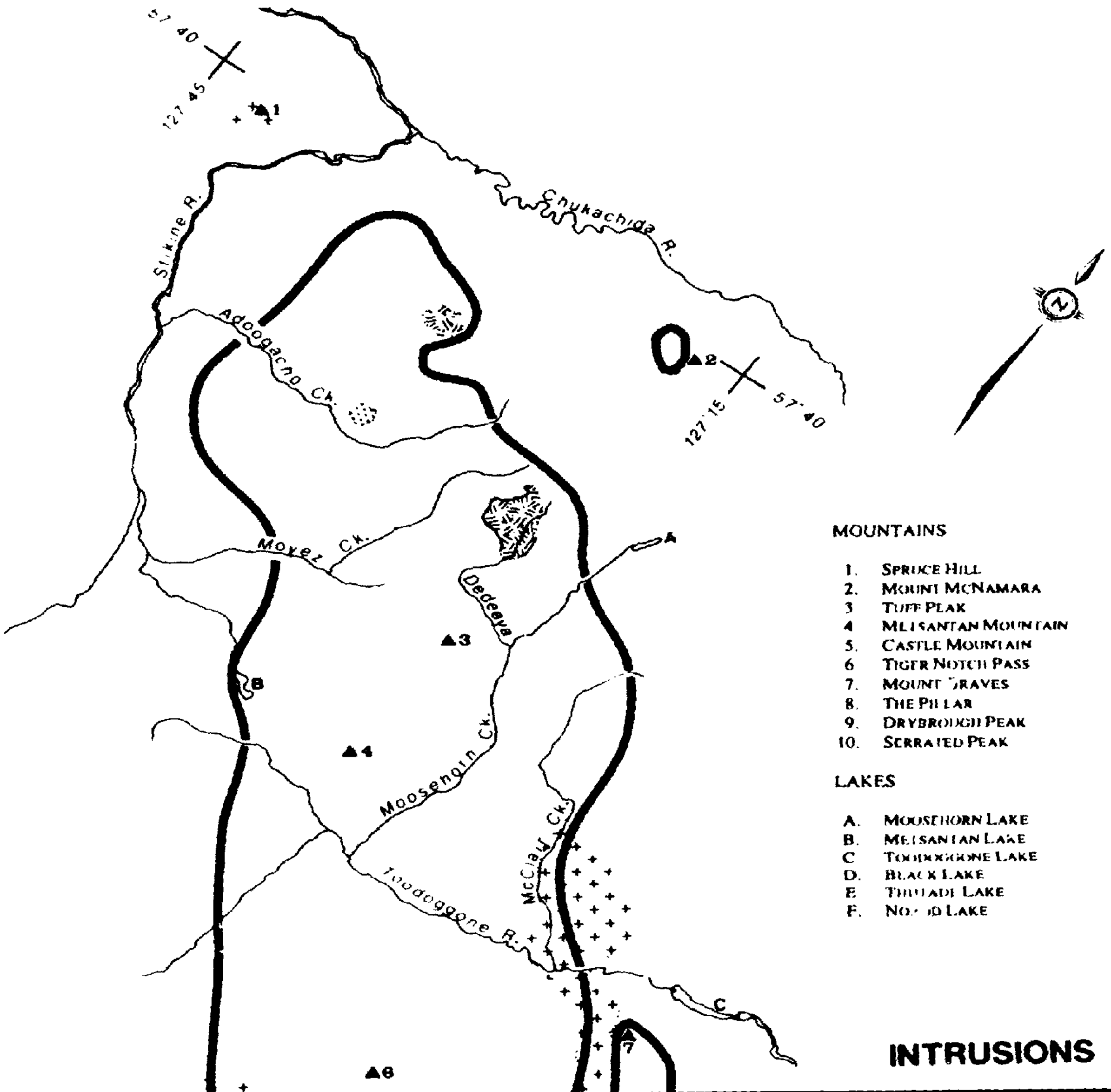
The Cold Fish volcanic-sedimentary sequence passes southwestward above an erosional contact into a dominantly sedimentary succession which is subdivided into formations, that are formally defined as the Spatsizi Group (Thomson, 1985; Thomson et al., 1986). The Spatsizi Group is interlayered fine clastic sediments, tuffaceous shale, conglomerate, and local limestone which contain Lower Pleinsbachian to Lower Bajocian fossils (Smith et al., 1984). Rocks of the Spatsizi Group extend northward into Cry Lake map area, where Toarcian shallow marine sedimentary facies onlap sections of the Hotailuh batholith (Anderson, 1983). East of the batholith and McBride River, marine and non-marine sedimentary rocks are associated with mainly rhyolitic tuffs, flows and breccias that have yielded collections of Lower Toarcian to Middle Bajocian fauna (Tipper, 1978). A Rb-Sr whole rock isochron age of 191±9 Ma is derived from porphyritic andesite and rhyolite flows in an epiclastic-volcanic sequence about 10 kilometres northeast of Mt. Sister Mary (Erdman, 1978).

The erosional unconformity that apparently marks the base of Lower Jurassic volcanic and sedimentary rocks along parts of the north and east margin of the Bowser Basin is broadly marked by local deposits of conglomerate. These conglomerates have similar pre-Jurassic clast compositions and they form interbeds or are in contact with volcanic strata of uncertain Late Triassic or Early Jurassic age. For example, polymictic conglomerate near Spatsizi River contains chert and limestone clasts with Permian and Norian microfauna (H. Gabrielse, personal communication, 1988), and granitic clasts. The conglomerate is locally overlain by augite porphyry flows that resemble those of the Stuhini-Takla Groups (Thorkelson, 1988). These conglomerates likely correlate with those that occupy the base of the Sikanni facies of the Telkwa Formation in McConnell Creek map area, although the stratigraphic position of conglomeratic deposits relative to the assumed top of the Late Triassic succession apparently differ between areas (Thorkelson, 1988; Monger and Church, 1977).

The superb faunal assemblages in sedimentary rocks of the Spatsizi Group supports correlation with coeval sedimentary deposits of Nilkitkwa and Smithers formations in McConnell Creek area. Thompson et al. (1986) interpret the depositional history of the Spatsizi Group in terms of transgressive-regressive cycles, during which sediments accumulated within a sedimentary basin that probably occupied a large part of the present Bowser Basin. The Spatsizi basin shallowed northward, indicated by shallower marine facies which interfinger or are replaced by dominantly volcanic facies that crop out extensively along the southern flank of the Stikine Arch.

3.9 Intrusive Rocks

Volcanic strata of the Toodoggone Formation are spatially associated with stocks and subvolcanic porphyritic plutons, and cut by a variety of dykes. The largest and most significant plutons are barely unroofed stocks that have low relief in the west and central study area (Figure 17). In contrast, craggy mountains expose their uplifted and more deeply eroded counterparts near Mount Cushing and Geigerich Peak, to the northeast and southeast of the study area. These granitiods are the northern extent of the Omineca intrusions, informally named by Armstrong (1949) in Fort St. James map area. They are part of an extensive, arcuate belt of Late Triassic and Early Jurassic granodiorite, quartz monzonite to quartz diorite stocks and batholiths that are exposed intermittantly east of the Bowser Basin then swing westward to occupy the cores of the Stikine and Skeena arches (Figure 18).


57 40
127 45
Stikine R.
Chukachida R.
Adoogacho Ck.
Moyez Ck.
Dedeeya
Moosehorn Ck.
McClair Ck.
Toodoggone R.
127 15
57 40
N
MOUNTAINS
1. Spruce Hill
2. Mount McNamara
3 Tuff Peak
4 Metsantan Mountain
5. Castle Mountain
6 Tiger Notch Pass
7. Mount _raves
8. The Pillar
9. Drybrough Peak
10. Serrated Peak
LAKES
A. Moosehorn Lake
B. Metsantan Lake
C Toodoggone Lake
D. Black Lake
E Thutade Lake
F. No__d Lake

INTRUSIONS

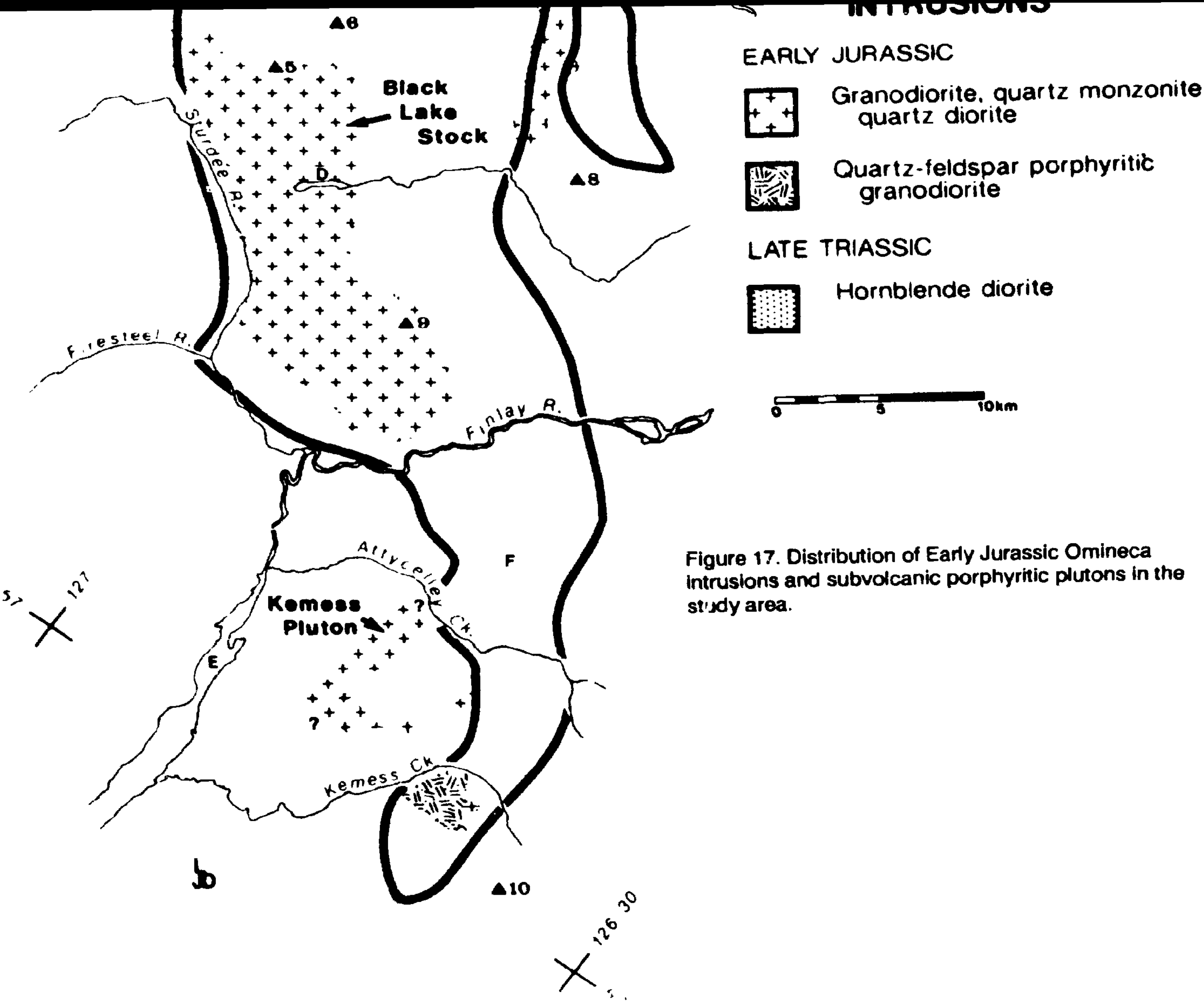


Figure 17. Distribution of Early Jurassic Omineca intrusions and subvolcanic porphyritic plutons in the study area.

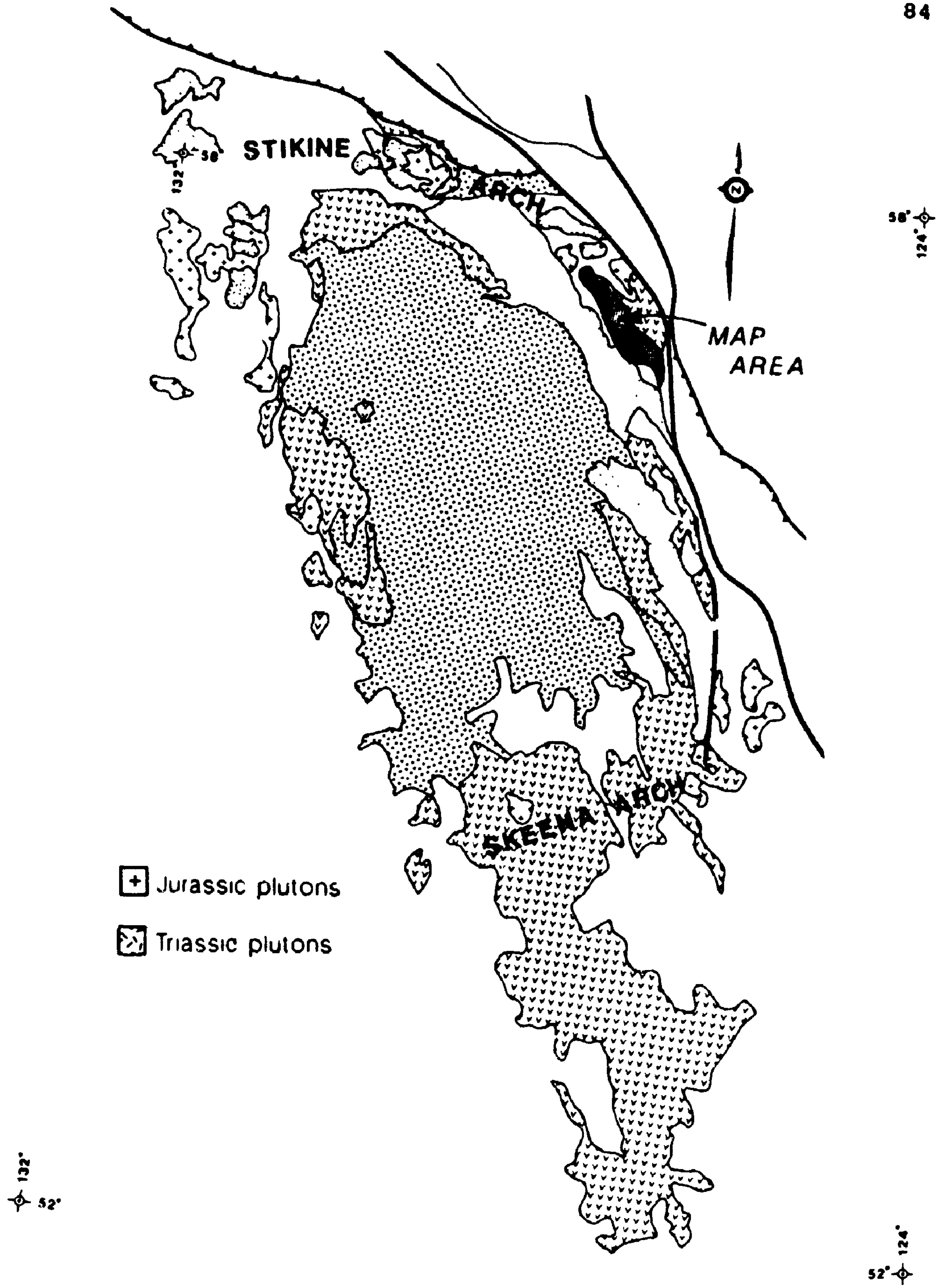


Figure 18. Distribution of Late Triassic and Early Jurassic plutons along the axes of the Stikine and Skeena arches.

Detailed studies of several of the larger intrusions; the Hotailuh batholith (Anderson, 1983), Stikine batholith (Anderson, 1984), and Hogem and Germansen batholiths (Meade, 1977; Garnett, 1978) confirm the spatial, temporal and genetic relationship of the intrusions and alkaline to calc-alkaline Upper Triassic and calc-alkaline Lower to Middle Jurassic volcanic successions.

Granitic stocks were not mapped in detail during this study. Consequently, detail pertaining to their physical character, intrapluton and interpluton relationships, composition and relationship to volcanic rocks of the Toodoggone Formation is meager.

3.9.1 Stocks

The Black Lake stock underlies 115 square kilometres centered on Black Lake. It is exposed from southeast of Castle Mountain to 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 Tooddoggone 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. 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 commonly are cut or associated with nearby pink porphyritic andesite dykes. Associated with the pluton near Kemess Creek is a porphyry Cu-Mo occurrence within a pendant of intense, 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.

3.9.1.1 **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 Cu-Mo occurrence (Cann and Godwin, 1980; Figure 19 and Table 7, sample locations are in 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 for the pluton. An age on whole rock of 182±6 Ma for intense 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 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 of 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.

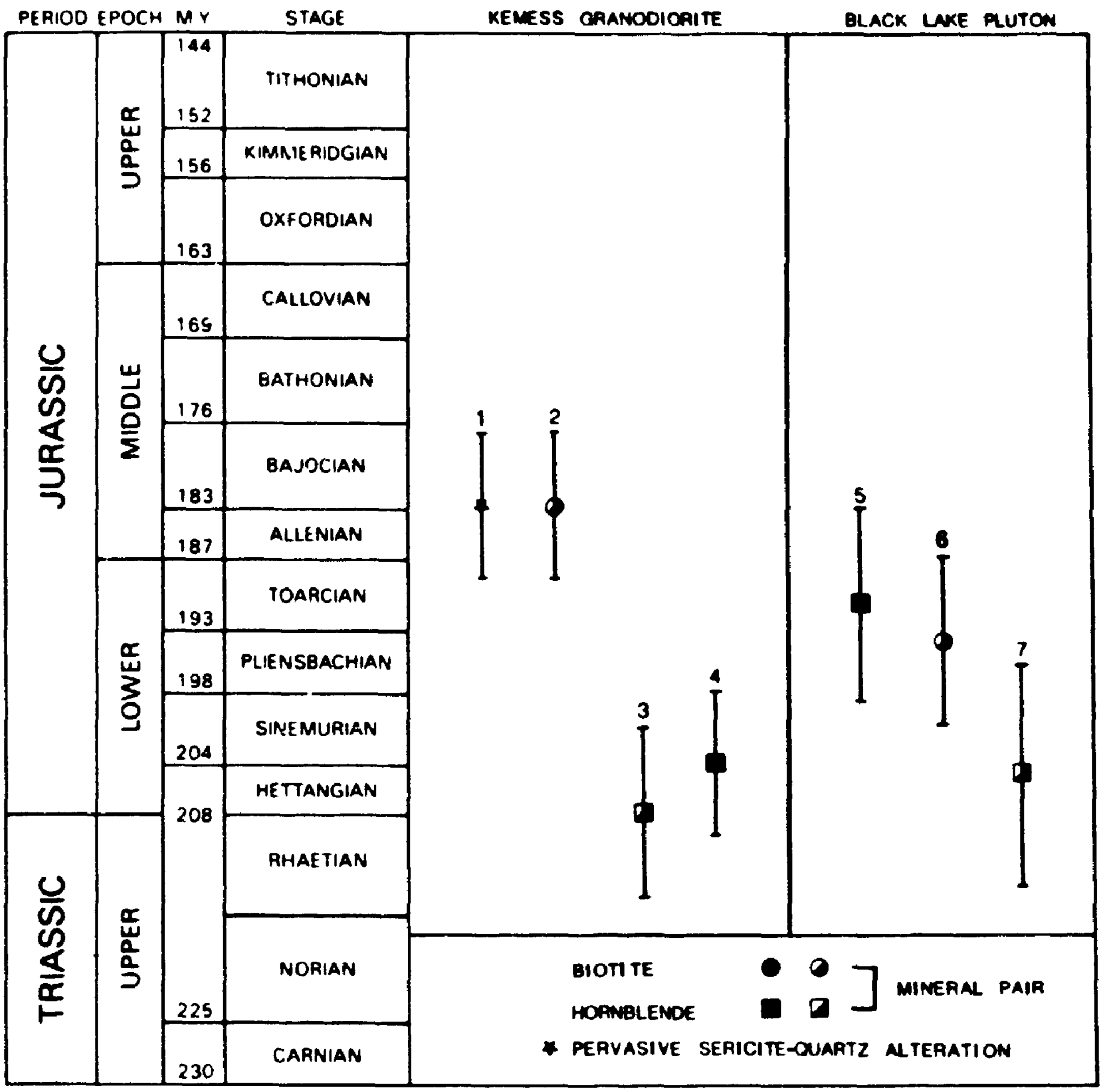


Figure 19. Published potassium-argon determinations on biotite and hornblende from Omineca intrusions in the study area. Numerals correspond with analytical data in Table 7. Stage boundaries are after the Geological Society of America Time Scale (Palmer, 1983). The Triassic-Jurassic boundary in British Columbis follows the time scale calibration of Armstrong (1982).

Table 7. Potassium-argon analytical data for Early Jurassic granodiorite and quartz monzonite intrusions in the study area.

Sample No.	UTM-Zone 9 Easting	UTM-Zone 9 Northing	Mineral Analyzed	%K	^{40}Ar rad. 10^{-6}cc/gm	%^{40}Ar rad. / ^{40}Ar total	Apparent[1,2] Age (Ma)	Reference
1. G76-CS7	636160	6326520	Whole Rock	1.27	9.438	38.8	182 $\pm$ 6	Cann and Godwin, 1980
2. G76-CS112	634960	6326500	Biotite	5.27	39.25	95.4	182 $\pm$ 6	"
3. G76-CS112	634960	6326500	Hornblende	0.439	3.759	77.3	207 $\pm$ 7	"
4. G76-CS113	635180	6324640	Hornblende	0.670	5.587	85.6	203 $\pm$ 6	"
5. GSC76-74	617780	6345948	Hornblende	0.447	3.486	76.8	190 $\pm$ 8	Wanless et al., 1978; Gabrielse et al., 1980
6. GSC76-75	618735	6337250	Biotite	6.40	50.679	94.6	193 $\pm$ 7	"
7. GSC76-76	618735	6337250	Hornblende	0.459	3.856	83.8	204 $\pm$ 9	"

1 Constants used: $\lambda^{40}K_{\epsilon} = 0.581 \times 10^{-10} yr^{-1}$; $\lambda^{40}K_{\beta} = 4.962 \times 10^{-10} yr^{-1}$; $^{40}K/K = 1.167 \times 10^{-4}$ (Steiger and Jager, 1977).

2 Errors are one standard deviation for sample numbers with prefix "G" and two standard deviations for sample numbers with prefix "GSC".

The different ages for hornblende and biotite may indicate crystallization cooling of the pluton below the closure temperatures for these minerals (Table I-3 in Parrish and Roddick, 1984).

3.9.2 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 Dedeeya creeks in the north, and immediately adjacent to Kemess Creek in the south. The circular pluton dissected by Dedeeya Creek is largest, encompassing roughly 5 square kilometres. Monolithic breccia, made up of poorly sorted blocks derived from the pluton, crop 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 ash-flows of the Adoogacho member ceased.

Phenocrysts are as much as 50 volume percent in these plutons.The dominant phenocryst is plagioclase. Remanents of amphibole and pyroxene, which make up 7 volume percent of the rock, are pseudomorphed by variable combinations of granular opaques, carbonate and chlorite. Resorbed and bipyramidal quartz is up to 2 volume percent and sanidine is rare. Carbonate, clay minerals and epidote of probable deuteric origin selectively replace plagioclase. Several percent pyrite is ubiquitous in the domes at Kemess and Adoogacho creeks. Xenoliths are throughout the rock and locally up to 10 percent by volume within the intrusion at Kemess Creek; most are basalts from the Takla Group and rare quartzite (A. Panteleyev, written communication, 1986).

3.9.3 **Dykes and Sills**

North and northwest trending dykes and few sills cut strata of the Toodoggone Formation. Although most dykes are widely spaced, solitary bodies, they form en echelon swarms in the general vicinity of the headwaters of McClair Creek to The Pillar. Individual dykes 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 dykes dominate, basalt is less common, and dacite to rhyolite dykes are rare.

3.9.3.1 **Andesite**

Andesite dykes 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 dykes cut broad areas of pervasively altered quartz-clay rocks at Silver Pond, at Alberts Hump and at the Kemess mineral prospect. Typically, the dykes 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; rarely, epidote is in altered adjacent host strata.

The dykes have a diagnostic pink to red color and a medium to coarse porphyritic texture which is imparted by plagioclase phenocrysts (Plates 9A,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 are absent, except for a single orthoclase megacryst in a plug near the headwater of McClair Creek.

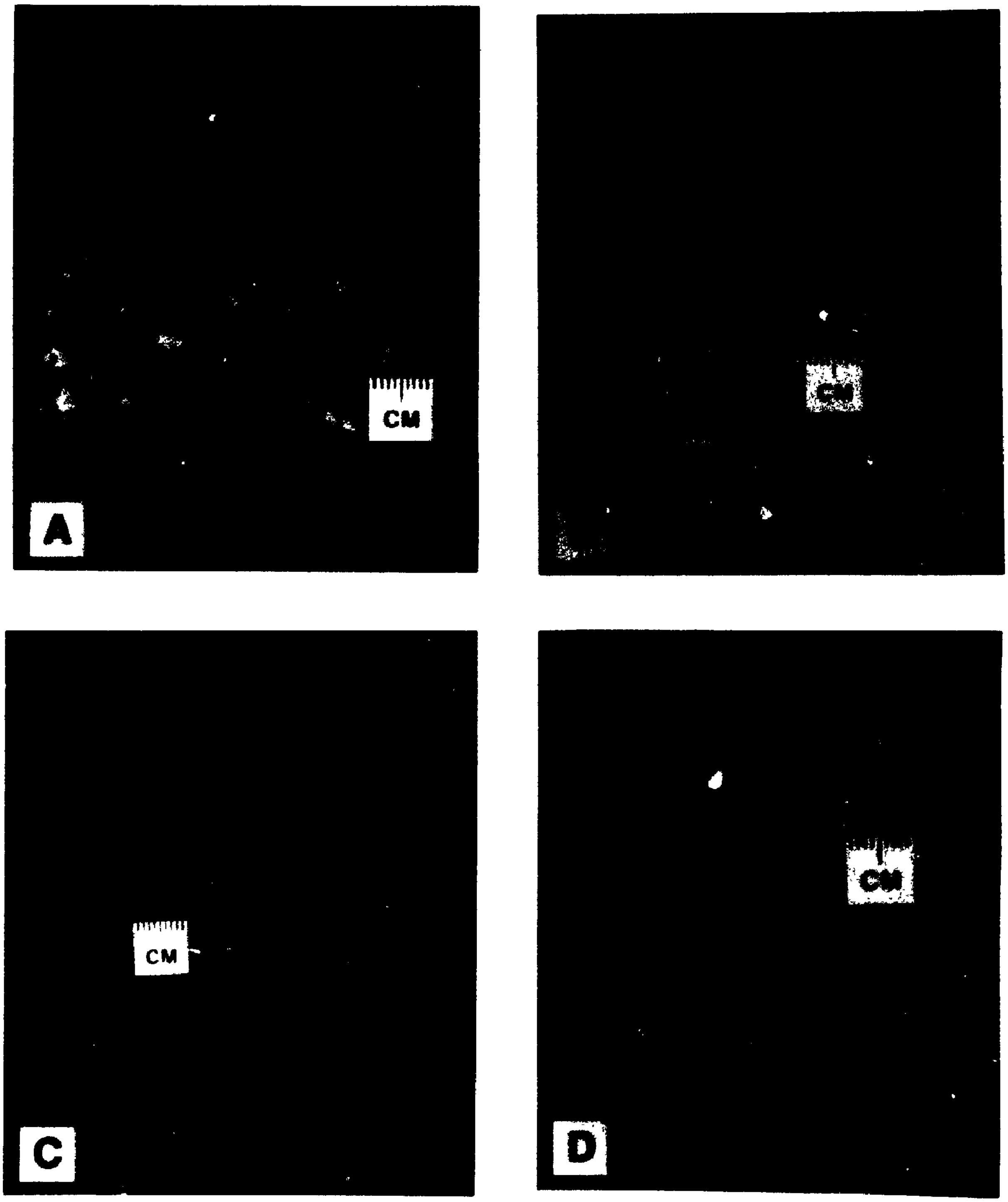
PLATE 9 - DYKES

A,B. Typical porphyritic andesite dykes with coarse, subhedral plagioclase and smaller mafic phenocrysts set within a pink to red colored matrix. Note the similar texture and phenocrysts with those in latite flows of the Metsantan member in Plate 5.

C. Basalt dyke with fine-grained, aphyric texture and vugs infilled with calcite.

D. Rare rhyolite dyke containing quartz and sanidine phenocrysts in an aphanitic flesh-pink colored matrix.

PLATE 9



3.9.3.2 **Basalt**

Basalt dykes crosscut andesite dykes 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 traversing the east-facing slope below the Lawyers AGB zone. Solitary dykes occur throughout the study area, although they are particularily widespread in the area east of Saunder Creek. Swarms of basalt dykes trend northwest between Mt. Graves and The Pillar. They always weather recessively and average about 1 metre wide, but locally can be 30 metres wide.

Basalt dykes typically have several percent amygdules in a fine-grained dark green groundmass (Plate 9C). In contrast the sills are porphyritic with augite phenocrysts or crowded felty plagioclase set within a purple or dark-colored matrix. Both the dykes 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 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 dykes are generally calcite and less commonly a mixture of the zeolites: thomsonite, analcime, natrolite and minor heulandite.

3.9.3.3 **Dacite and Rhyolite**

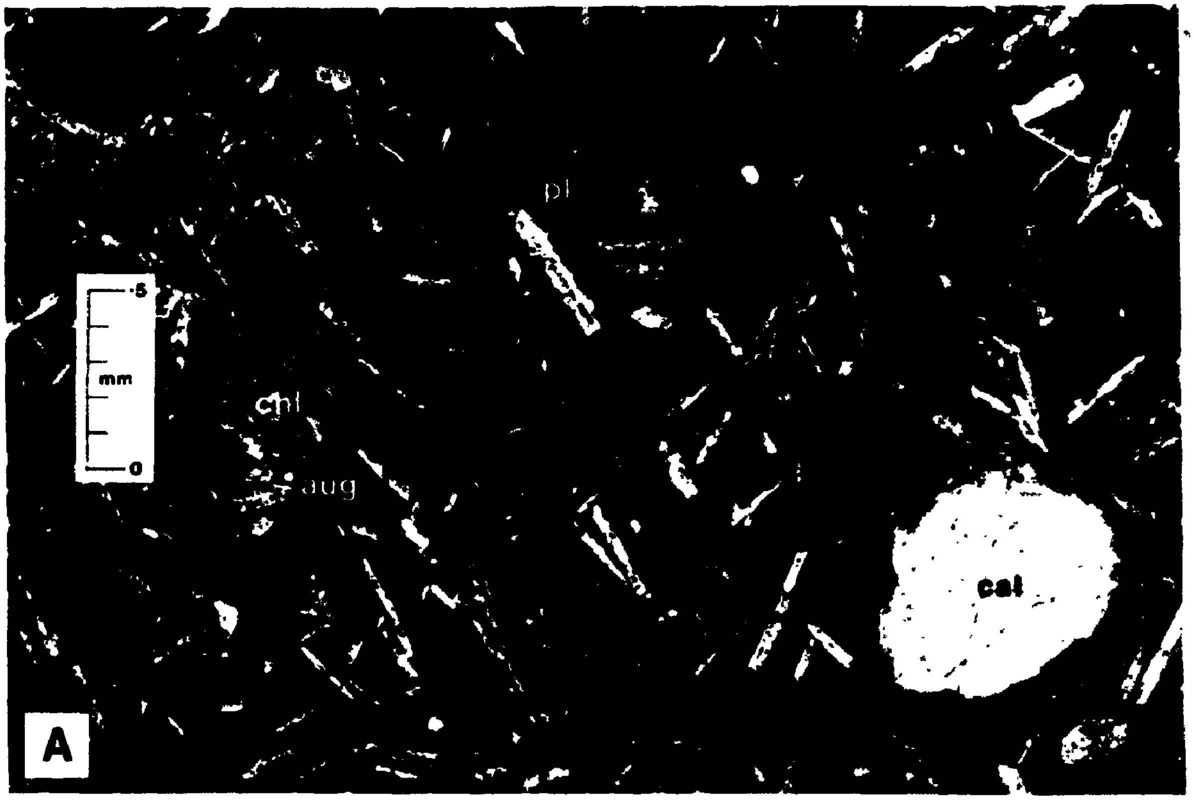
West-northwest trending dacite dykes cut the Saunders member west of the Baker minesite and Saunders Creek. These dykes contain sanidine and readily discernible quartz phenocrysts; features which distinguish them from texturally

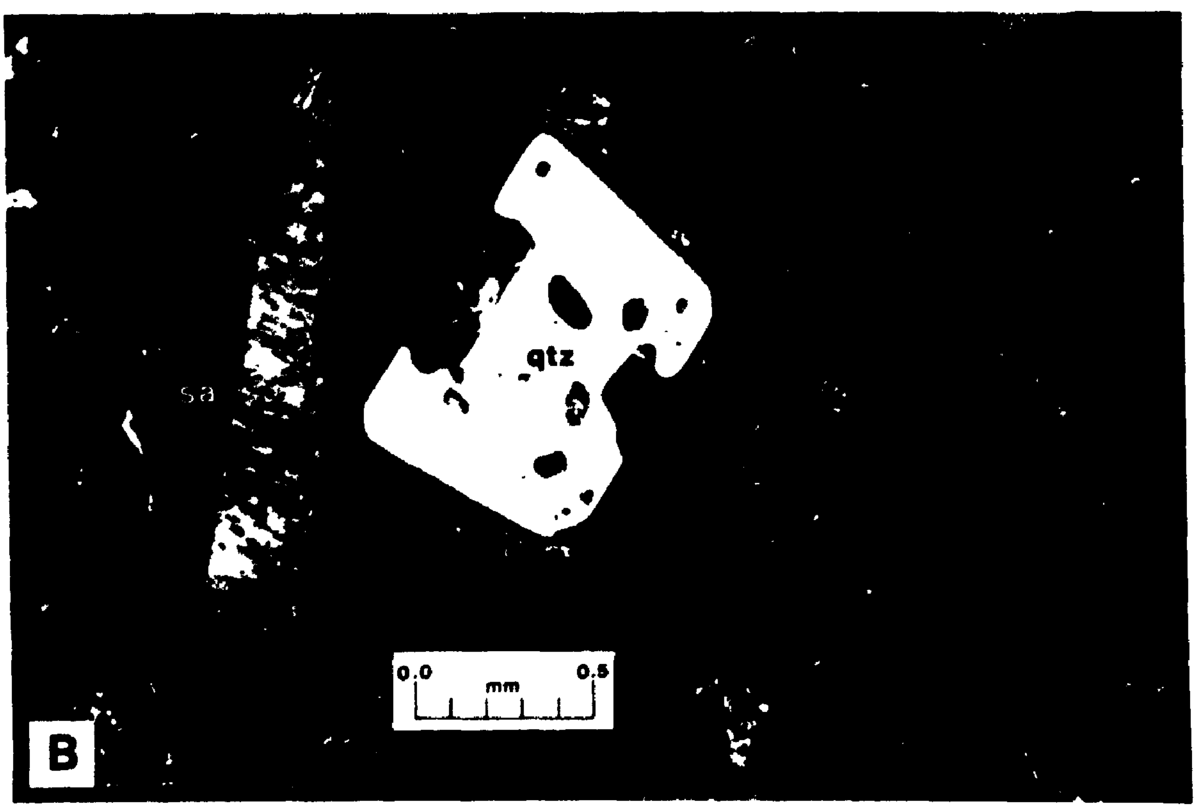
PLATE 10 - DYKES

A. Photomicrograph (ppl) of the basalt dyke from Plate 9C. Plagioclase (pl) microlites with felty texture and augite (aug) phenocrysts in a matrix of chlorite, epidote and opaque granules. Note the vugs filled with radiating aggregates of chlorite (chl) and calcite (cal).

B. Photomicrograph (ppl) of rhyolite dyke from Plate 9D with unaltered sanidine (sa) and resorbed quartz (qtz) phenocrysts in a fine-grained matrix of quartz and alkali feldspar.

PLATE 10





similar andesite dykes (Plate 9D). Dacite dykes are up to 30 metres wide; in places they have columnar joints.

Rhyolite dykes are grouped with the dacites, even though they only seem to cut strata as young as the Metsantan member. The rhyolite dykes 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.

3.10 **Metamorphism**

Volcanic strata of the Toodoggone Formation are typically non-schistose with original textures generally well preserved, and in places remanents 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)pseudomorpning phenocrysts and pyroclasts, and infilling matrix voids

2) in veins and lining fractures

3) as primary infillings of amygdules in basalt dykes

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.

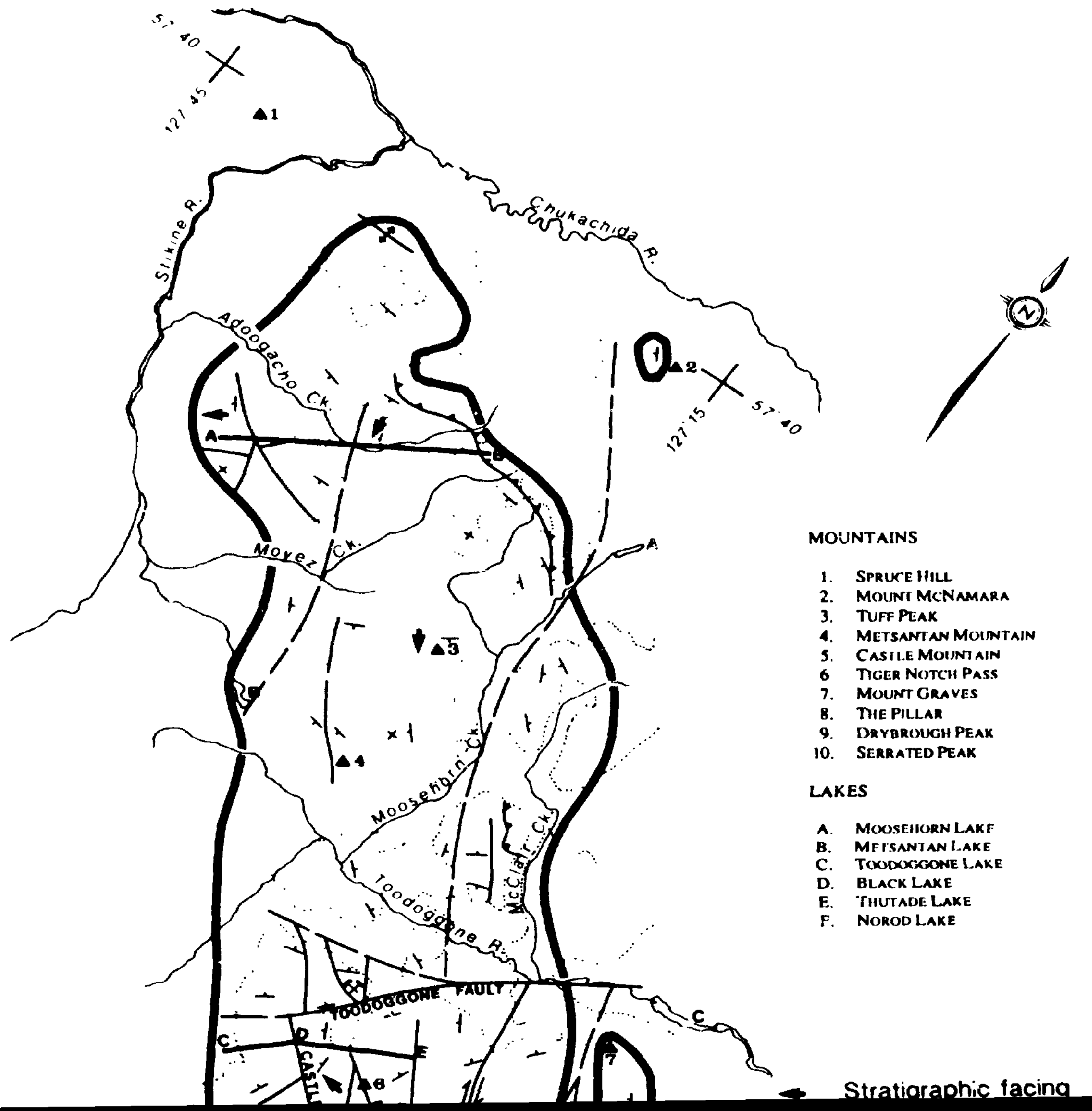
The most widespread zeolite minerals, confirmed by x-ray analysis, are laumontite and heulandite. Both zeolites coexist in the volcanic rocks with albitized plagioclase, quartz, and small amounts of calcite, chlorite, epidote and fine-grained illite-montmorillonite. Rarely, celadonite is in volcaniclastic rocks of the Metsantan member at Tuff Peak. Near Mount Graves prehnite-pumpellyite mixed with epidote coat a fracture hosted by volcanic rocks, which are presently mapped as the Hazelton Group, although they tentatively correlate with the Metsantan member in this treatise. 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.

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 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 wall rocks of the Takla Group at the Baker mine site. These veins may have a hydrothermal origin; there relationship with regional distributed authigenic hydrated calcium-aluminum silicates is uncertain.

3.11 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 flextures. In contrast, younger and older volcanic and sedimentary rocks are locally folded. The major faults are in Figure 20 and Map 1, structural sections are in Figure 21 (back pocket).



57°40
127°45
Stikine R.
Chukachida R.
Adoogacho Ck.
Moyez Ck.
Moosehorn Ck.
McClair Ck.
Toodoggone R.
TOODOGGONE FAULT
CASTL
127°15
57°40
N
MOUNTAINS
1. SPRUCE HILL
2. MOUNT MCNAMARA
3. TUFF PEAK
4. METSANTAN MOUNTAIN
5. CASTLE MOUNTAIN
6 TIGER NOTCH PASS
7. MOUNT GRAVES
8. THE PILLAR
9. DRYBROUGH PEAK
10. SERRATED PEAK
LAKES
A. MOOSEHORN LAKE
B. METSANTAN LAKE
C. TOODOGGONE LAKE
D. BLACK LAKE
E. THUTADE LAKE
F. NOROD LAKE
Stratigraphic facing

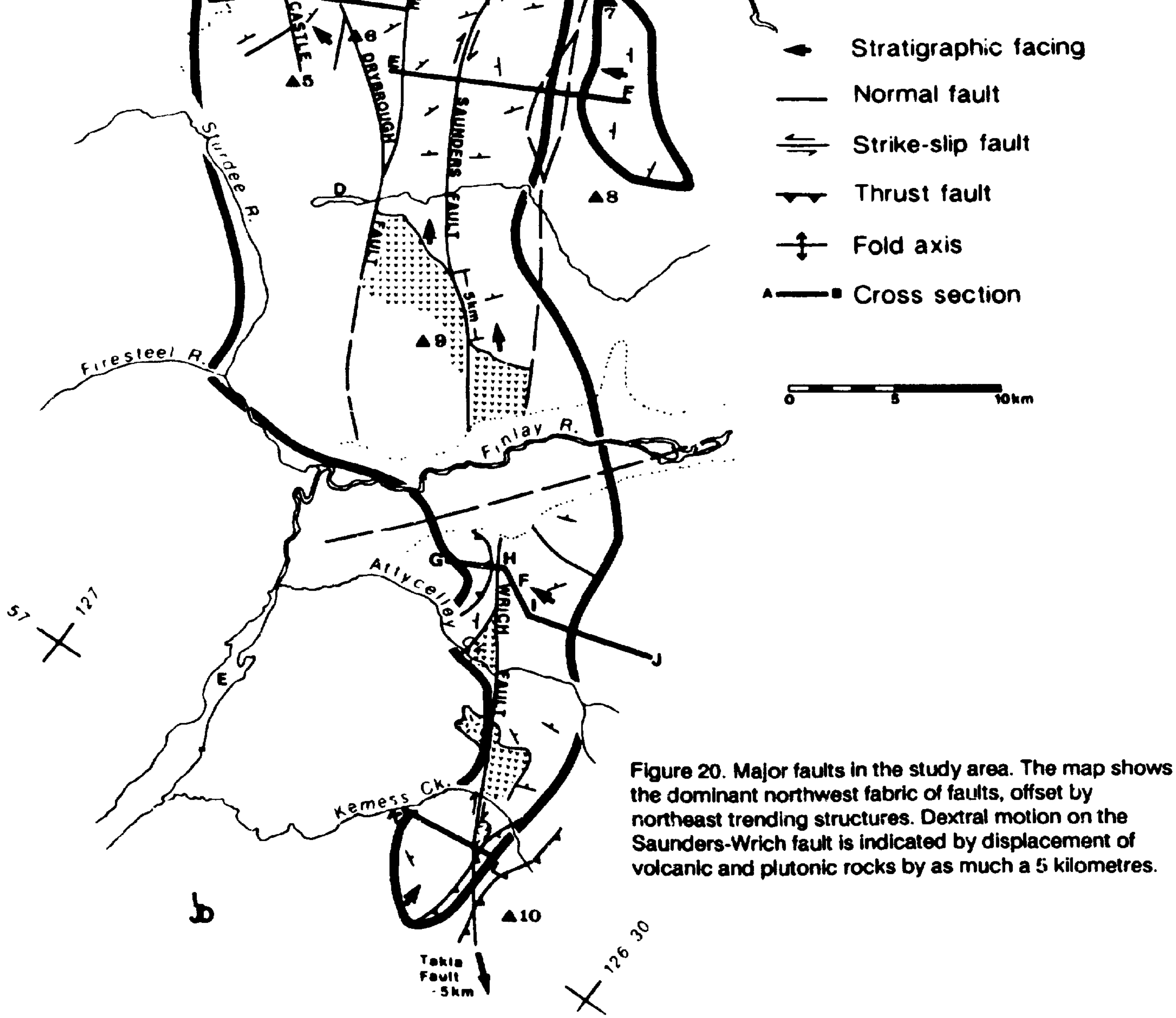


Figure 20. Major faults in the study area. The map shows the dominant northwest fabric of faults, offset by northeast trending structures. Dextral motion on the Saunders-Wrich fault is indicated by displacement of volcanic and plutonic rocks by as much a 5 kilometres.

3.11.1 Major Faults

The dominant structures are steeply dipping faults which define a prominent regional northwest 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 an unnamed 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 face 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 west and south 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 inturn 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 (see cross section C-F, Figure 21).

Feldspar porphyritic andesite and few basaltic dykes trend consistently north to northwest. Although solitary dykes are widespread, swarms are prevalent in the area between Saunders Fault, Mount Graves and The Pillar, and they extend northwest to the headwaters of McClair Creek. 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 to the thrust generally have west inclined bedding, but are unfolded. Chert, argillite and tuffs in the hanging wall 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 gentle 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 is inferred as a north dipping thrust fault, since 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 the 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 in strata of the Toodoggone Formation are uncommon. Despite this difficulty, the majority of faults appear to be extensional with normal and ra' ely 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 250 metres thick occupy the hanging wall 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 post-date eruptions of the Saunders member. The Saunders Fault is a significant northwest structure which forms a discrete east break for 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 appears to join 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.

3.11.2 Folds

With the exception of local broad warping, strata of the Toodoggone Formation are not folded. In general, the at :itude 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 form 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 in rocks of the Asitka and Takla groups near Attycelley Creek and at Castle Mountain, where they are related to compressional faults.

3.12 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 and 1989). 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 and 1989).

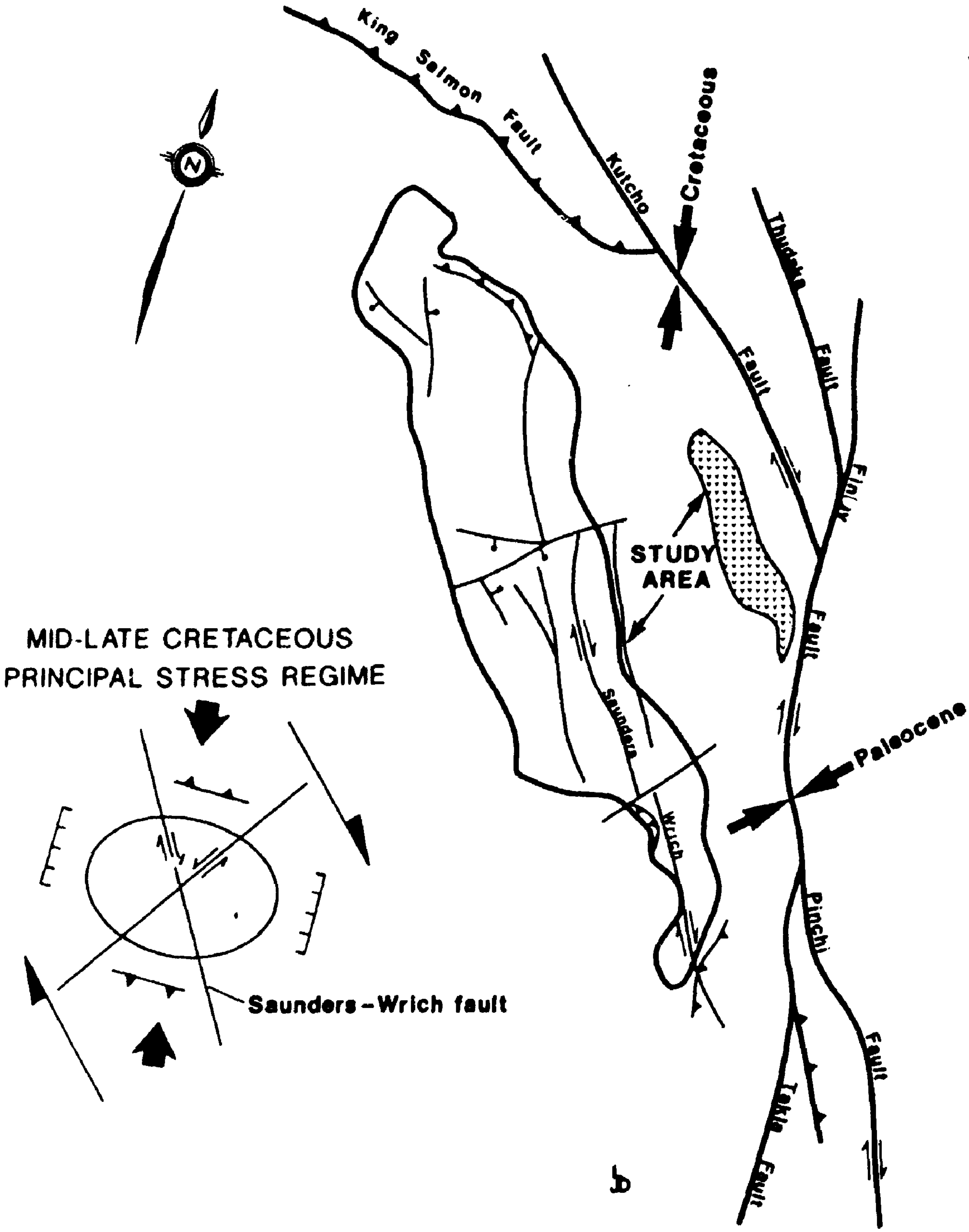
Southwest directed thrust faults are absent in north Bowser Basin of Spatsizi map area, although north and east of the Hotailuh batholith, in Cry Lake map area, they place Upper Triassic strata structurally above non-deformed Toarcian strata (Tipper, 1978, Anderson, 1983). An upper limit on the timing of southwest thrust movement is indicated by a potassium-argon age of 147 Ma. on the Snowdrift Creek Pluton (Wanless et al., 1982; p.11), which truncates structures that are related to compressional deformation of the nearby King Salmon Fault (Monger and Thorstad, 1978).

The Kutcho and Finlay are major faults, 5 to 15 kilometres east-northeast of the study area (Figure 22). 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 Crystalline 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 Fault and King Salmon Fault has been truncated and dextrally offset along a more northerly trend by the Finlay and Thudaka faults. This present pattern of faults 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 22). 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, in which evidence for tectonic disruption contemporaneous with eruptions of volcanic rocks is indicated by local conglomerate beds preserved within subsided blocks, and from ponding of ash-flow tuff. The magnitude of the faults is unclear, however the elongated shape of plutons and the local presence of dyke 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

Figure 22. 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).


King Salmon Fault
Kutcho Fault
Cretaceous
Thudaka Fault
Finlay Fault
STUDY AREA
Saunders
Wrich
Paleocene
Pinchi Fault
Takla Fault
MID-LATE CRETACEOUS
PRINCIPAL STRESS REGIME
Saunders-Wrich fault
b

fault. This structure is thought to be the dominant control localizing eruptions for 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 for Early Jurassic deformation resulting from transcurrent structures, that perhaps bound the study area in the west, is lacking.

CHAPTER 4

DEPOSITIONAL ENVIRONMENT OF THE TOODOGGONE FORMATION

4.1 General Statement

The Toodoggone Formation is a succession at least 2200 metres thick that is comprised roughly of 55% pyroclastic rocks, 30% lava flows and 15% epiclastic rocks. This sequence has evolved during essentially two major eruptive cycles which span roughly 22 million years of Early to Middle Jurassic 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 in the interval between the major volcanic cycles, 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 remanents and geometry of members is thought to closely reflect the distribution of primary eruptive products of differing processes of transportation and deposition.

4.2 Deposition of the Lower Volcanic Cycle

Rocks of the Adoogacho member, which is the base of the Toodoggone Formation, are products of volcanic activity that spans 4 million years of Sinemurian time. They rest immediately above a hiatus with intermediate to mafic volcanic rocks of the Takla Group. The duration of time represented by this post-Takla hiatus is unknown; however, the gentle angular discordance of this contact implies relative tectonic quiescence. It has no evidence of significant relief or epiclastic deposits with clasts of Triassic and older rocks, that would require major regional uplift and erosion. The low 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 variation. 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 indicates that oxidized conditions persisted throughout deposition.

The proponderance 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 non-welded to incipient welded state, and the absence of vapor 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 rapidly dissipate. 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 intervene pyroclastic deposits; they suggest erosion of poorly lithified volcanic rocks during periods between volcanic eruptions. 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 planar 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 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 non-welded 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 wide extent of uniform tuff beds. The absence of marine fauna in deposits of interlaminated marlstone and chert are interpreted as 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 quiecence.

Mineralogic similarity in tuffs of the Moyez member with those of the Adoogacho member implies the former are perhaps contemporaneous and representative of 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 within a broad basin. Elsewhere, correlative tuffs were likely removed during erosion and reworked into non-distinct epiclastic deposits.

Deposition of the Metsantan member began at least 200 million years ago and overlaps strata of the Adoogacho member 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 eruptions. Incision of flow surfaces during intermittant erosional episodes made channels, which subsequently were infilled with intraformational conglomerate. Finer epiclastic rocks, winnowed and transported by streams, emptied into small lakes producing laterally restricted redbed deposits of coarse sandstone grading upward into siltstone-mudstone cycles. 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 terrane like that of the Adoogacho apparently was a slightly 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 AGB 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 likely 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 change laterally along strike into thickly layered flows and pyroclastics is interpreted as a transition from a volcaniclastic apron to lower slope setting of a large stratovolcano. The lateral change from predominately pyroclastic and epiclastic facies near Mount Graves to flow dominated facies to the west within the study area is thought to indicate coalescing deposits from separate point sources; 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 SiO_2 and phenocrysts in early erupted Adoogacho member to 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 identical composition and cooling ages with 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. Dykes of porphyritic andesite are abundant in the Metsantan and McClair members. They contain the same phenocrysts as the enclosing volcanic rocks which suggests a cogenetic relationship.

The McClair member east of Moosehorn River is a complex mixture of pyroclastic rocks and 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. They formed by a similar mode of eruption that built stratovolcanoes in a extensional setting during Metsantan time.

4.3 Intercycle Marine Deposition

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 occur 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 since they represent the only remanent of marine sedimentary rocks within the Toodoggone Formation. 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 Metsantan member had waned in early Pleinsbachian time. This time interval coincides with significant sea level rise during a world wide transgressive event (Hallam, 1981). In Cry Lake map area, this event is manifest as shale deposits, in a marine basin, which in turn are overlain by silt and sand that represent a shallowing event in the middle to upper Toarcian (Thompson et al., 1986). In the Toodoggone River map area, correlative fine-grained sedimentary rocks with abundant large and coarse-shelled fauna indicate a shallow water, high-energy environment of deposition.

4.4 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 crystal-rich tuffs and some non-welded ash-flows that mark a resurgence of explosive activity. A minimum age of 189 Ma for this volcanic activity is determined near the upper contact of a tuff succession more than 500 metres thick, north of Attycelley Creek. This age suggests that eruptions of the Attycelley in the south may be synchronous in part with intervolcanic cycle marine deposition to the north.

Explosive eruptions built up a complex mixture of tuffs in which individual depositional units have rapid lateral change in thickness. Much of this variability is related to deposition of the Attycelley member upon pre-existing topography developed on the older successions. This is particularily evident northeast of Drybrough Peak where uplift and erosion of the Black Lake stock and Takla Group is 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 attest to pauses in volcanism and deposition in shallow lakes.

The upper volcanic cycle climaxed about 182 million years ago when more than 9 cubic kilometres of dacite ash-flow tuff of the Saunders member 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 tails out towards 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.

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 collapse, suggest 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 indica 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 eruption column collapse 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 indicate relatively hot eruption temperatures; however, uniform partial welding, even in the thickest single preserved section of about 250 metres, suggests that latent heat rapidly dissipated and load pressure was likely 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 unknown. 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 derived by partial collapse of a topographic rim bordering the depression.

CHAPTER 5

PALEOTECTONIC INTERPRETATIONS

5.1 Generalized Concept of Allocthonous Terranes in the Cordillera

There is a concensus that the Cordillera of western North America is a mosiac of lithospheric fragments, or terranes, of various Paleozoic and Mesozoic oceanic and volcanic arc successions that are allocthonous to the ancestral margin of North America (Davis et al., 1978; Coney et al., 1980; Saleeby, 1983). In the Canadian Cordillera these terranes have undergone a complex tectonic evolution which involved the amalgamation of lithospheric fragments into larger composite terranes that were subsequently accreted to the margin of North America (Monger, 1984). Monger and co-workers (1982) advocate that these composite terranes became docked during several accretionary events, each of which is marked by broad belts of uplift, metamorphism and deformation that coincide roughly with the mid-Jurassic Omineca Belt and the late Cretaceous to Tertiary Coast Belt.

Fossil fauna within climate sensitive zones, in particular those of Pleinsbachian age, indicate substantial latitudinal translation of the composite terranes relative to the static position of correlative biostratigraphic sequences deposited on the craton (Tipper, 1984; Taylor et al., 1984; Smith and Tipper, 1986). Long distance latitudinal transport is further substantiated by the paleomagnetic record of Mesozoic rocks underlying the east side of the largest lithospheric fragment, the Stikine terrane. These results indicate that the pre-mid Jurassic stratigraphy of the Stikine terrane may have formed at southerly paleolatitudes, and it has since moved 1300 kilometres northward during Late Cretaceous to Early Tertiary time (Monger and Irving, 1980). Such displacement is believed to be accomodated in part by motion on major transcurrent faults near the east margin of the Intermontane Belt, and also along structures in the Omineca Belt (Gabrielse, 1985). Restored cumulative movement of rock successions offset by these faults is considerably less than motion indicated from most paleomagnetic inclinations (Gabrielse, 1985). However, revision of Jurassic reference poles on the North American craton suggest that major latitudinal movement of the terranes is not required (May and Butler, 1986; Vandall and Palmer, 1990).

5.2 **Tectonic Setting of the Toodoggone Formation**

Volcanic activity in different tectonic environments is generally characterized by specific physical features and chemical composition. 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).

Volcanic rocks of the Toodoggone Formation imply they were erupted synchronously with crustal subsidence that formed an elongate structural depression. A model of intra-arc extension associated with oblique subduction is proposed for strata of the Toodoggone Formation.

5.2.1 **Physical Features and Chemical Composition**

The tectonic setting of the Toodoggone Formation is interpreted primarily on the basis of physical features and mineral assemblages of the strata and their depositional environment; and secondarily on their chemical compositions. The Toodoggone Formation is characteristically red and maroon pyroclastic rocks, subordinate lava flows, and related epiclastic rocks of two discrete cycles of subaerial extrusion. Shallow water volcanic wackes mark a brief marine incursion between volcanic cycles.

The lower volcanic cycle is mainly bedded air-fall tuffs and variably welded ash-flow tuffs erupted across a gently sloping paleosurface of Upper Triassic volcanic rocks. Capping, and in part synchronous with these flat-lying pyroclastic deposits are lava flows and coalescing pyroclastic and derived epiclastic rocks. These deposits are interpreted to be the remanents of one or more stratovolcanoes constructed upon the gently sloping volcanic surface late in the lower cycle. A quiescent period followed volcanic activity of the lower cycle and is indicated by local deposition of marine sedimentary rocks upon a submerged, possibly, downfaulted block of the volcanic pediment. A solitary erosional remanent of marine sedimentary rock was found, consequently it is believed that flooding was restricted to a fault-generated embayment connected to an ocean basin, west of the Toodoggone area, in which the Spatsizi Group was deposited (Thomson, et al., 1986). Volcanic activity during the upper cycle erupted pyroclastic rocks that are indistinguishable from those of the lower cycle; upper cycle lava flows are scarce. Late in the upper cycle, about 9 cubic kilometres of ash-flow tuff issued apparently from fissure-like vents. These fissures may have opened along a segment of the Saunders Fault which defines, and extends beyond the east boundary of the Central Toodoggone Depression. The depression is an asymmetric collapse feature that is interpreted to be synvolcanic and, in part, enhanced by sequential eruption of ash-flow tuffs.

Several stratigraphic and structural features, if considered together, indicate that heightened volcanic activity of the Toodoggone Formation occurred in an extensional stress regime. First a longitudinal section of the distribution of the Toodoggone volcanic rocks apparently defines a symmetric, northwest elongated downwarp. Older rocks are only exposed at the edges of the depression; inward toward the centre, only stratigraphically younger rocks crop out. Subsidence along the length of the volcanic depression was apparently uniform because ash-flow tuffs and flows are nearly 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. Additional evidence of localized subsidence of the volcanic plateau is provided by deposits of coarse epiclastic rocks that represent alluvial fans prograding outward from escarpments. The Moyez member is an areally restricted succession of parallel bedded tuffs with thin limestone in two intervals. These were probably deposited in depressions on the pediment; they are underlain by pyroclastic rocks of the Adoogacho member. The carbonate deposits suggest that lakes periodically occupied these depressions.

Stocks of granodiorite and quartz monzonite have a close spatial and temporal relationship with the volcanic rocks of the Toodoggone Formation. The Black Lake pluton, some smaller satellitic bodies, and several generations of dykes 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 augmented by extensional structures.

Calc-alkaline, high-potassium latites and dacites that dominate both eruptive cycles characterize the Toodoggone Formation. Except for some late dykes, basalt and rhyolite are notably absent from the succession. Variation in composition of progressively younger strata within the two volcanic cycles is minor; SiO_2 (volatile free) ranges between 58 and 65 weight per cent, and K_2O from 3.3 to 3.5 weight per cent. The lower cycle began with eruptions of dacitic pyroclastic rocks containing quartz, hornblende and sanidine phenocrysts; these are overlain by lava flows of latite composition in which the proportion of augite exceeds combined biotite and hornblende abundances. The upper cycle consists exclusively of dacitic fragmental rocks. Except for minor increases in modal abundances of quartz and sanidine, these rocks are nearly indistinguishable from those of the lower cycle.

The calc-alkaline magma series is typically associated with modern subduction-related magmatic arcs (Gill, 1981). Geochemical parameters of orogenic volcanic rocks have been used as a general indicator of arc maturity and also to distinguish island arc from continent margin settings (Jakes and White, 1972; Miyashiro, 1974).

Compositional zoning in time and space is observed in many Tertiary arcs. In general, high-K calc-alkaline volcanic activity occurs during an advanced stage of arc evolution. Because high-potassium, intermediate volcanic rocks characterize the Toodoggone Formation and less evolved rocks are absent, these volcanic rocks are believed to represent a mature stage of arc evolution. This interpretation is supported by their apparent consanguinity with calc-alkaline, epizonal granodiorite and quartz monzonite plutons which are also typical in mature magmatic arcs (Brown, 1982).

Compositions of arc volcanic rocks are influenced by the nature and thickness of underlying crust (Coulon and Thorpe, 1981). The proportion of calc alkaline series rocks increases with advancing development of continent-like crust (Miyashiro, 1974). For example, in the Tonga-Kermadec-New Zealand arc system tholeiitic associations dominate in island arc volcanoes above the thin, oceanic crust that underlies the Tongan-Kermadec segment. However, more highly evolved calc-alkaline volcanism occurs above thicker crust in a continent margin setting along the New Zealand arc segment (Coulon and Thorpe, 1981). High-potassium volcanic rocks of the Toodoggone area have physical and geochemical features that are most similar to arc assemblages developed in continent margin settings; particularily in northern Chile and southern Peru where crustal thickness is greatest beneath the Andean arc (Roobol et al., 1976; Thorpe and Francis, 1979).

Rocks of the Toodoggone Formation are superimposed upon a basement composed of two older arc successions; one of Permian and the other of Late Triassic age. It is conceivable that these arc successions formed a continent-like substrate, thus affecting the evolution of magma and style of Early-Middle Jurassic arc volcanic activity. Significant volumes of ash-flow tuffs 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 and 1982; Coulon and Thorpe, 1981); these features characterize the Toodoggone Formation. Thick crust is believed to have the effect of slowing ascent of the primary melt which might enhance fractional crystallization and the proportion of evolved compositions (Coulon and Thorpe, 1981). A long storage time of well-differentiated, hydrous and oxidized calc alkaline melt, perhaps produced by fractional crystallization of mantle-derived magma, is envisaged for homogenous compositions characterizing the Toodoggone Formation. Low initial strontium ratios of .7041 ± 0.0001 and .7040 ± 0.0001 of Toodoggone volcanic rocks and a nearby coeval pluton, respectively (Gabrielse et al., 1980; Cann and Godwin, 1980), suggest a source of magma derived either from mantle or crustal rocks containing low radiogenic strontium. Granitic xenoliths in ash-flows of the Saunders member are evidence of contamination of the melt; this however is perceived to be minor. These ratios are well within the range for intra-oceanic island arcs; they also overlap ratios for some continent margin arcs (Dickinson, 1980).

5.3 **Configuration of Jurassic Arcs in the Stikine Terrane**

Igneous rocks of Jurassic age in the study area are consistent with subduction-related magmatism of some modern arcs; particularily those developed upon thick crust. However, there is no exposed old continental lithosphere beneath the Toodoggone Formation.

The Toodoggone Formation is interpreted as a segment of an Early-Middle Jurassic island arc system, the Hazelton arc. Remanents of Jurassic arc-related rocks are widespread throughout much of the Stikine tectonostratigraphic terrane, adjacent to the border of the Bowser Basin.

An early reconstruction of the Hazelton arc (Tipper and Richards, 1976), is based on detailed stratigraphic study of the Jurassic Hazelton Group immediately south of the Toodoggone area and along the southeast margin of the Bowser Basin. They concluded that the Hazelton Group represented an island arc coupled with a subsiding "back-arc trough" called the Nilkitkwa Depression. In this model the back-arc is better interpreted as an intra-arc, fault-controlled depression, which confines a thick marine succession that is flanked by mainly subaerial and coeval volcanic belts. The apparent increase of alkali abundances in rocks of the east belt relative to the west belt (Tipper and Richards, 1976; de Rosen-Spence and Sinclair, 1987) may be analogous to many modern arcs in which a transitional rise in potassium content is correlated with increasing lateral distance from the trench axis and corresponding increasing vertical depth to the inclined seismic zone (Dickinson, 1975). Keith (1978) has shown that K-h relationships can be used to reconstruct the approximate geometry of past arc-trench systems. Lateral alkali zonation has lead to the inference of east-dipping subduction beneath the Stikine terrane during Early and Middle Jurassic time (Davis, et al., 1978).

The Toodoggone Formation is interpreted as a north extension of the aforementioned east volcanic belt of the Hazelton Group based on broadly similar stratigraphy, composition and age. Collectively, they represent parts of a solitary arc system, which presently trends north for a minimum distance of 500 kilometres along the east edge of Stikinia. Contrary to speculation of Hazelton stratigraphy south and east of the Bowser Basin as a west facing arc, a model of southwestward subduction is favored for these rocks and correlative strata underlying the Toodoggone area. This model agrees with the polarity of subduction conceptualized for Late Triassic and Early Jurassic arcs in northern Stikinia (Tempelman-Kluit, 1979).

In the Toodoggone area, steep, west to southwestward oblique subduction is proposed for the narrow arc in which volcanic activity occurred during a regime of intra-arc extension. During oblique subduction, stress associated with low degrees of frictional coupling of the downgoing and overriding plates (Uyeda and Kanamori, 1979), is resolved by extensional strike-slip faults, grabens and subsidence basins that develop within the arc and back-arc. Except for the presence of continental lithosphere, the Sumatrean section of the Sunda arc is the closest modern anologue for tectonic conditions during Jurassic island arc volcanism in the Toodoggone area. The narrow magmatic arc which presently occupies central Sumatra is forming as oceanic lithosphere is subducted at moderate to high convergence angles (Hamilton, 1988). Igneous activity is controlled by, and coincides through the length of the arc, with a major system of transcurrent and subordinate normal faults bounding structural depressions (Posavec et al., 1973). In this transtensional setting faults are synvolcanic; moreover, they enhance and localize the ascent of magma into sub-volcanic reservoirs. Differentiated magma in turn feeds stratovolcanoes and calderas which are regularly staggered along, and intimately associated with the extensive fault system in Sumatra. A similar interrelationship of arc volcanoes and extensional structures, concurrent with subduction, is also apparent in central Luzon of the northern Philippines (De Boer et al., 1980). The arc consists of linear belts of volcanoes perched on prominent "fault or rift zones" within a regional fault bounded basin (Wolfe and Self, 1982). The two largest volcanic centres are actually volcano-tectonic depressions with nested calderas from which high-potassium ignimbrites erupted; this resemble the setting of the Toodoggone Formation.

If intra-arc extension resulting from oblique westward subduction is a plausible model for the tectonic evolution of the Toodoggone area, it may have regional implications for the remainder of the Hazelton arc. Northwest elongated, fault controlled depressions of significant dimension have been mapped elsewhere along the Hazelton arc (Tipper and Richards, 1976). The Nilkitkwa Depression is the largest tectonic element. Stratigraphy indicates a protracted history of sedimentary and volcanic rocks accumulated in a marine environment for a time interval spanning the entire range of the Hazelton Group. A similar graben structure, situated northeast of the Nilkitkwa Depression, and midway to the Toodoggone area, contains coarse epiclastic and volcanic rocks of the Sinemurian (?) Sikanni facies. Tipper and Richards (1976; p. 39) suggest a tensional regime prevailed while the Sikanni facies was deposited; this may also be a younger manifestation of reactivated local faults which supposedly influenced, in part, the paleogeography and depositional patterns of the underlying Late Triassic Takla Group (Church, 1974, p.307; Monger, 1976).

The evidence cited above suggests that extension and subsidence of fault-generated depressions is an important feature of tectonic evolution for the Hazelton island arc east of and including the Nilkitkwa Depression. A similar interpretation of extension is supported by chemical composition of Tipper and Richard's west belt of the Hazelton island arc (de Rosen-Spence and Sinclair, 1988).

Because physical and chemical aspects of the Toodoggone Formation are so uniform throughout the 22 million year history of arc construction, this suggests the causitive processes relating to dynamics of the subducted plate and internal arc structure remained constant through time. Along the east margin of Stikinia, the Early-Middle Jurassic island arc 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 calc-alkaline 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 two cycles of volcanic activity; these are punctuated by an interval of marine deposits. Ash-flow tuffs driven by low volatile contents and less evolved lava flows erupted simultaneously during the earliest cycle. Except for the absence of significant flows, pyroclastic eruptions resumed during the upper cycle and culminated with ash-flows and collapse of the Central Toodoggone Depression. Steeply dipping faults controlled both the distribution and style of eruptions and emplacement of sub-volcanic 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 and advanced argillic alteration zones.

CHAPTER 6

MINERAL DEPOSITS

6.1 General Statement

The study area hosts 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. They are: 1) Volcanic-hosted epithermal gold-silver, 2) Porphyry Cu-Mo, 3) Skarn and 4) Placer gold (Figure 23 and Map 1, Table 8).

6.2 Volcanic-Hosted Epithermal Gold-Silver Deposits

Volcanic-hosted epithermal gold-silver deposits of Tertiary age have recently been reclassified based ore mineral type and associated gangue and secondary mineral assemblages into: a) adularia-sericite and b) acid-sulphate types (Hayba, et al., 1985; Heald, et al., 1987). Within the Toodoggone Formation notable examples of the adularia-sericite type are the Lawyers Mine and the Baker Mine; they are in volcanic rocks of Early Jurassic and Late Triassic age, respectively. Nearby, the broadly altered areas near Alberts Hump and Cloud Creek have features which closely resemble the acid-sulphate type.

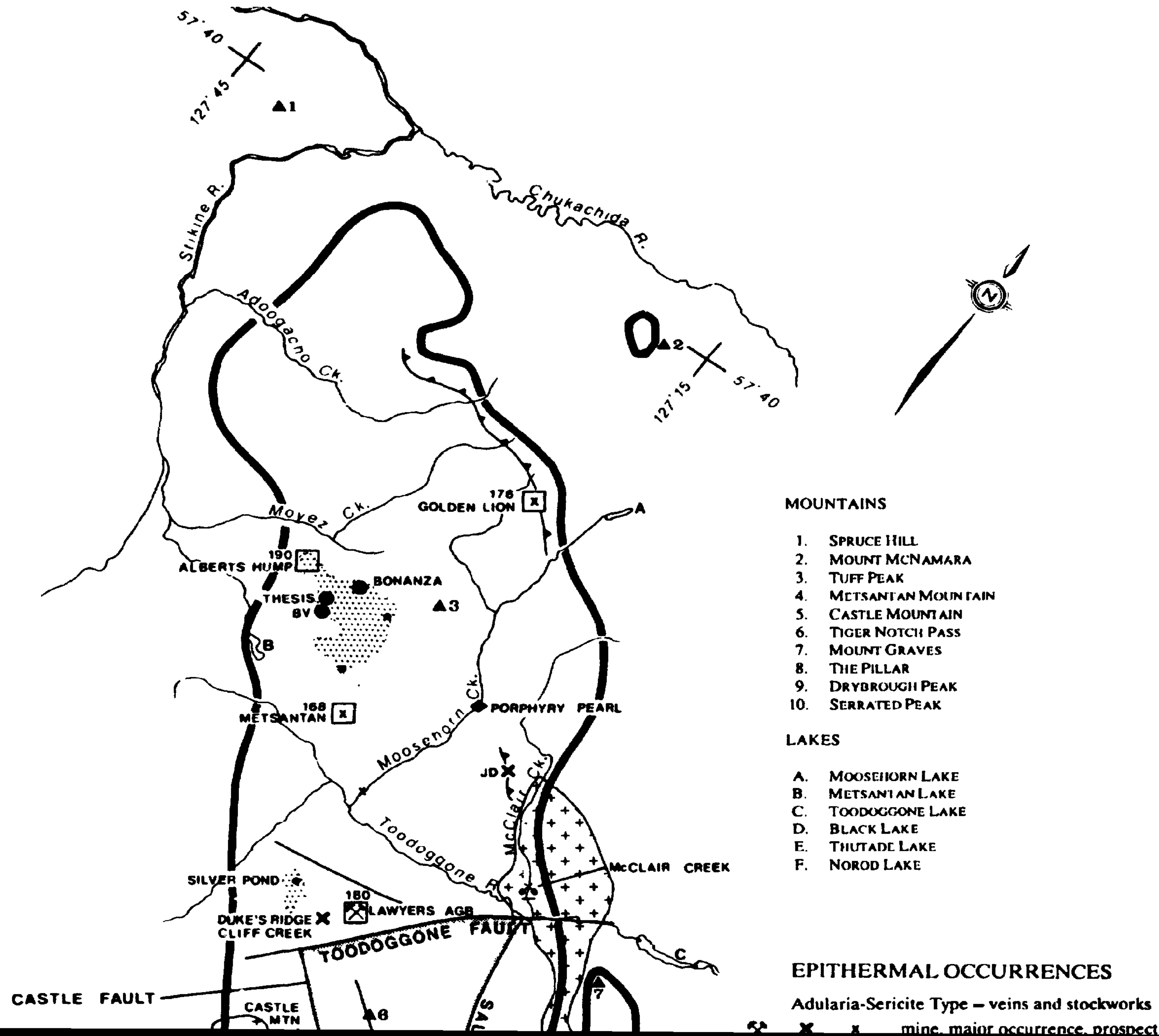
The terminology for secondary mineral assemblages used herein is slightly modified after that of Meyer and Hemley (1967). The dominant alteration assemblages recognized include:

1) Silicic - Microcrystalline quartz is added to other minerals in altered rocks

2) Potassic - Fine-grained potassium feldspar as adularia is with or without sericite

3) Argillic - Kaolinite and montmorillonite minerals

4) Advanced Argillic - Dickite or kaolinite, sericite, quartz, and commonly alunite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127°15
Stikine R.
Chukachida R.
Adoogacho Ck.
Moyez Ck.
Moosehorn Ck.
Toodoggone R.
McClair Ck.
176
GOLDEN LION
190
ALBERTS HUMP
BONANZA
THESIS
BV
168
METSANTAN
PORPHYRY PEARL
JD
McCLAIR CREEK
SILVER POND
180
LAWYERS AGB
DUKE'S RIDGE
CLIFF CREEK
TOODOGGONE FAULT
CASTLE FAULT
CASTLE MTN
MOUNTAINS
1. Spruce Hill
2. Mount McNamara
3. Tuff Peak
4. Metsantan Mountain
5. Castle Mountain
6. Tiger Notch Pass
7. Mount Graves
8. The Pillar
9. Drybrough Peak
10. Serrated Peak
LAKES
A. Moosehorn Lake
B. Metsantan Lake
C. Toodoggone Lake
D. Black Lake
E. Thutade Lake
F. Norod Lake
EPITHERMAL OCCURRENCES
Adularia-Sericite Type – veins and stockworks
mine, major occurrence, prospect

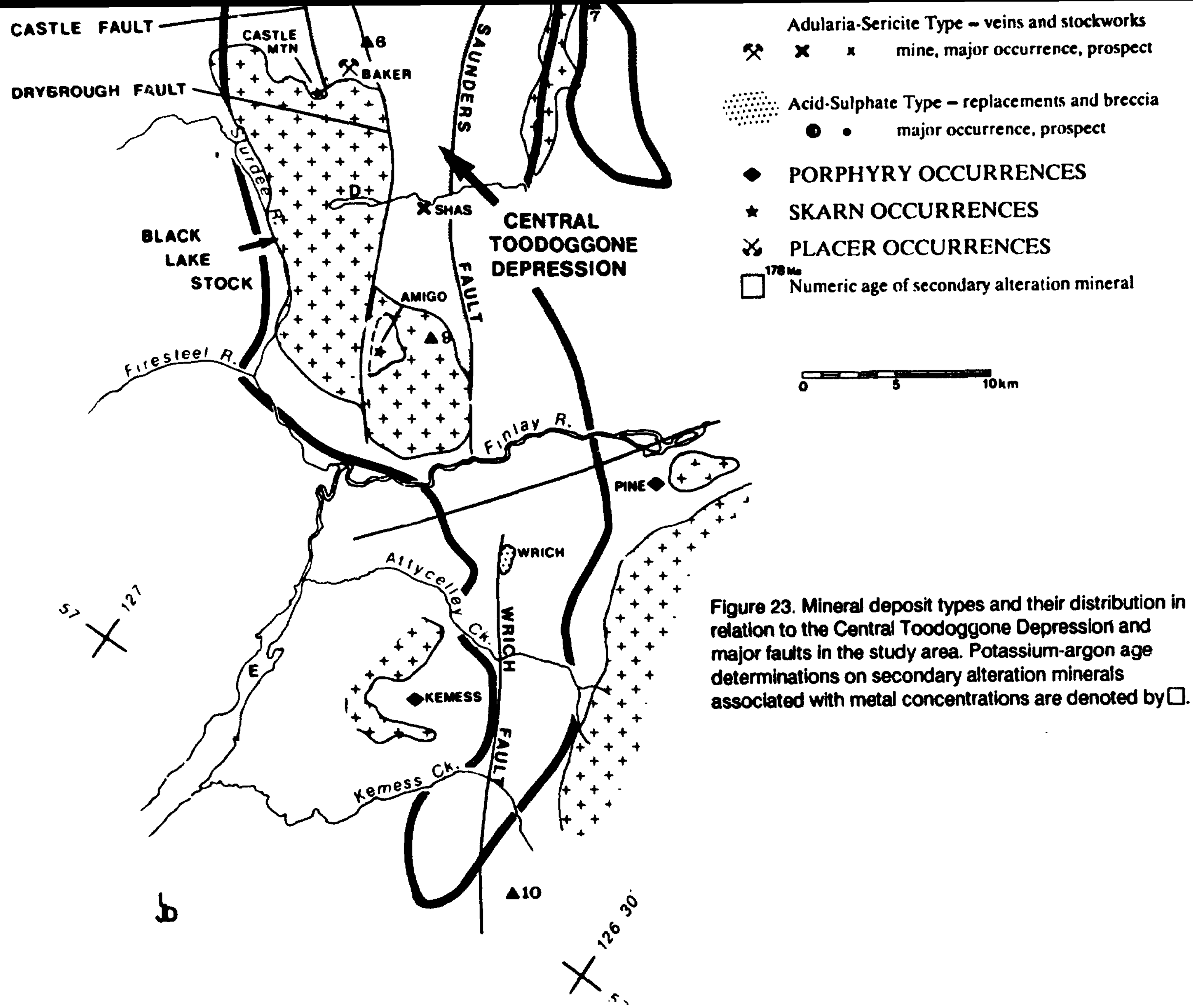

Figure 23. Mineral deposit types and their distribution in relation to the Central Toodoggone Depression and major faults in the study area. Potassium-argon age determinations on secondary alteration minerals associated with metal concentrations are denoted by □.

Table 8. Comparative features of mineral deposit ty

DEPOSIT TYPE	HOST ROCK	METALLIC MINERALS	GANGUE/ALTERATION
A. EPITHERMAL: Adularia-Sericite Type	Latite and dacite volcanic rocks of the Adoogacho, Metsantan and Attycelley members; locally basalt-andesite rocks of the Takla Group	Electrum, argentite native gold ± native silver. Chalcopyrite, sphalerite and galena are moderate to sparse. Polybasite, stromeyerite, molybdenite and linarite are rare	Quartz + adularia + calcite; minor illite, kaolinite, bari pyrite and hematite. Chlorit sericite and pyrite are particularly abundant at Bake with traces of fluorite
A. EPITHERMAL: Acid-Sulphate Type	Mainly latite flows of the Metsantan member; but locally dacite pyroclastic rocks of the Attycelley and Saunders members	Native gold, electrum, argentite, with minor tetrahedrite and chalcopyrite; trace sphalerite and galena	Quartz, pyrite, dickite, kaolinite, barite, alunite
B. PORPHYRY:	Early to middle Jurassic granodiorite and quartz monzonite intruding Takla Group and Toodoggone Formation volcanic rocks	Chalcopyrite, molybdenite ± gold	Broad propylitic with local quartz-clays-pyrite
C. SKARN:	Permain limestone of the Asitka Group near intrusive contacts with the Black Lake stock	Magnetite, sphalerite, galena, bornite, chalcopyrite ± gold	Marble, epidote, actinolite, pyrite

osit types in the study area.

ION	MORPHOLOGY	STRUCTURE	EXAMPLES
cite; , barite, hlorite, e at Baker e	Veins and stockwork veinlets that have banded, vuggy and comb structure. Breccia veins with massive microcrystalline quartz as matrix supporting earlier quartz and wallrock fragments are significant at Lawyers	Steeply dipping anastomising fractures and fault systems localized in a regional, northwest trending extensional zone	Deposit or major occurrence: Lawyers, Baker, Shas, JD Prospects: Metsantan, Golden Lion
e, nite	Pervasively altered zones in which disseminated ore minerals occur with crystalline barite in vugs, breccia and veinlets within intensively silicified country rock	Fracture systems possibly localized above high-level plutons	Major occurrence: Al property; includes the Thesis and Bonanza zones Prospects: Silver Pond, Wrich
local	Disseminations and quartz veinlets mainly within volcanic rocks near pluton margins	Steeply dipping fractures in volcanic and plutonic rocks	Prospects: Kemess, Pine, Porphyry Pearl
olite,	Irregular pods in carbonate rocks	Steep intrusive contacts or in screens of carbonate rocks on the Black Lake Stock	Prospects: Castle Mountain and Amigo

5) Propylitic - Epidote, chlorite, carbonate, albite and pyrite.

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

6.2.1 Adularia-Sericite Type

Gold and silver bearing quartz veins bound by wall rocks enriched in adularia and sericite are diagnostic of the adularia-sericite type. In the study area such deposits occur principally in either latite lava flows of the Metsantan member or dacitic tuffs of the Attycelley member at the Lawyers Mine and Shas respectively. The oldest host rocks are basalt to andesite flows of the Takla Group, which contain the formerly productive veins at the Baker Mine. These mineral deposits are all controlled by fractures and faults near the margin of the Central Toodoggone Depression. They also are evenly spaced with respect to smaller prospects for a distance of about 30 kilometres along a northwest trend that roughly coincides with major faults in the study area. The AGB zone at the Lawyers Mine and Baker Mine have significant surface and underground development; however, neither has had a detailed study of metal concentration and distribution of secondary alteration minerals. They are briefly described herein as key examples of adularia-sericite type deposits in the Toodoggone area.

6.2.1.1 Lawyers Mine

Gold-silver deposits at the Lawyers Mine include the Amethyst Gold Breccia (AGB) zone, Cliff Creek zone, and Duke's Ridge zone (Vulimiri, et al., 1985; Figure 24). They are within an 8 square kilometre area, about 4 kilometres south of the Toodoggone River. Since January, 1989, production has been from the AGB zone, where Cheni Gold Mines Inc. has reported ore reserves of approximately 1.938 million tons of .198 oz/ton gold and 7.09 oz/ton silver (Report of Directors to Shareholders, 1989).

LAWYERS AMETHYST GOLD BRECCIA ZONE

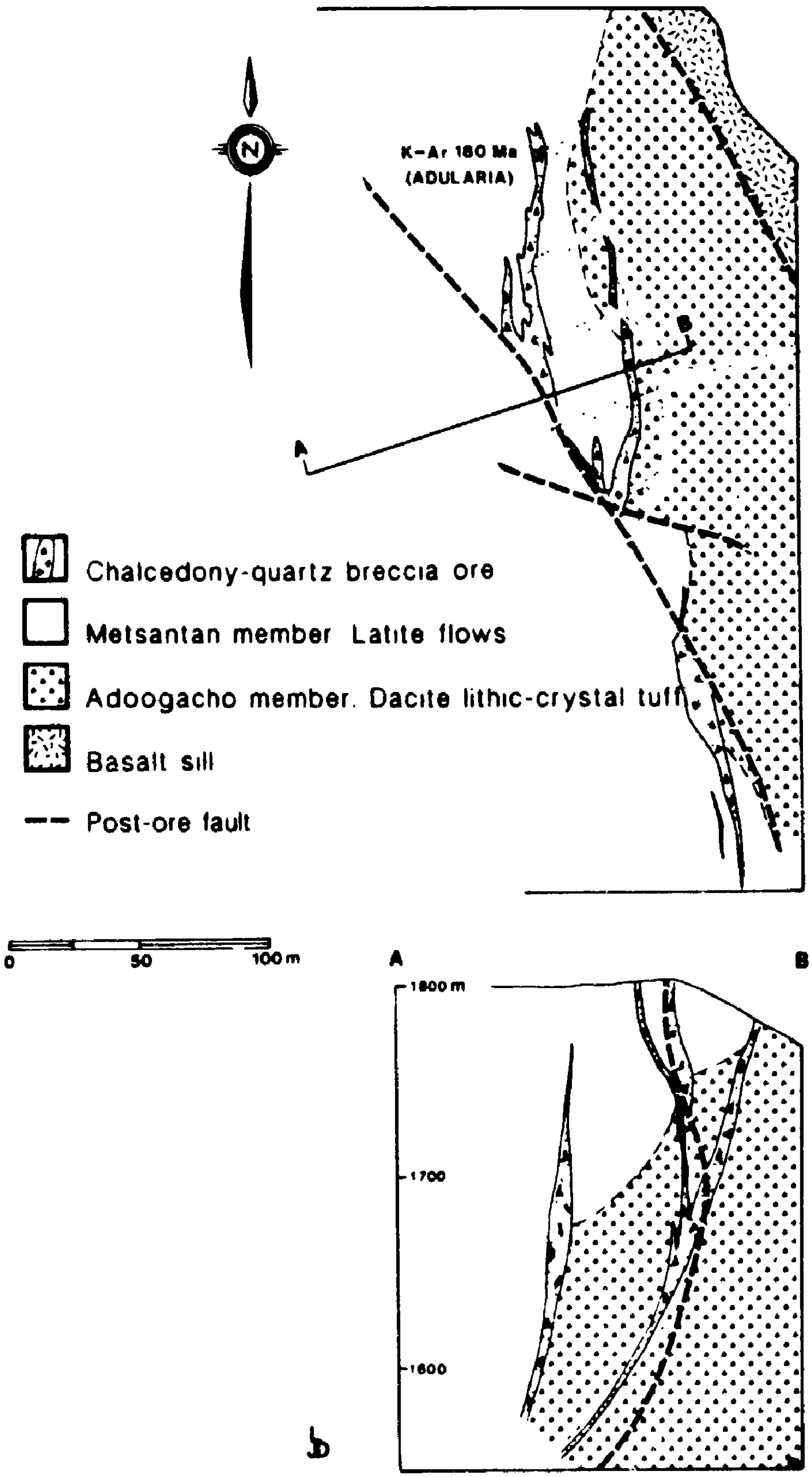

Figure 24. Generalized local geology and cross section of the Lawyers Amethyst Gold Breccia zone (AGB). Stippled lines are underground workings on the 1750 metre level (modified after Vulimiri et al., 1985). Location of the potassium-argon age determination on adularia from the margin of quartz veins is indicate by ★.

The deposits at Lawyers are along northwest trending faults which terminate at the Toodoggone Fault. The AGB ore body is along a steep west dipping and northwest trending fracture system that obliquely cuts comformable stratigraphic contacts. The mine section is a basal quartz-bearing dacitic tuff with variably welded ash tuff lenses. These rocks are believed to be part of the Adoogacho member; however, their age is equivocal. These rocks are comformably overlain by latite flows and interspersed volcaniclastic deposits of the Metsantan member. Because there is dramatic variation in thickness and dip southwestward across the ore zone, Vulimiri et al (1985) suggest that synvolcanic half-graben faults control the depositional patterns of host rocks and more significantly, localized mineralizing fluids within the AGB zone.

The AGB zone is thought to be temporally and spatially related to an incipient stage of graben formation, in which block faults incrementally step down toward the west (Vulimiri, et al., 1985). 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 Mesantan member and contemporaneous epiclastic rocks preserved in the downthrown block. Younger faults with northwest trend and left-lateral movement, in part, parallel the postulated graben structures; they subsequently offset stratigraphy and metal concentrations in the AGB zone. Post-ore basalt dykes are along the late faults.

The AGB deposit consists of fracture controlled breccia zones and stockwork veins. This system is at least 500 metres long and has a vertical extent of at least 150 metres with variable widths up to 75 metres. In section at depth the deposit is a near vertical solitary zone that bifurcates about 100 metres from surface into two discrete zones. Ore is finely disseminated electrum, acanthite, native gold, native silver with minor chalcopyrite, sphalerite and galena. Pyrite is uncommon but in places is up to 5 percent. The main gangue minerals are chalcedony, crystalline quartz, calcite and minor barite. The greatest ore grades are associated with chalcedony and hematite which are matrix in breccia zones. In places clasts in breccia are remanents of earlier vein chalcedony, amethyst quartz and calcite, and potassic altered wallrock fragments. Chalcedony and hematite also form the thinly banded margin of productive veins, within which the inner part of veins is commonly comb textured white and amethyst quartz. Sparry calcite with or without barite occurs locally in elongate discontinuous cavities at the centre of veins. Silver to gold ratios average 20:1, but variable trends occur both horizontally and vertically along the ore zone.

In the AGB zone a pronounced trend of K_2O enrichment and Na_2O depletion occurs near the ore zone (see analyses 41 and 42, Appendix A), relative to compositions of unaltered samples of the host rocks (compare to average compositions for the Adoogacho and Metsantan members, Table 3). Adularia 's diagnostic closest to metal-bearing veins. It 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 wall rocks. This potassic alteration grades outward to an assemblage of epidote-carbonate-chlorite-pyrite.

Silicic breccia ore that is diagnostic of the AGB deposit is not nearly as prominent at Cliff Creek and Duke's Ridge. Adularia is present nearest to veins; it has a diffuse outer contact with a flanking assemblage of kaolinite mixed with minor amounts of illite. Pyrite is ubiquitous in the argillic rocks in amounts up to 5 percent. At depth in the Duke's Ridge zone chlorite accompanies precious metal concentrations, and traces of chalcopyrite, pyrite and sulphosalts. Propylitic alteration dominates in country rocks peripheral to the argillic zone.

6.2.1.2 Baker Mine

The Baker Mine is approximately 7 kilometres southeast of the Lawyers Mine. The mine recovered 37,558 ounces gold and 742,210 ounces silver from 77,500 tons of ore milled between 1980 and 1983 (Schroeter and Panteleyev, 1985). Production at the Baker Mine was from vein "A"; it is the only productive precious metal-bearing vein occurrence of six known near the minesite (Barr, 1978). The A vein is within an uplifted fault block of highly ferruginous, basalt and andesite flows of the Takla Group in intrusive contact with the Black Lake stock (Figure 25). Moreover, it is immediately adjacent to several satellite granitoid intrusions and dykes, that are less than 1 kilometre away from the main mass of the Black Lake stock. A few mafic dykes with a northwest trend and lacking significant alteration locally cut propylitic altered wallrock near a south segment of vein A.

Vein A is a system of two or more closely spaced, subparallel veins trending northeast and steeply inclined to the northwest. Although the vein system is segmented by numerous northwest trending cross faults, the offsets are minor; together the vein segments have a strike length of more than 400 metres. The vein system varies in width from 10 to 70 metres, in which individual veins are between 0.5 and 10 metres wide, through a depth of 150 metres. Ore grade rock was primarily confined to a continuous shoot approximately 200 metres long by 3 metres wide and on average 40 metres deep. Recent exploration 400 metre to the northeast of the vein A, and along the same structural trend, has delineated a similar metal-bearing quartz structure with estimated reserves of 50,000 tons grading .71 oz/ton gold and 10.68 oz/ton silver (T.G. Schroeter, unpublished report, 1988).

Precious metal-bearing rock at the Baker Mine is very fractured, vuggy and brecciated milky white quartz with the greatest metal content in a grey, commonly, banded variety that contains chlorite-pyrite bands. Silver and gold minerals are predominately argentite and electrum; rarely native gold, polybasite and stromeyerite. They are typically associated with sulphide concentrations of 3 to greater than 15 percent, which are dominantly pyrite, subordinate chalcopyrite and sphalerite, and minor galena.

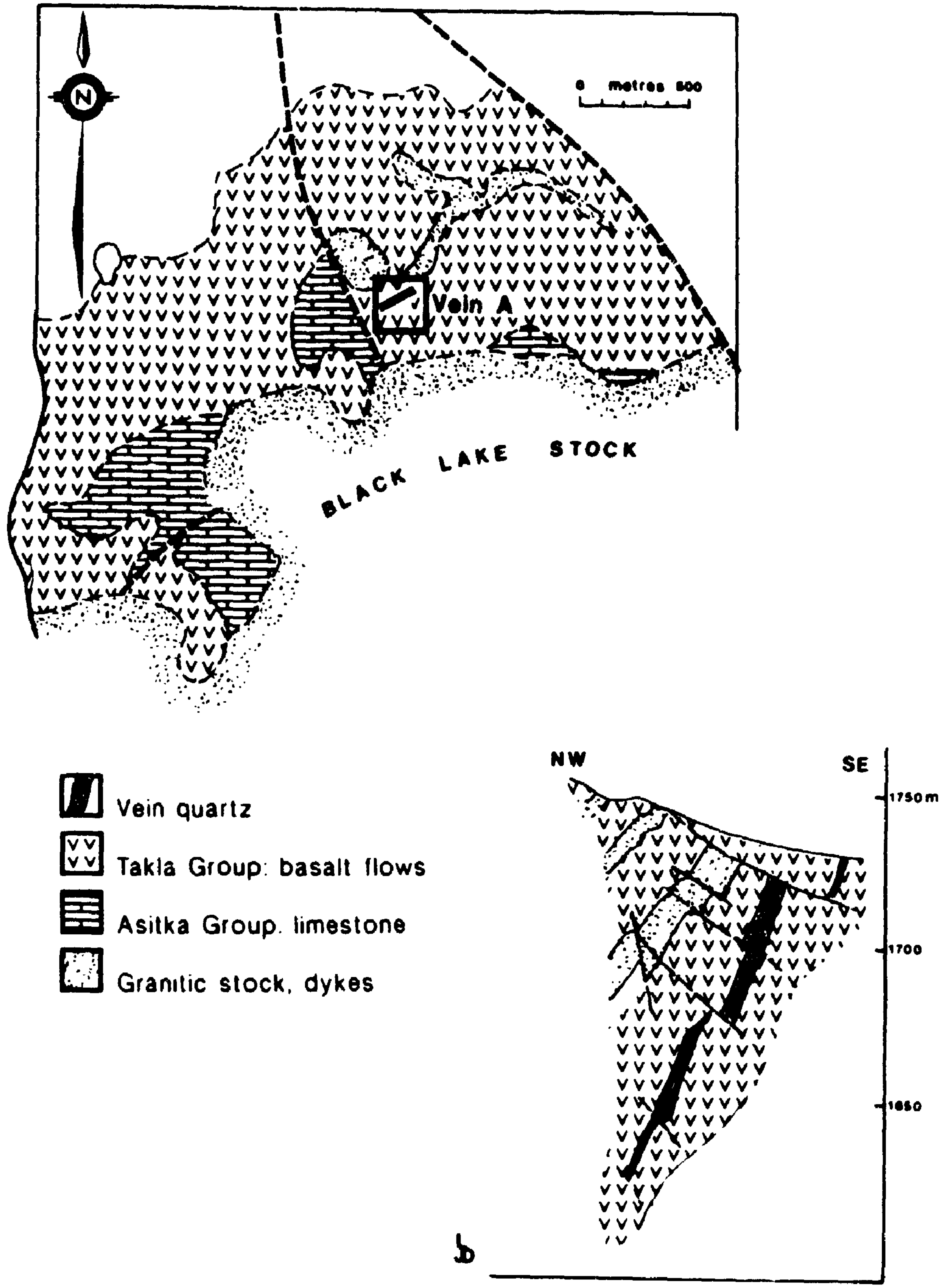

Figure 25. Generalized surface geology and cross section of Vein A, Baker Mine (modified after Barr, 1978).

There is a trace of molybdenite and fluorite (Schroeter and Lefebure, 1987; Peter, 1983). The silver and gold minerals are typically disseminated grains of micron size that commonly share mutual boundaries or occupy sites within pyrite and base metal sulphide grains (Barr, 1978; Peter, 1983). Alteration zoning vein A has chlorite commonly within vein quartz (Peter, 1983) which may reflect iron and magnesium mobilized from le·.ched mafic wallrocks flanking the veins. Kaolinite mixed with sericite in a light colored zone nearest veins passes outward to distal zone with chlorite-albite-epidote-pyrite. Veins of laumontite-calcite-quartz, with and without minor stilbite, cut altered wallrocks near the vein A; they apparently are post-mineral and perhaps associated with regional metamorphism.

6.2.1.3 **Other Vein Occurrences**

Polymetallic quartz veins and veinlets with galena, sphalerite, chalcopyrite, with or without bornite and pyrite commonly occur near the margins of granitoid intrusions. In general, they are sparsely mineralized with up to 3 percent sulphide minerals and have erratic, but wide distribution throughout volcanic successions of both the Toodoggone Formation and the Takla Group. Copper sulphide and oxide minerals associated with a quartz-epidote-calcite gangue in veins are particularily diagnostic of occurrences in mafic and intermediate volcanic rocks of the Takla Group.

Veins and stockwork veinlets of the Golden Lion, 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 hanging wall panel that is structurally above a footwall panel occupied by lahar and latite flows of the Metsantan member.

Galena, sphalerite and minor chalcopyrite are 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 is 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 on fractures; it is superimposed on vein related alteration.

6.2.1.4 **Potassium-Argon Age Determinations**

Three mineral separates of adularia from selvages along vein margins were examined by x-ray diffraction, then analysed by the potassium-argon method (Table 9). The samples collected are from widely spaced localities at the Lawyers AGB zone, and the Metsantan and Golden Lion prospects (Figure 23).

The oldest age of adularia is 180±6 Ma from the 1+65 north crosscut on the 1750 level of the Lawyers AGB zone (Figure 24). This adularia forms discrete margins up to 3 millimetres thick on amethyst quartz-calcite stockwork veinlets that cut the footwall of the ore zone. Although these veins are spatially associated with the ore zone, they are not known to carry precious metals. Vulimuri et al. (1985) interpret this gangue assemblage as a late stage in the evolution of mineralized veins and breccia zones. In effect the date provides an upper age for ore deposition. Adularia from the Golden Lion occurrence is associated with quartz veinlets which are mainly cored by a base metal assemblage with sporadically large argentite concentrations. It has an age of 176±6 Ma, and adularia from selvages on quartz-calcite-epidote veinlets at Metsantan are 168±6 Ma. The adularia from Metsantan was not from a metal-bearing vein, it is nonetheless typical of the narrow veinlets of comb textured quartz that reportedly contain disseminated pyrite, chalcopyrite, galena, sphalerite and a trace of polybasite (Schroeter and Lefebure, 1987).

Table 9. Potassium-argon analytical data for secondary alteration minerals associated with precious metal occurrences hosted by the Toodoggone Formation.

Sample No.[1]	Property	UTM-Zone 9 Easting	UTM-Zone 9 Northing	Mode of Occurrence	Mineral Analyzed	%K	^{40}Ar rad. 10^{-6}cc/gm	%^{40}Ar rad. / ^{40}Ar total	Apparent[2,3] Age (Ma)	Reference
1. 82AP-T107A -	Lawyers AGB	609500	6356450	Vein selvage	Adularia	7.66	56.564	95.0	180 ± 6	Diakow in Schroeter et al., 1986
2. LD84 -	Golden Lion	602550	6381430	Vein selvage	Adularia	10.38	74.377	97.9	176 ± 6	"
3. LD84 -	Metsantan	601905	6365381	Vein selvage	Adularia	6.09	55.277	96.4	168 ± 6	"
4. T81-191 -	Alberts Hump	595040	6371296	Pervasive alteration	Whole Rock (Alunite)	2.79	21.755	95.2	190 ± 7	Schroeter, 1982
5. G76CS-7WR -	Kemess	636180	6326520	Pervasive alteration	Whole Rock (Sericite)	1.27	9.438	38.8	182 ± 6	Cann and Godwin, 1980

[1] Samples analyzed for K at the Analytical Laboratory, Ministry of Energy, Mines and Petroleum Resources in Victoria, except for sample with prefix "G", which was analyzed with Ar at the Geochronology Laboratory, Department of Geological Sciences, University of British Columbia.
[2] Constants used: $\lambda^{40}K_{\epsilon} = 0.581 \times 10^{-10} yr^{-1}$; $\lambda^{40}K_{\beta} = 4.962 \times 10^{-10} yr^{-1}$; $^{40}K/K = 1.167 \times 10^{-4}$ (Steiger and Jager, 1977).
[3] All errors shown are one standard deviation.

Potassium-argon age determinations on adularia at the AGB and Golden Lion, 180 and 176 Ma, are indistinguishable; however, they contrast or only slightly overlap the analytical error of the 168 Ma age at Metsantan. This variability in age determinations for altered rocks can be explained if: 1) Alteration is associated with the circulation of similar fluids during separate hydrothermal episodes, or 2) Alteration is associated with an older mineralizing event(s), but there has been loss of radiogenic argon from adularia during younger magmatic or hydrothermal activity.

6.2.2 Acid-Sulphate Type

Acid-sulphate type precious metal-bearing deposits have an accessory mineral assemblage of enargite with pyrite ± covellite, which is associated with zones of advanced argillic alteration containing hypogene kaolinite and alunite (Heald, et al., 1987). Numerous zones of intensive and extensive clay and quartz, some of which host gold and silver, occur in a 10 square kilometre area that is roughly bound by Alberts Hump, Tuff Peak and Metsantan Mountain (Figure 23). Similarily at Silver Pond, less than 1 kilometre west of the Cliff Creek zone of the Lawyers Mine, altered rocks are well exposed in a circular area about 1.5 kilometres in diameter. In these areas the alteration is most prevalent in flows of the Metsantan member; it transcends the contact and extends into underlying ash-flow tuffs of the Adoogacho member near Alberts Hump. In both areas dykes of pink, porphyritic andesite transect country rocks replaced by pervasive quartz-clay-alunite minerals, but they themselves are relatively unaltered. 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 secondary mineral assemblages are unaffected by physical and textural parameters of the host rocks.

Alteration at Silver Pond (Diakow, 1983; Figure 26) is representative of similar, but comparatively less well exposed and more metalliferous acid-sulphide type deposits near Alberts Hump. The secondary minerals are typically zoned outward from a central core, in which the original texture and rock forming minerals are completely obliterated by microcrystalline silica with or without pyrite, and trace anatase and zircon. Irregular cavities and narrow open fractures that sometimes are lined by quartz druse and commonly contain interlocking tabular barite crystals occur in zones of microcrystalline silica. These zones of silica weather as low-lying mounds that vary from several metres to tens of metres across. The transition into an annular zone of less silicic rock is gradational; it is less resistant, and volcanic textures are better preserved as distance from the silicified core increases. Dickite and minor nacrite are diagnostic with quartz and trace amounts of Na-rich alunite throughout the matrix, and as discrete pseudomorphs after plagioclase. Although the rocks are generally hues of white, they are commonly tinted by limonite and goethite after the few percent of disseminated pyrite. The argillic zone grades outward to a broad peripheral zone with chlorite, epidote, and carbonate in part replacing plagioclase and mafic phenocrysts and matrix of the rocks. Pyrite is widespread in concentrations of up to 5 percent. 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.

Presently, the most significant precious metal-bearing concentrations of the acid-sulphate type are within a radius of 3 kilometres east-southeast of Alberts Hump at the Bonanza-Verrenass, BV and Thesis zones of the Al deposit. The Al deposit has published reserves of 246,000 tons at a grade of .29 oz/ton gold (Schroeter et al, 1989). The Bonanza-Verrenass is the largest and most intensely explored zone.

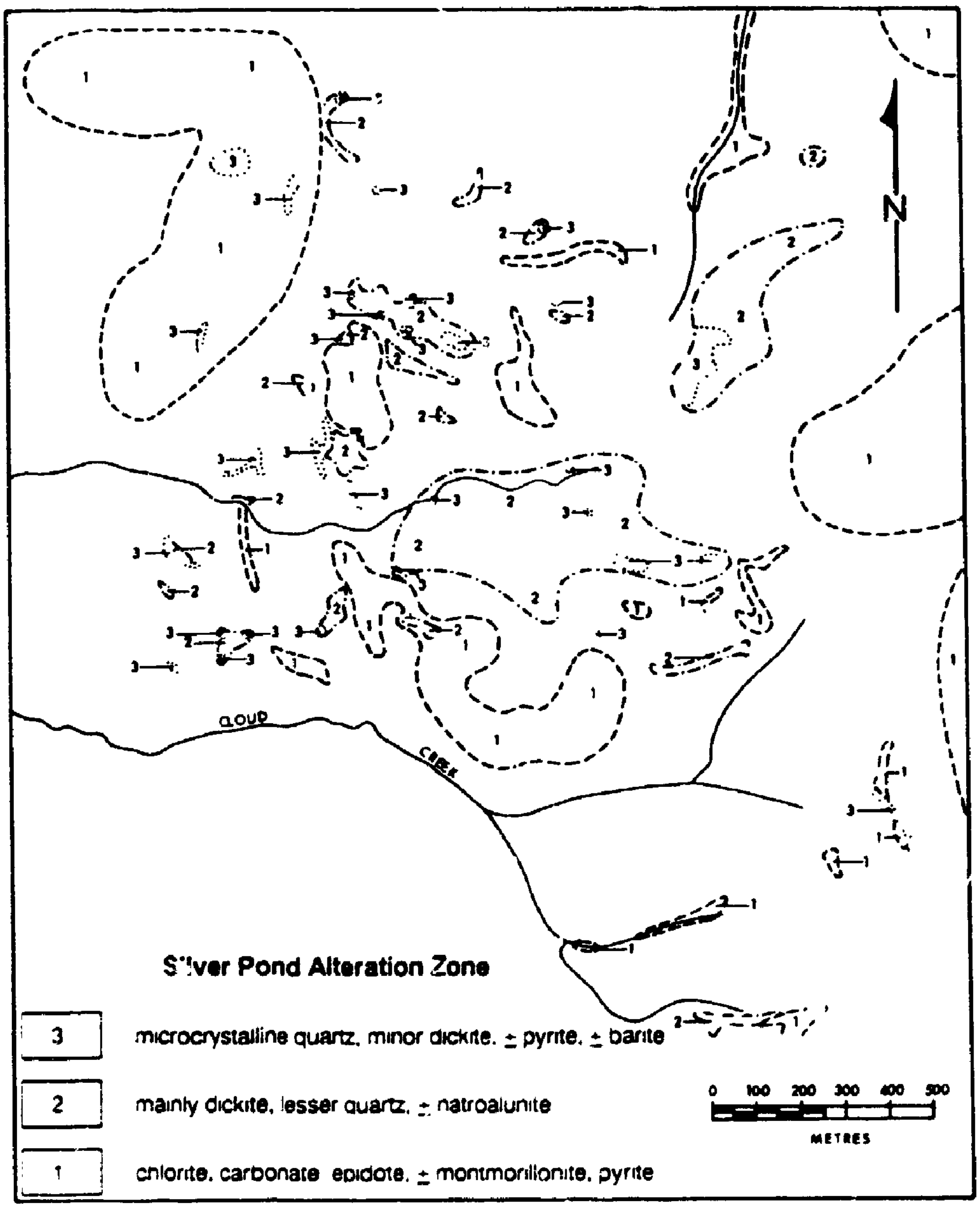

Figure 26. Surface distribution of secondary mineral assemblages at Silver Pond.

The ore is native gold mutually associated with barite in open-space cavities of a clay-silica core that is flanked by inner quartz-dickite, and outer quartz-illite-hematite assemblages (Clark and Williams-Jones, 1986). Minerals present in minor amounts include: pyrite, electrum, tetrahedrite, argentite, chalcopyrite galena and sphalerite. Although the BV zone also has a gold-barite association it differs from the Bonanza zone in that ore is in discrete barite-quartz-pyrite veins, and sericite is abundant while an advanced argillic mineral assemblage is notably absent (Clark and Williams-Jones, 1989)

The external geometry of the silicic core is generally crudely circular to elliptical with a clay-rich annular zone that passes outward into a broad propylitic zone. At Silver Pond a control for the morphology and apparent random distribution of alteration is difficult to reconcile in terms of mappable structures or differences in the physical character of host strata. Although in places at Silver Pond and at the summit of Alberts Hump a crude stratiform relationship of altered rocks apparently concordant with relatively unaltered rocks hints at the importance of bedding parallel controls. Metal-bearing zones east-southeast of Alberts Hump, however, are crudely elliptical and discontinous along variable linear trends, mainly to the north and the northwest; in places breccia ore is on faults within a complex fracture system. This fracture system coincides with a regional northwest structural trend of aligned precious metal deposits and prospects to the southeast of Alberts Hump. Along this corridor of metal deposits, particularily in the vicinity of Tiger Notch Pass, several elongate zones of pervasive silicic and advanced argillic alteration occur along splay faults projecting from the Drybrough Fault (Mihalynuk, 1983). Further south at the Wrich prospect, 5 kilometres south of the Finlay River, a silicic and advanced argillic core zone is enclosed by a zone of propylitic alteration that is situated 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 advanced argillic alteration with major faults. Moreover, the secondary mineral assemblage in zones adjacent to these major structures are identical to those at Silver Pond and Alberts Hump areas; however, they are in younger pyroclastic rocks of the Attycelley and Saunders members.

6.2.2.1 Potassium-Argon Age Determinations

At Alberts Hump alunite and microcrystalline quartz form a resistant node that grades outward to a broad area of quartz-clay alteration. A sample of alunite has a K-Ar age determination of 190±8 Ma (Schroeter, 1982; Table 9). Precious metals are not known to be directly associated with the advanced argillic alteration at Alberts Hump. From this date may be inferred a period of hydrothermal activity which may also have caused similar intense alteration hosting precious metal concentrations at the Bonanza and BV deposits. However potassium-argon age determinations on sericite from these deposits are 171±6 Ma and 152±5 Ma respectively (Clark and Williams-Jones, 1989). They suggest that the hydrothermal activity was either a repetitive event occurring in intervals of about 20 Ma, or the discordance in ages is a result of a loss of radiogenic argon in sericite. A zone of quartz-alunite-dickite called Jan, which is on a ridge 9 kilometres due east of the Shas precious metal deposit, has a K-Ar age on alunite of 193±7 Ma (Clark and Williams-Jones, 1989). This date is concordant with alunite alteration at Alberts Hump. Near Alberts Hump, as well as at Silver Pond, slightly altered pink, porphyritic andesite dykes cut the pervasively altered rocks. These dykes have similar texture and composition as dykes cutting the Black Lake stock. They possibly represent a phase of the Black Lake stock that is perhaps synchronous or post-dates the youngest K-Ar ages for the pluton of 193 Ma and 190 Ma (Gabrielse, et al., 1980).

6.3 Porphyry Copper-Molybdenum Prospects

Copper with or without molybdenum is in quartz veinlets or disseminations within volcanic rocks cut by Early Jurassic plutons of granodiorite to quartz monzonite composition. Kemess, 11 kilometres southeast of the Finlay River, is one of the better known prospects of this type in the study area, which was actively explored during the late 1960's and the early 1970's. The metal-bearing rocks at Kemess are volcanic rocks of the Takla Group that have been intruded by an Early Jurassic granitoid stock and dykes (Cann, 1976). Chalcopyrite disseminations and veinlets are widespread in a broad gossan marked by extensively developed chlorite-carbonate-epidote-pyrite. Copper grades apparently are greatest adjacent to a local zone of quartz-sericite-pyrite, in which there are scarce molybdenite coated fractures (Cann, 1976).

A K-Ar whole rock age of 182±6 Ma from the zone of intense quartz-sericite-pyrite is interpreted as a period of hydrothermal activity which is temporally related to the deposition of metallic minerals (Cann and Godwin, 1980). This age is identical to that of biotite from the nearby granodiorite pluton. It apparently post-dates cooling of the intrusion (see Section 3.9.1.1).

Elsewhere in the study area sparse disseminated copper occurs in broad areas of propylitic alteration that commonly correspond with gossans; however, not all of them have exposed granitic plutons nearby.

6.4 Skarn Prospects

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 is sporadically distributed pods which are rarely more than 1 or two metres long. They are magnetite-sphalerite-galena with green amphibole, garnet, epidote and pyrite within marble. At the Amigo prospect approximately 1300 metres southwest of Drybrough Peak, native gold is reportedly associated with massive magnetite over 10 metres at the contact of limestone and granodiorite (Schroeter, unpublished report, 1987).

6.5 Placer Deposits

As early as the mid-1920's, prospectors worked small scale placer deposits on McClair Creek near the confluence of Toodoggone River. Gold valued at 17,500 dollars was recovered by this operation. The lower part of McClair Creek is a gossanous zone along a structural contact between volcanic rocks of the Toodoggone Formation and granodiorite.

6.6 Discussion

Panteleyev (1986) integrated available geological and mineralogical data for various mineral deposit types in the Toodoggone area within a broader context to formulate a British Columbia Epithermal Model. In the Toodoggone area, the model proposes a continuum of mineralized environments that range from porphyry type deposits and skarn spatially associated with granitoid intrusions at depth, to quartz veins at shallower levels that pass upwards into near-surface acid-sulphate alteration zones.

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 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 wallrock alteration, and 2) precious metals with barite are in fractures cutting broad zones of pervasive quartz-alunite-clay alteration. Both types of precious metal-bearing deposits formed in fractured and faulted volcanic rocks of Late Triassic to Middle Jurassic age.

In general, the mutual association in veins of ore minerals with hydrothermal silica and other gangue minerals implies simultaneous precipitation from aqueous thermal fluids. Studies of fluid inclusions in quartz from vein deposits in the Toodoggone area indicate that ore minerals were deposited by low temperature (230 to 270°C) and low salinity (3.3 to 6.5 equivalent weight percent NaCl) fluids (Forster, 1984). Barite associated with gold in acid-sulphate alteration at the Al deposit near Alberts Hump, were also generated by cool (180 to 200°C) and dilute (3.0 equivalent weight percent NaCl) solutions (Clark and Williams-Jones, 1986). The character of these fluids resembles those of geothermal fluids and deeper epithermal deposits in which the hydrologic regimes are dominated by meteoric water. Veins with comb, 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, veins with silica-rimmed breccia fragments are healed by microcrystalline quartz. This might suggest hydrostatic rupture or hydraulic fracturing during episodic boiling. Boiling, in addition to mixing of hydrothermal and meteoric fluids provide the two most effective mechanisms for deposition of precious metals in epithermal systems (Drummond and Ohomoto, 1985; Henley, 1985).

The ages of the alteration minerals indicate that episodes of hydrothermal activity closely followed emplacement of Toodoggone volcanic and plutonic rocks. However, the relatively young dates, in particular those from adularia and sericite compared to alunite dates, demonstrates the difficulty in relating the alteration and associated mineralization to specific magmatic-hydrothermal events. Despite this uncertainty, two periods of ore deposition are proposed, based on type of mineralization, radiometric ages of potassium-bearing secondary minerals and the stratigraphic position of alteration zones.

The earliest hydrothermal mineralization is barite-gold veins associated with advanced argillic alteration at the Bonanza-Verrenass 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 at Alberts Hump based on dated alunite. Sericites associated locally with the metal-bearing advanced argillic alteration, yielded significantly younger K-Ar ages of 171 Ma at the Bonanza-Verrenass and 152 Ma at the BV zones (Clark and Williams-Jones, 1989). This discordance likely reflects loss of radiogenic argon from poorly retentive hydrothermal sericite rather than discrete hydrothermal activity nearly 40 million years younger. Clark and Williams-Jones (1989) suggest the younger radiometric ages from sericites may result from resetting during a local thermal episode related to dyke emplacement.

The apparently younger hydrothermal mineralization is represented by the various zones of adularia-sericite metalliferous veins at the Lawyers Mine as well as the related acid-sulphate alteration at Silver Pond less than 1 kilometre to the west. The Lawyers snd Silver Pond zones are thought to represent different structural levels and stages in one large hydrothermal system. The 180 Ma timing of metal deposition at the Lawyers AGB zone based on an adularia date is believed to be an upper limiting age. This is implied by the range of K-Ar dates from identical occurrences with adularia in vein selvages from Golden Lion (176 Ma) and Metsantan (168 Ma). The range of adularia dates suggests that variable loss of radiogenic argon occurred, possibly during regional low grade metamorphism. Because there is a striking resemblance in alteration mineralogy at Alberts Hump with that at Silver Pond, it is tempting to suggest that they formed independently, but roughly at the same time. This would also necessarily imply that ore deposition at Lawyers and at Alberts Hump are also contemporaneous around 190 Ma. However, the precious metal bearing veins at Lawyers have very similar metallic and alteration assemblages as veins at the Shas deposit, which are in strata as young as the Attycelley member. If the association of Lawyers with Shas based on physical similarities is valid; these deposits represent a discrete, younger mineralizing event distinct from that 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 epithermal districts described by Heald et al. (1987). Sillitoe (1989) emphasizes the association between acid-sulphate and adularia-sericite gold deposits and intrusions in volcanoplutonic island arcs in the western Pacific. Interestingly, the acid-sulphate alteration zones at Alberts Hump and in the Jan area have K-Ar ages from alunite that are identical to cooling ages of 190 Ma and 193 Ma for the Black Lake stock. Although there is no evidence for large plutons closer than 6 kilometres from Silver Pond and 12 kilometres from Alberts Hump, these deposits have relatively unaltered dykes cutting the advanced argillic alteration zones. The dykes 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 vapors commonly along with base metal sulphides. As the magmatic activity wanes this early fluid regime is overprinted by meteoric water dominated fluids. Mixing of the different source fluids and boiling induce precious metals to precipitate in deeper and more peripheral adularia-sericite veins; whereas, the earlier deposited metals 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 earliest epithermal-type mineralization dated in the Toodoggone area is related to acid-suphate type alteration. It is associated with hydrothermal systems closely related in time to cooling of the Black Lake and similar stocks. Adularia-sericite type mineralization appears to post-date acid-sulphate type by 10 million years or more. Timing of this ore deposition appears to be associated with the waning stages of volcanic activity that comprises the Toodoggone Formation. This style of ore deposition is in accord with magmatic events 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 in short-lived events within a longer period of local hydrothermal activity. This most commonly occurs during the waning stages of volcanism or post-dates it by 1 million years or more.

Major Toodoggone precious metal deposits including Lawyers Mine, Baker Mine, Al and Shas all lie within a northwesterly trending corridor. Elongation of the Black Lake stock, other smaller plutons and dyke 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 relative cool and dilute hydrothermal waters. Steeply dipping fracture and fault systems host all major precious metal deposits in the study area. In particular, the vein systems at the Lawyers, Shas and Baker Mine 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.

CHAPTER 7

CONCLUSIONS

1. The Early and Middle Jurassic Toodoggone Formation is a new time-stratigraphic division of the Hazelton Group in the Toodoggone River map area. The Toodoggone Formation has six members which represent subaerial eruptions during two major eruptive cycles. Marine sedimentary rocks locally occupy the interval between eruptive cycles. The volcanic rocks are high-potassium, calc-alkaline dacite ash-flows and tuffs, and quartz-bearing latite flows. The lower contact of the Toodoggone Formation is an unconformity with Late Triassic and older submarine, volcanic and sedimentary rocks of the Takla and Asitka Groups. The upper contact is an unconformity with Late Cretaceous continental sedimentary rocks of the Sustut Group.

2. The Toodoggone Formation was erupted during a span of roughly 22 million years. Extension by block faulting characterizes the tectonic history of the Toodoggone Formation. It is believed to be the mechanism which regulated the emplacement of granitic plutons and dykes, and the geometry of cogenetic volcanic deposits that erupted from central and possibly fissure vents.

3. Volcanic, and cogenetic plutonic rocks of the Toodoggone Formation record magmatism in an east-facing island arc constructed upon a thick, continent-like lithosphere that comprises at least two older island arc successions. Although involvement of the crust in magma genesis is not proven, it seems probable; initial strontium ratios are intermediate at 0.7041. Passage possibly through thick crust slowed the rate of ascent of rising magma bodies causing them to differentiate, partly crystallize and ultimately extrude the crystal-rich and remarkably uniform intermediate compositions that characterize volcanic rocks of the Toodoggone Formation.

Apparently, the Toodoggone east-facing arc segment was generated by steep, perhaps oblique westward subduction which resulted in intra-arc extension and magmatism that is spatially and temporally related to the development of an elongate volcanic depression. This tectonic evolution is consistent with that documented for the Hazelton Group south of the Toodoggone area, which suggests that a Jurassic, east-facing, extensional island arc was constructed along much of the present eastern boundary of the Stikine terrane.

4. Prolonged extension and magmatism during construction of the Toodoggone island arc provided the right environment to form a variety of mineral deposit types. The most important of these are gold and silver-bearing quartz veins and near-surface zones of intense acid-leached volcanic rocks. Potassium-argon dates from alteration minerals indicate two ore-forming, hydrothermal episodes. The earliest mineralizing episode corresponds with the lull between volcanic cycles. The younger mineralizing event is apparently close in time and spatially related to waning ash-flow volcanism and accompanying structural subsidence that mark the final extrusive event within the Toodoggone Formation.

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

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

Determination of CO_2 was by KOH absorption with volumetric gas measurement on a Leco induction furnace. Determination of H_2O^- is by drying two grams of sample powder at 110°C overnight then weighing the cooled sample for weight loss. Determination of H_20^+ 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 programme which monitors and corrects for instrument drift. Precision of analyses is about 0.3% relative standard deviation (RSD) with accuracy, estimated from runs of international standards, of 0.5% 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 percent, most are within the range of 99 to 100 percent.

The composition of volcanic rocks from the Toodoggone Formation are 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 lessthan 4 weight percent.

Major Elements Analyses and CIPW Molecular 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-26
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	0.59	0.56	0.50	0.53	0.46	0.52	0.50
Al_2O_3	16.16	16.66	15.53	16.24	16.83	17.52	15.95	15.31	15.24	16.77	15.36
Fe_2O_3	4.49	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	1.59	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	3.55	4.41	3.52
K_2O	3.65	3.04	3.42	3.93	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	0.65	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*	4.53	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	2.76	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	13.65	8.70	11.10
c	-	3.94	-	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	28.70	22.81	5.09	1.75	17.33
di	5.96	-	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	0.45	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 2. Specimen number prefix indicates collector: AP - A. Panteleyev, D - L. Diakow, MM - M. Mihalynuk, TS - T. Schroeter.

Hetsantan 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	55.83	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.[illegible]	16.05
Fe_2O_3	3.44	3.89	4.80	5.08	5.72	6.02	6.93	5.91	[illegible]	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	3.69	2.80	2.94
P_2O_5	0.25	0.34	0.26	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	0.46	0.71	0.54	0.35
CO_2	0.21	0.35	0.42	0.26	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	99.68	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	0.76	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	9.16	3.65	8.44	12.54	12.21
c	0.16	-	-	-	-	-	0.44	1.95	-	-
or	17.96	19.67	20.94	18.38	22.25	16.72	19.86	24.09	16.86	17.93
ab	32.91	33.41	37.85	31.76	45.69	32.95	42.29	41.49	35.09	35.05
an	21.06	20.25	16.76	21.40	11.52	21.79	13.67	6.39	16.69	16.05
di	-	2.73	3.38	5.45	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	0.75	-	3.53	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	39.60	24.69	13.35	30.47	29.66

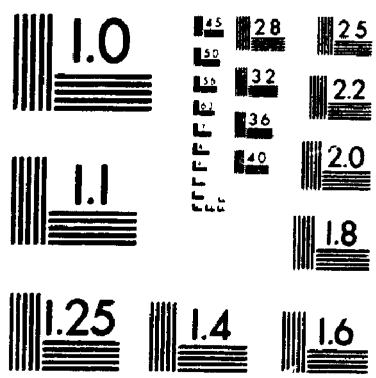
Metsantan member (map units 3, 3a)

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	58.71	57.86	60.29	59.01	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	16.63	16.08	16.76	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	0.22	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	4.15	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	2.06	0.99	0.62	1.99	2.08	2.57	2.24	2.04	2.68
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	5.63	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	11.66	12.66	10.43	10.23	6.12	5.89	14.29	14.10	2.99
c	1.00	-	0.80	-	-	-	0.16	-	-	-
or	24.99	18.99	21.51	19.41	21.20	2[illegible].06	23.63	32.02	28.08	19.26
ab	36.74	33.16	37.80	37.05	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)

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	55.83	57.75	59.30	61.62	68.24	60.24
TiO_2	0.70	0.61	0.61	0.64	0.63	0.60	[illegible]	0.45	0.40	0.50
Al_2O_3	15.61	15.66	15.44	16.34	16.49	15.64	15.39	15.58	12.92	15.22
Fe_2O_3	4.40	6.00	4.75	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	2.57	3.59	2.67	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	2.45	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	0.15	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	96.92	99.44	99.21	99.54	100.29	99.46	99.99	99.61	99.62	100.26
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	21.5	2.28	-	-
K_2O/Na_2O	1.79	0.53	1.60	1.02	1.23	0.76	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	27.59	35.93	40.64	-	-
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	5.03	5.11	4.44	-	-
mt	6.25	-	2.20	0.59	1.68	5.69	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	0.27	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	-	-

3 of/de 3



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No 2)

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	2.5[illegible]	3.01	2.88	3.26	3.62	2.48	2.77
FeO	1.85	2.10	2.04	2.31	2.28	2.34	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	1.69	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	16.74
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	0.84	2.74	1.69	-	-	-	-
hy	6.77	5.77	6.08	4.64	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	37.86	36.09	33.33	35.50	24.51	39.58	38.10

Sample*	51 D163	52 D197	53 D200	54 D201	55 MM-1	56* D198	57* AP-7	58 D300-3	59 AP-15
	Saunders member (map unit 6)					Attycelley member (map unit 5)			
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	0.46
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	0.2[illegible]	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	3.60	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	3.65	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	[illegible].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	0.45	0.63
AN	35.68	48.27	35.12	-	-	29.18	27.40	16.81	[illegible].69

	Hypabyssal domes (map unit E)					(D)	(D)	(A)	(C)	(B)	(B)
						Dykes, sills and small plutons (map unit)					
Sample	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	0.56	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	2.05	8.49	6.04	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	0.16	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	13.76	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 potassium-argon 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 handpicking techniques.

Mineral concentrates weighed to 0.2 grams were fused in 2 grams of $LiBO_2$ at 1050°C. The glass was dissolved in 4 percent HNO_3 and stabilized with 3 millitres of 50 percent HF; a small amount of CsCl is 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, 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 Jager, 1977).

APPENDIX C

FOSSIL IDENTIFICATIONS

Macrofossils from the Toodoggone Formation

Identification: Fossils collected and studied in 1975, by Dr. H.W. Tipper of the Geological Survey of Canada, were also studied 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, and Giselle Jacobs collaborated with Howard in confirming generic identification of some of the ammonites. Dr. Tipper's revised report (GSC report J2-1989-HWT) and previous written correspondence are quoted in the following report.

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

Host Rock: In situ blocks of limey tuffaceous sediment that are restricted to a glacial meltwater channel

Fauna:

Ammonites

Phylseogrammoceras sp.

Phymatoceras sp.

Haugia? spp.

hildoceratid ammonite?

Bivalves

Myaphorella sp.

Pholadomya sp.

Oxytoma sp.

astartidae

gryphaeidae

ostreidae

various other bivalves

Coleoids

belemnites

Age and Correlation: The ammonites indicate a mid to upper 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 Mt. 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 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 From the Toodoggone Formation

Identification: 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.

Host Rocks: Sample 83LD-268-1: marlstone and chert in a well-bedded succession of siltstone and coarse sandstone from the Moyez member, which unconformably rest on nearby ash-flow tuffs of the Adoogacho member. Sample 83LD-290-4: plant debris from maroon-colored mudstone and fine-grained sandstone forming a 20 metre thick lense 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

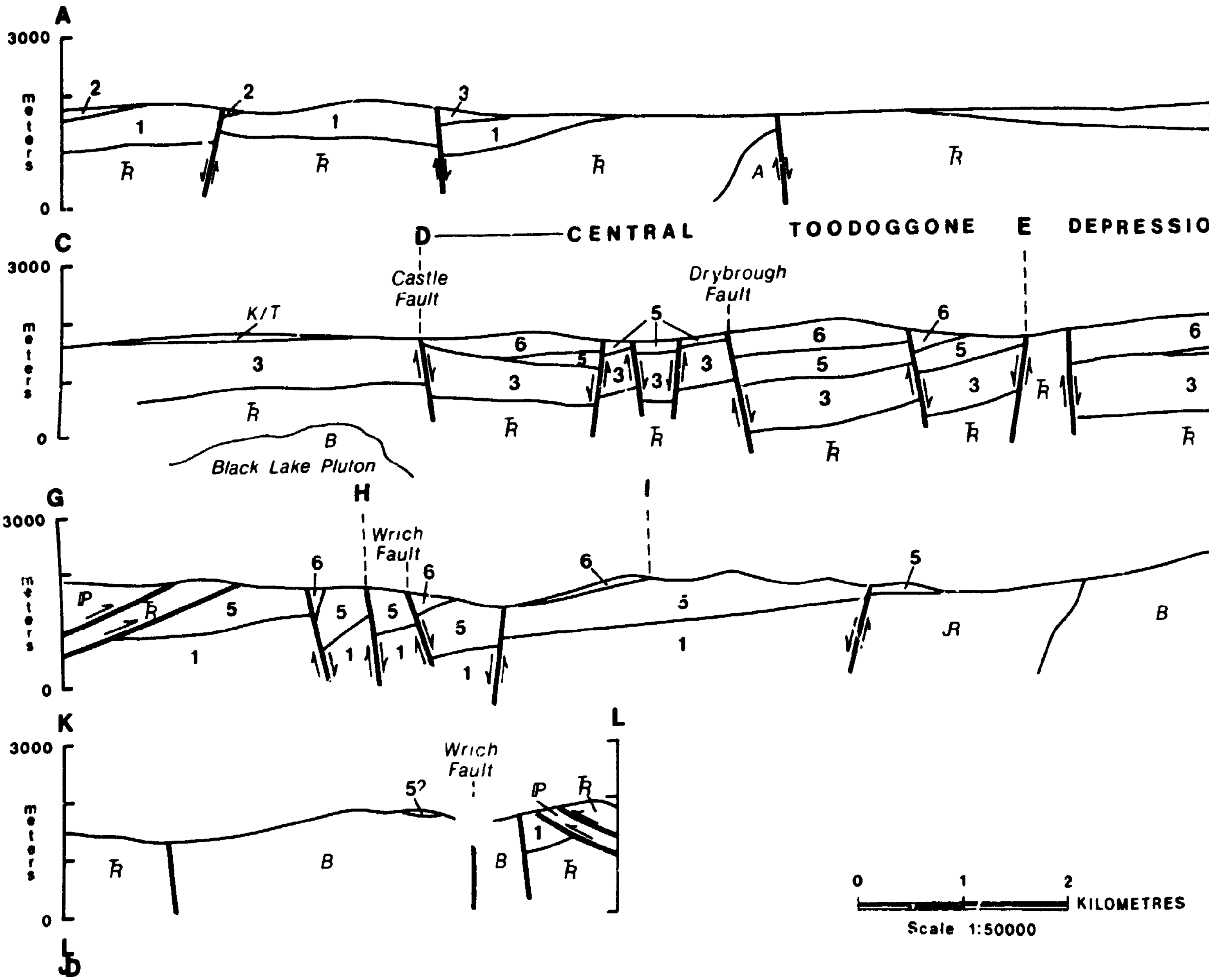
Vallasporites antonii

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 non-marine 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 carbonitized (TAI of 5) which indicates heat generation during burial of at least 270°C and perhaps over 300°C.


A
3000
meters
0
C
D
CENTRAL
TOODOGGONE
E
DEPRESSIO
Castle Fault
Drybrough Fault
K/T
B
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2
KILOMETRES
Scale 1:50000

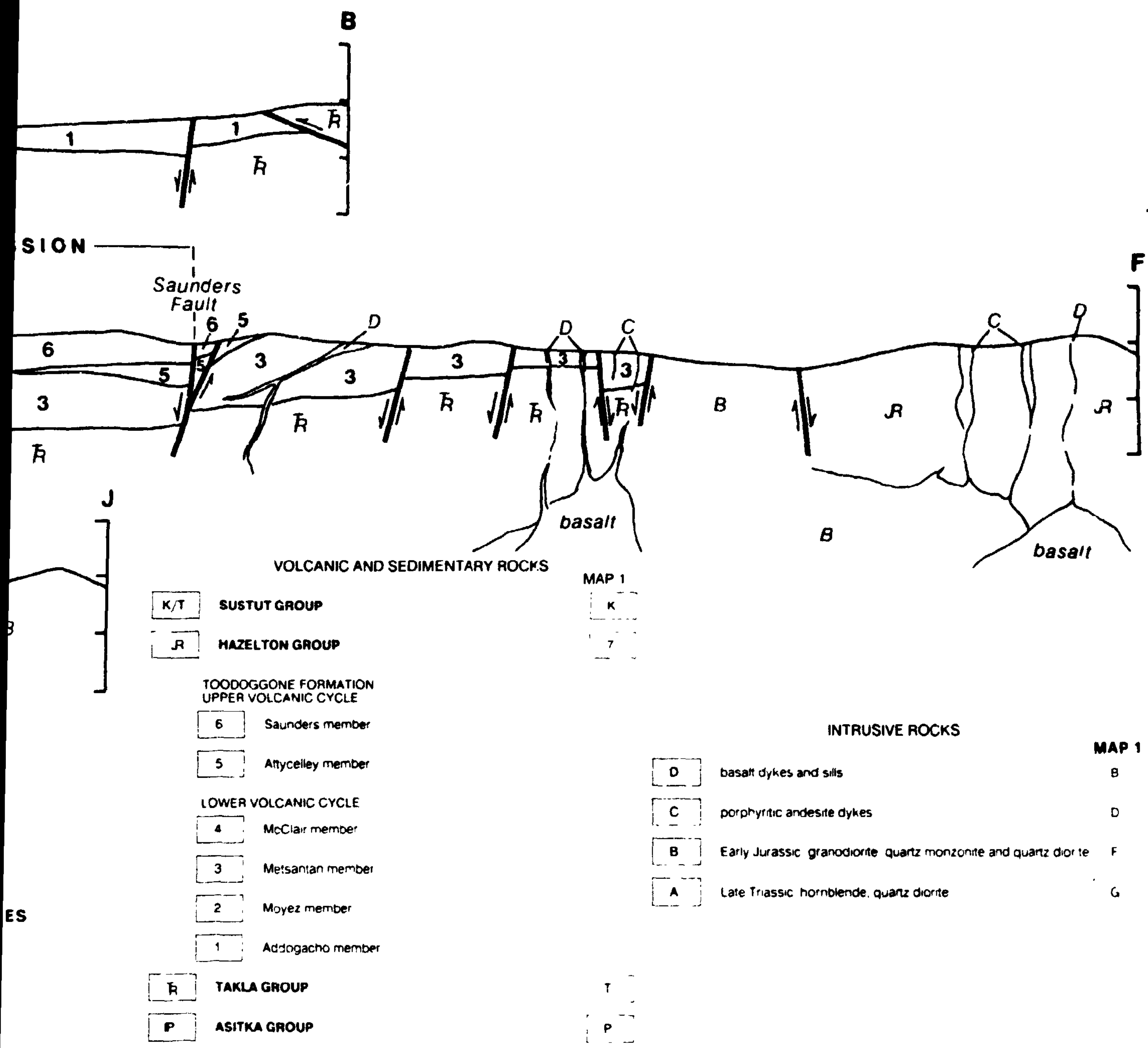
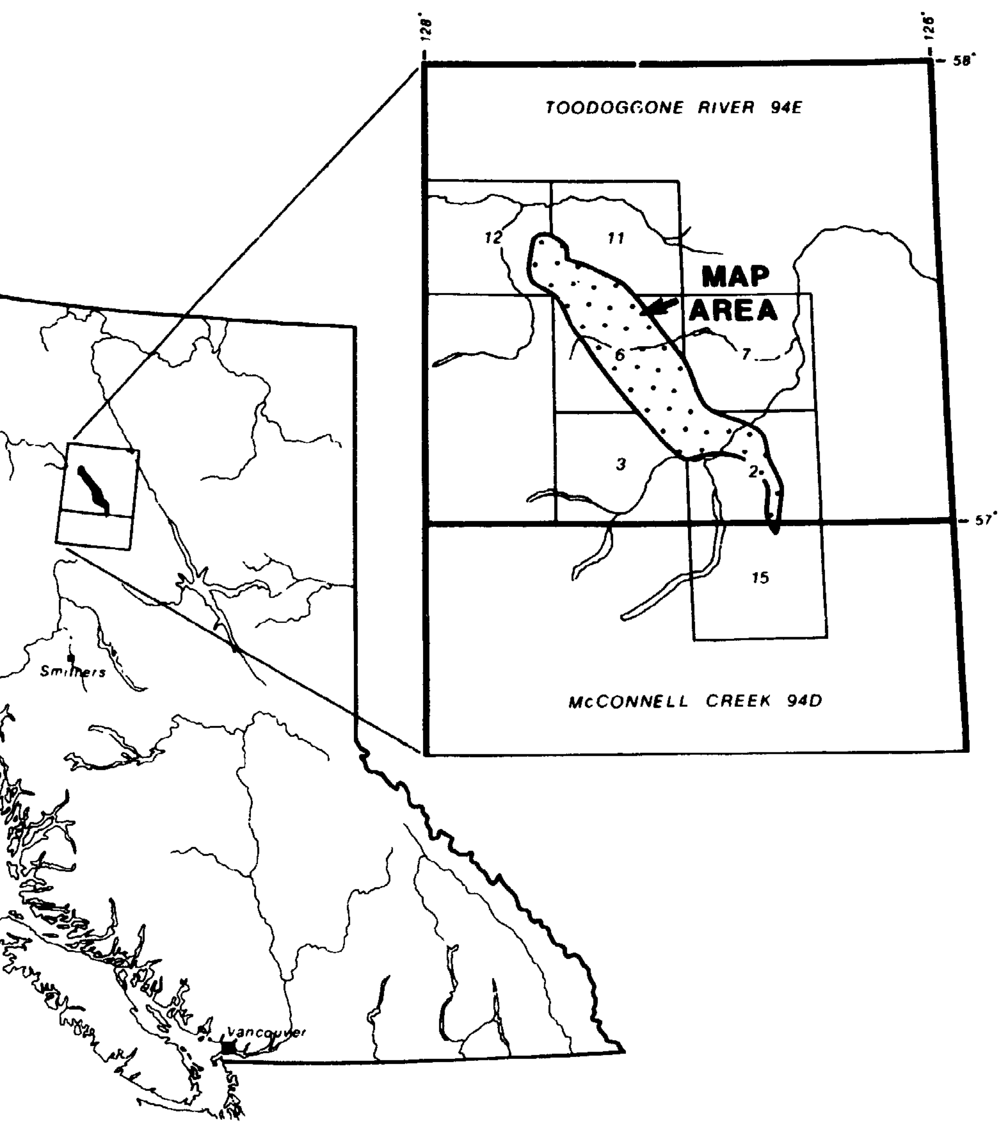


Figure 21. Cross sections, Toodoggone River area. Sections correspond with locations illustrated in Figure 20 and Map 1.

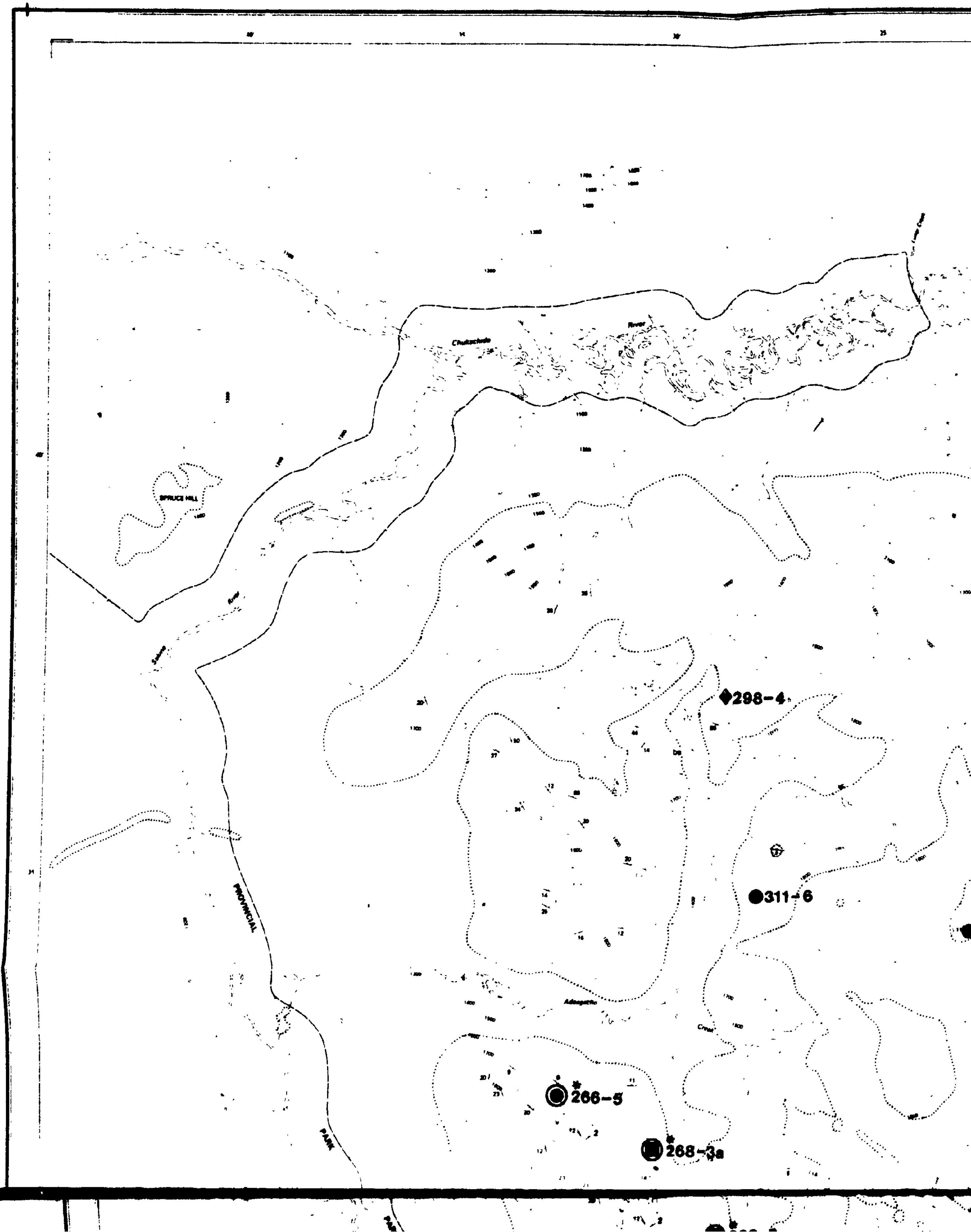

SPRUCE HILL
Chukachida
River
Lower
Bajocian
(GSC)
PROVINCIAL
PARK


CLAW MOUNTAIN
HARMON PEAK
BRECCIA PEAK
352
202
F
T
E
D
7
1a
3b

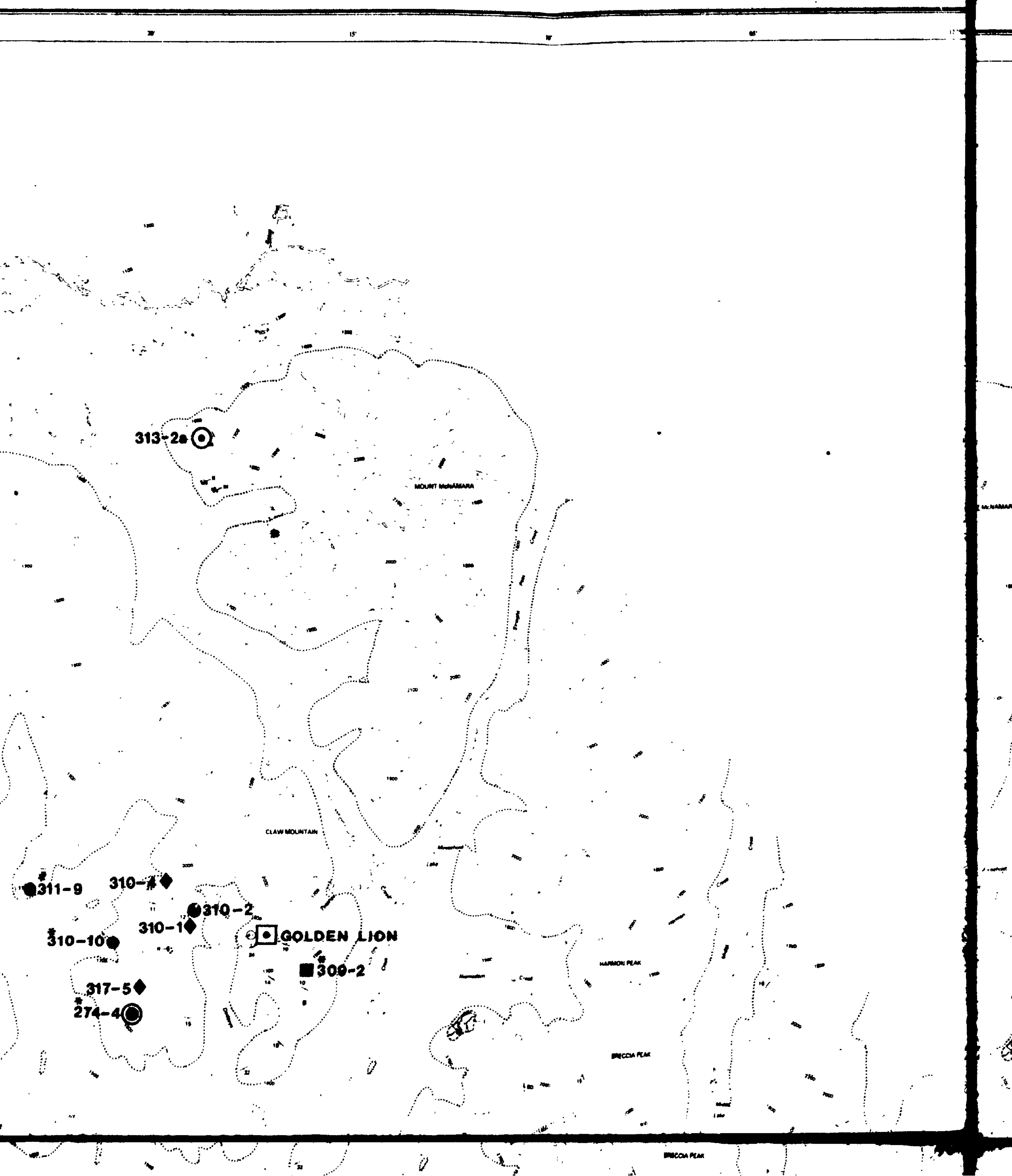

MOUNT McNAMARA
CLAW MOUNTAIN
HARMON PEAK
BRECCIA PEAK
CONTACT PEAK
Lake

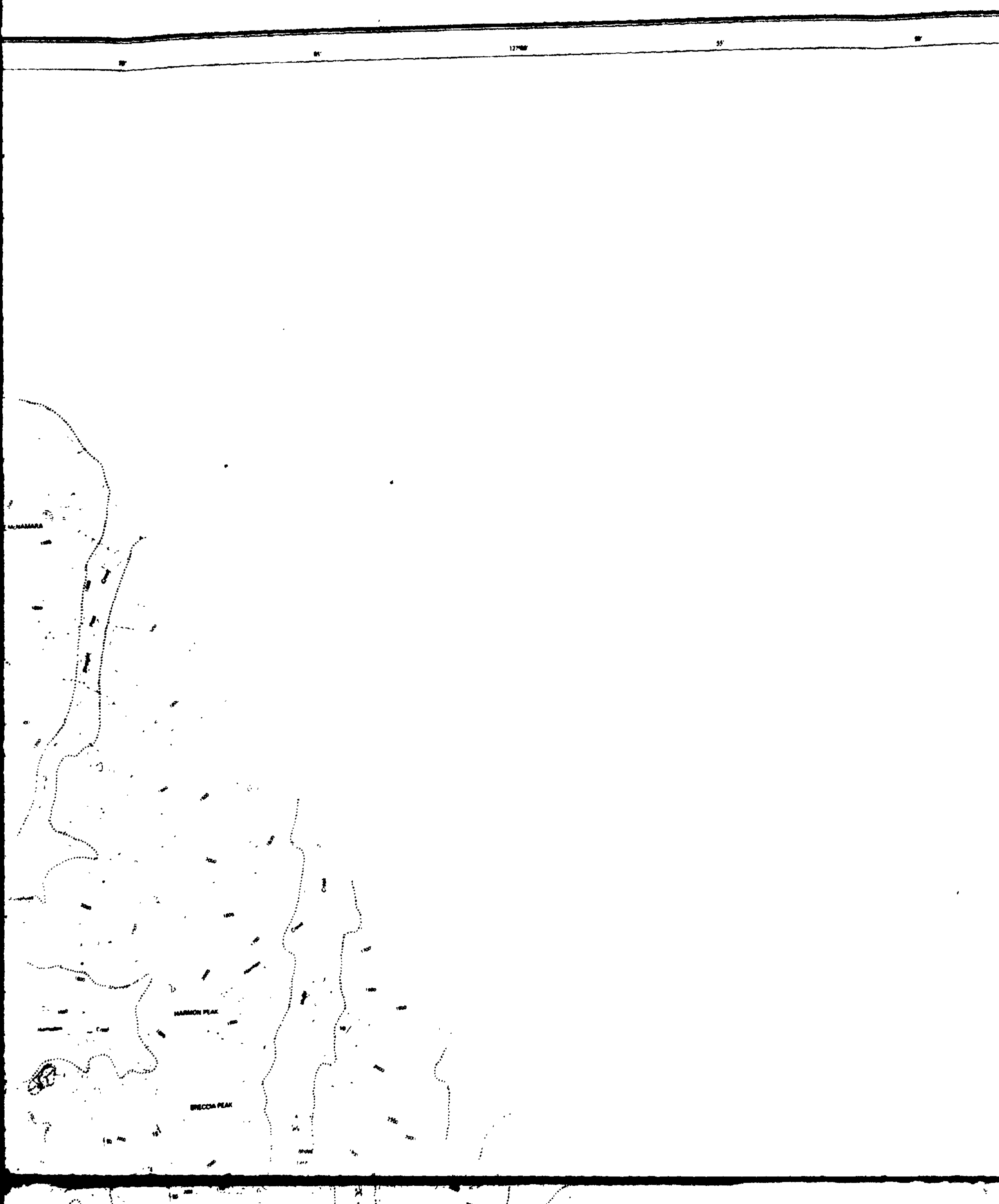


LOCATION MAP

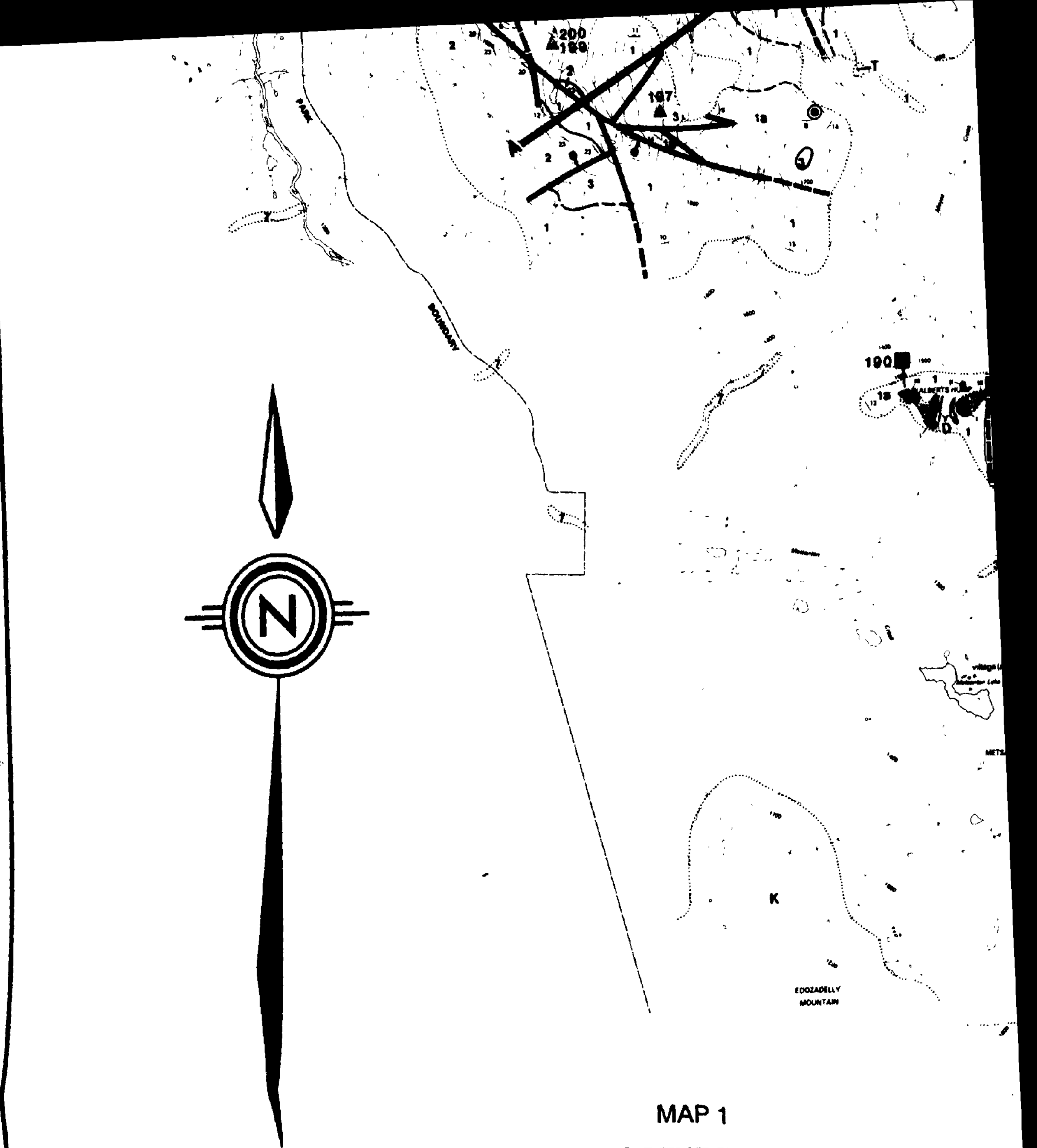


Chutachute
River
SPRUCE HILL
PROVINCIAL
PARK
Adsapattle
Creek
298-4
311-6
266-5
268-3a


313-2a
MOUNT McNAMARA
CLAW MOUNTAIN
311-9
310-2
310-1
310-10
GOLDEN LION
309-2
317-5
274-4
HARMON PEAK
BRECCIA PEAK
BRECCIA PEAK



55'
McNAMARA
HARMON PEAK
BRECCIA PEAK



MAP 1

GEOLOGY OF THE TOODOGGONE FORMATION, TOODOGGONE RIVER AREA, NORTH-CENTRAL BRITISH COLUMBIA (NTS 94E)

LEGEND

LAYERED VOLCANIC AND SEDIMENTARY ROCKS

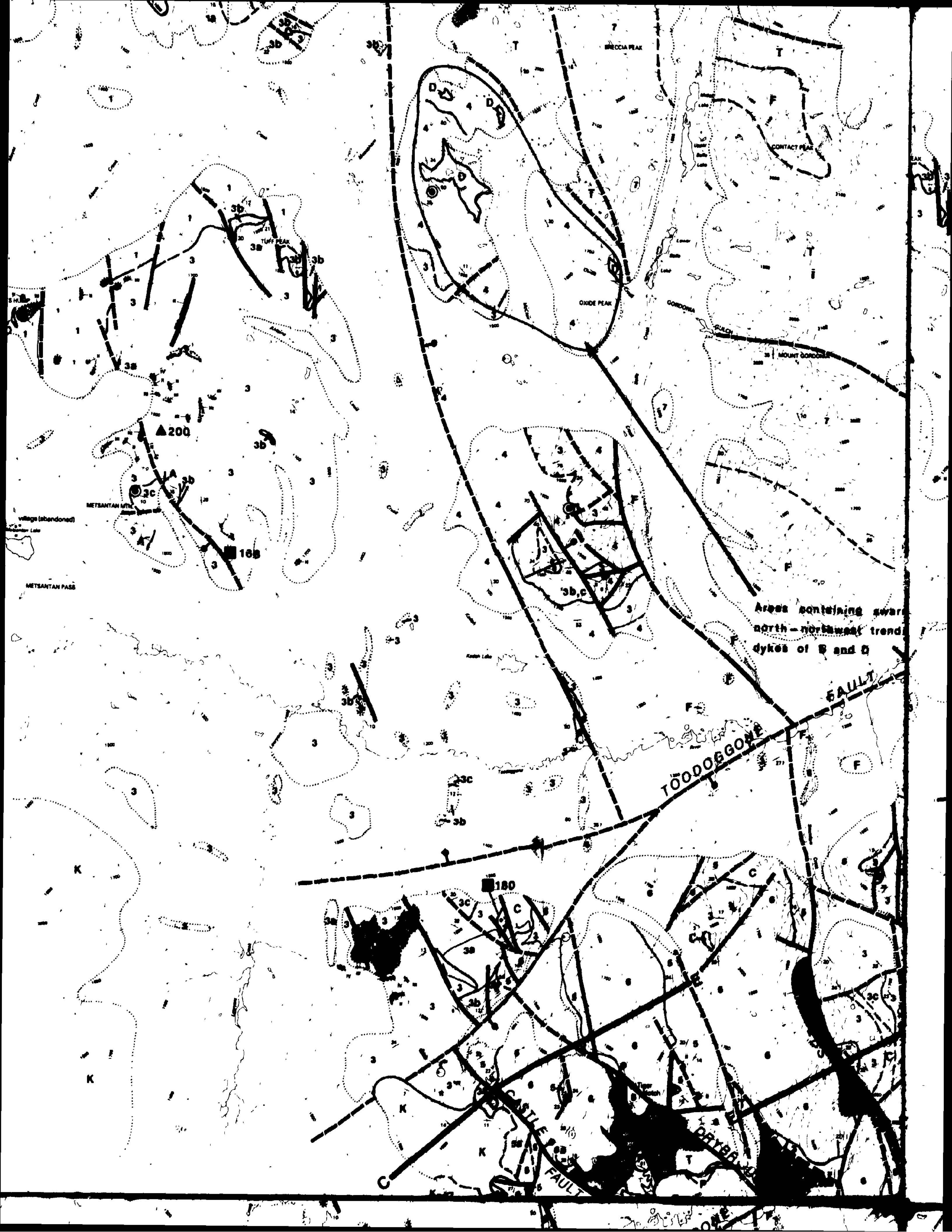
QUATERNARY

	unconsolidated glacial, alluvial, and colluvial deposits

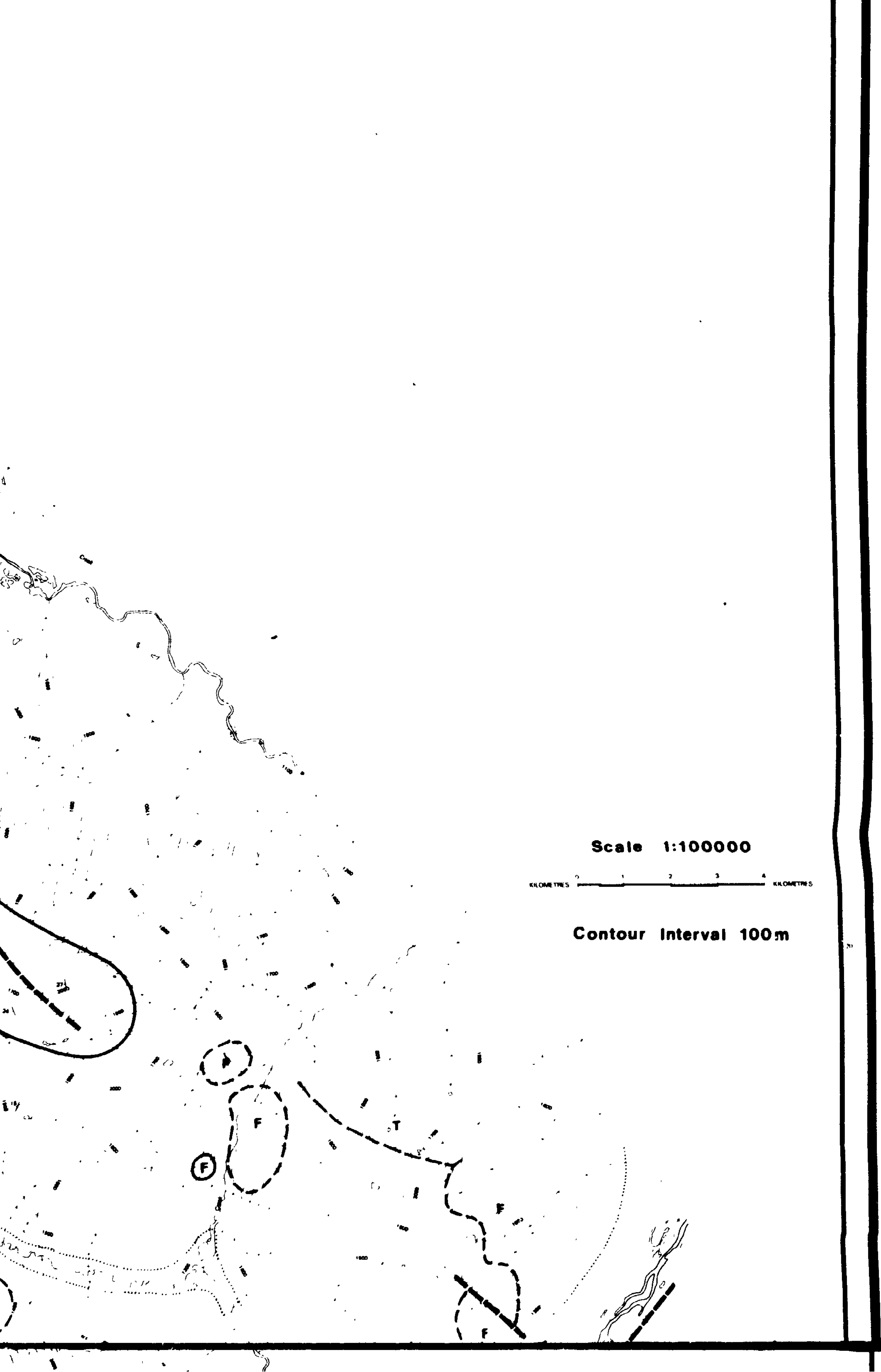
CRETACEOUS
UPPER CRETACEOUS

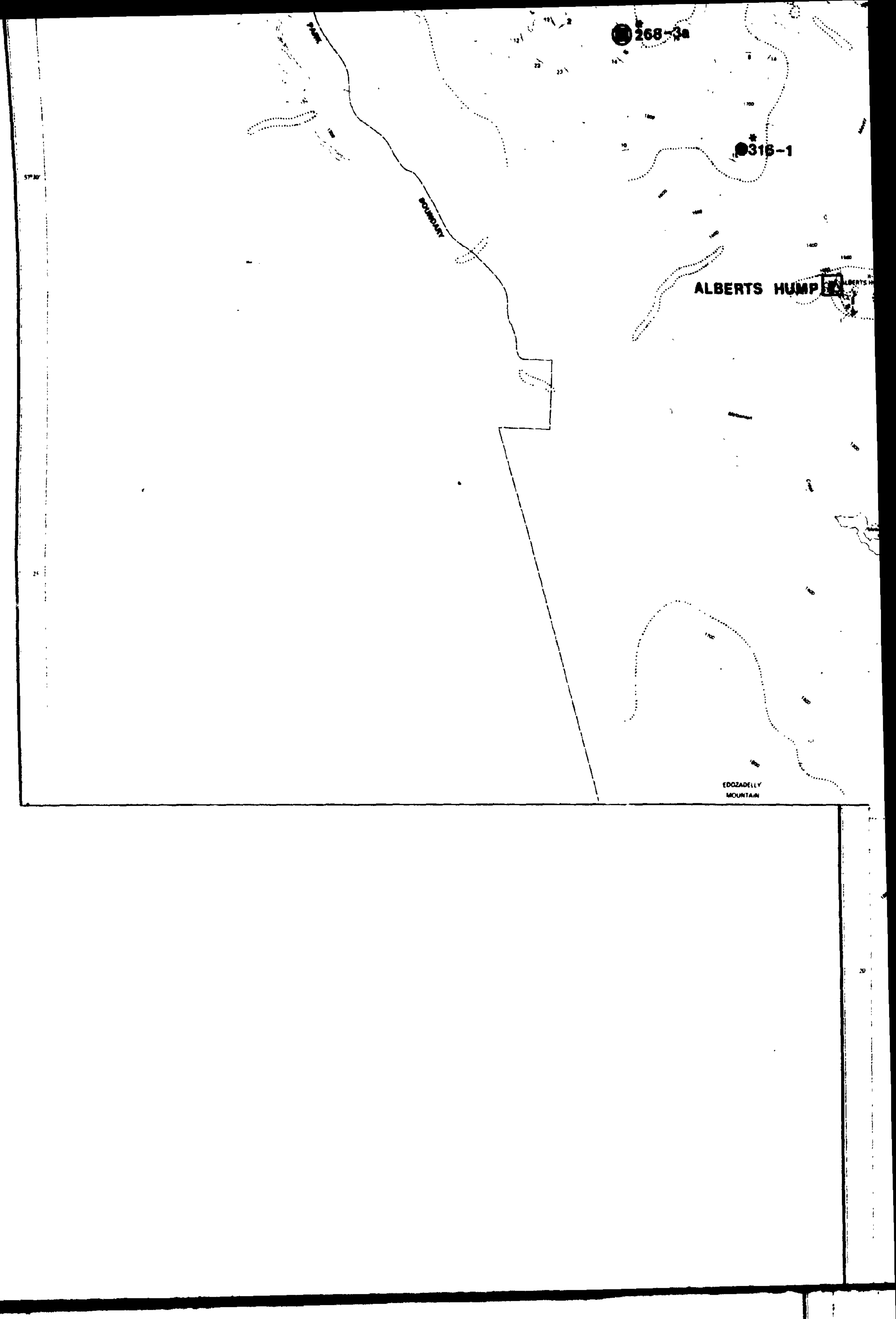
SUSTUT GROUP
TANGO CREEK FORMATION

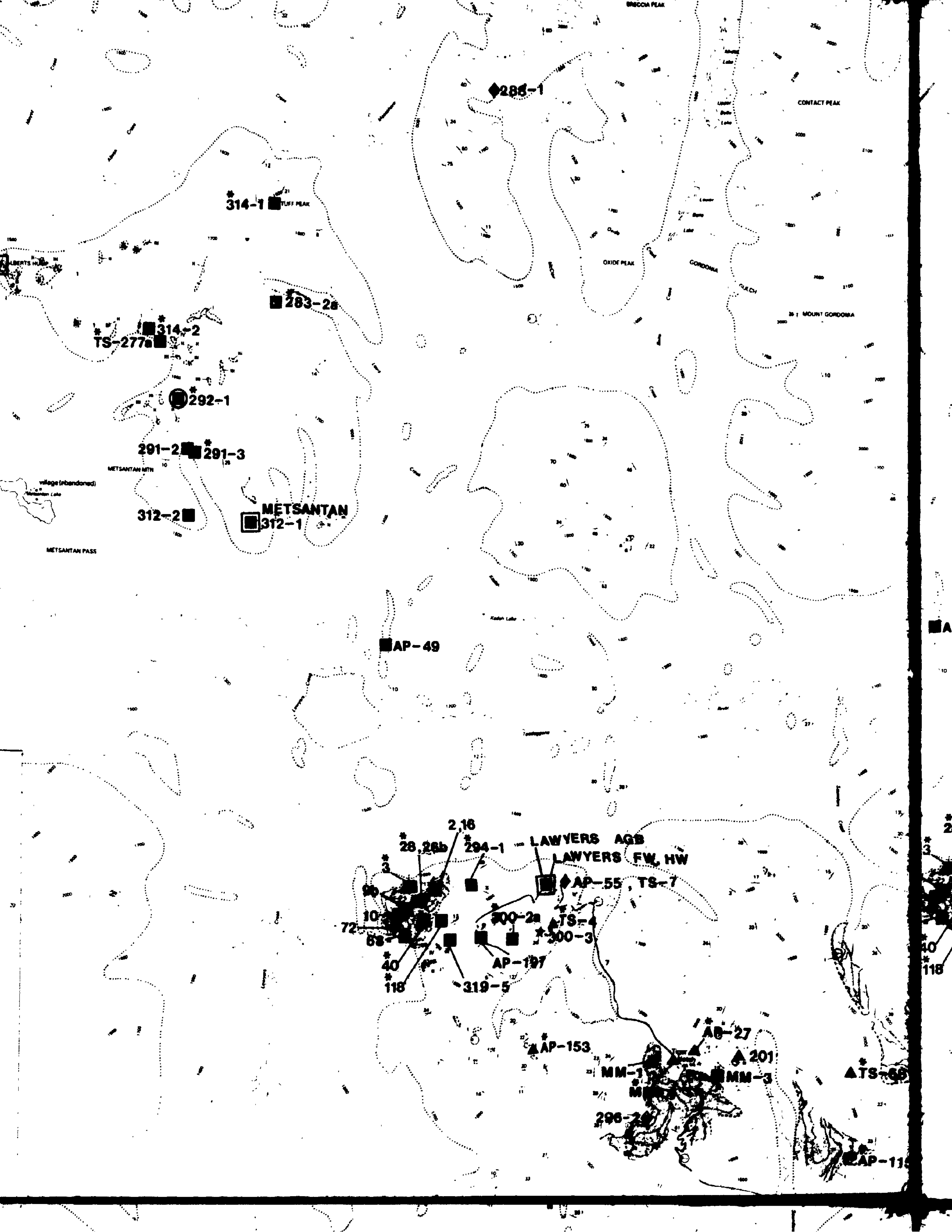
K	polymictic conglomerate, sandstone, shale, and

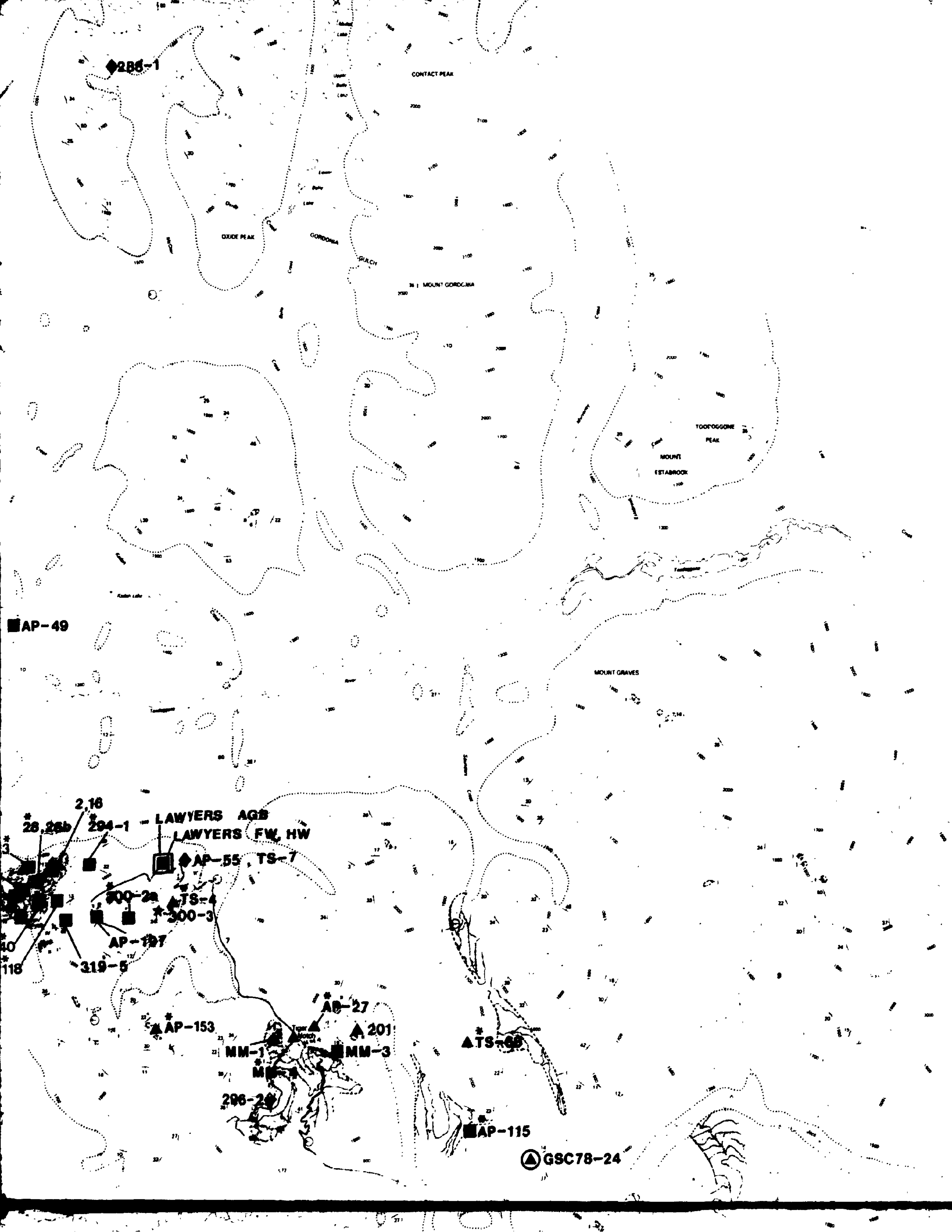

BRECCIA PEAK
CONTACT PEAK
TUFF PEAK
OXIDE PEAK
GORDONIA
MOUNT GORDONIA
METSANTAN MTN
village (abandoned)
METSANTAN PASS
▲200
■168
■180
Areas containing
north – northwest
dykes of
TOODOGGONE
FAULT
CASTLE
FAULT


CONTACT PEAK
OXIDE PEAK
GORDONIA
GULCH
MOUNT GORDONIA
TOODOGGONE PEAK
MOUNT ESTABROOK
Areas containing swarms of north-northwest trending dykes of B and D
TOODOGGONE FAULT
MOUNT GRAVES
CASTLE FAULT
Tiger Notch
MOUNT GRAVES

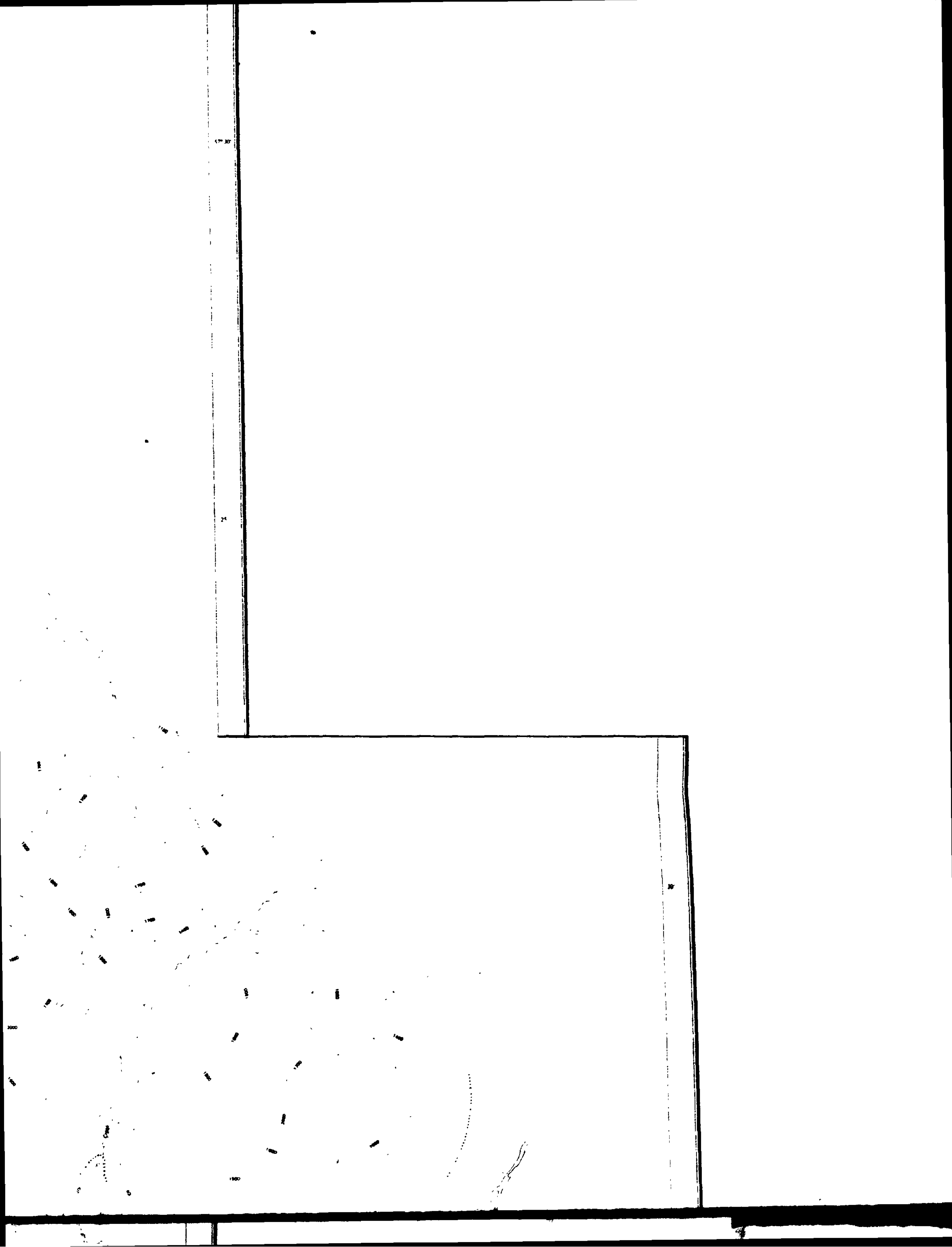

Scale 1:100000
KILOMETRES 0 1 2 3 4 KILOMETRES
Contour Interval 100m
F
F
F
F
T

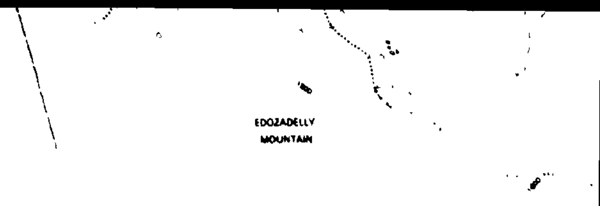

268-3a
316-1
PARK
BOUNDARY
ALBERTS HUMP
EDOZADELLY
MOUNTAIN


BRECCIA PEAK
288-1
CONTACT PEAK
314-1
TUFF PEAK
OXIDE PEAK
GORDONIA
GULCH
MOUNT GORDONIA
283-2a
314-2
TS-277a
292-1
291-2
291-3
METSANTAN MTN
village (abandoned)
312-2
METSANTAN
312-1
METSANTAN PASS
AP-49
2,16
28,26b
294-1
LAWYERS AGB
LAWYERS FW, HW
3
9b
AP-55, TS-7
10
72
68
300-2a
TS-4
300-3
40
118
AP-197
319-5
AP-27
AP-153
201
MM-1
MM-3
TS-66
296-2
AP-11



286-1
CONTACT PEAK
OXIDE PEAK
GORDONIA
GULCH
MOUNT GORDONIA
TOODOGGONE PEAK
MOUNT ESTABROOK
MOUNT GRAVES
AP-49
2,16
26,26b
294-1
LAWYERS AGB
LAWYERS FW, HW
AP-55, TS-7
300-2a
TS-4
300-3
AP-107
118
319-5
AP-27
AP-153
201
MM-1
MM-3
TS-68
AP-115
GSC78-24





MAP 1

GEOLOGY OF THE TOODOGGONE FORMATION, TOODOGGONE RIVER AREA, NORTH-CENTRAL BRITISH COLUMBIA (NTS 94E)

LEGEND

LAYERED VOLCANIC AND SEDIMENTARY ROCKS

QUATERNARY

[ ] unconsolidated glacial, alluvial, and colluvial deposits

CRETACEOUS
UPPER CRETACEOUS

SUSTUT GROUP
TANGO CREEK FORMATION

K polymictic conglomerate, sandstone, shale, and carbonate mudstone

JURASSIC
LOWER TO MIDDLE JURASSIC

SPATSIZI GROUP (?)

8 siltstone and mudstone, grey-black, thinly laminated with elliptical concretions (erosional remnant above angular unconformity with unit 1A, 18 5 kilometres at 316° azimuth from tuff peak

HAZELTON GROUP (Mount Graves to the Pillar, and Mt. McNamara areas)

7 andesite, rare basalt and rhyolite flows, well layered lapilli tuff and breccia with interspersed volcanic conglomerate, siltstone and mudstone, cut by swarms of dykes from "B" and "D".

TOODOGGONE FORMATION

UPPER VOLCANIC CYCLE (189 to 182 Ma)

SAUNDERS MEMBER

6 high-K dacite ash-flow tuff, grey-green, variably welded with locally well-developed compaction layering, contains diagnostic cognate crystal-vitric, and locally abundant accessory granodiorite fragments

6a polymictic conglomerate with abundant Takla clasts, epiclastic sandstone, thin local deposit at the base of unit 6

6b sandstone and pebble conglomerate locally overlying unit 6

ATTYCELLEY MEMBER

5 heterogeneous, crudely layered succession of lithic-crystal and lapilli tuffs includes some welded tuffs and rare surge deposits, abundant epiclastic interbeds of volcanic sandstone (limited exposures north of Drybrough Peak and south of Kemess Creek)

LOWER VOLCANIC CYCLE (204 to 197 Ma)

MCCLAIR MEMBER

4 mainly crowded fine to medium grained porphyritic andesite flows, abundant lapilli tuff, minor breccia, local well-layered conglomerate, sandstone, and rare mudstone with plant debris Totally or in part equivalent to the Metsantan member

METSANTAN MEMBER

3 high-K latite (trachyandesite) lava flows, maroon and green

3a flows similar to unit 3 but characterized by the presence of sparse orthoclase megacrysts

3b conglomerate and coarse debris flows with clasts of units 3 and 3a, well layered, graded, and cross-laminated sandstone and mudstone interbeds

3c crystal-lithic and lapilli tuffs, local interspersed laharic breccia, includes minor lenses of sandstone and mudstone with scarse plant imprints

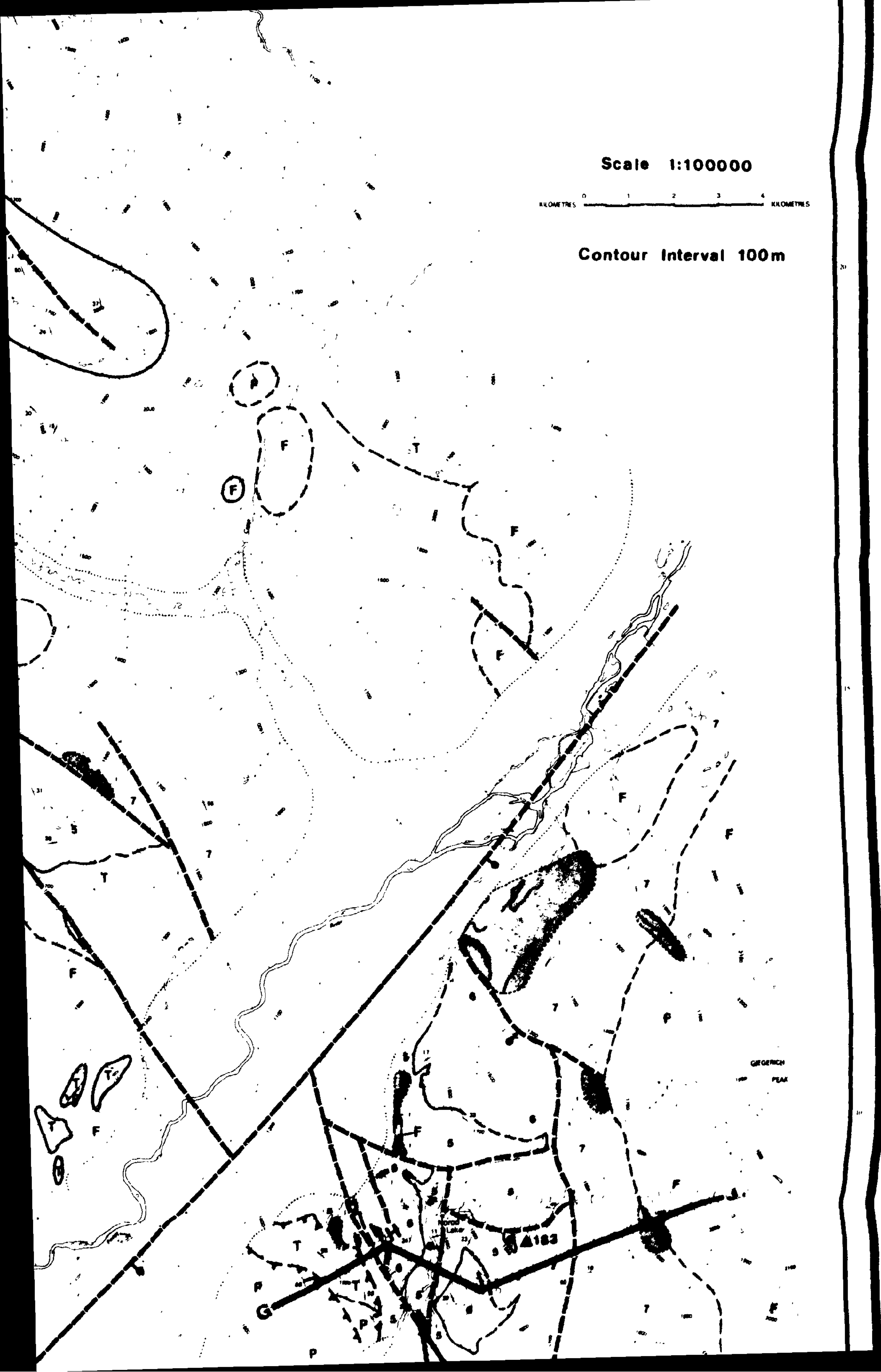
MOYEZ MEMBER

2 well-bedded succession of crystal-ash tuff and lapilli tuff conglomerate interbeds at the base are composed of clasts derived from unit 1 local

6a polymictic conglomerate with abundant Takla clasts, epiclastic sandstone, thin local deposit at the base of unit 6


TOODOGGONE
CASTLE
FAULT
FAULT
180
180
182
204
193
Sturdee Valley
Airstrip
K
F
T
C
3
3b
3c
5
6


TOODOGGONE
CASTLE
FAULT
DRYBROU
FAULT
FAULT
180
182
190
204
193
Sturdee Valley
Airstrip
DRYBROUGH PEAK
PROVINCIAL PARK BOUNDARY
C
E
F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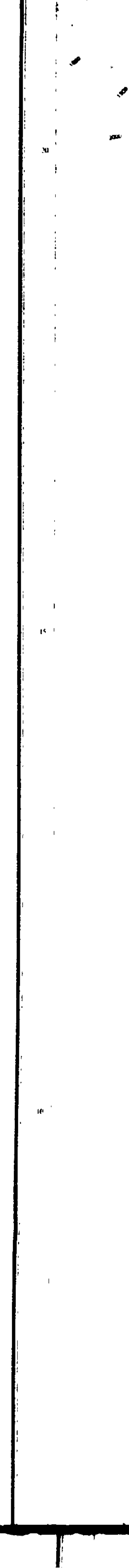
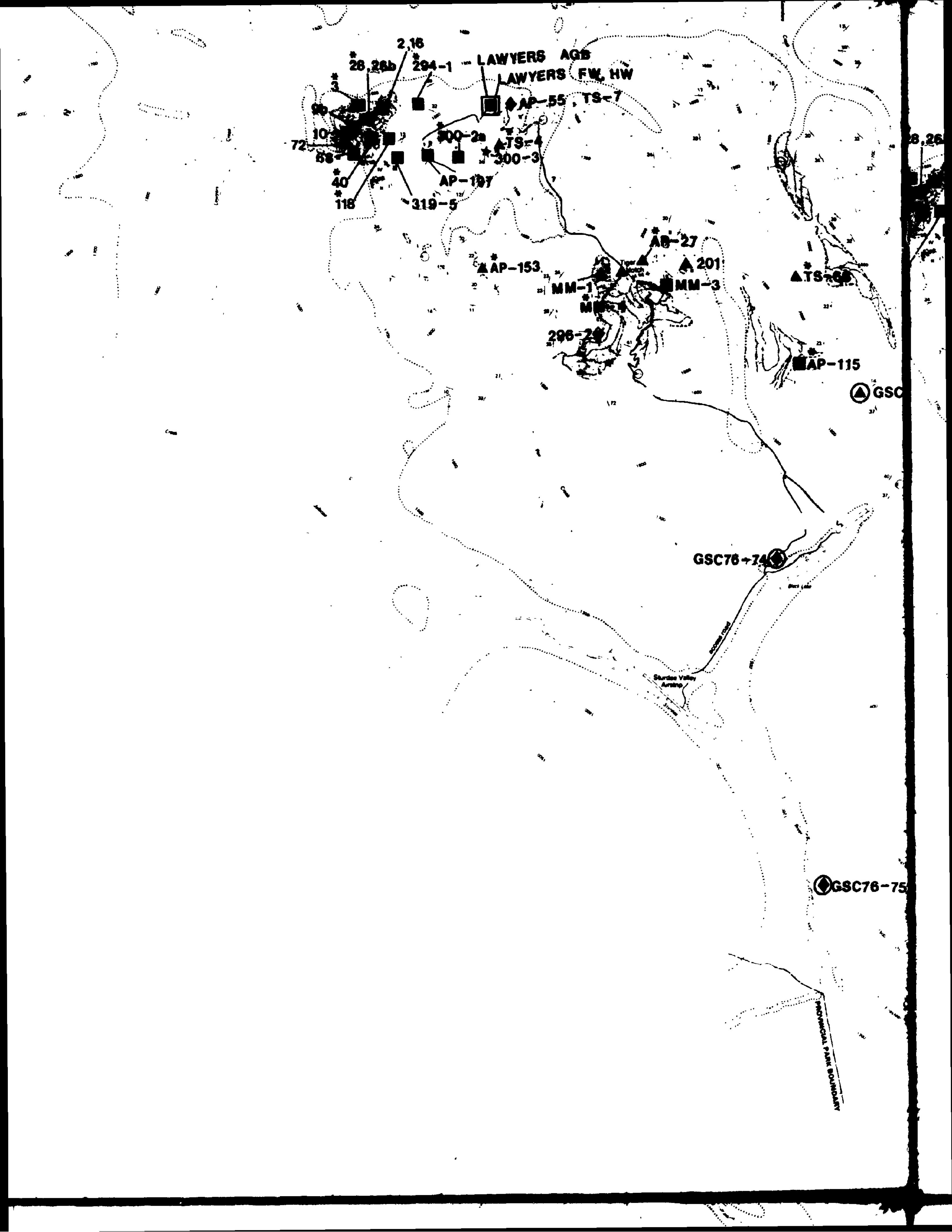
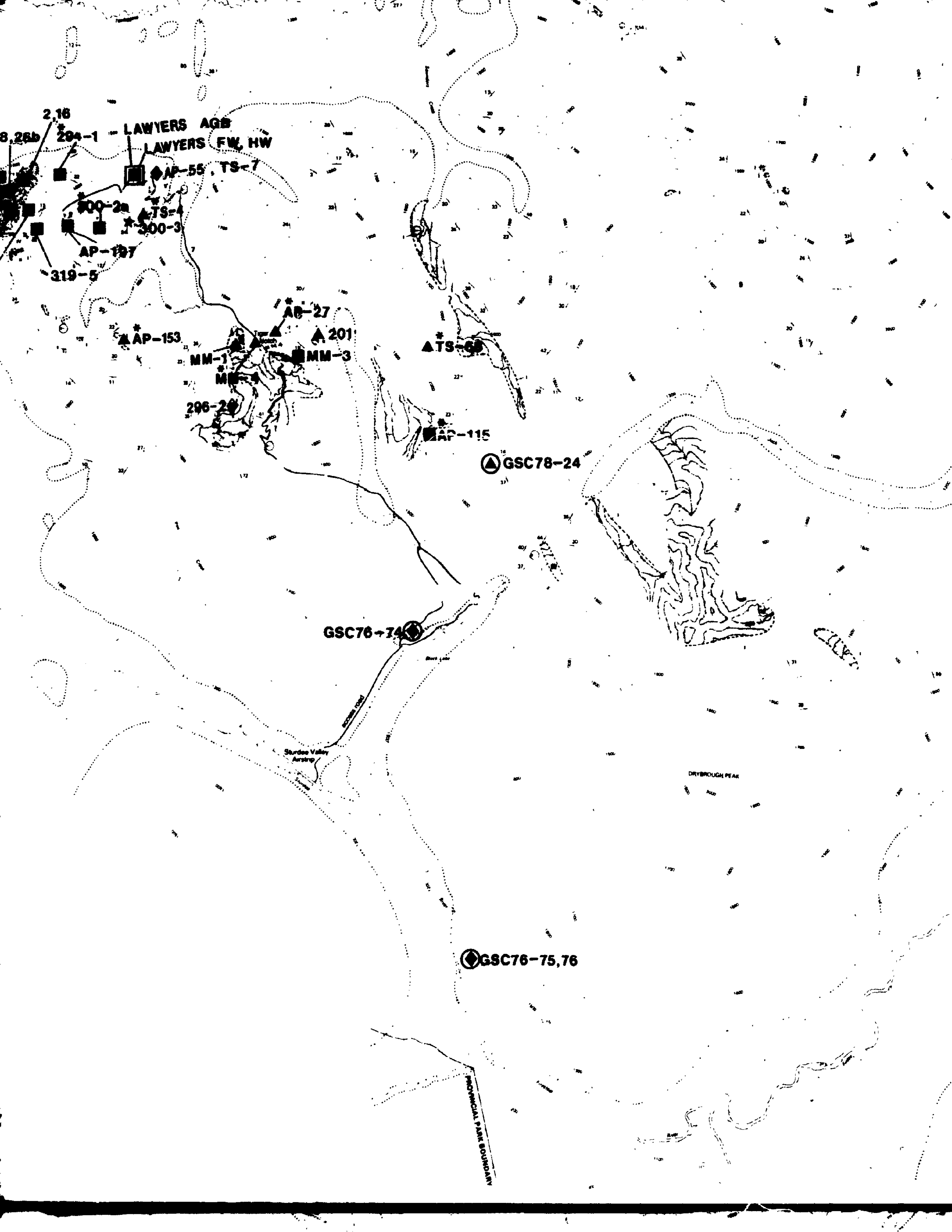
KILOMETRES 0 1 2 3 4 KILOMETRES
Contour Interval 100m
GIEGERICH PEAK
183

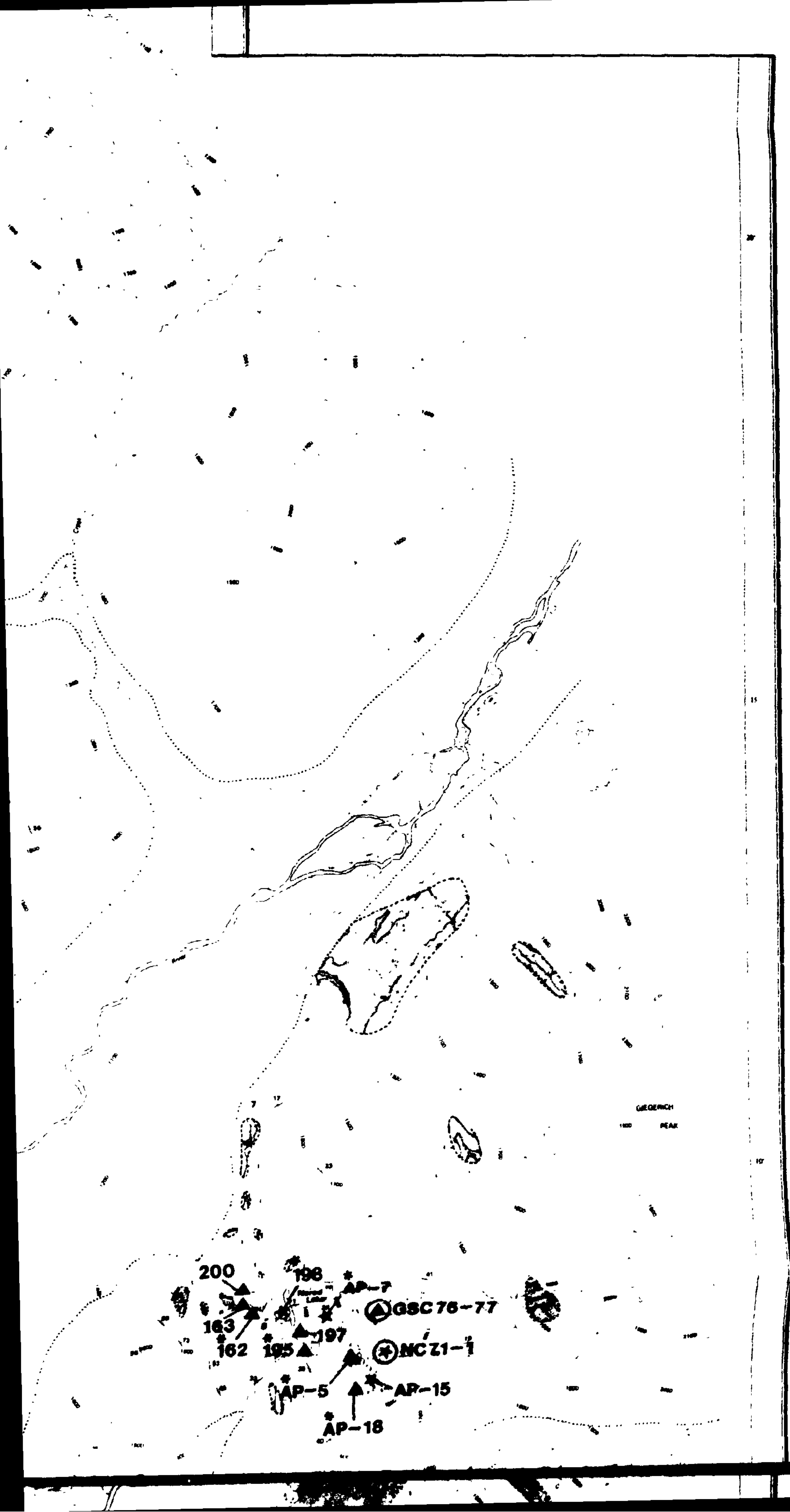




2,16
28,28b
294-1
LAWYERS AGB
LAWYERS FW, HW
AP-55
TS-7
3
10
72
40
118
300-2a
TS-4
300-3
AP-197
319-5
AB-27
201
AP-153
MM-1
MM-3
AP-115
GSC76-74
GSC76-75
Black Lake
Sturdee Valley Airstrip
PROVINCIAL PARK BOUNDARY



2,16
294-1
LAWYERS AGB
LAWYERS FW, HW
AP-55, TS-7
300-2a
TS-4
300-3
AP-197
319-5
AB-27
201
AP-153
MM-1
MM-3
MM-4
TS-68
296-20
AP-115
GSC78-24
GSC76-74
Sturdee Valley Airstrip
DRYBROUGH PEAK
GSC76-75,76
PROVINCIAL PARK BOUNDARY



200
198
AP-7
GSC 76-77
163
162
195
197
NC Z1-1
AP-5
AP-15
AP-18
PEAK

6a thin local deposit at the base of unit 6.

6b sandstone and pebble conglomerate locally overlying unit 6

ATTYCELLEY MEMBER

5 heterogeneous, crudely layered succession of lithic-crystal and lapilli tuffs, includes some welded tuffs and rare surge deposits, abundant epiclastic interbeds of volcanic sandstone (limited exposures north of Drybrough Peak and south of Kemess Creek)

LOWER VOLCANIC CYCLE (204 to 197 Ma)

MCCLAIR MEMBER

4 mainly crowded fine to medium grained porphyritic andesite flows, abundant lapilli tuff, minor breccia, local well-layered conglomerate, sandstone, and rare mudstone with plant debris. Totally or in part equivalent to the Metsantan member

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3c crystal-lithic and lapilli tuffs, local interspersed laharic breccia, includes minor lenses of sandstone and mudstone with scarce plant imprints

MOYEZ MEMBER

2 well-bedded succession of crystal-ash tuff and lapilli tuff, conglomerate interbeds at the base are composed of clasts derived from unit 1, local coarse slide debris with layered intervals of sandstone, minor thinly laminated limestone-chert interbeds

ADOOGACHO MEMBER

1 high-K dacite ash-flow tuff, pale red, flattened, cognate crystal-vitric fragments define local compaction foliation, rare porphyritic lava flows south of Kemess Creek resemble unit 3

1a mainly heterogeneous lapilli tuff, ash-crystal tuff, minor lapilli breccia tuff and rare ground surge deposits, overall crude layering with local well bedded sections, scarce deposits of coarse sandstone to siltstone with plant debris

UPPER TRIASSIC

TAKLA GROUP

T green, augite porphyry and coarse-bladed plagioclase porphyry basalt flows, fine grained andesite flows, local lapilli tuff and minor breccia, limestone and scarse fossiliferous mudstone

PERMIAN

ASITKA GROUP

P limestone (including marble and skarn) with chert layers, argillite

INTRUSIVE ROCKS

MIDDLE JURASSIC

A rhyolite and dacite dykes, pink, quartz phyric

B basalt dykes, recessive, amygdaloidal and aphyric, occur in swarms between the Pillar and Oxide Peak area

C basalt, uncertain sill or flow origin, purple to dark green, augite phyric and crowded fine-grained plagioclase porphyritic texture, possible cogenetic relationship with dykes of unit B

EARLY JURASSIC

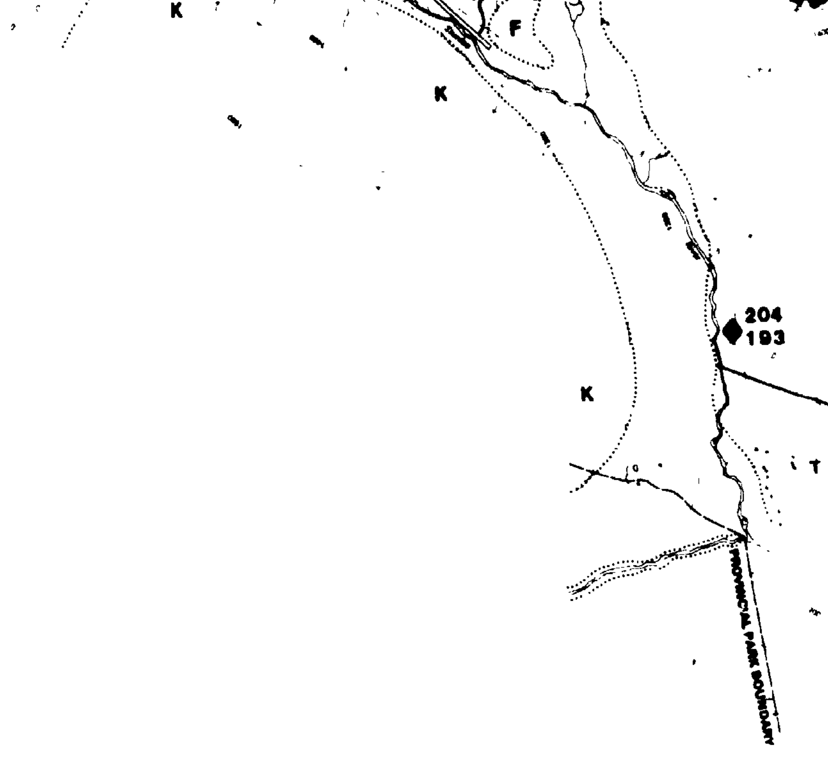
D1 andesite dykes and small plutons, pink to red, plag-phyric ± rare quartz, occur as solitary intrusions and in swarms with unit B, probable feeders to parts of unit 3

E subvolcanic andesite to dacite domes with local talus breccia deposits, medium grained porphyritic texture with and without quartz phenocrysts. Takla xenoliths abundant in the pluton at Kemess Creek

F Omineca intrusions, stocks and smaller plutons, hornblende biotite granodiorite, quartz monzonite to quartz diorite

LATE TRIASSIC

G plug of hornblendite, biotite hornblende quartz diorite in marginal phase



SYMBOLS

Geological contact: defined, assumed

Bedding, igneous layering: horizontal, inclined, vertical

Fold axis

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

Thrust fault; teeth on upper plate: defined, approximate

Radiometric age sample location: volcanic, plutonic, alteration; age in Ma

Fossil locality: plant debris, macrofossils

Park boundary

Road

Main outcrop areas

Alteration:

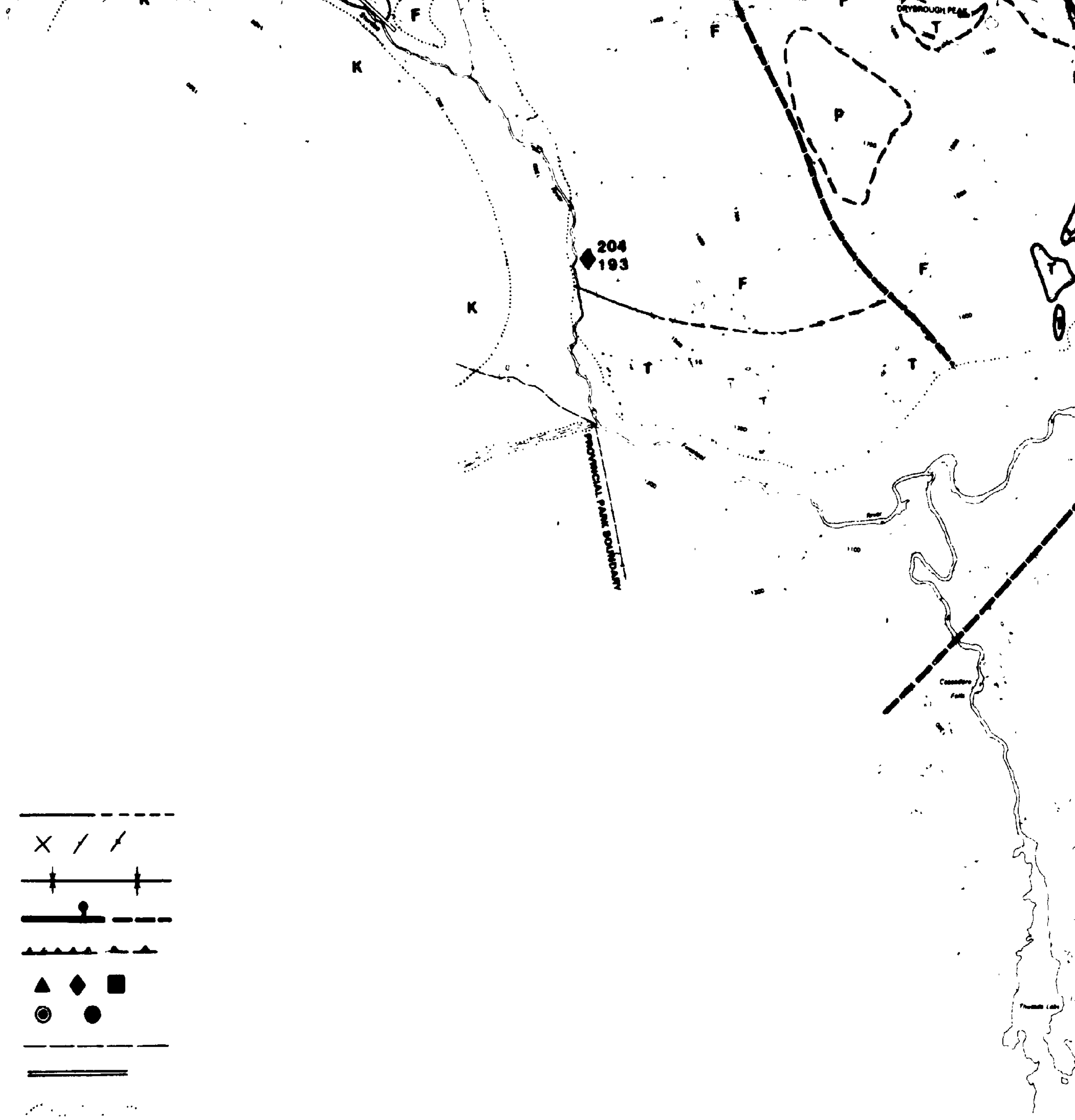
Ferricrete, ferrugenous breccia (iv)

Microcrystalline quartz, minor dickite ± pyrite ± barite (iii)

Mainly dickite, lesser quartz ± natroalunite (ii)

Pyrite ± chlorite ± carbonate ± epidote (i)

Revised 1989 by L.J. Diakow after L.J. Diakow et al., 1985. Geology by L.J. Diakow 1981 to 1984 and A. Panteleyev 1981 to 1983. Mineral deposit studies by T.G. Schroeter and A. Panteleyev. Additional sources of information: Carter (1972), Gabrielse et al., (1977), Marsden and Moore (1989), and assessment reports. Potassium-argon radiometric ages by J. Harakal, The University of British Columbia, Gabrielse et al., (1980), and Cann and Godwin, (1980)



LS

ed, vertical

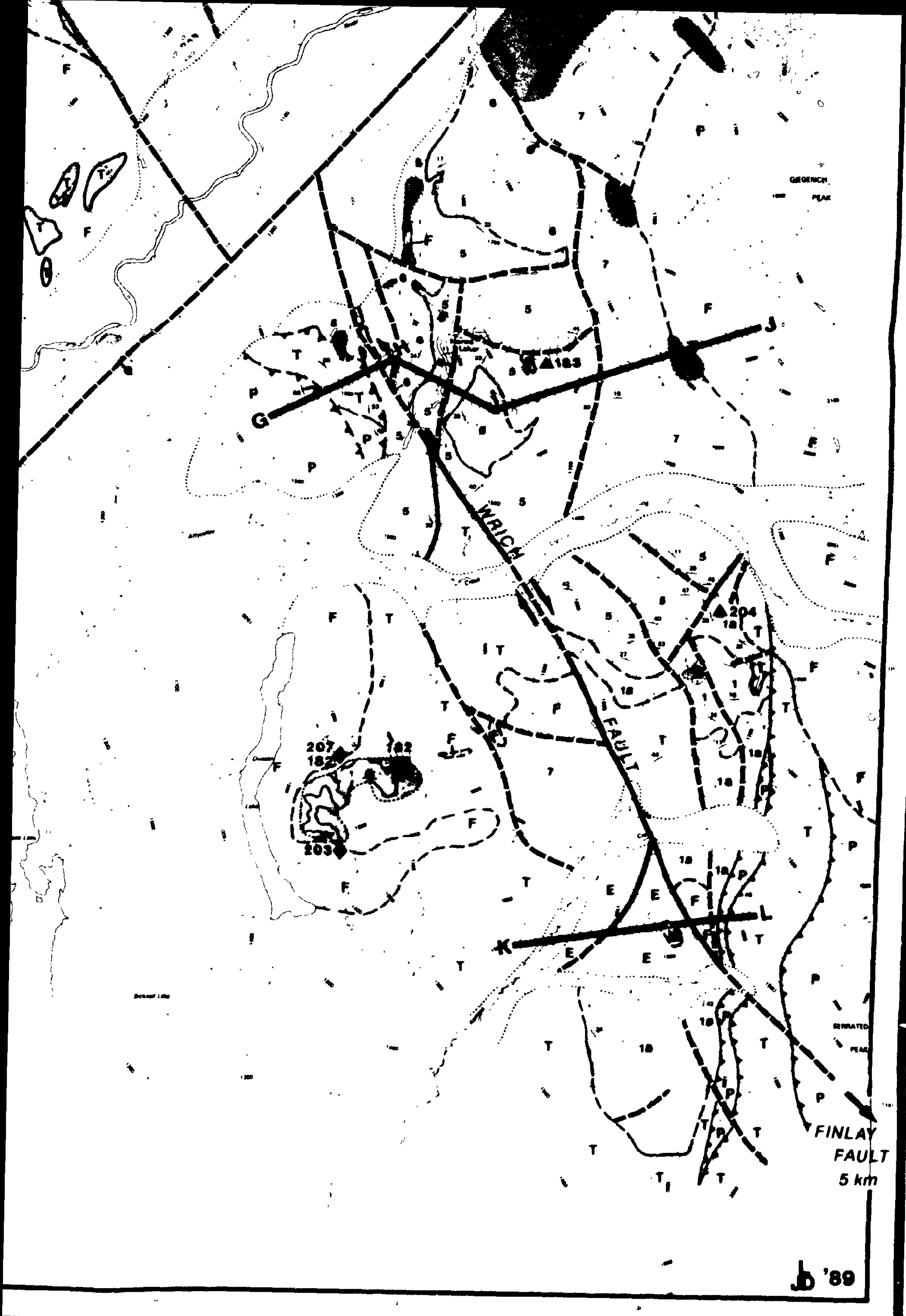
ate sense of strike slip movement

pproximate

plutonic, alteration; age in Ma

e ± barite

ow et al, 1985 Geology by L.J
1 to 1983. Mineral deposit studies by
l sources of information Carter
d Moore (1989), and assessment
by J Harakal, The University of British
n and Godwin, (1980)



G
J
K
L
WRICH
FAULT
FINLAY
FAULT
5 km
▲183
▲204
207
182
203
SERRATED
PEAK
'89

MAP 2
SAMPLE LOCATIONS

SYMBOLS

□ ○ ▲162 Sample location/ *specimen number[1]

○ → Location of volcanic or plutonic numeric age site

□ → Location of secondary alteration mineral numeric age site

*Specimen plotted on geochemical discrimination diagrams

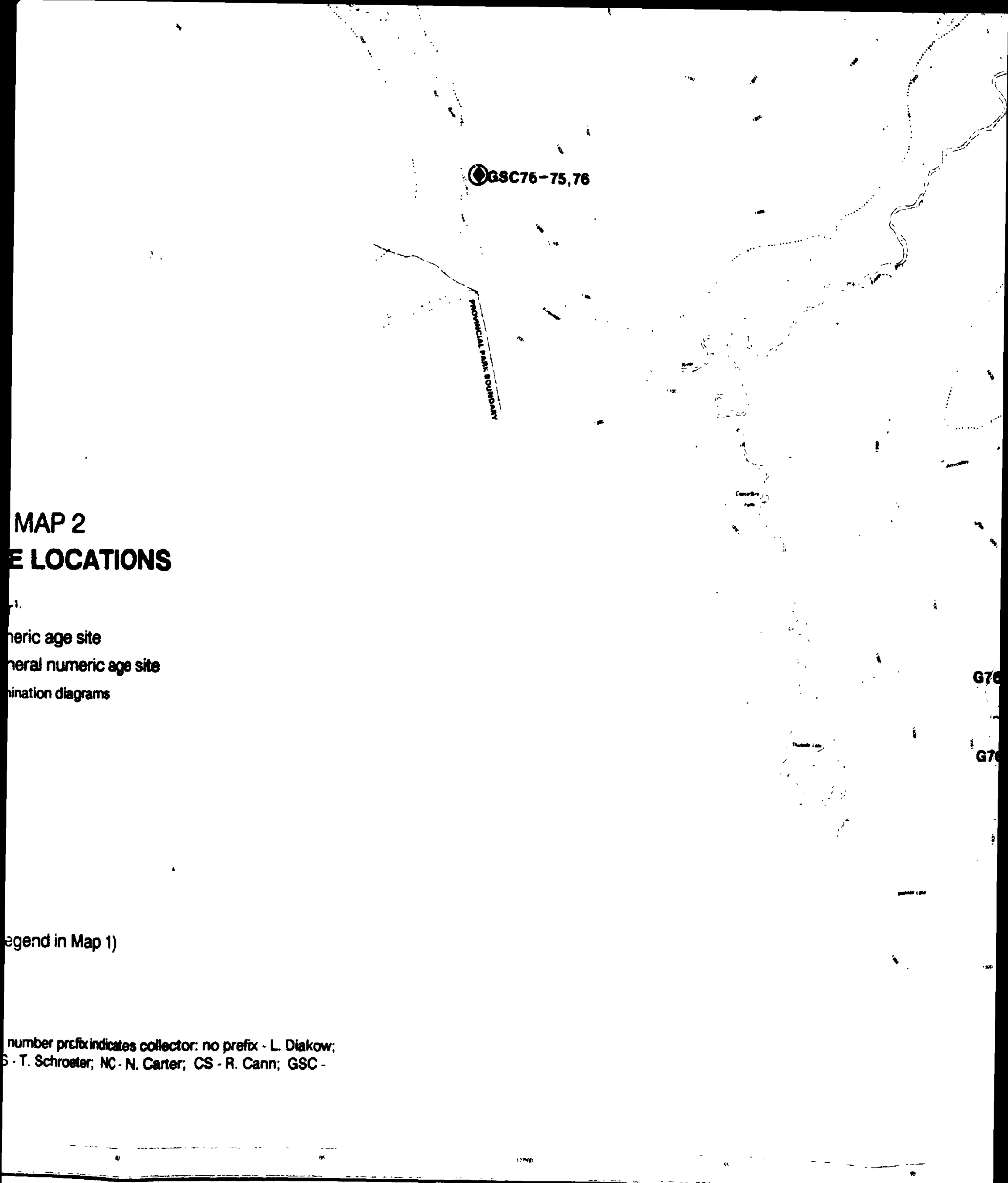
VOLCANIC

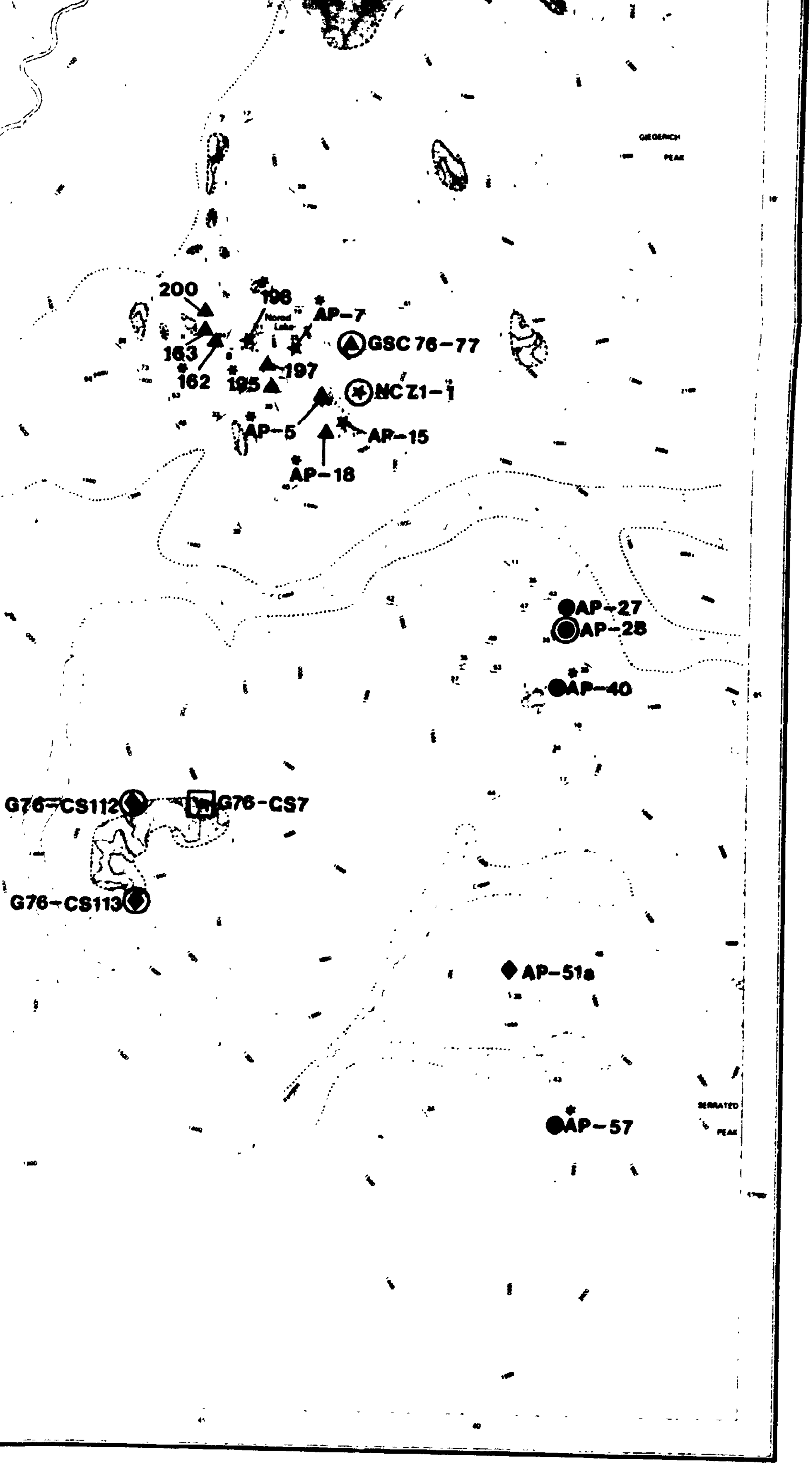
- ▲ Saunders member: Ash-flow tuff
- ★ Attycelley member: Crystal-ash tuff
- ■ Metsantan member: Lava flows
- ● Adoogacho member: Ash-flow tuff

PLUTONIC

- ◆ Small plutons of C,D, or E (refer to legend in Map 1)
- ◆ Dykes of A or D

1. Analytical 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.


GSC76-75,76
PROVINCIAL PARK BOUNDARY
MAP 2
E LOCATIONS
-1.
neric age site
neral numeric age site
nination diagrams
egend in Map 1)
number prcfix indicates collector: no prefix - L. Diakow;
S - T. Schroeter; NC - N. Carter; CS - R. Cann; GSC -


GIEGERICH
PEAK
200
198
Norad Lake
AP-7
163
162
195
197
GSC 76-77
NC Z1-1
AP-5
AP-15
AP-18
AP-27
AP-28
AP-40
G76-CS112
G76-CS7
G76-CS113
AP-51a
SERRATED
PEAK
AP-57