Venus Mine etc

GEOLOGY OF THE MONTANA MTN
AREA, YUKON

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compliments
J.O. Wheeler.

GEOLOGY OF
THE
MONTANA MOUNTAIN AREA
YUKON

By

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ABSTRACT

Montana Mountain area, 100 km south of Whitehorse, contains a late Cretaceous volcanic complex, 6 km in diameter. It correlates with both Mount Nansen plug domes in south-central Yukon and layered Sloko piles in northern British Columbia.

The southern part of the complex is a down-faulted block of andesite lavas and breccias at least 1200 m thick. Sedimentary horizons and distinctive breccias suggest caldera formation.

The northern part consists of subvolcanic intrusion breccias which were emplaced as fluidized rubble by hydrothermal systems that may have been related to growth of andesite plug domes. Subsequent intrusion of a granite pluton emplaced fluidal-layered quartzofeldspathic dikes in the breccias.

Gold- and silver-bearing quartz veins postdating the intrusions fill fractures controlled by previous volcanic structures.

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CHAPTER I

INTRODUCTION

Location and Physiography

Montana Mountain (60° 03'N; 134° 41'W) is a prominent peak (7233'/2204 m) in a region of high ridges and plateaux immediately north of the British Columbia (B.C.)-Yukon boundary (Figure 1). The area is bounded by Bennett Lake on the west and narrow arms of Tagish Lake to north and east. The study area, 8 km (east to west) by 12 km, encompasses a high-standing region of volcanic rocks, here referred to as the Montana Mountain volcanic complex.

Most of the highlands are covered with coarse rock rubble which is sparsely vegetated or bare. Steep mountain slopes drop 1500 m to Windy Arm of Tagish Lake (elevation 2150'/655 m) east of the volcanic complex. Continuous outcrop is uncommon, except in impressive cliffs on the northeast sides of the three major peaks. Abundant lichen hampers observation of rock textures, except in cirques below 'lichen trimlines' where glaciers have retreated in recent times and snow

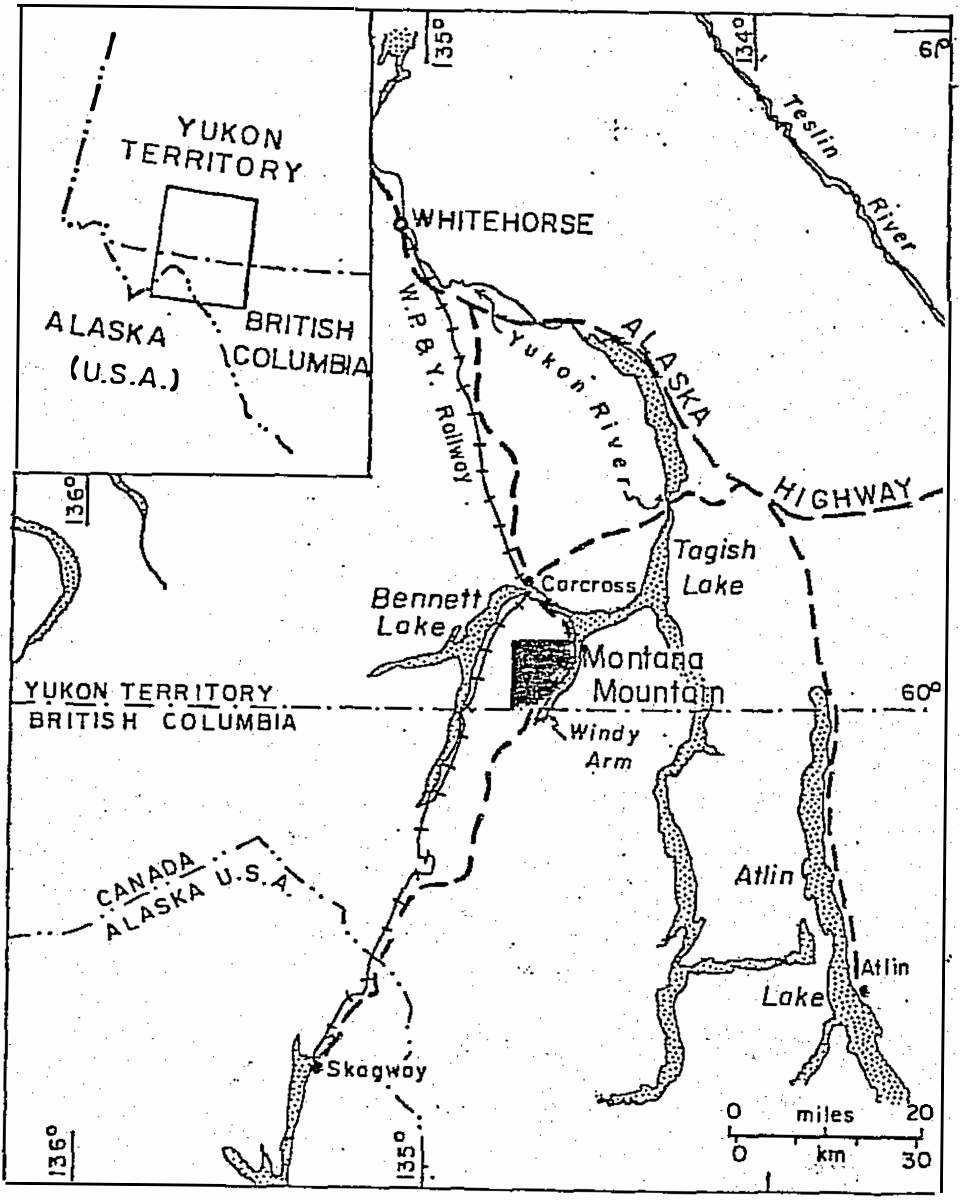


Figure 1. Location of the Montana Mountain area, Yukon.

patches melt back in late summer. Only lower slopes show evidence of continental glaciation; thick till covers granitic rocks north of the study area. A persistent ice remnant lies below Montana Mountain summit, and there is one active rock glacier (lobe 150 m wide by 250 m long) on the west side of Windy Arm at an elevation of 3800'/1160 m.

Access

The study area, 120 km south of Whitehorse, is skirted by an all-weather road (No. 2; known as the Klondike Highway) which links Yukon with Skagway, Alaska. The community of Carcross, 12 km north of Montana Mountain, is clustered around bridges where the road and railway (White Pass and Yukon Route) cross the outlet of Bennett Lake. The only mine in the area, called Venus, is near the road 3 km north of the territorial boundary. Major mining prospects in the highlands, known as the Arctic Caribou and Montana, are accessible by four wheel drive vehicles over unmaintained tracks. Foot travel is rugged on felsenmeer and scree slopes, but only a few major cliffs are impassible.

History

Gold- and silver-bearing quartz veins were discovered on Montana Mountain in 1901 and 1903. The Windy Arm mining camp flourished until 1917; only two sites have undergone extensive development and several mining attempts since that time. Stone ruins, tramline towers and overgrown mule trails are visible reminders of the early days (see McConnell, 1906; and Cairnes 1907, 1908, 1917); bulldozer trenching and strewn debris mark the ventures of the last decade. Recent mining attempts have been short-lived, apparently because of poor management, less-than-expected gold recovery (Ralfs, 1975) and the unpredictable nature of the small ore-bodies. United Keno Hill Mines Limited (Whitehorse, Yukon) worked the lower Venus mine for six months in 1981.

Early geological investigations were limited to areas of mining activity. Reconnaissance mapping by Wheeler (1961) served to identify major rock units and contacts in the study area. Wheeler included the volcanic rocks of the Montana Mountain complex in the Hutshi Group, a name and rock unit no longer recognized; these rocks are here correlated with the Mount Nansen Group. The nearby Bennett Lake complex, with numerous dacitic and rhyolitic eruption centres and cauldron subsidence, were documented by Lambert (1974). Montana Mountain complex is smaller, and consists of rocks more mafic and less pyroclastic in nature. Paragenesis of the ore minerals in the Venus mine was studied by Ralfs (1975). The present investigation, summarized in Roots (1981), is the first general geological study of the rocks within the volcanic complex.

Scope of the Investigation

The Montana Mountain complex was mapped in the summer of 1980 during investigation of mineralized quartz veins and related abandoned workings. Distinctive breccias on Montana Mountain led to speculation that the volcanic rocks might be equivalent to the Mount Nansen Group. The Mount Nansen area consists of poorly exposed volcanic and subvolcanic rocks which contain gold and silver in quartz veins as well as 'porphyry copper' mineralization.

The purpose of the thesis is to describe and interpret the Montana Mountain volcanic rocks; to provide a model of their evolution that can be applied to less-well-exposed Mount Nansen-type occurrences; and to present evidence for magmatic and structural controls upon vein mineralization in the complex.

The basis for the thesis consists of mapping at 1:25,000 scale, supplemented by detailed local examinations. Conclusions from field observations were tested or supported with petrographic study and chemical analyses. The mineralogy of some veins and the composition of phenocrysts were identified with the aid of the X-Ray diffractometer at Carleton University. The standard computer program LEMNORM9 of the Department of Geology at Carleton University was used to calculate normative compositions.

The thesis consists of nine chapters. The regional framework is presented first, followed by descriptions of rock units around the volcanic complex, and discussion of volcanic centres of similar age. Successive chapters deal with the principal layered and intrusive rock types, the structure and geochemistry of the Montana Mountain volcanic complex. Discussions of age of the complex and mineralization conclude the study.

CHAPTER II

REGIONAL FRAMEWORK

The Montana Mountain area lies in the Whitehorse Trough, consisting of interleaved oceanic crust, island arc volcanic rocks and fore-arc basin sediments (Figures 2 and 3). These stratigraphic successions in southern Yukon form the Intermontane Belt; an allochthonous tectonic assemblage thought to have been accreted to the ancient North American continental margin during the Mesozoic era (Monger and Price, 1979; Templeman-Kluit, 1979). Late Cretaceous volcanism at Montana Mountain and elsewhere along the belt probably occurred during the waning stages of this arc-continent collision.

The oldest rocks in the study area are late Paleozoic mafic volcanic flows considered to be among the basal units of the Atlin Terrane (Monger, 1975). These are overlain in the region by bedded carbonate rocks which locally attain thicknesses of several thousand metres. Atlin Terrane is part of the Cache Creek Group, interpreted by Monger to be oceanic crust

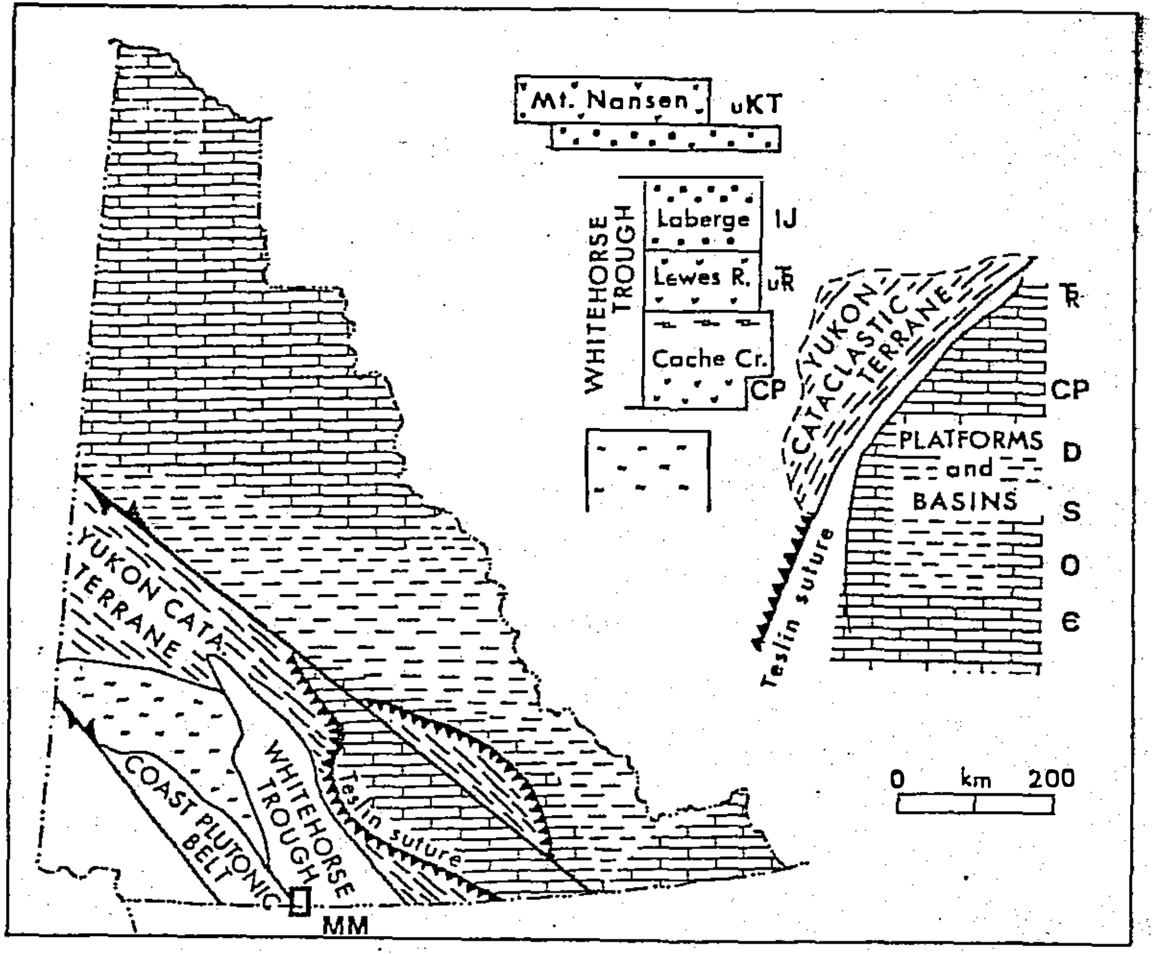


Figure 2. Diagram of tectonic elements in Yukon. Simplified from Tempelman-Kluit (1981). MM = Montana Mountain area.

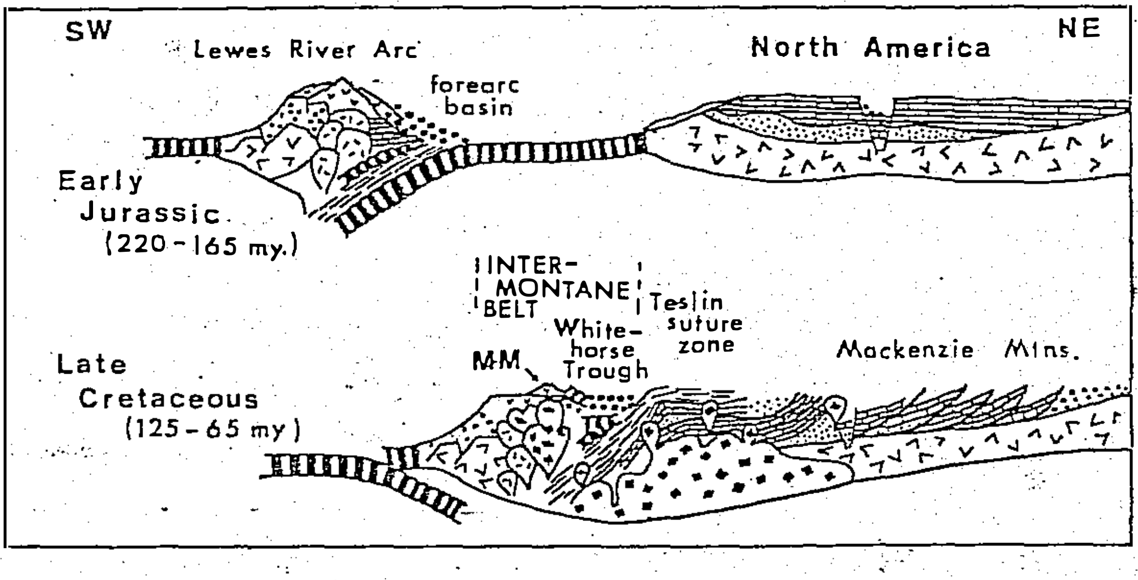


Figure 3. Schematic cross-section of the northern Cordillera before and after collision of an island arc terrane. MM = position of the Montana Mountain complex. From Templeman-Kluit (1979).

and reef complexes that were built west of the ancient North American shelf margin.

The Whitehorse Trough is an elongate Mesozoic basin containing volcanic and sedimentary rocks that were derived from the southwest. Volcanic flows, pyroclastic deposits and limestone reef complexes, collectively termed the Lewes River Group, are overlain by molassic sediments of the Jurassic Laberge Group. Tempelman-Kluit (1979) interpreted this succession as the constructional (Lewes River) and erosional (Laberge) stages of an island arc system. Eventual collision of this arc with North America caused oceanic crustal rocks to be thrust over the continental platform (Figure 3). The resulting Teslin Suture Zone is a north- to northwest-striking depression, 90 km east of Montana Mountain.

The Sloko Volcanic Province (Souther, 1977 includes the Mount Nansen, Carmacks, Skukum and Sloko Groups (Table I). Generally they occur near the boundary of the Coast Plutonic Complex and Intermontane belt in Northern B.C. and southern Yukon. The Mount Nansen andesitic centres and the Carmacks basaltic flows are late Cretaceous in age. The Sloko centres in B.C. consist of intermediate pyroclastic rocks that are contemporaneous with or younger than these. The mid-Tertiary Skukum Group is primarily felsic, and

TABLE 1

Era	Period or Epoch			Rock Unit (thickness in metres)	Principal rock types
CENOZOIC	Pleistocene or Recent				Glacial drift, alluvium
	Unconformity				
	Eocene				Granite porphyry, rhyolite
				Intrusive contact	
				Skukum Group (1300+)	Ignimbrite, rhyolite and basaltic lava; volcanic and granitic breccia
					Andesite and dacite lava, basal ignimbrites
Unconformity					
MESOZOIC	Late Cretaceous			Coast Plutonic Complex	Quartz monzonite
					Intrusive contact with granodiorite
					Leucogranite, biotite granite, alaskite
					Intrusive contact
					Hornblende-biotite granodiorite, quartz diorite
				Intrusive contact	
				Nisling Range Alaskite	Rhyolite, trachyte porphyry, Felsic dikes and sills
				Intrusive contact	
				Carmacks Group	Plateau basalts
				Conformable contact: in places coeval	
				Mount Nansen Group (1000+)	Andesite, intrusion breccia
					Ignimbrites, debris flows
					Andesite and dacite lavas
	Intrusive, locally disconformable contact				
	Lower Jurassic	Whitehorse Trough		Laberge Group (3400+)	Conglomerate Siltstone, argillite, hornfels
				Disconformity, local angular unconformity	
	Upper Triassic			Lewes River Group (3300)	Volcanic greywacke, limestone reefs
					Volcanic breccia, agglomerate
					Porphyritic andesite
	Faulted, possible disconformity				
PALEOZOIC	Permian	Atlin Terrane		Atlin Intrusions	Serpentinized gabbro, pyroxenite, dunite
			Cache Creek Group	Intrusive contact	
				Horsefeed Fm. (1600)	Limestone reefs, minor pyroclastic interbeds
				Disconformity	
	Pennsylvanian			Nakina Fm.	Amphibolite, breccias, minor chert interbeds

Table of Formations in south-central Yukon. Compiled from: Aitken (1959), Wheeler (1961), Lambert (1974) and Tempelman-Kluit (1974).

produced widespread ignimbrite sheets in north-central B.C. In general, the Sloko Volcanic Province consists of calc-alkalic rocks that range in age from 73 Ma (Grond, 1980) to 50 Ma (Lambert, 1974).

CHAPTER III

GEOLOGY OF THE MONTANA MOUNTAIN AREA

Summary

Paleozoic volcanic rocks of the Cache Creek Group and clastic sediments of the Laberge Group flank a partly circular region of volcanic rocks (Figure 4, in pocket) that is referred to in this study as the Montana Mountain volcanic complex. The complex consists almost entirely of lava flows and breccias which correlate with the Mount Nansen Group. A granitic intrusion, informally designated as the 'Carcross Pluton', has metamorphosed the northern margin of the complex, and swarms of felsic dikes have intruded the volcanic and sedimentary rocks. Late quartz veins, some containing economically significant grades of gold-bearing arsenopyrite and silver-bearing galena, cut the southern part of the 'Carcross pluton' and the Montana Mountain volcanic complex.

ROCK UNITS

Cache Creek Group

Amphibolite with thin, interlayered limestone and chert crops out northeast of Montana Mountain.

Exposures are steep with a splintered, dark greenish-grey aspect. In a cirque north of Pooly Canyon, weathering outlines northeast-dipping layers that may have been volcanic flows. Their thickness is unknown. Thin sections of the amphibolite show uralitized clinopyroxene phenocrysts in a chloritic groundmass (Wheeler, 1961).

The lower contact of the amphibolite is not exposed. The Montana Mountain volcanic complex intrudes these deformed rocks near Pooly Canyon. There the andesite breccia (equivalent to the Mount Nansen Group) can be distinguished from the older Cache Creek amphibolite by its lighter weathering colour and lesser degree of recrystallization.

Wheeler (1961) assigned the amphibolite to the Taku Group; on a regional scale the rocks match descriptions of the Nakina Formation in Atlin map-area to the southeast (Aitken, 1959; Monger, 1975). The volcanic rocks, of probable Mississippian age, are considered by Monger to be among the oldest units of the Cache Creek Group.

Pods of ultramafic rocks are common in the Cache Creek Group in the Atlin Terrane. Several serpentinized pyroxenite bodies are exposed in new roadcuts near Windy Arm, and a 500 m wide plug occurs 1 km north of Montana Mountain. The latter is fault bounded between the volcanic complex and the 'Carcross pluton' that are younger, intruding structures (Figure 5). It is composed of serpentinized dunite and gabbro, with antigorite veinlets and magnetite crystals (to 1 cm) near its margins. The contact is a sheared zone 4 to 5 m wide occupied by mafic dikes.

Lewes River Group

Rocks belonging to this unit occur in the study area only as clasts within Laberge conglomerate, although they are extensive further to the west and north. In other places the volcanic rocks have been confused with the Mount Nansen Group (Bostock and Lees, 1938 in Tempelman-Kluit, 1974). Purple, grey and green volcanic breccias (fragments up to 1 m across), plagioclase-phyric andesite and volcanic wacke are the most common rock types. There are also thick reef complexes of upper Triassic age further north (for example, Reid, 1981). Pyroclastic and conglomerate beds, from the lower part of the Lewes River Group, were noted by Wheeler (1961), 8 km west of Montana Mountain.

Laberge Group

Lower Jurassic conglomerate, siltstone and

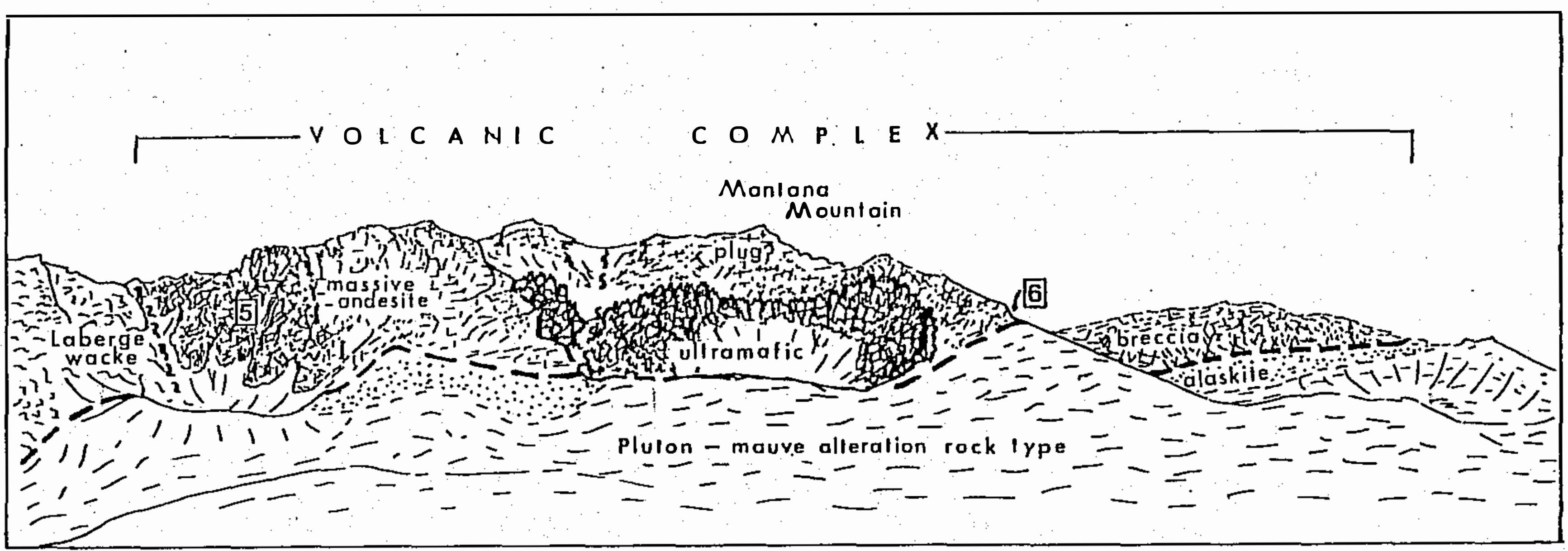


Figure 5. View of the north end of the volcanic complex, looking south from Big Thing Creek (area about 2.5 km wide; location shown on Fig. 11). Intrusion of the 'Carcross pluton' (foreground) has thermally metamorphosed Laberge sediments (left) and volcanic breccia (both sides of Montana Mountain andesite bodies). Serpentinized pyroxenite is sheared along its contact with the volcanic rocks. Clear area in centre is a snow-filled cirque. Sketch from photo.

shale of the Laberge Group flank the west boundary of the volcanic complex. Additionally, a narrow strip east of the complex separates younger volcanic and granitic rocks from the Nakina Formation. Best exposures are found on Brute Mountain, a craggy ridge in the northwestern part of the study area. Here Wheeler (1961, p. 59) measured 1100 m of siltstone and argillite, with greywacke beds increasingly abundant upward in the section, capped by 400 m of massive conglomerate. Conglomerates occur as 1-2 m thick layers traceable for more than a kilometre, as well as 50 m to 300 m thick lenses that interfinger with greywacke along strike. Rounded porphyritic volcanic clasts and granitic pebbles and boulders, mixed with more angular fragments of greywacke, chert and quartzite make up the conglomerate. Clasts average 5 to 10 cm, but many are larger. Wheeler interpreted the upper part of the Brute Mountain section as a subaqueous alluvial fan deposit containing channels filled with larger clasts.

Fine clastic sediments of the Laberge Group are characterized by a reddish weathering rind resulting from oxidation of mafic mineral grains. The sediments are compositionally immature, consisting of angular to subangular grains of feldspar, pyroxene and hornblende in a clay matrix. Dark greywacke and finely laminated siltstone with argillite rip-up clasts predominate on the eastern and southern sides of the volcanic complex.

In Big Thing Creek, a poor exposure reveals Laberge strata in disconformable contact with Nakina Formation, but elsewhere the Laberge Group is presumed to be faulted against the older rocks (Wheeler, 1961). The 'Carcross pluton' also intrudes Laberge strata, incorporating xenoliths and interpreted pendants near the contact. Most sediments in the north part of the study area were thermally metamorphosed to biotite and pyroxene hornfels (see also Wheeler, 1961, p. 89).

Mount Nansen Group

Dirk Tempelman-Kluit (pers. comm., 1980) first suggested that the volcanic rocks on Montana Mountain might be part of the Mount Nansen Group. The complex was found to have distinct and comparable features to both the Mount Nansen volcanic centres in south central Yukon and those of the Sloko Group in northwestern B.C. (Figure 6). These two groups comprise a late Cretaceous-early Tertiary volcanic suite distributed over 500 km.

Mount Nansen Group, named by Bostock (1936) in the Dawson Range (Carmacks map-area), is a heterogeneous assemblage of andesite and basalt flows,

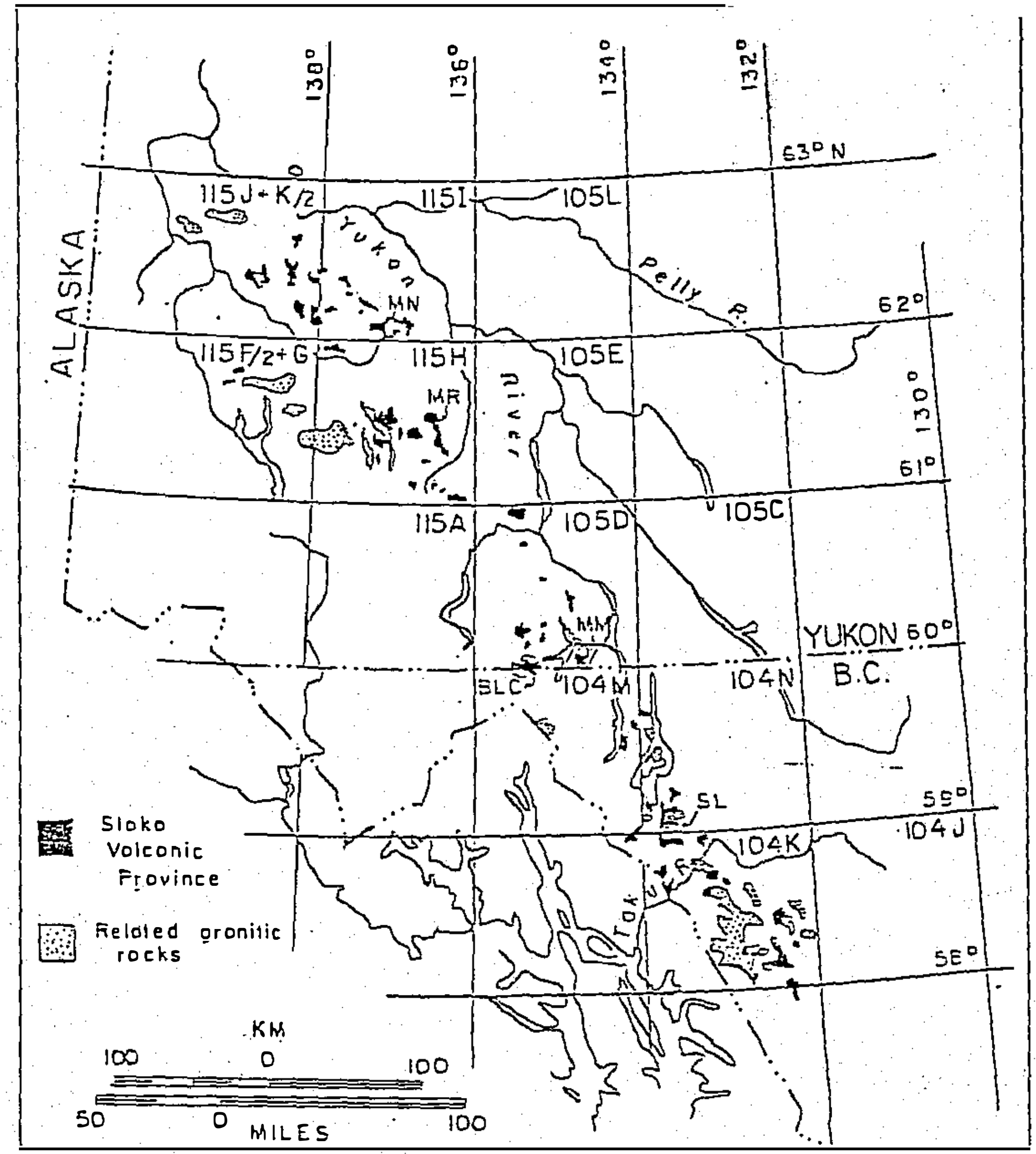


Figure 6. Distribution of Sloko (south; from Souther, 1971) and Mount Nansen (north; from Tempelman-Kluit, 1974) volcanic and related rocks. MN -Mount Nansen; MR -Miners Range; MM -Montana Mountain; BLC -Bennett Lake Complex and SL -Sloko Lake. The map is also an index to these regional geological data sources:

104K - <u>Tulsequah</u> - Souther, 1971
104M - <u>Bennett</u> - Christie, 1959
104N - <u>Atlin</u> - Aitken, 1959
105C - <u>Teslin</u> - Mulligan, 1963
105D - <u>Whitehorse</u> - Wheeler, 1961
105E - <u>Laberge</u> - Bostock and Lees, 1938; Tempelman-Kluit, 1978, 1980.
115A - <u>Dezadeash</u> - Kindle, 1952
115 F/2 and G - <u>Kluane</u> - Muller, 1967
115H - <u>Aishihik Lake</u> - Tempelman-Kluit, 1974
115I - <u>Carmacks</u> - Bostock, 1936 and Tempelman-Kluit, 1980
115J and K/2 - <u>Snag</u> - Tempelman-Kluit, 1974.

breccias and less common tuffs and agglomerate. A section measured by Bostock included 300 m of fragmental rocks overlain by 300 m of grey, thin-bedded tuff. Most Mount Nansen occurrences are flat-lying upon deeply weathered sedimentary rocks, and are in places intruded by granitic stocks. Bostock concluded that they were roof pendants of late Jurassic or Cretaceous age.

Volcanic rocks with similar characteristics south of Mount Nansen were named the Hutshi Group (Bostock and Lees, 1938; Wheeler, 1961). Recent mapping by Tempelman-Kluit (1974) indicated that many occurrences are equivalent to the Mount Nansen Group. Because the Hutshi Group also included upper Triassic volcanic rocks, its use has been abandoned.

Based upon his mapping in south-central Yukon, Tempelman-Kluit (1974, 1978, 1980) interpreted the Mount Nansen centres as remnants of plug domes and differentiated volcanic piles that were deposited on a deeply dissected land surface (Plug domes are cylindrical masses of congealed magma or tephra that are pushed upward by gradual pressure, and not directly by explosive activity; from Macdonald, 1972, p. 378). The Carmacks Group flood basalts cover large areas northeast of the Mount Nansen centres and were probably contemporaneous (Churchill, 1980; Grond, 1980).

The Sloko Group, first described by Aitken (1959) in the Atlin (B.C.) map-area, includes dark-coloured amygdaloidal basalt and andesite, overlain by volcaniclastic sediments that are interbedded with trachyte tuffs and breccia. He reported volcanic piles up to 1130 m thick. They are better exposed than the Mount Nansen centres, and commonly contain beds of coal, sandstone and volcanic conglomerate.

Souther (1967, 1971) described several volcanic centres in Tulsequah map-area to the south. They consist of brightly coloured, intermediate to acidic, dominantly pyroclastic units 3-15 m thick. Some textures observed on Montana Mountain resemble Souther's descriptions of fluidal-banded rhyolite fragments and flattened, devitrified lenticles. Flat-lying beds and volcanic rocks bounded by steep normal faults led Souther (1971) to suggest that subsidence and related volcanism produced some of the complexes which were preserved by down-faulting below the present erosion level. Late Cretaceous ages were obtained from plant remains interbedded with the volcanic rocks, and isotopically (K-Ar method) from adjacent plutons (Souther, ibid.).

The Skukum Group (Whitehorse map-area) contrasts with the Mount Nansen and Sloko units because it occurs within the Coast Plutonic belt and intrudes Paleozoic and older rocks. The centres are located west of the trend of Mount Nansen Group and are probably younger. The Bennett Lake complex (Lambert, 1974) is up to 30 km in diameter, and consists of two cycles of thick ignimbrite deposits overlain by increasingly mafic breccias and lava flows. Lambert concluded that major ash flow eruptions resulted in major stages of caldera formation. Evidence for the cauldrons includes ring faults and fault-block terrain. The slight age difference between the base and top of the volcanic succession (51 and 52 +/- 3.0 Ma; K-Ar method, recalculated by Morrison et al, 1979) suggests that the complex was formed in less than a million years (Lambert, ibid.).

Montana Mountain lies between the type localities of Sloko Group and Mount Nansen centres. Although the rocks are similar in overall composition and age, it is noteworthy that descriptions of the two groups emphasize different volcanic structures. The coarse Mount Nansen breccias and their massive exposures suggest an intrusive style, but the fine fragmental layered rocks of the Sloko Group probably formed composite volcanoes. In the Montana Mountain complex are features that imply both of these origins. It is an ideal locality to investigate the different structural models that have been applied to similar and probably contemporaneous rocks.

Granitic Intrusions

Compositionally variable plutonic rocks are exposed north of the volcanic complex, and may lie at shallow depths beneath it. They form the south end of a 22 km-long body informally known as the 'Carcross pluton'. From the pluton about 3 km south of Carcross, an age of 63.4 Ma was determined by Morrison et al (1979, by K-Ar method).

The typical plutonic rock, a pink-weathering, medium- to coarse-grained granite to granodiorite (Figure 7), is exposed in creek canyons at the northern limit of the study area. Its mode is shown in Table II. Salmon-orange calcite veining and xenoliths of dioritic composition are common.

A distinctive mauve-coloured variety of altered chlorite granite; the 'mauve alteration type', extends from the contact with the volcanic complex up to 3 km toward the center of the pluton. Slightly oxidized fresh surfaces are easily mistaken for medium-grained quartzite. Quartz has a distinct purplish hue, and mafic minerals are replaced by

Rock type and Method	Quartz	Potash feldspar	Plagioclase	Biotite	Hornblende	Chlorite
Biotite hornblende granite						
$+_1$ 1000 point count (Wheeler, 1961)	25	34	36	4	1	-
$+_2$ average hand sample (estimate)	20	15	55	-	5	1
Chlorite granite (mauve)						
× average (estimated from 5 samples)	20	50	25	-	-	5
Alaskite						
△ average (estimated from 4 samples)	25	60	10	-	-	5

Table II. Volume percent composition of the 'Carcross pluton' in the north part of the study area.

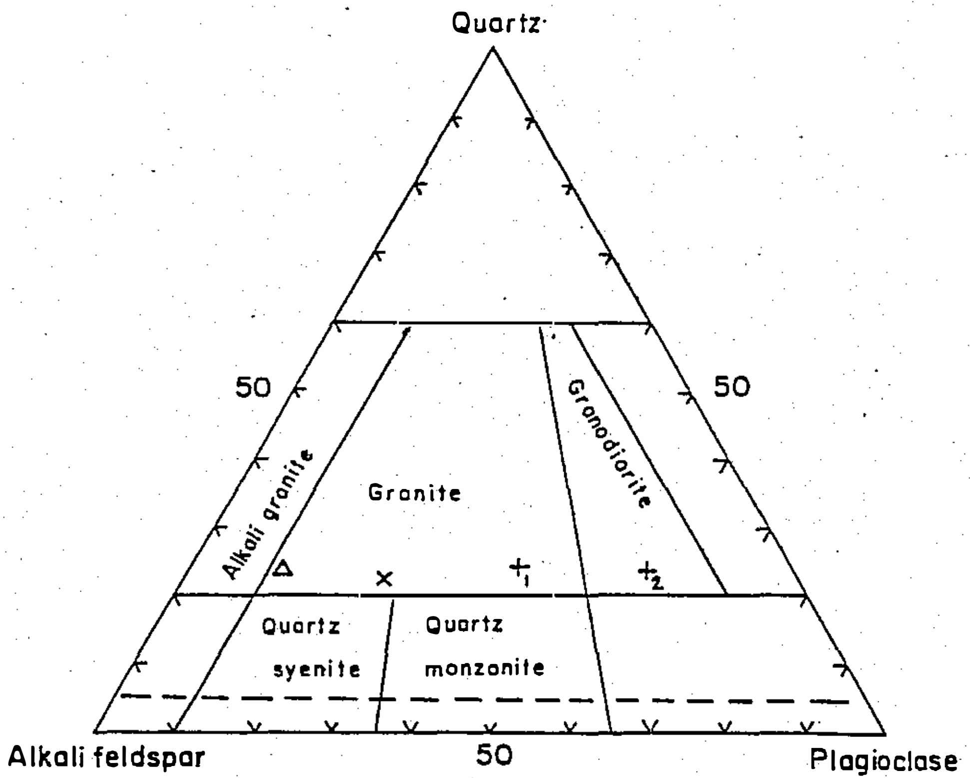


Figure 7. Modal classification of samples from the 'Carcross pluton' on the Q-A-P triangle (from Streckeisen, 1973). Symbols are shown in Table II.

chlorite clots. Notably enriched in potassium, it may be a marginal phase of the pluton that forms a 'cap' extending beneath the volcanic complex.

Along the contact with the volcanic complex, a zone 4-5 m thick of aplite and alaskite borders the chlorite granite. Commonly rust-stained, it is buff, fine-grained and granular. Dikes of similar composition extend into volcanic rocks structurally above the pluton, and into adjacent Laberge strata. The dikes and border phase host tourmaline veinlets and drusy chalcedony in fractures and openings.

The 'Carcross pluton' is compositionally variable and more granitic than rocks of the Coast Range batholith 15 km to the west (see Wheeler, 1961, for comparison). Elsewhere, medium-grained, miarolitic and leucocratic stocks and plutons are spatially related to Mount Nansen and Sloko volcanic centres (Souther, 1971).

Tempelman-Kluit (1974) proposed an intimate connection between the granitic and volcanic rocks because he observed feldspar porphyry dikes that were gradational into both alaskite and extrusive Mount Nansen flows. Similar felsic dikes both below, and intrusive into, the Sloko volcanic piles were noted by Souther (1971). The synchronous nature of these intrusions is postulated to result from relaxation of the compressive stress after arc-continent collision (Figure 3, after Tempelman-Kluit, 1979).

CHAPTER IV

MONTANA MOUNTAIN VOLCANIC COMPLEX

Introduction

Breccias and lava flows correlated with the Mount Nansen Group occur in a roughly circular, high-standing area about 6 km across. Montana Mountain, Mount Matheson and Dail Peak are high points near its north, west and south margins respectively. This section describes the field relations of the complex, and defines rock units. It is succeeded by chapters on the structure and petrochemistry of the volcanic rocks. A concluding chapter presents a model for the evolution of the complex, followed by short notes on its age and mineralization.

General Description

The Montana Mountain complex consists of igneous extrusive rocks, with areas interpreted as subvolcanic breccias and plugs, as well as horizons of volcanic sediments. Figure 8 shows localities and place names referred to in the descriptions.

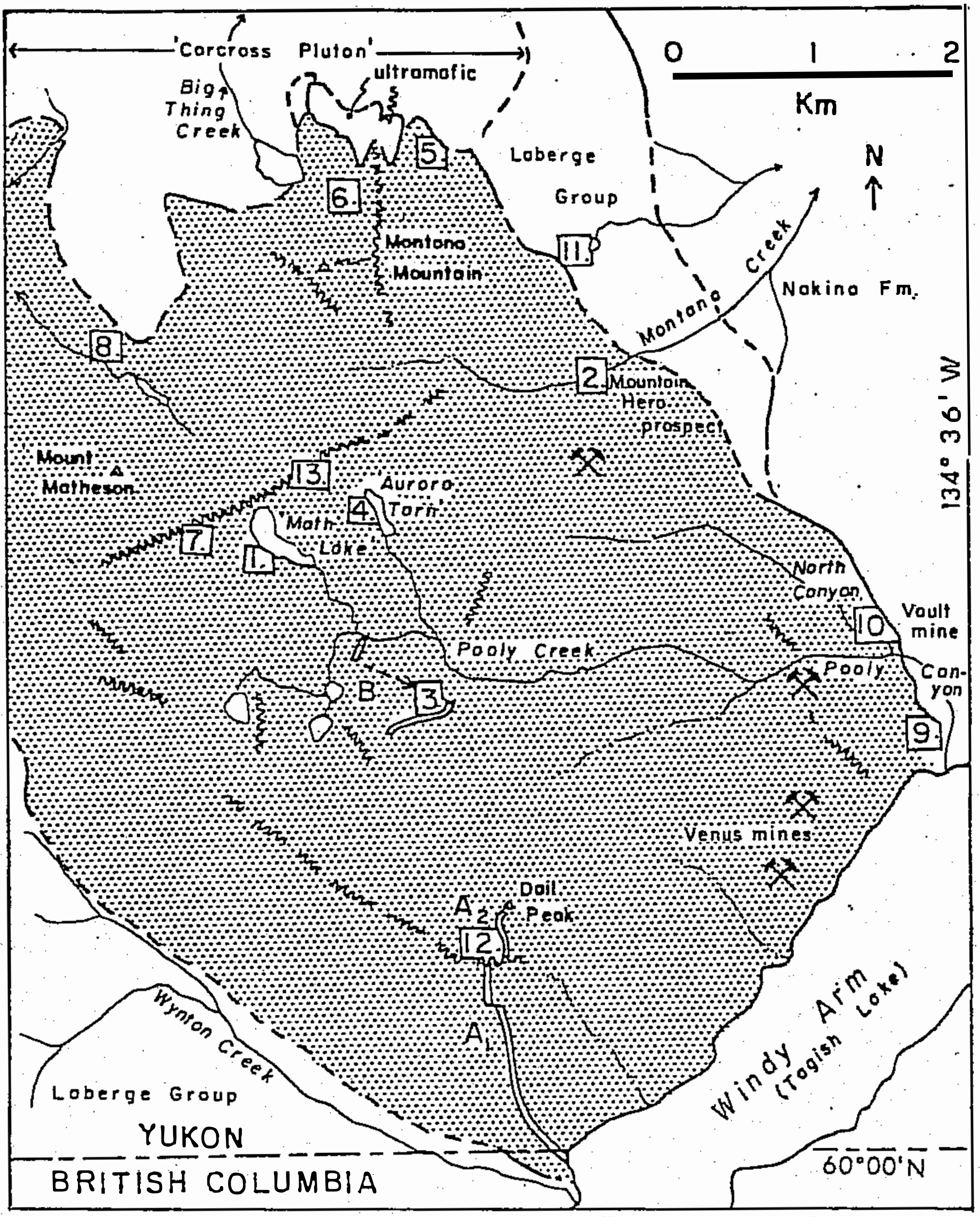


Figure 8. Sketch map of the volcanic complex, showing localities mentioned in the text. 'Math Lake','Aurora Tarn' and 'Carcross Pluton' are unofficial names.

A_1, A_2 and B are stratigraphic sections (Figure 9).

1. Math Lake breccia
2. Mountain Hero breccias
3. Pooly bench Ignimbrite
4. Aurora layers
5. Fluidal textures
6. Flow banded outcrops
7. Breccia dikes
8. Felsic breccia dikes
9. Protomylonite contact
10. Fault contact
11. Gradational brecciated contact
12. Dail Peak fault
13. Matheson fault

Various breccias are the most common rock type in the complex. Extensive in the northern half are massive, homogeneous bodies of coarse fragmental rocks, here termed intrusion breccias, that may have resulted from subterranean stoping and churning. Layered breccias interpreted as ignimbrites and debris flow deposits predominate in the central region. The southern slopes expose over 1200 m of lava flows and breccias. Most layers are flat-lying or gently tilted; random dips of units near intrusions and margins of the complex were probably caused by faulting that accompanied volcanic activity.

In the Montana Mountain complex the rocks are of lower greenschist metamorphic grade and are generally undeformed. Since Cretaceous time this region has been emergent (Souther, 1977) and shaped by erosion. The term 'volcanic centre' (source area with one or several vents) refers in this study to the original edifice (complete dimensions unknown) while 'volcanic complex' refers to the present, deeply eroded structure. The Montana Mountain complex is a remnant of a large centre that perhaps was situated over the 'Carcross pluton'. Arching of the centre caused by intrusion of the granitic magma may have escalated erosion of the volcanic edifice.

In addition to the complex are a few

occurrences of volcanic rocks that may also be remnants of one large edifice. A locality southeast of Windy Arm described by Monger (1975, p. 28) contains flows and breccias similar to those typical of the Mount Nansen/Sloko Groups. At this locality they unconformably overlie the Cache Creek Group. Another occurrence, 15 km northwest of Carcross was mapped by Wheeler (1961; Hutshi Group) and abuts the north end of the 'Carcross pluton'. If the volcanic centre covered regions now occupied by the pluton, its primary vent area may now be entirely removed.

Two factors are important to the preservation of the Montana Mountain complex. Because lava flows and other extrusive rocks are now exposed more than 600 m lower than adjacent ridges of older Laberge sediments through which they have intruded, down-faulting of the volcanic rocks must have occurred. Fault zones form the southern and southwestern boundaries of the complex, suggesting that block subsidence, rather than regional faulting, occurred. Additionally, the higher elevations adjacent to the 'Carcross pluton' suggest that thermal metamorphism during intrusion of the granitic rocks has increased the resistance of surrounding rocks to weathering. The present erosion surface of the volcanic complex is thus at a higher stratigraphic level than that of rocks in the surrounding region.

Metamorphism and Alteration

Four types of alteration and metamorphism have affected the complex:

1) Alteration and probable devitrification produced homogeneous aphanitic textures;

2) Sausseritization by meteoric waters and hydrothermal fluids;

3) Thermal metamorphism due to magmatic intrusions; and

4) Local oxidation, hydration and bleaching of rocks adjoining conduits of silica-rich fluids.

Non-fragmental volcanic rocks are medium to dark green or grey, fine-grained and of lower greenschist metamorphic grade. Thin sections of flow rocks show oligoclase partly converted to albite, and rare actinolite, some of which replaces augite. In most samples the groundmass is composed of plagioclase microlites and altered glass with a hyalopilitic texture. Patches and vugs of secondary quartz, chlorite and calcite are ubiquitous in the flows.

Fragments in volcaniclastic rocks are commonly metasomatized. Tuffs are altered to tough, slightly porous aggregates of chlorite, actinolite and albite. Probable bombs in beds near 'Aurora Tarn' are extensively converted to epidote. Lenticles are rimmed with quartz, chlorite and dark clay minerals in some pyroclastic fragments. Although textures of moderately welded pumice fragments are preserved, some fragment components have altered to clays rich in iron oxides.

Subvolcanic intrusion breccias are laced with veins composed sequentially of chlorite-epidote-quartz, quartz-feldspar intergrowths, and quartz-tourmaline. This order suggests increasing temperatures that may have been caused by plutonic intrusion. Many well-rounded clasts have thick, epidotized rims. Their susceptibility to alteration, as well as to erosion, could have resulted from higher porosity and larger grain size than other fragments in the breccia.

Around the southern end of the 'Carcross pluton', rocks are darker, and volcanic textures are obscured in an aureole 100-250 m wide. Hornblende and biotite crystals in these rocks are up to 2 mm long. Although coarse breccias and layered rock types are recognizable, many fine-grained rocks in this zone are more appropriately identified as hornfels.

Oxidation and hydration along faults, felsic dikes and quartz veins have resulted in thick sericitized envelopes that obliterate original mineralogy and obscure primary textures. Rocks surrounding the Venus quartz vein contain considerable limonite and yellow iron oxides, as well as pyrolucite and irregular concretions of dark brown yukonite (Sabina, 1972). This soft altered rock was the site of many of the early mine workings.

Stratigraphy

Stratigraphic sections through layered volcanic rocks exposed in the long southern slopes and in cirques in the centre of the complex are depicted in Figure 9. Although layering can be viewed from a distance, in outcrop primary features are rarely seen and contacts are difficult to distinguish. Because many volcanic units are lenticular and bedding highly variable, the sections provide only general examples of the stratigraphy. They are useful to indicate proportions of various rock types and may illustrate general trends or changes that occurred in the volcanism.

The south section (A), from the shore of Windy Arm through cliff bands to Dail Peak, is dislocated by a 10-50 m wide fault zone at an elevation of 5700' (1740 m). This break, referred to as the Dail Peak fault, is significant because the layered rocks

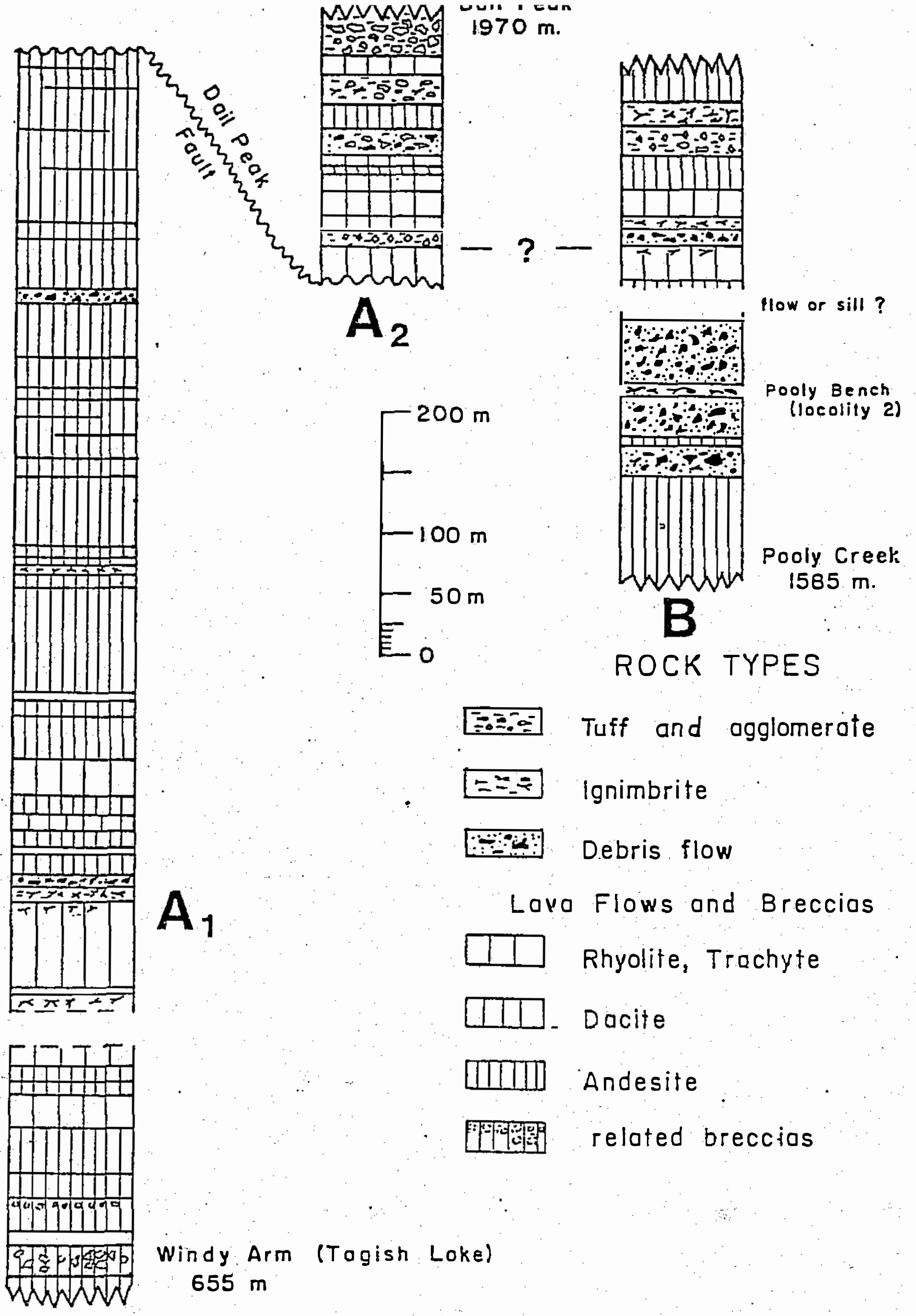


Figure 9. Stratigraphy of the south side and center of the Montana Mountain volcanic complex. Locations are shown on Figure 8.

and their attitudes do not match across it.

The lower part of the section (A1) consists of at least 930 m of dark green massive lava flows and breccias that dip gently to moderately south (outward from the centre of the complex). Andesite and dacite comprise 73% of the succession, commonly as flows averaging 10 m thick. Those at lower elevations contain horizons of spherical and elongated vesicles (1-4 mm long) that are commonly filled with calcite and clay minerals. Andesite breccias (5%) consist of blocky, angular to sub-rounded cobble-sized fragments that are compositionally similar to the enclosing matrix; but are distinguished by different hues (commonly maroon) and greater vesicularity. They are interpreted as lava flow-top breccias. Other breccias are lenticular bodies 2-10 m thick containing heterolithic fragments, and are probably intercalated pyroclastic flow and laharic (debris flows composed of volcanic fragments in a fine matrix) deposits.

The section above the fault (A2) follows craggy spurs to Dail Peak. Although contacts and textures are obscure in the oxidized rocks, the succession appears to consist of grey-green and maroon porphyritic lava flows overlain by heterolithic breccias. The upper 150 m contains a varied assemblage of fine, dominantly felsic fragmental layers that dip gently southeast and north. Because the latter exhibit fluidal textures with swirled, plastically deformed clasts (Plate I, d), they are thought to have deposited as agglutinate (cooled spatter) deposits. These and the pyroclastic beds on the summit of Dail Peak are unique in the complex, and may represent a later, separate period of volcanism.

Section B, measured through rubble slopes and cliffs south of upper Pooly Creek, displays about 450 m of the internal stratigraphy of the complex. Light green-grey lava flows (55%) constitute the lower section, with heterolithic breccias and felsic rocks forming recessive intervals. Whether the orange-weathering trachyte or rhyolite were sills or thick extrusive flows could not be determined. Near the middle of the section, a moderately welded ignimbrite layer several metres thick was encountered in rubble (locality 3).

No marker units were discovered. However, the two sections can be tentatively correlated by thick felsic layers which separate the lower predominantly andesitic flows from an upper succession of breccias, ignimbrites and more felsic rocks.

CHAPTER V, a

DESCRIPTIONS OF ROCK TYPES

LAYERED UNITS

Lava Flows

The dominant rocks in the southern two-thirds of the complex are blocky, dark green, brown and maroon volcanic rocks interpreted as intermediate and mafic lava flows. In large exposures they appear as uneven layers, from 5 to 15 m thick, and some sub-horizontal units are continuous over 2 km. The package of lava flows with intercalated breccias is at least 900 m thick south of Dail Peak.

The flow rocks are generally aphanitic, dense and relatively soft; most are partly recrystallized to amphibole and chlorite aggregates. Fresh surfaces of individual layers are dark green, purple, or a distinctive pale green. The chemical analyses (Appendix A), indicate that the dark green rocks (average 55% silica) are of andesitic composition and that the light green rock type (64% silica) is dacite.

About 25% of the lava flow units are

vesicular. In some outcrops at the head of Pooly Canyon, spherical and elongate amygdules up to 2 cm in length comprise 20% of the rock. Vesicles are locally filled by calcite, quartz or dark green clay (celadonite?); in altered zones they contain epidote or limonite. Cross sections of the lava flow layers locally show horizons of small holes; in good exposures, changes in vesicularity are useful aids in locating contacts of individual flow units. Although most vesicles are smoothly rounded (implying that the gas exsolved from relatively fluid magma), pinched and irregularly elongated bubbles in rocks near the Vault mine resemble vesicles of more viscous 'aa' lavas. Rocks with large and abundant vesicles are maroon or deep purplish throughout; this oxidation colour suggests that some of the rocks were extruded subaerially.

Most lava flow rocks are massive and homogeneous. Flow structures, such as trains of vesicles, gradual changes in abundance of phenocrysts and colour streaking were observed in some outcrops. Contacts between lava flow units are not easily discerned. Those observed consist of: 1) thin, irregular cracks above darkened zones (1-5 cm thick) and in places fractured, epidotized rocks; 2) abrupt changes in phenocryst content, vesicularity or weathering aspect, and in places in the pattern and spacing of joints; and 3) breccia interbeds. Some of these breccias, composed of monolithic subangular lava fragments, are interpreted as flow-top breccias; other heterolithic types that may be laharic deposits are described later.

Some of the thick layers exposed in cirques at the head of Pooly Creek consist of several individual flows ranging from 1-3 m thick. In most places these flows appear conformable with each other, although a distinctive pale green unit south of Aurora Tarn overlies different breccia types, suggesting a step-like, blanketing deposit.

The layers are inferred to have been groups of fluid sheet lavas that spread over wide, gently sloped areas. Most were extruded into a subaqueous environment, but some highly vesicular and maroon rocks may have resulted from subaerial activity. The lava flows comprise at least 90% of the volume of the extrusive part of the complex, and occur throughout the exposed succession. Detailed examination and tracing of the flow units could lead to reconstruction of the morphology of the original volcanic centre.

Laharic and Pyroclastic Flow Deposits

Unsorted, layered breccias composed of coarse, dominantly volcanic fragments suspended in a detrital matrix are interpreted as flow deposits that were once surficial features of the volcanic centre. Most units are considered to have resulted from lahars, block avalanches and mudflows; however those rocks containing chlorite lenticles and a vesicular matrix may have originated as pyroclastic flows.

The dark green and brown breccias have a blocky appearance, but cannot be distinguished from lava flows at a distance. In places the fragmental textures are similar to those of subterranean intrusion breccias, but can be distinguished by: 1) detrital chips visible in the matrix; 2) a greater variety of clast types and sizes, and 3) conformable or erosionally disconformable contacts.

The breccias occur as tapered or lenticular beds within lava flow successions (south of Dail Peak, and at the head of Pooly Creek) and comprise a section more than 120 m thick near the Mountain Hero prospect (locality 2). The breccia layers at Mountain Hero are 1.5 to 5 m thick, and their particular textures and distinctive clast or matrix compositions permit identification in adjacent outcrops where external contacts are not exposed. Some of the flow deposits were extensive; a layer noted for abundant bluish quartz chips is exposed over 1.5 km in the cirques of upper Pooly Creek.

The matrix is commonly dark green to grey and comprises 20% to 40% of the breccias. Detritus (1-5 mm angular chips) of andesite, dacite or quartz is almost always present in the very fine-grained matrix. Thin sections show patches of chlorite, and foliation within fragment trains as if some flowage had occurred. Flows rich in glass are suggested by the isotropic matrix in many of the altered deposits. Eutaxitic chlorite lenticles up to 3 cm long, commonly with tricuspate edges and thin, streamer-like projections, may have been glass shards or pumice fragments.

Clasts in flow deposits vary greatly in size, shape and composition. Many weather light green or maroon, in contrast to the uniformly dark green or brown fragments of intrusion breccias (described in Chapter V, b). The pebble- to boulder-sized clasts are commonly sub-angular and equant, and probably were derived from andesite and dacite lava flows. Many clasts are vesicular or porphyritic, and in some breccias they are mixed with fragments derived from previously existing breccias, tuff layers and felsic volcanic rocks.

Most breccias in the Montana Mountain complex are unsorted and chaotic (Plate I, a). Those interpreted as debris and pyroclastic flow deposits show crude stratification in places, commonly as trains of large clasts sub-parallel to the base of certain flows. Clasts are rarely touching, but may be concentrated in broad or narrow zones (10 cm to 2 m) separated by bands entirely lacking or containing only small fragments. Fine-grained laminations that bend around larger grains suggest some internal reworking during final movements of the flow. Such unsorted textures, however, reveal little about the environment of deposition (Lajoie, 1979).

Contacts between debris flow deposits are sharp, irregular breaks. In many places they have served as conduits for later solutions and are extensively coated with chlorite, but some depositional surfaces are pristine. At the Mountain Hero locality, thin siltstone interbeds appear erosionally truncated by the overlying breccias. Because the fragmental textures of debris flows are in places superficially similar to those of intrusion breccias, depositional and semi-conformable contacts were useful criteria to distinguish these deposits from the intrusive bodies with steeply cross-cutting margins. Some of the depositional breccias may grade into reworked

PLATE 1 - LAYERED BRECCIA TEXTURES

a) Fragments of massive andesite (rectangular), porphyritic andesite (rounded; speckled) and quartz (white) in coarse granular matrix, now siliceous. Irregular lighter patches around some clasts are epidote alteration. From laharic deposit, Mountain Hero prospect (locality 2). Tape is marked in cm.

b) Ignimbrite containing grey lenticles (now chlorite) and more rounded dacitic fragments (lighter grey) showing eutaxitic foliation. From Pooly Bench (locality 3).

c) Negative print to show texture of matrix of pyroclastic flow or tuff. Lithic tuff fragments (dark) show vague alignment in the patchy chloritic groundmass. Fine dark ribbons near bottom are probably altered glass shards. Dark cross-cutting lines represent quartz-filled microfractures. From Mountain Hero prospect (locality 2).

d) Negative print to show texture of pyroclastic fall deposits. Irregular, plastically deformed felsic lithic clasts (lighter parts are hematite-enriched) containing euhedral feldspar phenocrysts and relicts of pumice and glass shards (dark) are enclosed in a sericitized matrix. From layers at Dail Peak.

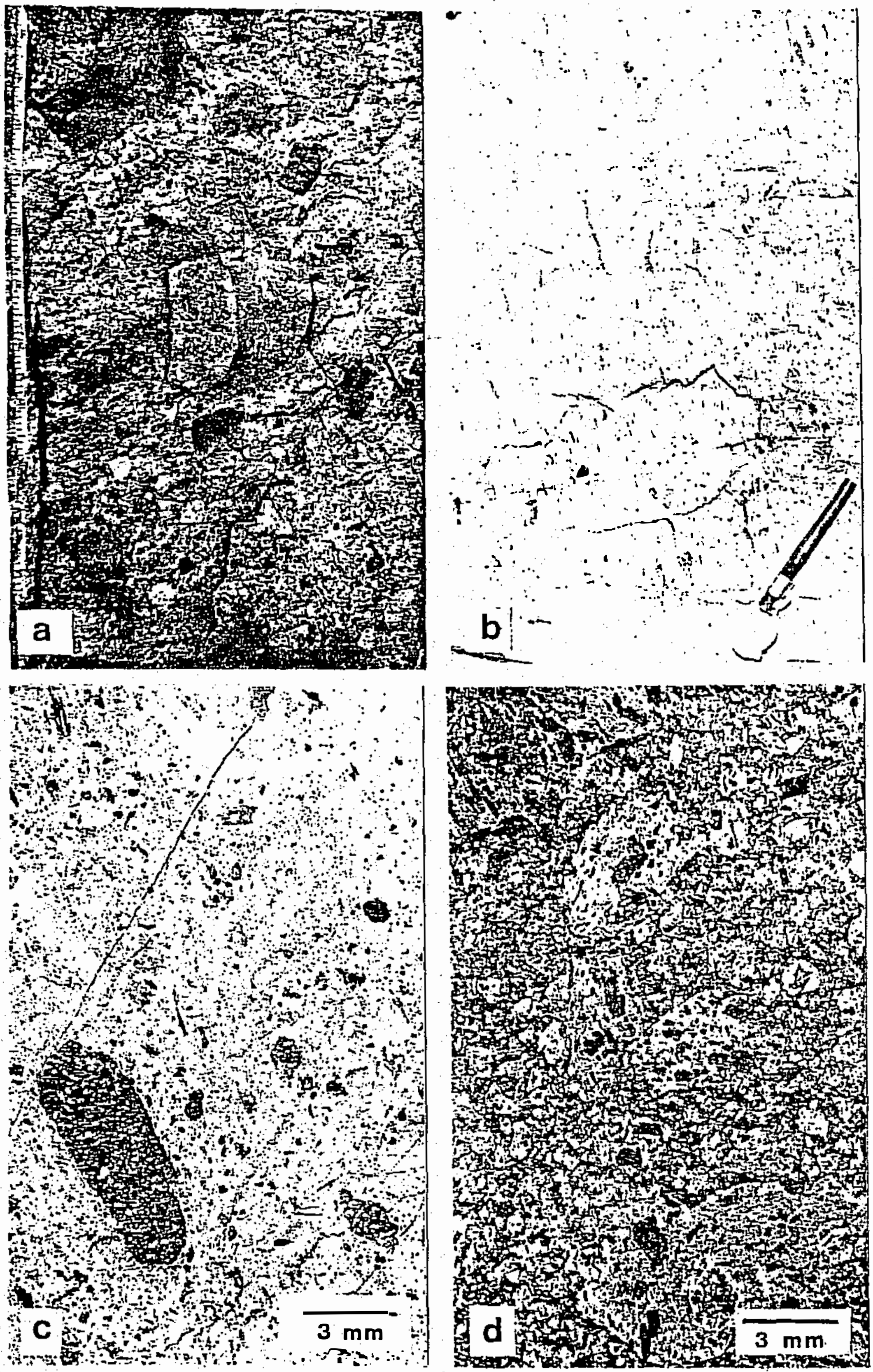


Plate I

epiclastic sediments, but because the outcrops are discontinuous the relations are not clear.

These breccias are inferred to have been lahars, except where altered pumice and shards are present to suggest pyroclastic flow deposits. Distribution of these breccias was influenced by the topography at the time of deposition, and they are now discontinuously exposed so that the direction and distance to source area are unknown. Their great abundance and thickness in central regions of the complex suggests that these breccias may have occupied a depression within the centre. Possibly they were shed from an edifice situated to the north of the present complex.

Breccias that contain a mixture of primary and secondary volcanic fragments are unusual because they indicate that pyroclastic eruptions mobilized coarse lithic debris. Three possible mechanisms have been suggested:

1) An incandescent gravity slide (the 'Merapi type' ash flow of Williams, 1957) caused by partial collapse of an active volcanic dome;

2) Eruption of a tuff-breccia formed within a volcanic conduit (c.f. Parsons, 1967); or

3) A fissure eruption at the edge of a subsiding block which incorporated slumped scarp debris.

Although none of these possibilities can be definitely ruled out, the phenomenon of ash and rubble slides originating on the flanks of a volcano or growing dome (#1 or #2) appears most likely. The third possibility depends upon recognition of a fault scarp; but none of the faults within the complex could be directly linked either to volcanic activity or to these deposits.

Detailed Study: Math Lake Breccia (Locality 1)

A well-exposed breccia lens in cliffs south of 'Math Lake' provided an opportunity to investigate the nature of layered breccia deposits. The exposure is an oblique cross-section (Figure 10) about 50 m wide and up to 12 m thick. The upper and lower contacts are generally parallel, dipping moderately south into the face. Above and below the breccia are thick (15 m and greater than 5 m) andesitic flows; the upper one is uniformly porphyritic. Rubble covers extremities of the breccia body. The deposit appears to be limited in extent because nearby the upper and lower lava flows are in contact.

Large fragments are unsorted and spaced apart in the dark matrix. Subangular massive and porphyritic andesite and dacite cobbles predominate; they could have been derived from units lower in the volcanic succession. In addition there are unusual fragments such as one highly vesicular maroon boulder and pebbles of pinkish quartz; their source is unknown.

The dark matrix of the breccia is filled with angular andesite fragments and quartz; in places fine laminations appear plastically deformed. Because boulder-sized clasts are supported by the matrix, it may have been a thick mud. White clay rims on some fragments suggest reaction with the matrix, probably during regional low-grade metamorphism. Breccia dikes cut the matrix, clasts, and overlying andesite.

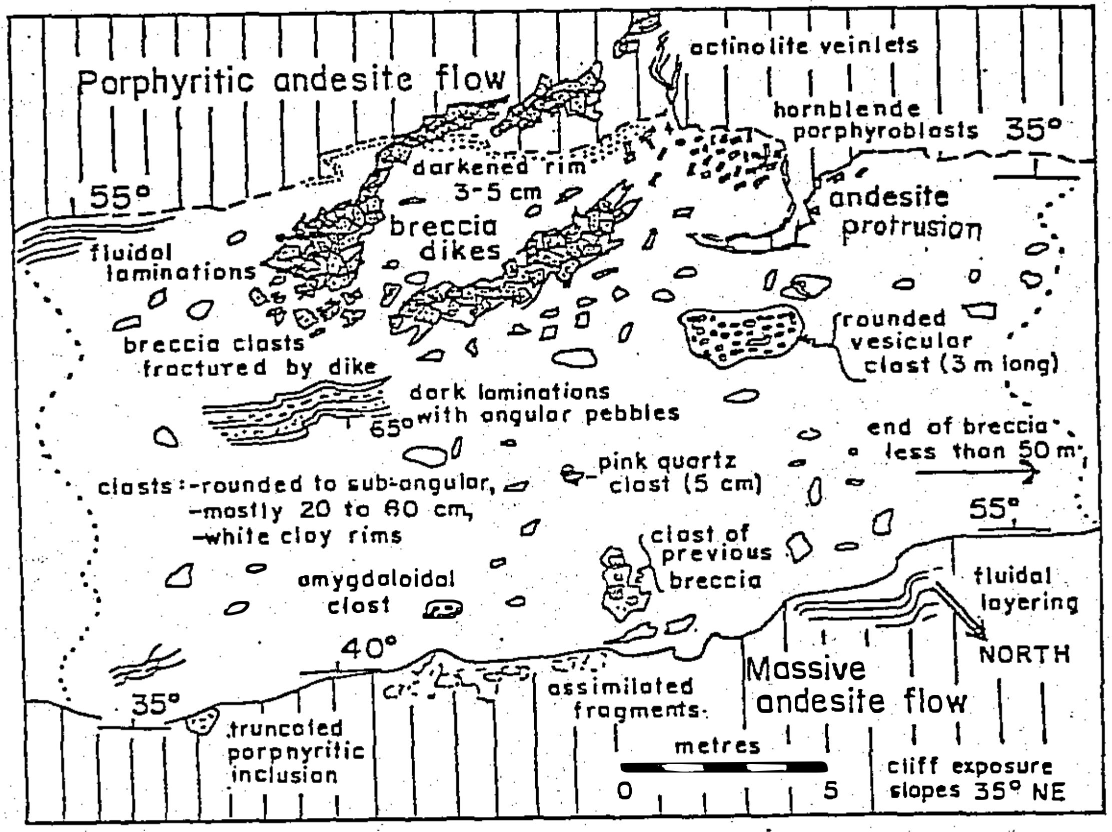


Figure 10. Sketch map of the Math Lake breccia (locality 1).

That the Math Lake breccia was deposited (rather than injected) between flows is shown by differences in its upper and lower contacts. The breccia disconformably overlies a massive lava flow which contains partly assimilated andesite fragments; the upper surface of which may have been a flow-top breccia. This contact is unaltered, and some clasts in the Math Lake breccia body form vague trains parallel to it. The upper contact of the breccia has small offsets (10-90 cm) and a dark, siliceous rim 1-5 cm thick. Hornblende porphyroblasts fill irregular alteration patches along this zone. In one place, the overlying porphyritic andesite intrudes 5 m downward into the breccia body, suggesting that it may be a crack filling. The breccia must have been well-consolidated to open fissures and remain undeformed by the overriding lava flow.

The Math Lake breccia is interpreted as a slide that consolidated rapidly after deposition. Its upper surface was probably baked and infilled by the succeeding lava flow.

Detailed Study: Mountain Hero Breccias (Locality 2)

Outcrops along Montana Creek near the Mountain Hero prospect (elevation 5600'/1710 m) consist of fine fragmental rocks interpreted as laharic and pyroclastic flow deposits. They comprise a layered succession at least 250 m thick, interbedded with minor lava flows. Relation of these beds to the volcanic pile to the south is not known, but their moderate dips and higher elevation imply that they are younger.

About 20 separate breccia layers (Plate II, a), from 1-10 m thick, were recognized. Depositional contacts are exposed, including a smoothly undulating surface of andesite overlain by heterolithic breccia (Plate II, c). Some breccia layers are separated by thin argillaceous partings that lie conformably on the flow beneath, but appear erosionally truncated by breccia above (Plate II, b).

Clasts in Mountain Hero breccias range from 1-20 cm, although sparse larger clasts are concentrated in several coarser layers. Most are dark-coloured, fine-grained, and vesicular; they were probably derived from lava flow rocks.

Dark argillaceous matrix forms more than half of most breccia layers. It may have been ash, now recrystallized to sericite. Some layers contain angular chloritic knots and lenticles that may be altered shards or ash, as well as chips of andesite and blue quartz. In thin section the matrix shows microvesicular fiamme replaced by clinozoisite. The

PLATE II - LAYERED BRECCIAS

a) Breccia layers at Mountain Hero prospect (locality 2). The rocks have been subjected to low grade regional metamorphism, and break along weathered joints. The layers are 2-3 m thick and contain pebble-sized and smaller fragments. Inset area is shown in (b).

b) Siltstone and shale between breccia layers in (a). White streaks are manganese and iron precipitate along fractures. The upper contact is irregular and in places disconformable with the overlying breccia. From locality 2.

c) Lower contact of laharic breccia (at hammer point). The upper surface of the vesicular andesite is uneven and polished. The overlying breccia contains scattered large clasts, but these are not present immediately adjacent to the contact. From below the Mountain Hero prospect (locality 2).

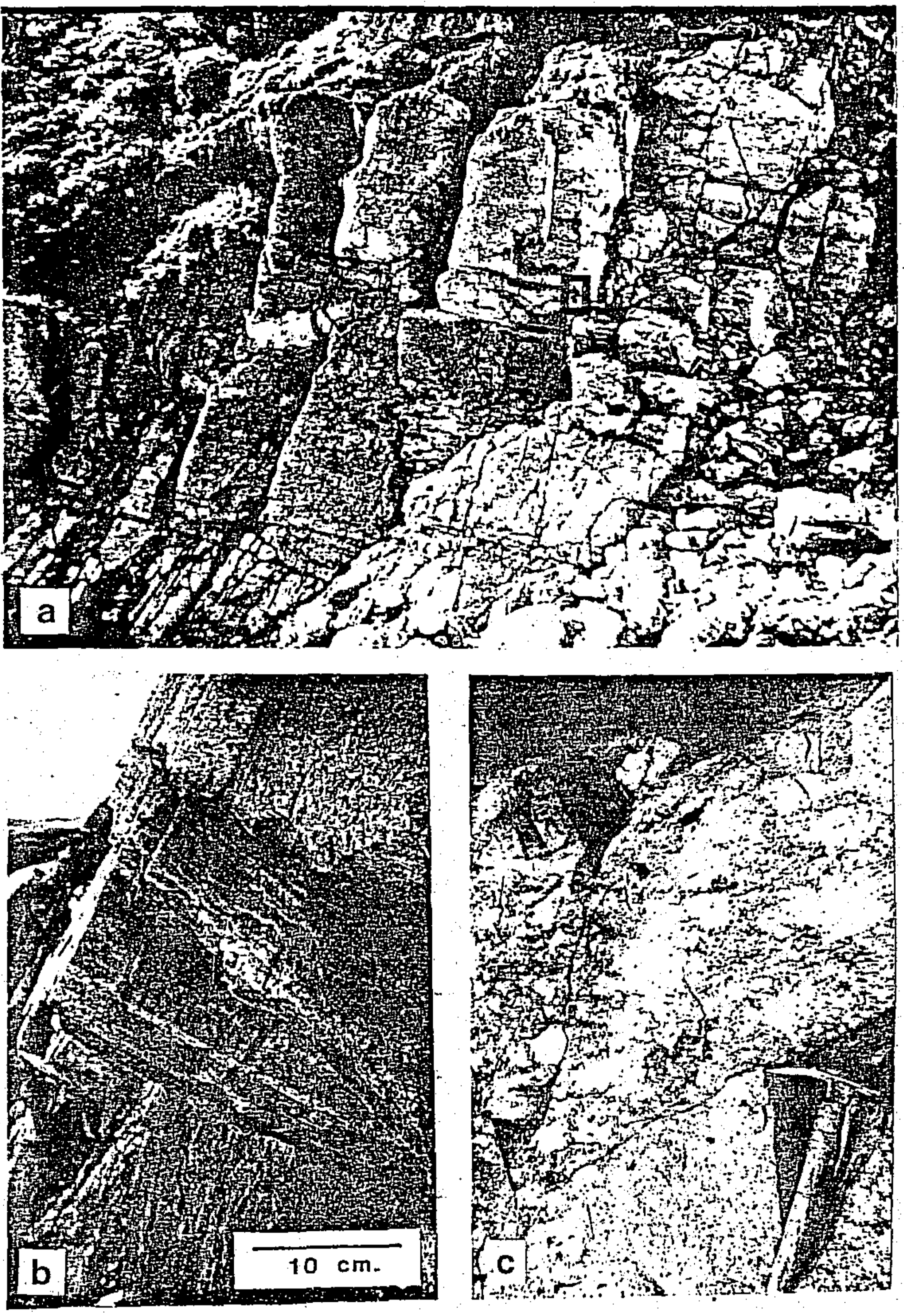


Plate II

combination of altered pumice and fiamme indicates that both solidified and partly molten clasts were present. Along fractures, surface textures are obliterated by mottled chloritic alteration.

Depositional contacts, internal homogeneity and contrasts between breccia layers suggest fragmental flows or slides were deposited in the Mountain Hero area. Plastically deformed lapilli and the predominance of small clasts suggest that they were concurrent with explosive eruptions.

Ash Flows - Pooly Creek Ignimbrite (locality 3)

In this study, the term 'ignimbrite' is used to designate the rocks formed from the deposition and consolidation of ash flows (Lambert, 1974), but do not contain abundant lithic blocks (a characteric of pyroclastic flow deposits described previously). An ignimbrite is exposed on a bench in cliffs at an elevation of 5300'/1610 m on the south side of upper Pooly Creek. It occurs within a layered succession interpreted to be laharic deposits, volcaniclastic sediments and lava flows (lower stratigraphic section B, Figure 9). The white-weathering boulders that cover a 25 m by 50 m area contain dark, chloritized lenticles that show eutaxitic foliation (Plate I, b).

These devitrified pumice shards compose 10-15% of the rock. Their length to thickness ratios are between 2 and 10, which is within the range of partly welded ignimbrites determined by Lambert (1974, p. 26). Less common 10 cm clots are not flattened, and contain 2 mm equant feldspar phenocrysts. Probably the crystals formed deep within the volcano before their eruption, and the clasts may have been partly solidified when they were ejected from the vent.

Lapilli-size and smaller lithic clasts form up to 50% of the rock; light grey microporphyritic and rhyolitic fragments predominate. Others include finely laminated chips resembling siltstone fragments, and medium-grained leucogranitic pebbles that indicate the magmatic source for this ignimbrite.

Two possibilities for the origin of the ignimbrite may be considered: 1) it was emplaced during a distinct, probably short-lived explosive eruptive phase; or 2) it could be a distal volcanic deposit derived from a centre simultaneously erupting elsewhere. If the deposit was derived within the complex, the felsic and vesiculated fragments could be related to unwelded pyroclastic deposits near Dail Peak (following description). The ignimbrite may have erupted late in the period of volcanism, because granitic clasts resemble those of the 'Carcross pluton' that later intruded the volcanic complex. The second possibility is based upon the textural and compositional similarity of this rock to ignimbrites of the MacAuley Creek Formation in the Bennett Lake complex (Lambert, 1974). Volcanism at Bennett Lake is thought to have occurred some 10-15 million years later than at Montana Mountain, and possibly some of its effusive products were preserved in deep depressions (such as a possible caldera at Montana Mountain) 20 km distant.

Pyroclastic Fall Deposits

Fragmental rocks that show good sorting, stratification, and contain vesicular and altered pumiceous fragments are interpreted as tuff, lapilli-tuff and agglomerate. The two occurrences, on Dail Peak and in upper Pooly Creek, are different in character but both appear to be near the top of the volcanic succession.

Detailed Study: Aurora Layers (Locality 4)

Cliffs along the south sides of a rectangular tarn (informally named after the abandoned Aurora adit nearby) consist of lava flows and two layers of thinly stratified pyroclastic deposits and sediments 15 to 30 m thick.

The layers are interpreted as beds of pyroclastic ejecta and reworked tuffs. They are intercalated with thin, highly vesicular lava flows that have irregular protuberances on upper surfaces which resemble pillows. Hollows in the irregular flow top are infilled by laminated grey claystone and siltstone, which show soft sediment deformation structures. Some of the sedimentary layers appear truncated by erosion, and exhibit dark, siliceous rims in contact with lava flows, possibly the result of baking by the over-riding lavas.

Fine-laminated beds are 1-7 m thick and continuous over 250 m. Weathering highlights alternating bands of medium- and fine-grained recrystallized minerals, but stratification is barely discernible on the dark fresh surfaces. In thin section, a dense mesh of plagioclase and actinolite shows slight differences in grain size coincident with stratification. Uncommon 1-3 mm lithic clasts (Plate III, c) and tricuspate fragments that may be recrystallized broken bubble-wall shards are present.

At least two of the fine-grained horizons contain cobble-sized fragments with irregular or smooth symmetrical shapes (Plate III, a). Because elongate vesicles in the clasts lie at angles to the stratification of the enclosing tuffs, they must be

PLATE III - VOLCANICLASTIC TEXTURES (Locality 4)

a) Epidotized vesicular fragments in fine-grained layers, (dashed outlines) interpreted as bombs. From Aurora layers (locality 4).

b) Weathered-out boulder below outcrop in (a) consists of vesicular core and siliceous rims; interpreted to be a spindle bomb. From Aurora layers (locality 4).

c) Microtrachytic clasts (upper left) in sericite-chlorite matrix, interpreted to be a lithic fragment in devitrified tuff. From Aurora layers. Polarized light.

d) Lithic fragment, quartz chips (white) and chlorite lenticles (dark clots) in fine clastic groundmass. From debris and ash flow near Mountain Hero prospect. Plane light.

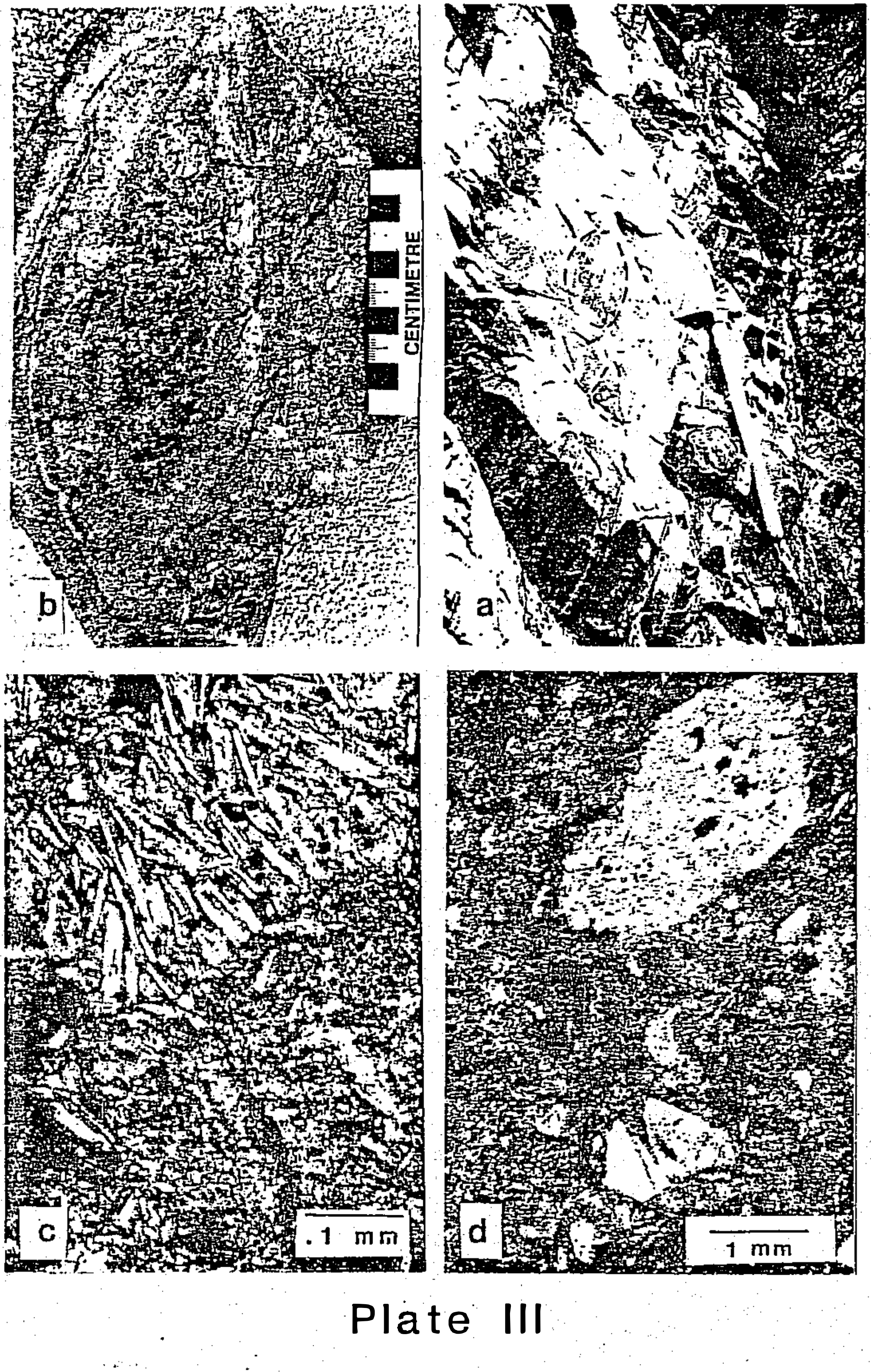


Plate III

exotic fragments; at least some are bombs. Talus fragments show characterisic shapes with highly vesicular cores and concentric rims (Plate III, b).

Along the north side of Pooly Creek valley are several outcrops of thin, alternating maroon and green beds. Weathering outlines sand- and silt-sized clastic textures indicating normally graded bedding 1-10 cm thick with abundant soft-sediment deformation. The beds may be ash layers that are now recrystallized. Discontinuous lenses of coarse, clast-supported debris erosionally truncate the fine sediments.

The Aurora layers are accumulated products of volcanic activity and erosion. They were probably deposited in water, and could represent infilling of a central depression.

Dail Peak Layers

The summit cone of Dail Peak (6300'/1920 m) consists of gently south-dipping oxidized breccia layers, 7-10 m thick, containing amygdaloidal maroon, greenish and turquoise (alteration colour) fragments. Some clasts have interdigitating boundaries and foliated lenticles 1-4 mm long that may be collapsed gas cavities. Layers below consist of fine oxidized matrix enclosing flattened, irregular-edged lapilli

(Plate I, d) and sparse felsic cobble-sized clasts. Thin sections of the matrix show vaguely aligned broken feldspar phenocrysts that are corroded and filled with inclusions. Granular pyrite, probably filling vugs, is abundant in the lower layers.

Dail Peak breccias have eutaxitic textures that resemble those of hot ash tuffs. Fragments in summit layers appear plastically deformed and may have been molten when they were deposited. Their stratigraphic position, at the top of the layered volcanic succession, and felsic composition suggest that they may have been accumulations of pyroclastic spatter derived from eruption of sheeted trachyte or latite dikes with similar composition that are abundant in the units immediately below.

CHAPTER V, b

INTRUSIVE UNITS

Introduction

Three distinct intrusive rock types are recognized in the Montana Mountain complex. Intrusion breccias and plugs, as well as fluidal layering, were investigated because their interpretation bears significantly upon models of the evolution of the complex. Felsic and breccia dikes are then briefly described. Quartz veins are treated in a later chapter because they were precipitated from solutions rather than intruded as solid or semi-solid magma and appear to be later than the main volcanic activity.

Andesite Plugs

Large bodies, including the masses comprising Montana Mountain, Mount Matheson and steep-sided ridges west of them are composed of homogeneous porphyritic andesite. The rock is medium green or grey, fine grained, and contains 10-20% oligoclase blades up to 5 mm long. In a few places, equant epidote has pseudomorphed hornblende phenocrysts. No vesicles, foliation, or flow structures were discerned in these rocks.

The andesite bodies are unlayered and display regular vertical jointing that extends from top to base of some exposures. Some apparently single masses are very large: the bulk of Mount Matheson, up to 1 km wide (Figure 11), has two sheer sides 500 m high. Other bodies are smaller, but equally homogeneous; a glacially polished knob north of Montana Mountain is 50 m broad by 30 m high, and of similar composition. No stratification, breccia zones or alteration systems were observed in the bodies; a marked contrast to other rock units of the complex.

The contacts of the andesite masses are mostly obscured by rubble; those exposed are sheared zones or appear to grade into coarse breccias. Fragmental rocks, interpreted as intrusion breccia, surround the masses. These bodies lack internal structures, but show pervasive and persistent jointing patterns, suggesting that they solidified as complete units. They could be cores of plug domes. The masses are not remnants of lava lakes because layering and lava flows are not common in the vicinity (classic examples described by Mathews, 1958; and Macdonald, 1972). Plug domes are consistent with interpretations of the surrounding breccias presented here.

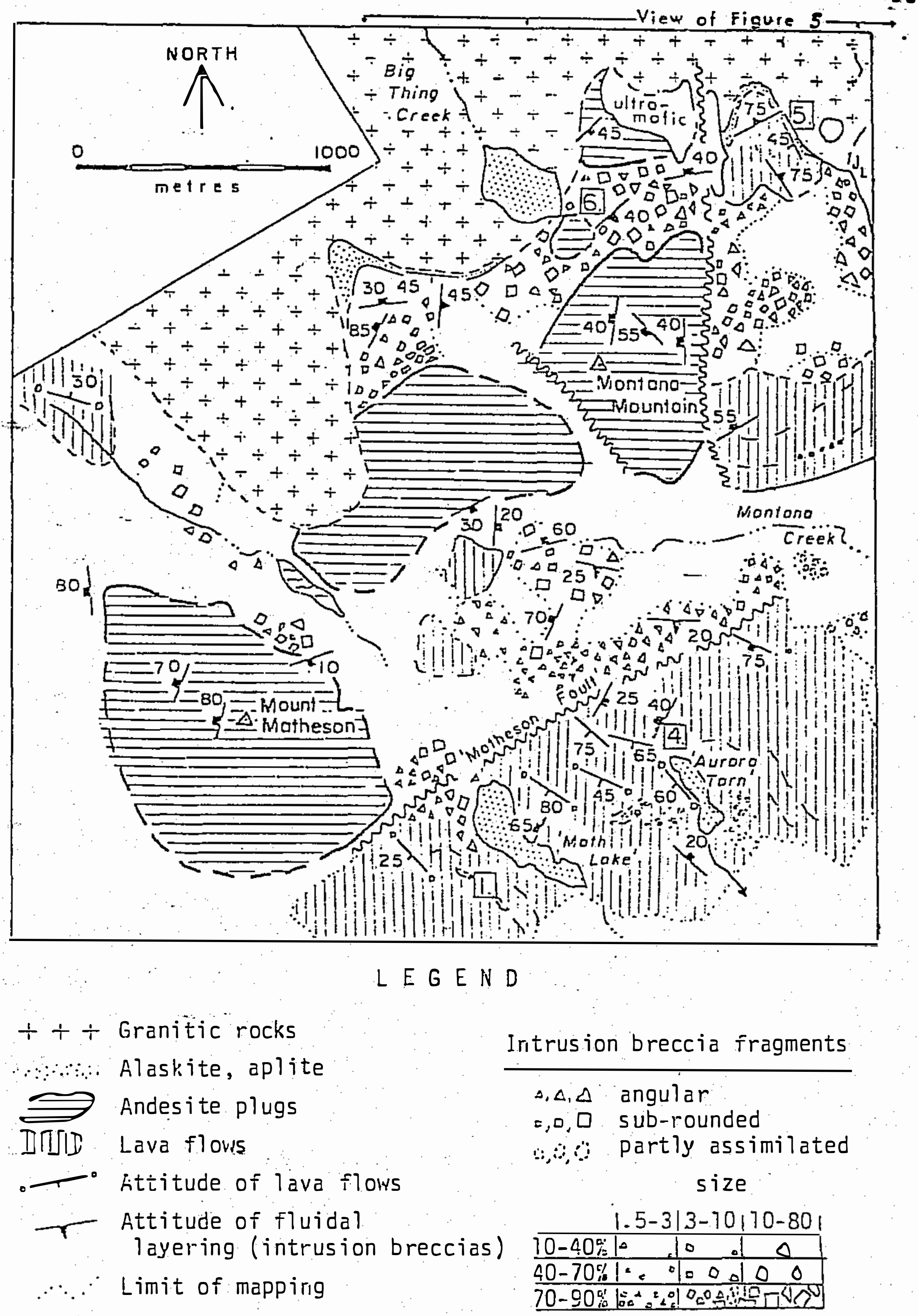


Figure 11. Geology of the north end of the volcanic complex, showing the distribution of interpreted plug domes and intrusion breccias. Shape, size and density of the breccia fragments are depicted where known. Numbers refer to localities mentioned in text.

Subvolcanic Intrusion Breccias

Matrix-supported breccias consisting of clasts that are angular to well-rounded predominate in the north part of the complex. They are believed to be unlayered because cliffs show massive, well-exposed breccias that extend vertically for tens of metres. Andesite clasts weather brown in a lighter, more siliceous-looking matrix (Plate IV, a). Irregularly oriented fluidal layers within the intrusion breccia are diagnostic of this unit.

The contacts of breccias against other rocks are rarely exposed. In exposures near the andesite masses previously described, fragments increase in size and are more tightly fitted together, so that breccia appears to grade into massive andesite. On spur ridges in North Canyon of Pooly Creek, similar breccias form pipes 30 to 50 m in diameter with steeply sheared, encircling contacts. Larger bodies near Mount Matheson and Montana Mountain contain many cross-cutting relations (Plate IV, b) that suggest the breccia resulted from multiple intrusive events.

In contrast to the detrital groundmass of fragmental flow deposits, intrusion breccias contain an interlocking crystalline matrix between fragments. It

PLATE IV - INTRUSION BRECCIAS

a) Rounded and irregular epidotized fragments in siliceous matrix; Hammer handle in shadow is 40 cm long. From intrusion breccia 200 m north of Montana Mountain.

b) Breccia with angular clasts crosscutting intrusion breccia composed of smaller, closely spaced fragments. From cliffs 300 m west of 'Math Lake'.

c) Heterogeneous breccia near Laberge contact contains smooth rounded clasts derived from adjacent greywacke; angular banded fragments (above pack) are andesitic. From 1 km east of Montana Mountain.

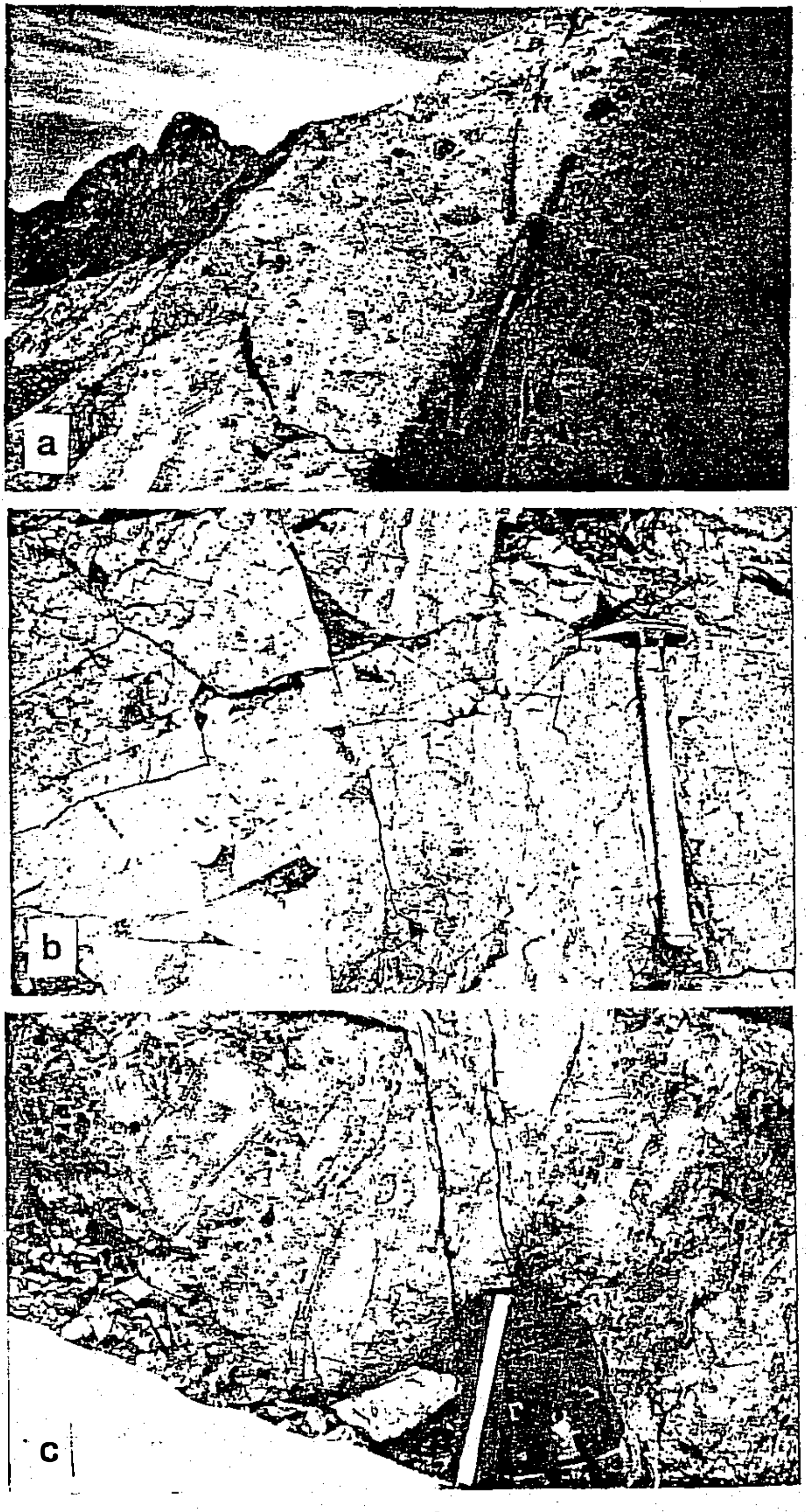


Plate IV

PLATE V - INTRUSION BRECCIA MICROTEXTURES AND FLUIDAL LAYERING

a) Two andesite fragments (top and bottom; now consisting mainly of plagioclase microlites) in intrusion breccia matrix composed of sericite and interstitial quartz, with microlitic chips. Polarized light. From breccia 300 m NW of Montana Mountain.

b) Fibrous quartz-rimming vugs in recrystallized matrix of intrusion breccia with feldspar megacrysts (dark euhedral shape at middle right). From North Canyon, Pooly Creek. Plane light.

c) Fluidal layers with medium-grained weathered surfaces (grey) and siliceous laminae containing dark clasts. From 200 m N of Montana Mountain. Tape marked in cm.

d) Negative print to show texture at the margin of siliceous laminae. Crystalline intrusion breccia matrix (white, at top) is truncated (finest laminae are grey; iron oxide patches are white; note normal and reverse grading near centre). Clastic horizon contains microporphyritic fragments and biotite crystals. From layer in intrusion breccia; 200 m N of Montana Mountain.

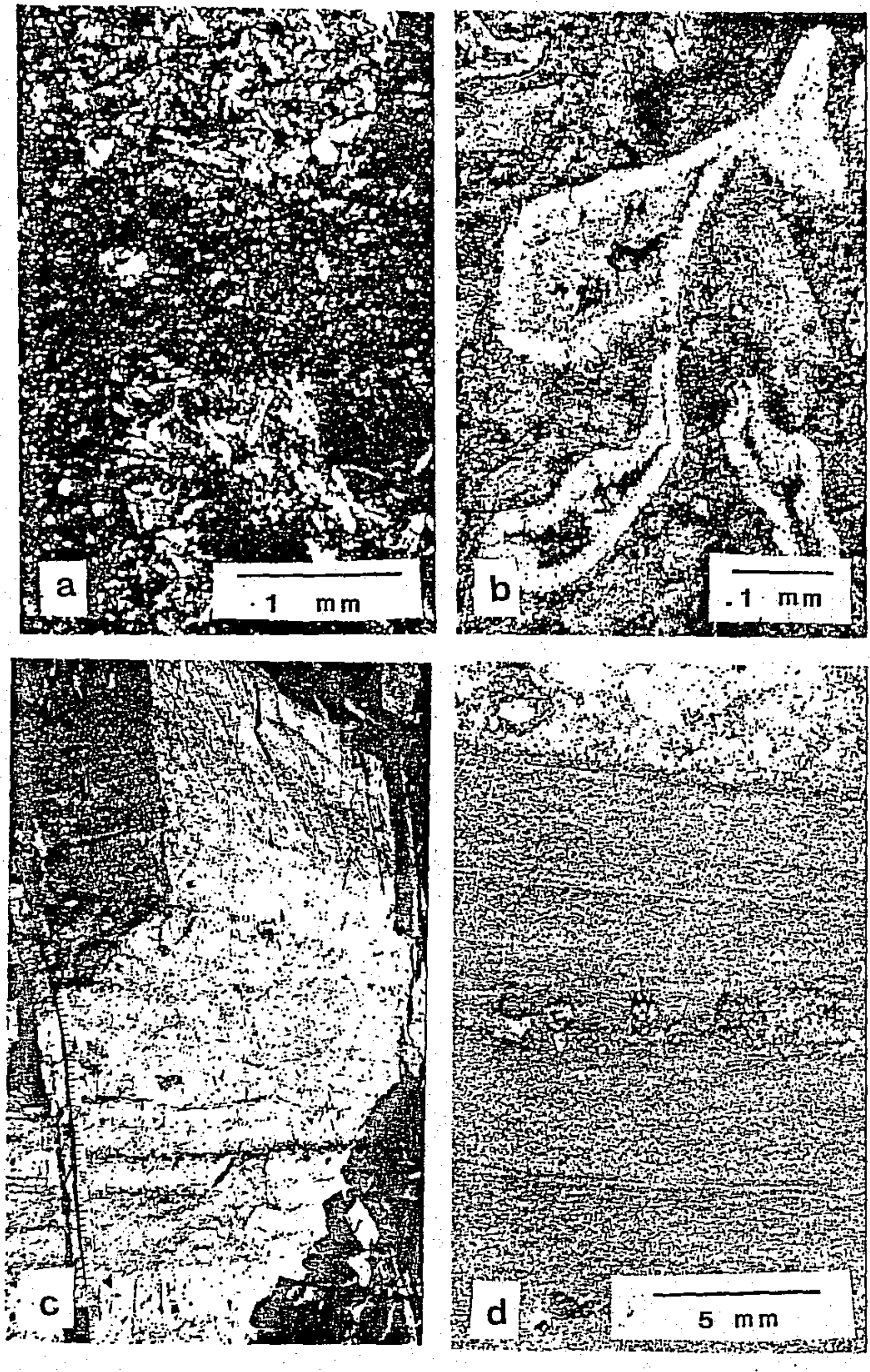


Plate V

is a saussuritized mesh of sericite, epidote and hornblende in which clinopyroxene is replaced by clinozoisite. Although now recrystallized, the coherent igneous texture suggests that the breccia matrix was of molten, magmatic origin. Scattered quartz-filled druses (Plate V, b) attest to gases contained in the melt. The breccias are dissected by abundant chloritic and quartzofeldspathic veinlets.

Intrusion breccias have a high proportion of clasts; commonly they are rounded, and cobble-sized, with rare boulders up to 2.5 m across. Large pieces are roughly equidimensional, in contrast to fragments smaller than 10 cm which have thin, projecting corners. Clasts are well mixed and spaced evenly in the lighter matrix, giving the breccia a texture resembling that of a nutty fruit cake. Less than 10% are vesicular or plagioclase-phyric. Most fragments are fine-grained or aphanitic, and some corrosive reactions with the matrix are indicated by altered rims and partly assimilated clasts.

Although most fragments are dark and fine-grained, breccias near the edge of the volcanic complex are more heterogeneous. In a cirque 1 km east of Montana Mountain, host Laberge strata are progressively more fractured near the contact with the complex. Unusual amoeboid fragments in the adjacent breccia are hornfels that could have been derived from the sedimentary rocks (Plate IV, c). The breccia near this contact also contains medium-grained leucocratic clasts that may be of plutonic origin, suggesting that some fragments were vertically transported.

The shapes of the intrusion breccia bodies and time of emplacement are unknown. Upper contacts are not preserved. Indirect evidence, including a complete lack of extrusive features, the massive nature of the bodies and intrusive contacts, as well as uncommon clasts of rocks that could have been derived from beneath the volcanic pile, suggest late, subvolcanic emplacement.

Fluidal Layering

Within the intrusion breccias are zones of coarse to fine laminations ranging from 20 cm to 10 m thick. Some can be traced over 50 m through discontinuous outcrops, but these terminate in both directions as apophyses into the breccia. Because of their continuity and features such as vertical textural grading and included clasts (Plate V, c), the zones might be mistaken for sedimentary beds. In places, however, the layers swirl and stream together, implying that they once moved as fluids, and could not have been formed by gravitational settling of the grains.

Flow layers appear restricted to the intrusion breccia of the complex. Some are well exposed (Figure 12). They have sharp, undulating contacts which occasionally appear to flow around projections of the enclosing rocks. Most dip moderately to steeply, and lack preferred orientation. Cliffs reveal thin vertical layers interpreted as subparallel dike sheets around inclusions of surrounding rocks (Figure 13).

The flow layers are composed of a mesh of sericite with chlorite and plagioclase microlites, with variations in grain size (0.01 to 0.5 mm) that are proportional to the weathering textures. Analyzed samples of the fine, medium and coarsest-textured layers (Figure 14) show an increase in silica (up to 18%) and potassium in the fine laminae. Greater proportions of metal oxides and CaO in coarser layers suggest higher mafic mineral and calcic plagioclase content. In thin section, some laminae show trains of inclusions (Plate V, d); many of these have cores of biotite and hornblende. There are faint swirling textures within the finest laminae. The microtextures and chemical variations attest to crystallization from, and emplacement by, a liquid.

Flow bands can be grouped into 'sets' that are composed of coarse to fine textures (corresponding

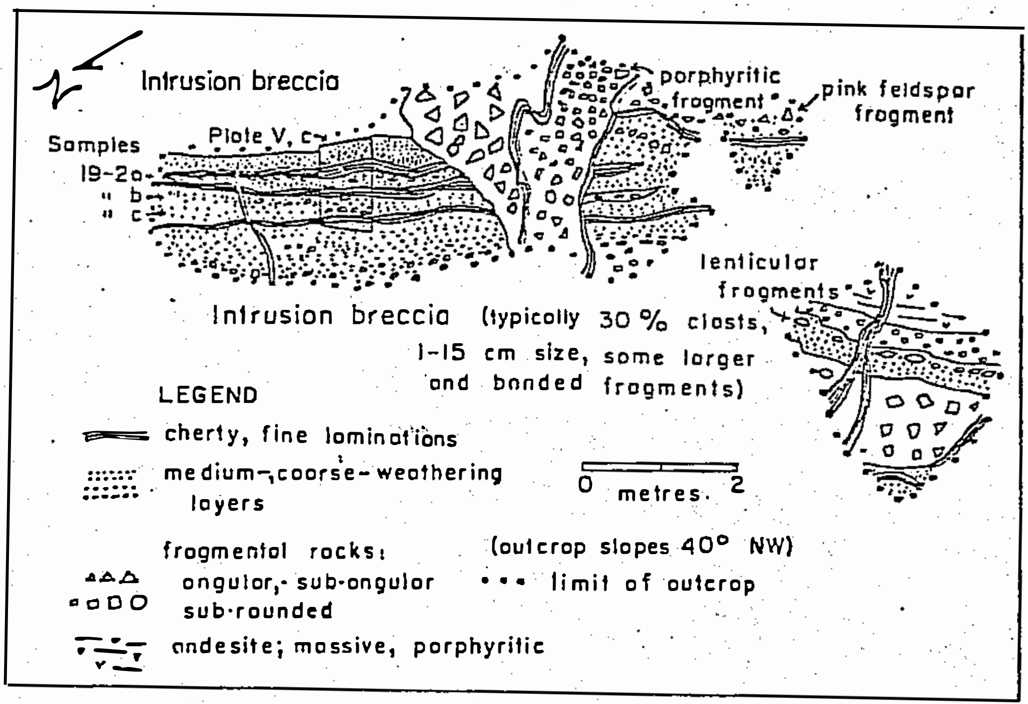


Figure 12. Sketch map of fluidal layers at locality 6. The margins of the cross-cutting breccia are the same texture and composition as the finest laminae.

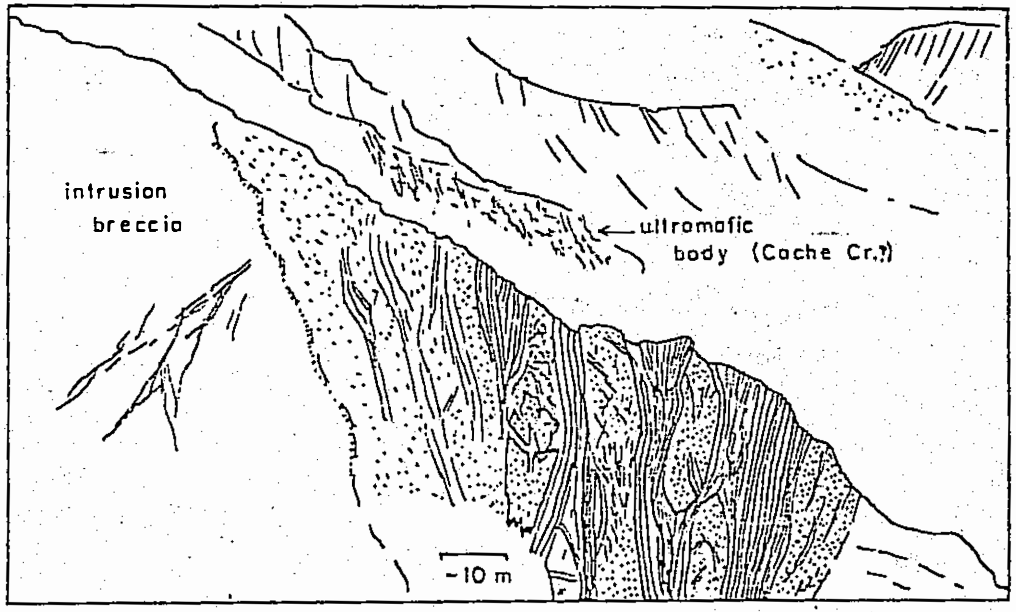
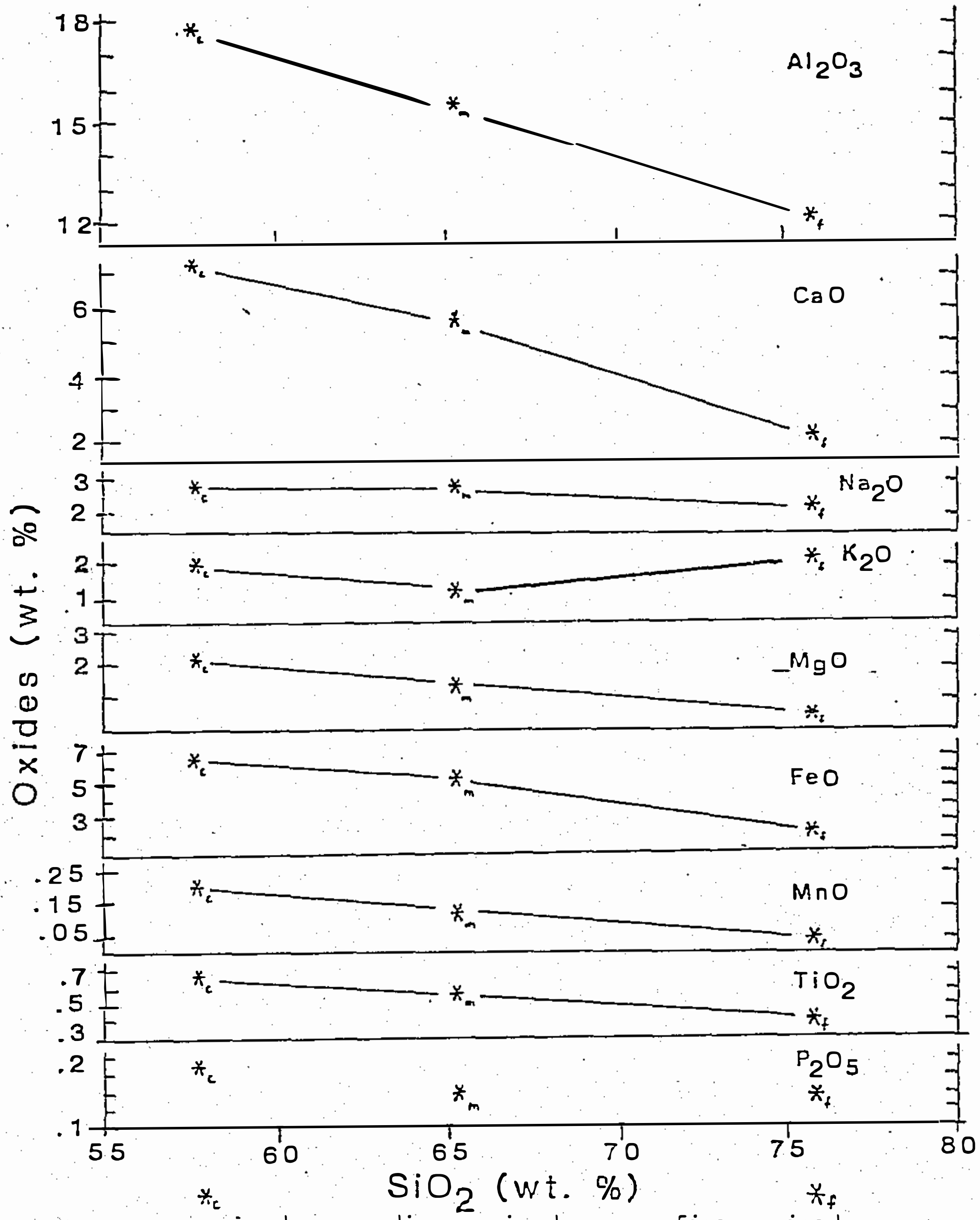


Figure 13. Fluidal-banded sheeted dikes cutting intrusion breccia near the northeast margin of the volcanic complex. Sketch from photo: looking west at locality 5.



*c
coarse-grained
(19-2c)

medium-grained
(19-2b)

*f
fine-grained
(19-2a)

1 kg samples of variable-textured fluidal layers

Figure 14. SiO_2-variation diagrams of major oxides of fluidal layer in intrusion breccia at locality 6, north of Montana Mountain. Sample locations shown on Figure 12, analytical results in Appendix A.

to the size of the microlites) which form inversely and normally graded sequences. In places these 'sets' appear symmetrical about the centre of the layer: normally-graded laminae below and reverse above, so that the fine siliceous laminae are in the middle (although these are less consistent or concordant with the enclosing coarser layers). Fine laminae also line margins of breccia dikes that crosscut all the layers.

Flow layers are interpreted to have been conduits for fluids escaping through the intrusion breccia bodies; they are typically exposed in cross section. The relations described could result from deposition of crystals precipitated from through-flowing magmatic solutions. Mafic constituents, represented by coarsest laminae, could have precipitated first to coat the walls of the fissure, and siliceous or volatile-rich residues filled the last open spaces in the centre. Asymmetric and truncated banding might have occurred when the fissure, a zone of weakness, was repeatedly opened and injected with fluids.

Flow structures occur in a variety of geological settings but are imperfectly understood. Fluidal textures similar to those on Montana Mountain are present in the matrix of a diatreme breccia in northern Yukon described by Tempelman-Kluit (1981;

photo p. 300). There, angular sand- to boulder-sized clasts of country rock are evenly spaced in fine fluxion-textured matrix; a 300 m wide central zone contains no clasts. The entire body exhibits compositional flow banding, which is attributed by him to intrusion by fluidized magmas.

Small vein systems which crosscut both intrusion breccias and flow layers near Montana Mountain were examined for information about the origin of flow bands. White-weathering quartzofeldspathic veinlets and larger dikes containing clasts of wall-rock form reticulate networks (Plate VI, c) in the intrusion breccias and adjacent rocks on either side. Because dike walls are not symmetrical. and wall rock inclusions are common in the dikes (Plate VI, a), they appear to be the 'non-dilational' type (that is, their width is due to erosion of the walls, rather than filling of previously-opened cracks). Reynolds (1954) described texturally similar granophyric veins in a Tertiary volcanic complex in northern Ireland and deduced that they were were emplaced as an abrasive spray with entrained molten particles. The subsequent discussions consider fluidization as well as other mechanisms that might apply to the Montana Mountain breccias and fluidal layers.

PLATE VI - QUARTZOFELDSPATHIC DIKES

a) Dendritic network of quartzofeldspathic intrusions containing wall rock clasts (left), and showing non-dilational passage around fragments (left of notebook). From intrusion breccia overlying granitic rocks; 300 m northwest of Montana Mountain.

b) Rounded and jagged dacitic clasts in a quartzofeldspathic dike. Note offset of clast above knife blade. From the west end of 'Math Lake'.

c) Reticulate fissures in Laberge greywacke. Fine streaming is outlined by darker chlorite along veinlets. From near the eastern Laberge/pluton contact in Big Thing Creek.

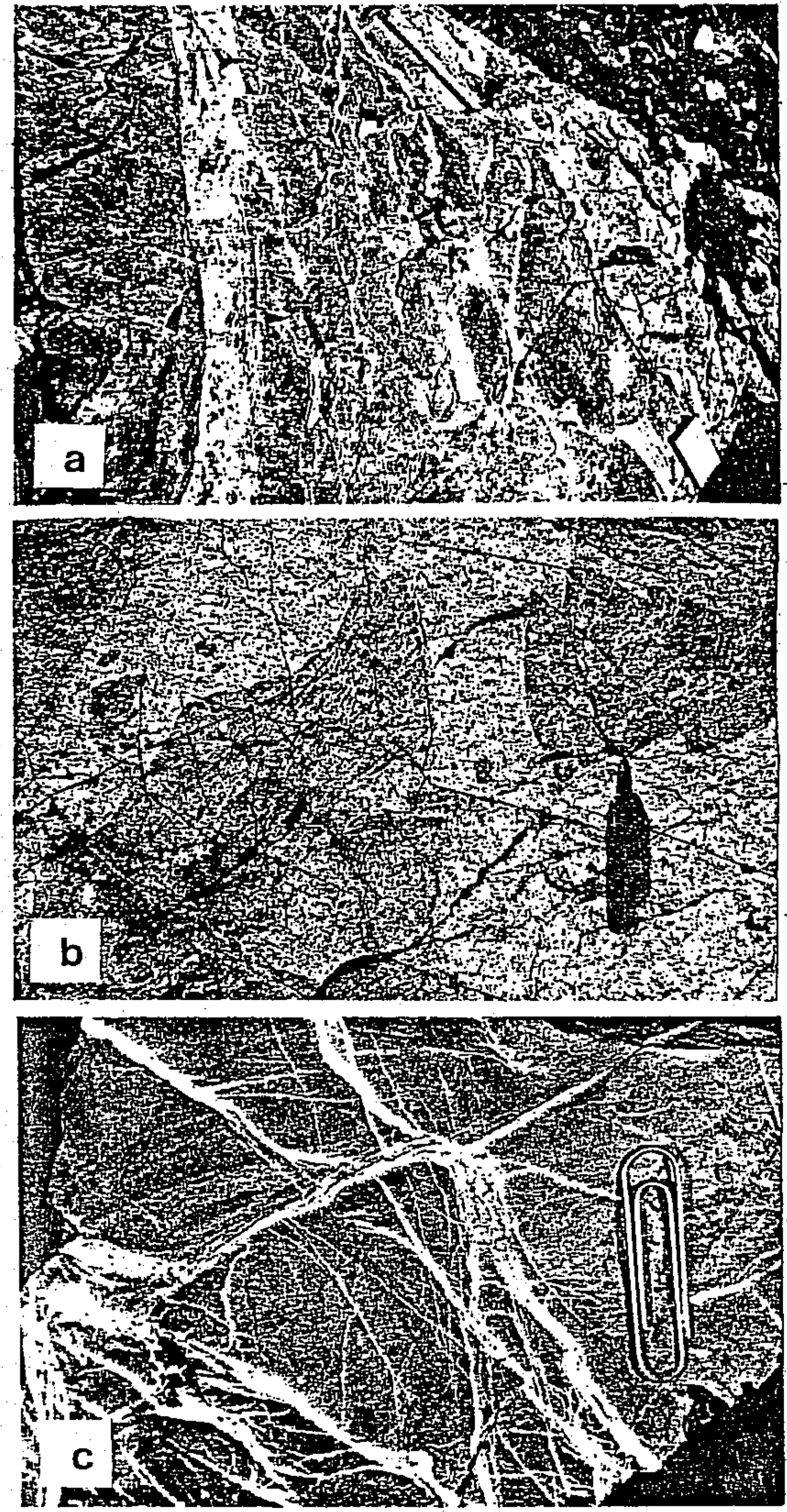


Plate VI

Discussion: 1) Terminology of Intruding Breccias

The term "intrusion breccia" refers to rocks that have been fragmented by "mechanical disruption of country rocks due to the forcible intrusion of magma" (Harker, 1908; in Wright and Bowes, 1963). This definition contrasts with that of "intrusive breccia"; a broader term applied to all broken rocks that show cross-cutting relationships. Several breccia dikes in the Montana Mountain complex are included under "intrusive breccia"; the former, more restricted term is here applied to areally extensive bodies. Although the above definition of intrusion breccia connotes origin, evidence for the "intruding magma" of the complex is indirect. The intrusive bodies responsible for brecciation are inferred to be the massive andesite plugs. Although this origin cannot be proven, the intrusive evidence is unequivocal.

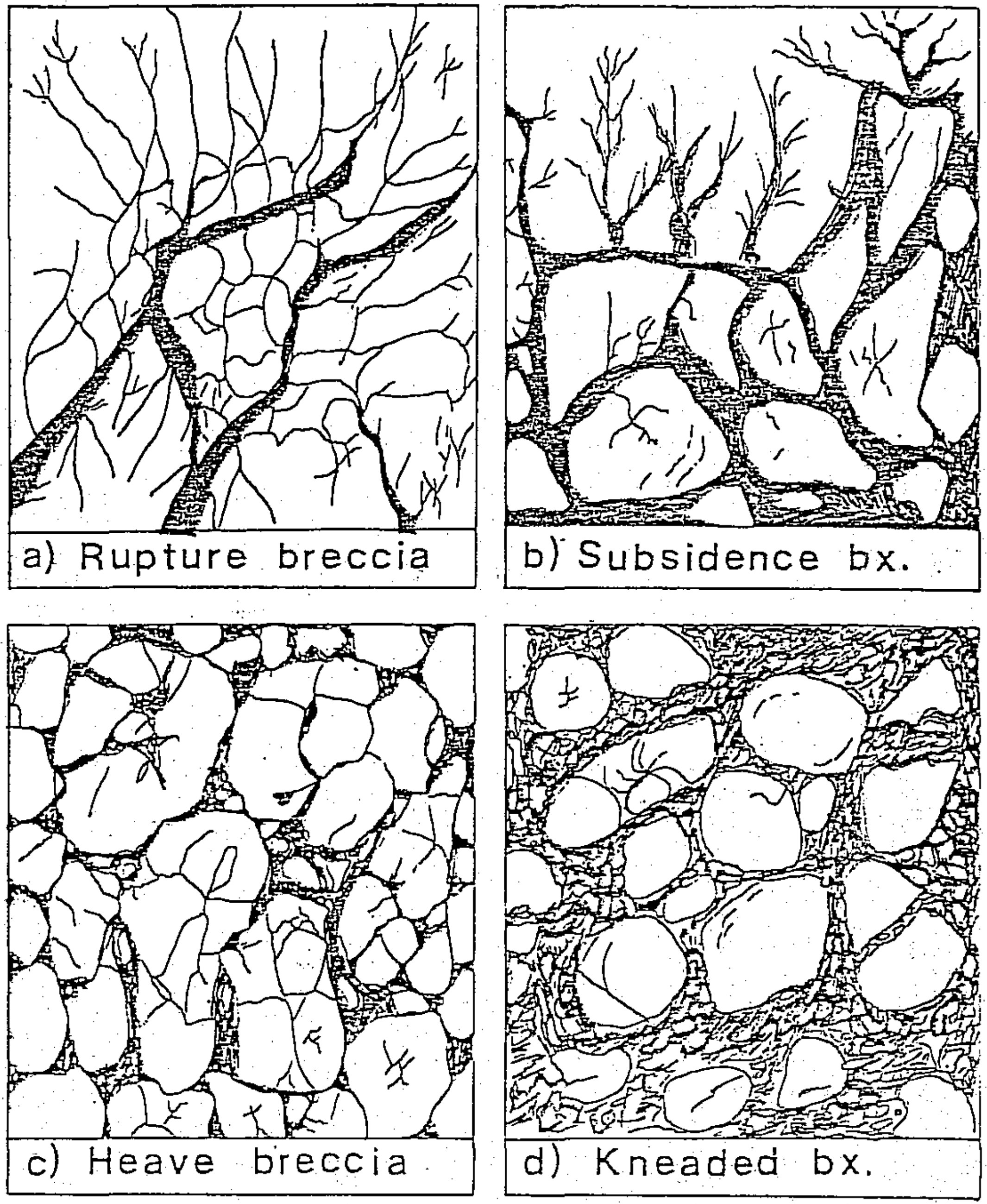
Discussion: 2) Nature of the Volcanism

The 1200 m (or greater) thickness of the complex and extensive exposure of intrusion breccias suggest that the original centre was characterized by frequent, predominantly effusive, volcanic activity. At centres where volcanism consists of long dormant periods followed by cataclysmic eruptions, the record is often destroyed or fragmentary. If violent eruptions took place at this complex, little would be preserved of the intrusive bodies. The rock types in the complex and textures in the intrusive units have led to the conclusion that repeated, relatively mild, intrusions predominated near the end of volcanic activity on the Montana Mountain area.

Discussion: 3) Subterranean Brecciation

Although breccias related to intrusions cannot be observed as they form, fractured carapaces over plutonic stocks (with economic 'porphyry-type' mineralization potential that has invited extensive study) have many similar features, and may have formed in a similar manner. These breccias differ considerably according to the strength, duration and rate of intrusion. Fracturing may progress rapidly because hydrothermal solutions driven into cracks exert unequal pressures and act as a lubricant, facilitating detachment of the overlying rocks.

Kents (1964) proposed qualitative breccia terms (Figure 15) based upon his observations of subvolcanic intrusions at Andean copper prospects. The first signs of brittle strain, consisting of shattered rocks remaining in place and commonly peripheral to the



a) Rupture breccia

b) Subsidence bx.

c) Heave breccia

d) Kneaded bx.

Figure 15. Stages of brecciation resulting from periodic or pulsing intrusive events. Compiled from photos and descriptions in Kents (1964).

intrusion, are called "rupture breccia". Repeated shocks cause "subsidence breccia", where detached blocks have caved into the intrusion, and "heave breccia", in which fragments have been shifted and comminuted during a subsequent intrusive pulse. "Kneaded" or "milled" breccia, characterized by well-rounded blocks in a matrix of fine debris, result from focussed pulsations. According to Kents, they represent a final stage, beyond which fragments become ground to powder or are assimilated.

Intrusion breccias on Montana Mountain might be considered an intermediate stage, because well-rounded blocks are common. Comminution by mechanical means is indicated by the gradational boundaries (progressively less-fractured rocks) and the great extent of the intrusion breccia bodies. The proposed mechanism is less appropriate, however, to explain the great vertical extent and textural uniformity of these bodies.

Breccia bodies similar to but better exposed than Montana Mountain were studied by Parsons (1967) in the Absaroka Range (Wyoming and Montana). There, andesite blocks supported by tuffaceous matrix fill numerous vents and also occur as bedded pyroclastic flows which grade laterally into laharic breccias. Both vent and flow deposits have an igneous microbreccia matrix (dense angular grains in a pilotaxitic groundmass), and both contain aphanitic and microvesicular andesite blocks that he concluded were derived from the vent walls.

Parsons interpreted the Absaroka breccias to have formed as a churning mass of blocks in a volcanic vent which periodically overflowed to cause debris avalanches. Rising plug domes may have generated the non-explosive eruptions. A similar mechanism might apply to the Montana Mountain breccias, although the relationships between intrusive and extrusive breccias are less clear.

According to Gates (1957), relaxation of built-up pressures can be more effective than repeated impacts for breaking rocks. Sudden drops in the pressure of the magma chamber, perhaps due to rapid steam escape, cause compressed gases in adjacent fractures to exert unbalanced stresses and spall rocks into the cavity. In addition, a partial vacuum or 'Venturi effect' caused by the escaping gases may pluck rocks from the passage walls. Thin, curved or jagged fragments that might be incorporated in this manner were not observed on Montana Mountain, but they may have been elutriated within the chamber. Turbulent mixing indicated by fluidal textures and clasts suggest percolating magma could have been important in the formation of the complex.

Discussion: 4) Fluid Abrasion and Transport

'Fluidization' and 'Froth Flotation' are processes widely used in modern manufacturing and combustion industries. When jets of gas or spray pass through liquid or particulate beds, rates of reaction and mixing are greatly enhanced. The mechanism has numerous examples in geology (Reynolds, 1954), and is relevant to discussion of some textures of Montana Mountain intrusion breccias because it might explain their great vertical extent, and the mixture of rounded and angular clasts in a fine-grained igneous matrix. The fluidal layers may thus represent the final streams of the escaping fluids.

A detailed examination of tuff-breccia pipes in southern West Germany by Cloos (1941) is a benchmark study of fluidized intrusions. Originally these features were considered explosion-fall-back breccias; but Cloos observed that orientations of included limestone clasts were relatively undisturbed. He suggested that the great erosive power of comminuted wall rocks entrained by a gas stream had widened fissures until large blocks subsided into the pipe beneath (Figure 16, a and b).

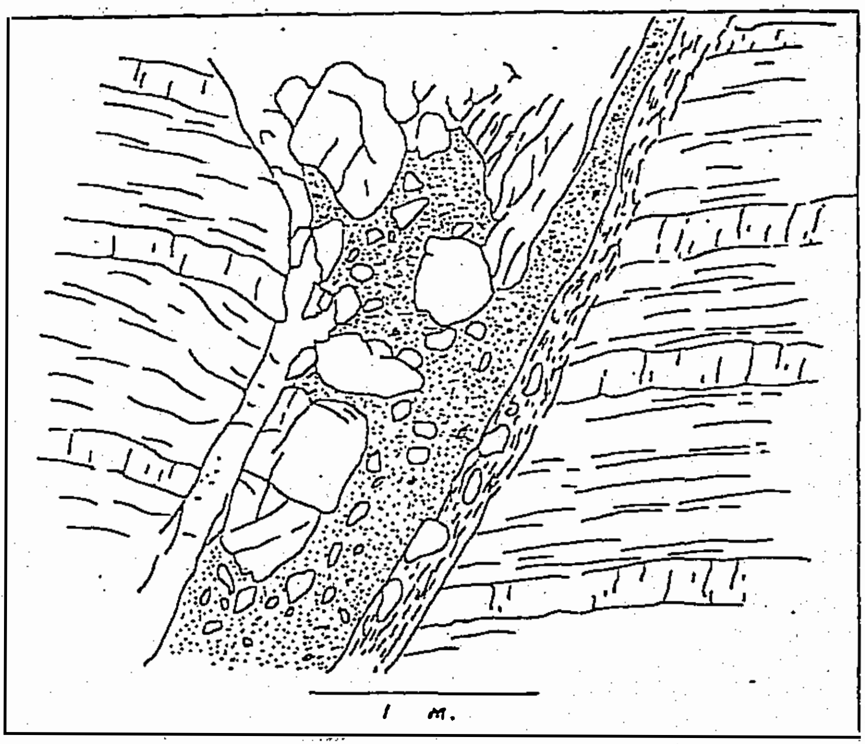


Figure 16a. Tuff dike composed of basalt lapilli and fine rock fragments from lower horizons, in addition to large blocks stoped from adjacent limestones. The marginal intrusive tuff has fluidal textures and contains comminuted wall-rock fragments. From Cloos (1941).

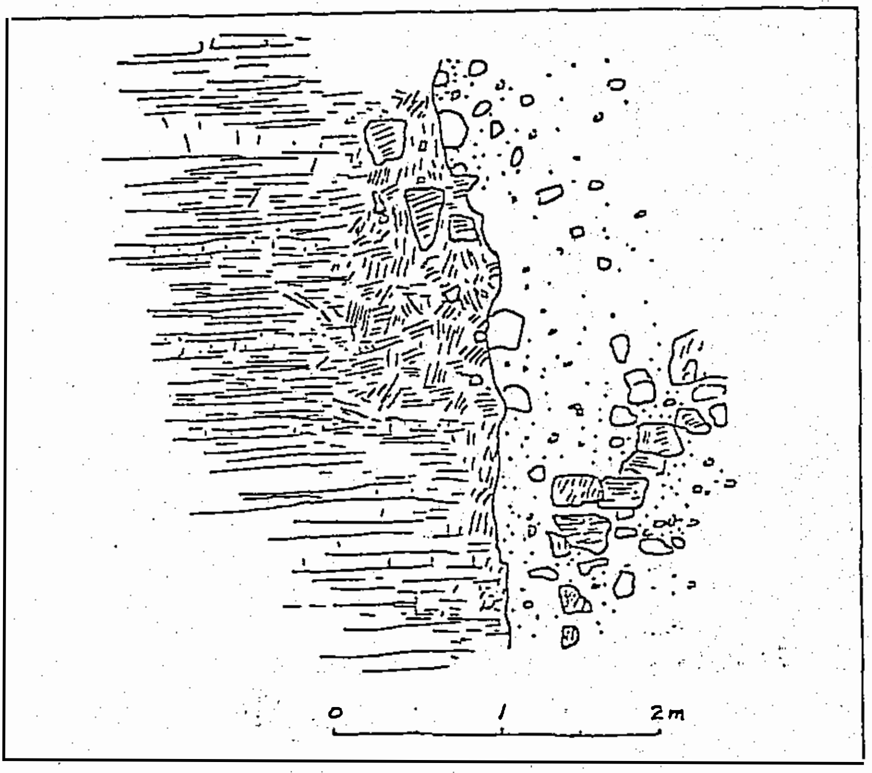


Figure 16b. Well-defined contact of tuff pipe (to the right) with locally brecciated limestone host. From Cloos (1941).

Reynolds' (1954) compilation of geological examples of fluidization emphasized three characteristics of gas-particulate breccias:

1) the association of turbulent flow structures with well-rounded clasts that had not been transported far from their source areas;

2) a lack of grading and other features of sedimentary deposition; and

3) the possible presence of druses.

Whether fluidization is important or essential to the formation of intrusion breccias cannot be established using these criteria. Drusy cavities are common in some parts of the intrusion breccia matrix (Plate V, b), but other criteria noted above are not necessarily unique to fluidized breccias.

Fluidization, particularly involving a vesiculating magmatic liquid, rather than gas, could conceivably account for observed textures, but difficulties remain with this interpretation. The mechanism is inadequate to explain the internal intrusive relations, gradational margins and large fragments that appear suspended in the matrix. In contrast to most fluidized pipes (diatremes) which are cylindrical or flaring near the surface and have defined margins, intrusion breccias on Montana Mountain are more extensive, and do not have clear-cut boundaries.

Discussion: 5) Brecciation by Hydrothermal Systems

The traditional theory that diatremes were caused by energized gases boring their way to surface is supported by some (Macdonald, 1972, p. 382) and questioned by others (McBirney and Williams, 1979, p. 54). The latter authors pointed out that high vapour pressures and large gas volumes are unlikely to have been generated by slowly cooling magma plugs. Because magmas do not vesiculate at great depths, high velocity gases must be generated within several hundred metres of the surface. An alternative theory, in which phreatic (steam) explosions propogate downward to breach magma chambers, does not universally apply because some breccia pipes apparently never reached surface.

McBirney and Williams (1979) proposed that hydrothermal circulating systems, driven by repeated intrusive surges, create breccia pipes. In combination with mechanical rupturing and gas streaming mechanisms, this model appears best to explain the features of the Montana Mountain intrusion breccia. The remaining evidence of these systems are fluidal layers and quartzofeldspathic veinlets, which may represent last streams of fluid during waning stages of volcanic activity or later intrusions.

Discussion: 6) Character of the Residual Melts

Intrusion of semi-viscous residual melts in pegmatite dikes was considered by Hyndman (1972; non-symmetrical flow banding shown in photo, p. 82). He reasoned that dissolved volatile components which become increasingly concentrated in a magma reach a 'second boiling point', when the vapour pressure exceeds that of the enclosing rocks, and the mobilized fluid then crystallizes in closed fractures as pegmatites. On the other hand, it is noted that high concentrations of volatiles inhibit crystal nucleation to produce fine-grained rocks. In this way both the gradationally-textured layers and the fine siliceous laminae could have formed in Montana Mountain breccias.

The cross-cutting relations, with abundant veins and alteration, indicate several intrusive events and fluid circulation systems. The proposed model for the north part of the complex incorporates two stages: first, rise of a congealed magma plug within a breccia sleeve causing progressive fracturing; followed by churning and circulation of the volatile components through the fractured rocks.

Breccia Dikes

Two varieties of volcanic breccia dikes occur in the Montana Mountain complex. The more abundant, heterolithic type, consisting of angular fragments in a chlorite-rich matrix, occur in the layered units near 'Math Lake' and are particularly common in the deep valley of the 'Matheson fault' (locality 13). A second kind, containing tightly packed, equidimensional rhyolite clasts in a siliceous granular matrix, was observed north of Mount Matheson.

The chloritic type forms jagged, irregularly-tapering dikes from several centimetres to metres in width, and up to 10 m long. Their texture is distinctive, consisting of sharp-edged, pebble- to cobble-sized fragments that are jammed together, although not closely packed (Plate VII, a). These dikes are interpreted as the result of brief, violent injections of broken rocks and gases along fissures. In a few places the dikes consist of fine debris and detached wall rocks, and lack heterolithic (transported) fragments (Plate VII, c). Such zones are thought to have occurred when constrictions blocked the flow of larger clasts.

Most clasts are vesicular andesites or dacites that probably were loosened from walls of the

PLATE VII - BRECCIA DIKES

a) Closely-packed, angular, heterolithic fragments in cloritic matrix. Pressures of emplacement are indicated by indented clasts (arrows). From Matheson fault zone, south of 'Math Lake'.

b) Breccia dike containing ragged chloritic lenticles (devitrified pumice?) and partly resorbed dacitic fragments (lower left; beneath 2 cm cartridge). From 100 m west of 'Aurora Tarn'.

c) Fine clastic dike containing wall rock fragments, where no heterolithic fragments have penetrated. From 1 km S of 'Aurora Tarn'.

d) Silicified breccia dike containing microporphyritic and flow-banded clasts closely packed in matrix of interstitial rock dust. The rock type of these clasts is not exposed elsewhere in the complex. From 500 m north of Mount Matheson.

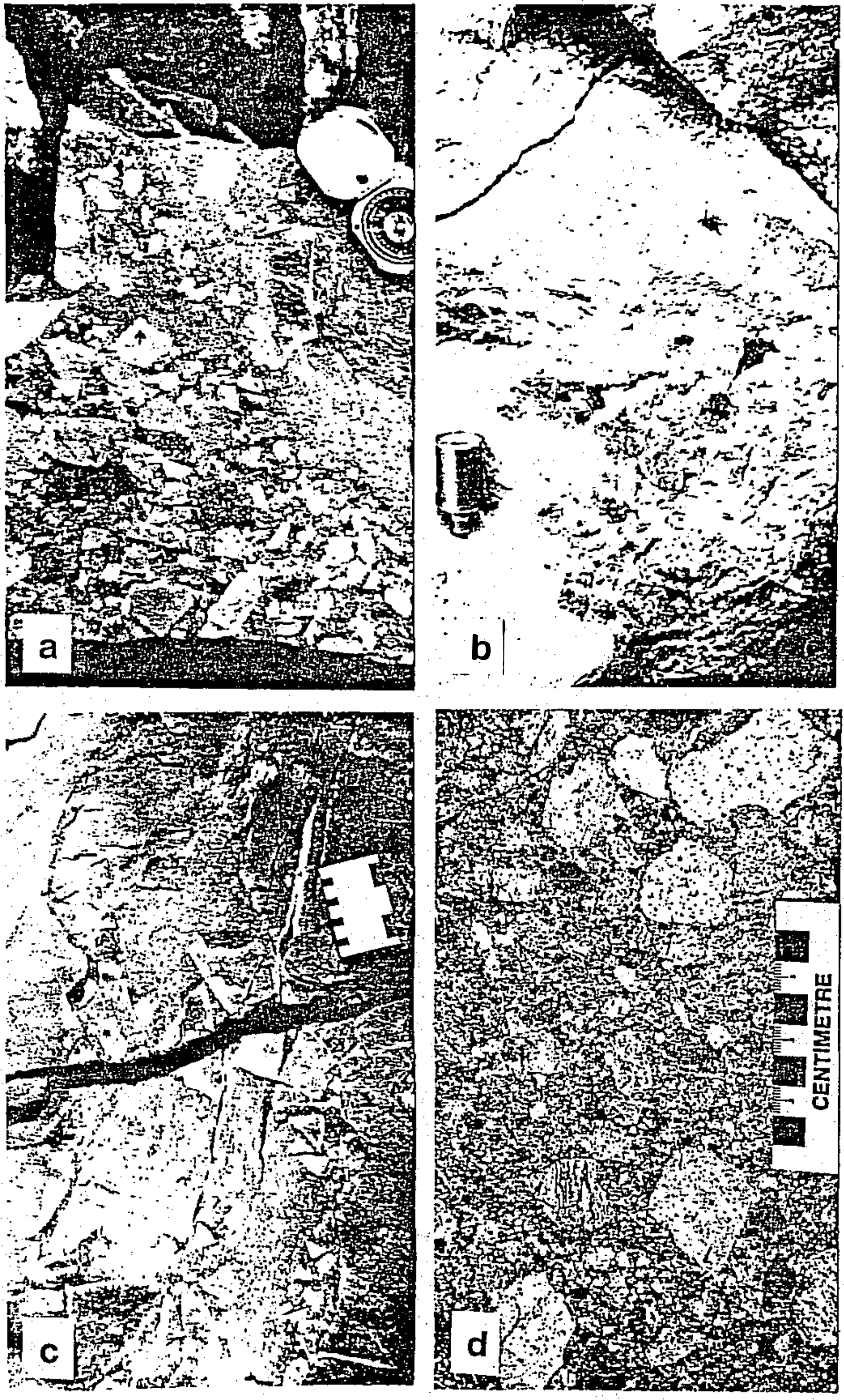


Plate VII

fissure. Other fragments are beige, fine-grained and siliceous, resembling aplite, or more rarely, hornblende-phyric dacite; both of which may be of subvolcanic origin. In places the fragments indent and deform one another, implying high pressure and temperature during emplacement.

Interstitial matrix is sparse and in some places the original spaces between fragments remain. Where present, the chloritic groundmass contains finely comminuted andesite chips. Most bodies are also characterized by abundant epidote- and tourmaline-lined vugs. Near 'Aurora Tarn' some ragged lenticular, chloritic clasts (Plate VII, b) may represent former pumiceous clots; elsewhere vesicular fragments and vugs imply that the matrix was frothy during emplacement.

The rhyolite breccia dike in the valley north of Mount Matheson contains small (rarely larger than 3 cm), subrounded fragments that are light grey, finely banded and tightly fitted together. The matrix is grey, highly siliceous, and filled with comminuted chips and broken feldspar phenocrysts (Plate VII, d). The rock types represented are unknown elsewhere in the complex; the banded rhyolitic fragments resemble those of the ignimbrite (locality 3). Possibly the breccia was derived from a partly solidified siliceous melt located beneath the northern part of the complex.

Two possibilities are offered to explain the formation of the breccia dikes. Fragments could have been driven up fractures by phreatic explosions and rapid steam generation, perhaps as a result of seepage of meteoric waters into heated rocks. However, subvolcanic clasts and chlorite alteration of pumice fragments in dikes indicate that explosions tapped at least the upper levels of the magma chamber.

Alternatively, the breccia might be caused by escaping underground gas blasts. A possible mechanism involves collapse of an underlying chamber roof during formation of a caldera. Lambert (1974, p. 135) described breccia dikes containing clasts of granitic basement rocks and suggested that they could have resulted from rapid lowering of roof rocks into subterranean openings. The brief blasts of compressed gases would sweep rock particles into fractures with little elutriation. Because the chlorite-matrix dikes are concentrated in a broad fault zone, this proposed mechanism implies subsidence along the 'Matheson fault'; a possibility further examined in chapter VI.

Felsic Dikes

Widely distributed quartz latite and trachyte dikes form about 5% of the area of the volcanic complex, but their bright orange-weathering talus is widespread and conspicuous. Major dike systems that occur on the south and east slopes below Dail Peak and in Pooly Canyon. The dikes cut all volcanic rock types, and commonly occupy fault zones. Thick sericitized weathering rinds are ubiquituous. In contrast, several dikes that cut Laberge and Cache Creek rocks northeast of Montana Mountain weather pinkish with opalescent plagioclase phenocrysts. Although not observed in the pluton, they may be related to the aplite because the two dike compositions are difficult to distinguish near the volcanic-granitic contact.

The dikes are usually porphyritic and fine- to medium-grained. Typically they contain 20-25% plagioclase (An 35) and 15-25% potassic feldspar (probably microcline) in equant and fine slender crystals. Some dikes above Venus mine contain only potassic feldspar. At Vault mine, rounded quartz granules to 3 mm diameter are present in the dikes. Biotite flakes, calcite and polygonal quartz have partially replaced many phenocrysts, and in places sericite and hematite have replaced the matrix.

Cliff exposures in places show intertwining sheeted dikes in fault zones (Figure 17). Evidence of successive emplacement suggests that faults must have

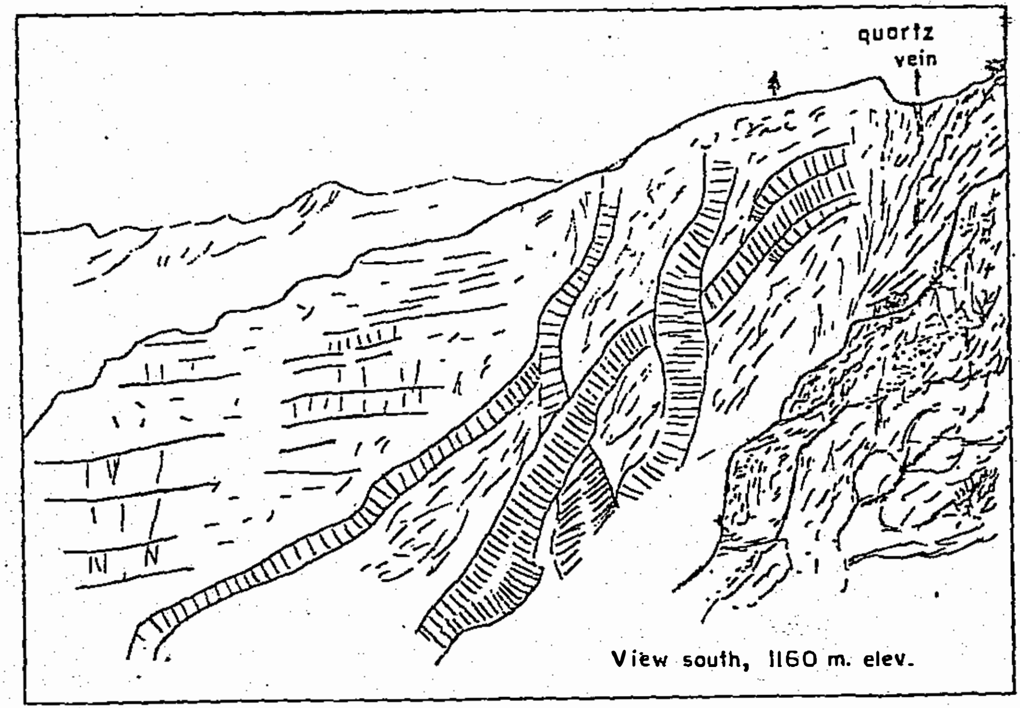


Figure 17. Quartz latite dikes along fault zone in andesite flow layers on the south wall of Pooly Canyon. Venus quartz vein also occurs in fault; the Vault mine is below, to the left (Sketch from photo).

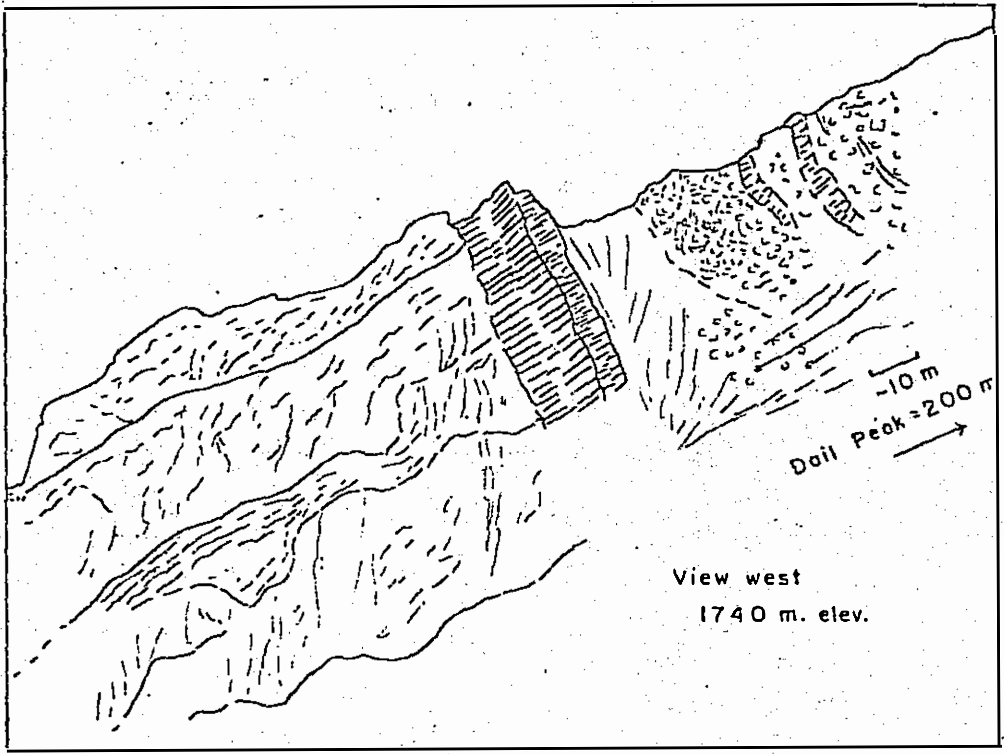


Figure 18. Dail Peak fault zone occupied by latite dike (locality 11). Lava flows (left) dip outward from complex; debris flows at right are tilted inward. (sketch from photo).

been recurrent lines of weakness. Moreover, quartz veins partly follow the dike swarms, and mining of them has revealed slickensided walls implying subsequent movement along these zones. Dikes that occur south of Dail Peak (Figure 18) may have erupted, because felsic pyroclastic piles on the nearby summit are compositionally similar.

Felsic dikes swarms are extensive in other Mount Nansen centres in south central Yukon. Tempelman-Kluit (1974, 1980) observed their close association with both the volcanic rocks and the associated Nisling Range alaskite. The dikes may represent escape of the lighter fraction of a subvolcanic alaskite magma. Dikes in the south-central Yukon range in age from 50 to 60 mA (K-Ar method; Tempelman-Kluit and Wanless, 1975).

The latite and trachyte dikes, which fill fractures that may in part be caused by arching of the complex, are probably related to the intrusion of the 'Carcross pluton', which in turn may be equivalent to subvolcanic bodies recognized elsewhere.

CHAPTER VI

STRUCTURAL GEOLOGY

The rock bodies built by volcanic activity to form the Montana Mountain complex are now deeply eroded, so that structural features are largely covered by extensive rubble. Weathering does not highlight depositional or structural elements because of uniform regional and thermal metamorphism. Structural models and interpretation must be developed from inferred faults, internal contacts and stratigraphic breaks, and to be consistant with characteristic behaviour of the interpreted rock units.

The complex appears to be a remnant of a volcanic edifice in its south part, and deeply eroded subvolcanic intrusions in the north. Probably the area of volcanic activity once extended far beyond its present exposed remains; its distal parts have since been removed. It is unclear whether the complex is a preserved source area, or was derived from vents originally in the area now occupied by the 'Carcross pluton', and since obliterated.

General Structure

The north half of the complex, occupied by intrusion breccia and massive andesite, is unlayered. Its boundaries are steep faults and in places gradationally brecciated contacts.

Thickly layered debris and lava flow units, discernible in cliffs of upper Pooly Creek, suggest a broad dome-like structure for the south part of the complex.

Relationships of the Volcanic Complex to the Surrounding Rocks

The complex is bounded by steeply dipping fault zones. A fault of possible regional significance is inferred to lie beneath Windy Arm, separating rocks of the Cache Creek Group from the volcanic complex and Laberge strata.

The contact with the Nakina Formation 100 m south of Pooly Canyon (locality 9) is a 1 m wide vertical cleft of protomylonite with lenticles of andesite (Mount Nansen Group) and amphibolite (Cache Creek Group). Fragmental rocks of the complex adjacent to the fault resemble intrusion breccia, but rocks of the shear zone are not recrystallized. The contact is therefore interpreted to result from intrusion of a partly solidified breccia mass.

In North Canyon of Pooly Creek, the contact of oxidized Mount Nansen rocks dips 60 degrees beneath Nakina amphibolite (locality 10). It is a 3-5 m wide zone of argillaceous gouge containing lenticular clasts, probably of dike rocks. Its outward dip suggests intrusion; locally abundant latite suggests that the large blocks of Mount Nansen breccia near the contact have been rafted up by felsic dike swarms.

The northeastern margin of the complex with Laberge strata is exposed in a cirque 1 km east of Montana Mountain (locality 11). Pebble-bearing greywacke is fused and chloritized, with increasing alteration and fracturing toward the volcanic rocks. The contact appears to be gradational because blocks of greywacke are detached and partly rounded within the adjacent intrusion breccia (Plate IV, c).

In a saddle west of Mount Matheson a 50 m shear zone dips 70 degrees outward beneath deformed Laberge strata, and appears similar along the length of the west side. Massive andesite, interpreted as part of a plug, is adjacent to the fault zone. Quartz-tourmaline veins are common in the black gouge of the contact. Locally the country rocks are steeply tilted away from the complex.

In general the intrusive contacts of the complex are better exposed, because fracture zones from them do not extend into the volcanic rocks, and they are at higher elevations. Subsidence faulting has resulted in wider fracture zones that are more rapidly eroded and filled with rubble.

The contact of the volcanic complex with the granitic pluton is exposed northwest of Montana Mountain. Along the sides of a ridge spur it dips 45 degrees to the south beneath darkened, chloritized intrusion breccia. Fractured alaskite with abundant tourmaline veinlets, and common pyrolucite and malachite occurs in a 5-7 m wide zone below the sharp contact. The pluton probably underlies most of the west part of the volcanic complex because quartz-tourmaline and aplitic veinlets are common in this area, particularly near 'Aurora Tarn'. Granitic float is present, and a small outcrop was reported near the Math Lake Breccia (K. Watson, pers. comm., 1980). If the top of the pluton were projected southwest from the northern exposed contact, it would lie about 500 m below the surface here, and it is possible that a knob or large dike may bring plutonic rocks to the level of the present surface.

Faults

Three major faults over 3 km long have topographic expression. Numerous shorter faults, locally outlined by scarps and clefts, or occupied by felsic dikes, are partly obscured. Layering exposed in cirques around the head of Pooly Creek show vertical offsets of 15-20 m, and commonly the downdropped side is to the north.

Two of the major faults are regarded as structurally significant, and similar interpretations can apply to several others. 'Matheson fault' (locality 13) separates intrusion breccia and massive andesite from a debris and lava flow succession near 'Math Lake'. Its trace is a deep trough 100 m wide with glacially scoured walls. Chlorite-matrix breccia dikes are abundant in the valley. Where the fault crosses ridges and spurs it is an orange-weathering, sericitized zone 10 m wide that dips 70 degrees southeast (toward the layered units). Two steeply dipping andesitic dikes show right lateral offsets of about 95 m, but no disruption is apparent at the ends of the fault. Possibly this was a zone of vertical movement, with only small horizontal displacements.

The Dail Peak fault is marked by a broad shear zone and coincident dike swarms across the south slope of the volcanic complex. On a spur south of Dail Peak it is 15 m wide, dips 65 degrees to the north (into the complex) and contains black gouge and quartz chips. South of the fault, andesite lava flows of irregular thickness dip southward; but debris and ash flows on the other side dip to the north (Figure 18). These relations imply considerable movement; perhaps the result of lowering of the central part of the complex. Dikes in the fault are unsheared, and compositionally resemble the felsic pyroclastic deposits on Dail Peak. They may represent fissure eruptions late in the history of volcanism at Montana Mountain.

Steep-dipping fault traces cross the Montana Mountain ridge. The more continuous easterly one also cuts the ultramafic plug (Cache Creek Group) but not adjacent granitic rocks. In part both faults separate the andesite plug that forms the summit of Montana Mountain from intrusion breccias on either side. These faults may have resulted from differential stresses caused by the subvolcanic intrusion.

CHAPTER VII

PETROCHEMISTRY

Chemical analyses of major oxides and minor elements for representative rock samples provide an indication of the nature of the Montana Mountain complex. Detailed interpretations could not be made from the data because their accuracy is unknown and they may not truly represent the chemistry of the complex.

Sampling and Analysis

Samples were chosen from the typical rock types within the study area. Their descriptions and localities are noted in Appendix A. Most were hand specimens with minimal clasts, phenocrysts and weathered surfaces; but 1 kg chip-samples were taken from dikes and fluidal layers.

For 16 samples, 11 major oxides and 3 minor elements were determined by X-ray fluorescence spectroscopy (XRF) at X-Ray Assay Laboratories, Toronto, Canada. No reference samples were provided. The laboratory analyses claim accuracy of +/- 0.01 %

for oxides and +/- 10 p.p.m. for Rb, Sr and Zr analyses.

Normative Calculations

C.I.P.W. (weight percent) normative compositions were calculated for the 16 samples. Individual differences in volatile content were eliminated by recalculating the oxide concentrations to 100%. Total iron, determined by XRF, was recalculated by placing an arbitrary maximum limit on ferric iron (hematite = titanium oxide * 1.5; because parallel variation of these elements has been observed in suites of unaltered rocks) and treating the remainder as FeO. Normative minerals were calculated using the computer program LEMNORM9, written by R.K. Herd and W. Yzerdraat (Department of Geology, Carleton University), based on the findings of Lemaitre (1976).

Results

Metasomatized samples may be distinguished from altered rocks that retain their original composition by using the 'Igneous Spectrum' (proposed by Hughes, 1972, and modified by Stauffer et al, 1975). All but two samples from Montana Mountain fall inside the domain for typical, unaltered volcanic suites (Figure 19b). Potassium enrichment is the most

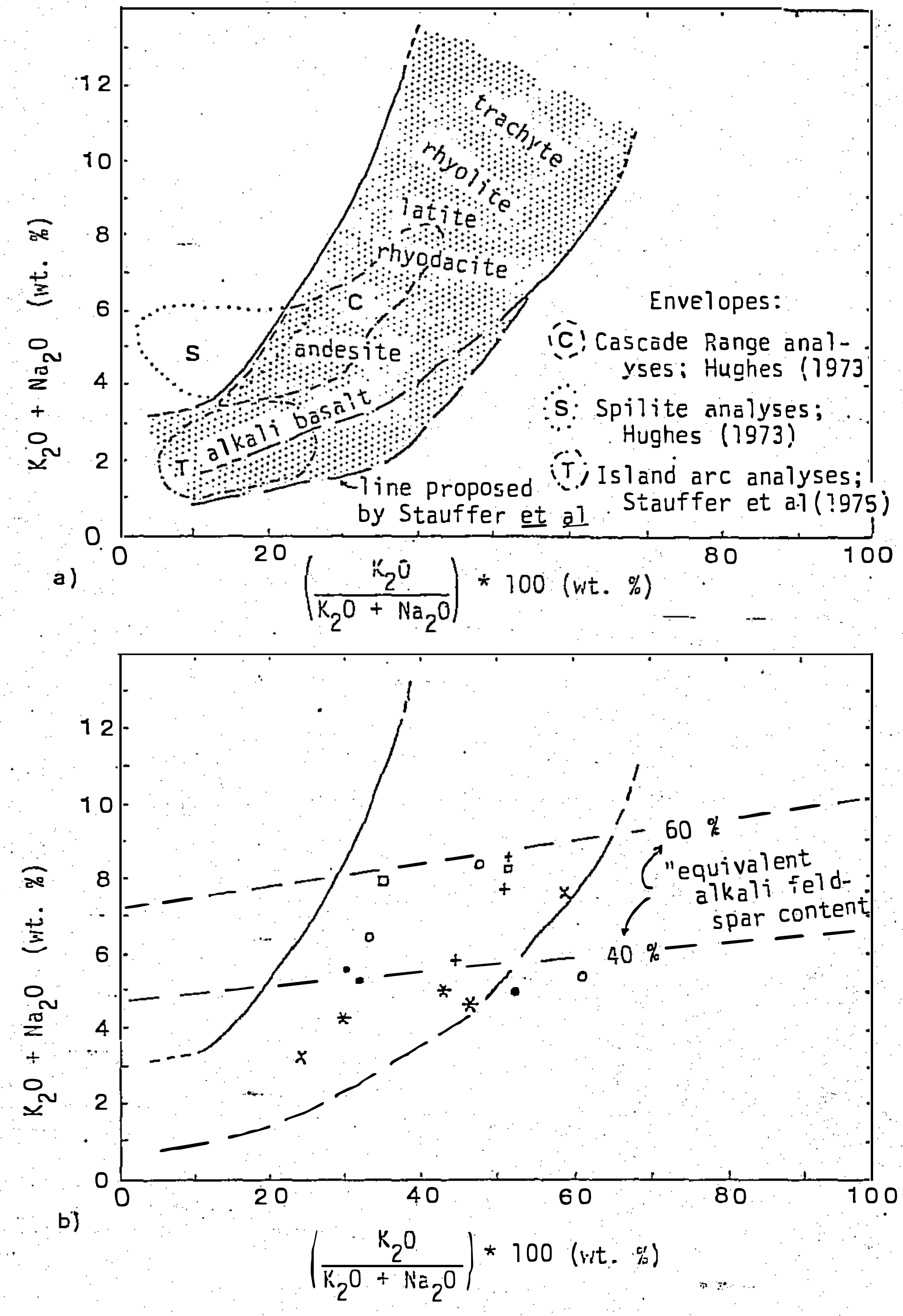


Figure 19. The 'Igneous Spectrum', showing the positions of samples from the Montana Mountain complex in (b). The envelope (proposed by Hughes (1973) and modified by Stauffer et al (1975) encloses average unaltered volcanic suites. "Equivalent feldspar content" is a measure of alkalinity, assuming the total alkali content of the rock is in the form of potassic feldspars.

significant alteration, as shown by Figure 20. The Montana Mountain suite does not plot near the envelope for spilitic rocks (Figure 19a).

The standard classification system, recommended by Irvine and Baragar (1971) is followed here. Alkalic and subalkalic assemblages are distinguished on the Ol'-Ne'-Q' triangle (Figure 21) and the Alkali-Silica diagram (Figure 22). Montana Mountain volcanic rocks are subalkalic, as are those of the Mount Nansen Group in the Miners Range (Grond, 1980). In general they contain more silica and less alkalis than samples from the Bennett Lake Complex.

Subalkalic rocks are subdivided into calk-alkaline and tholeiitic suites by the A-F-M diagram (Figure 23). Montana Mountain rocks appear to be calk-alkaline, and plot in the same field as those from the Bennett Lake complex and Miners Range.

On the diagram of normative colour index versus normative plagioclase, the Montana Mountain volcanic rocks plot within the average andesite and dacite fields (Figure 24). Other volcanic rocks that were not analyzed, such as the ignimbrite, are probably rhyolitic. Plutonic rocks and dikes are much higher in normative albite than extrusive rocks. This diagram may also be useful for distinguishing true rhyolite

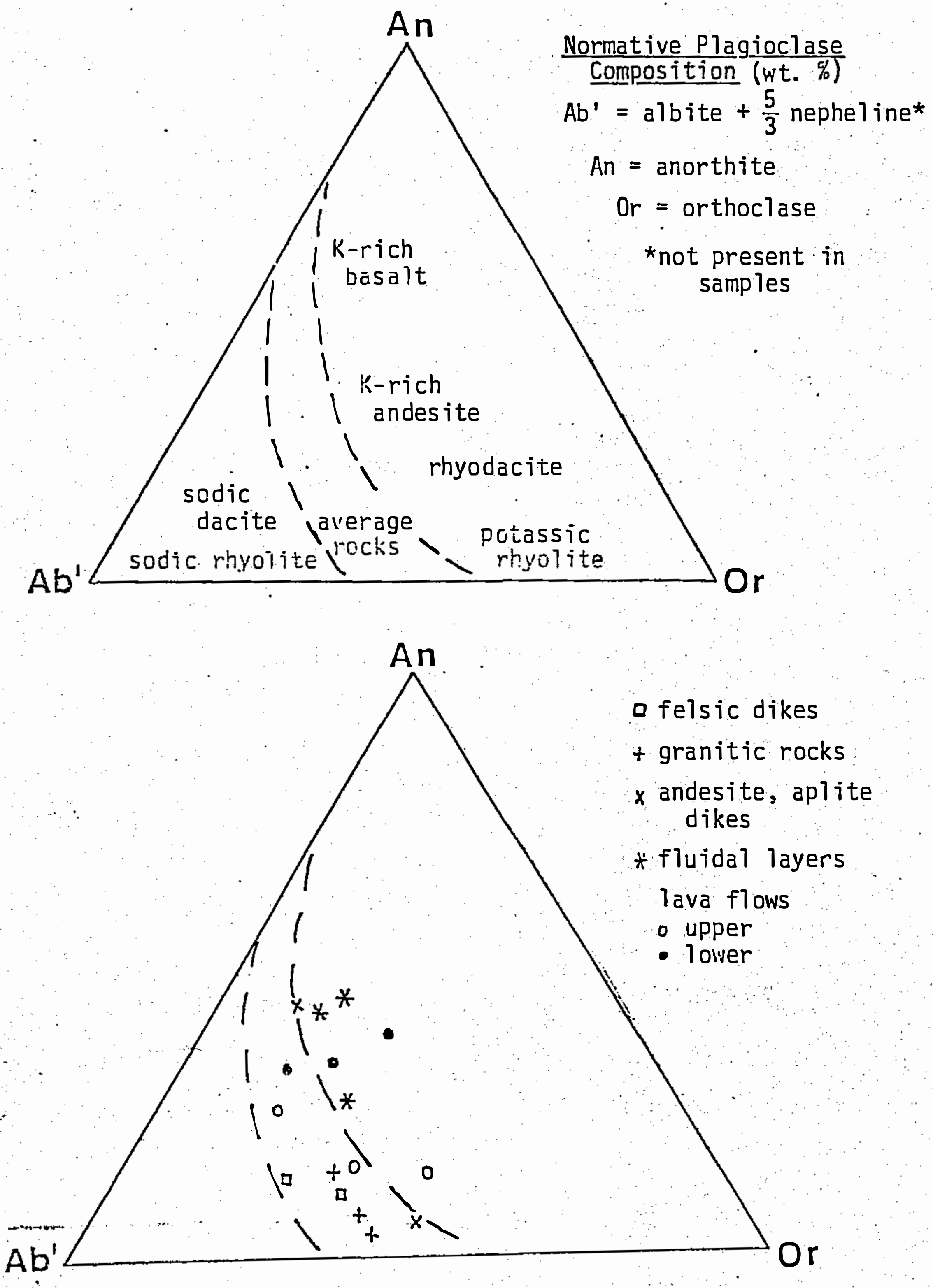


Figure 20. Subdivision of sub-alkalic rocks using the normative albite-anorthite-orthoclase diagram, after Irvine and Baragar (1971).

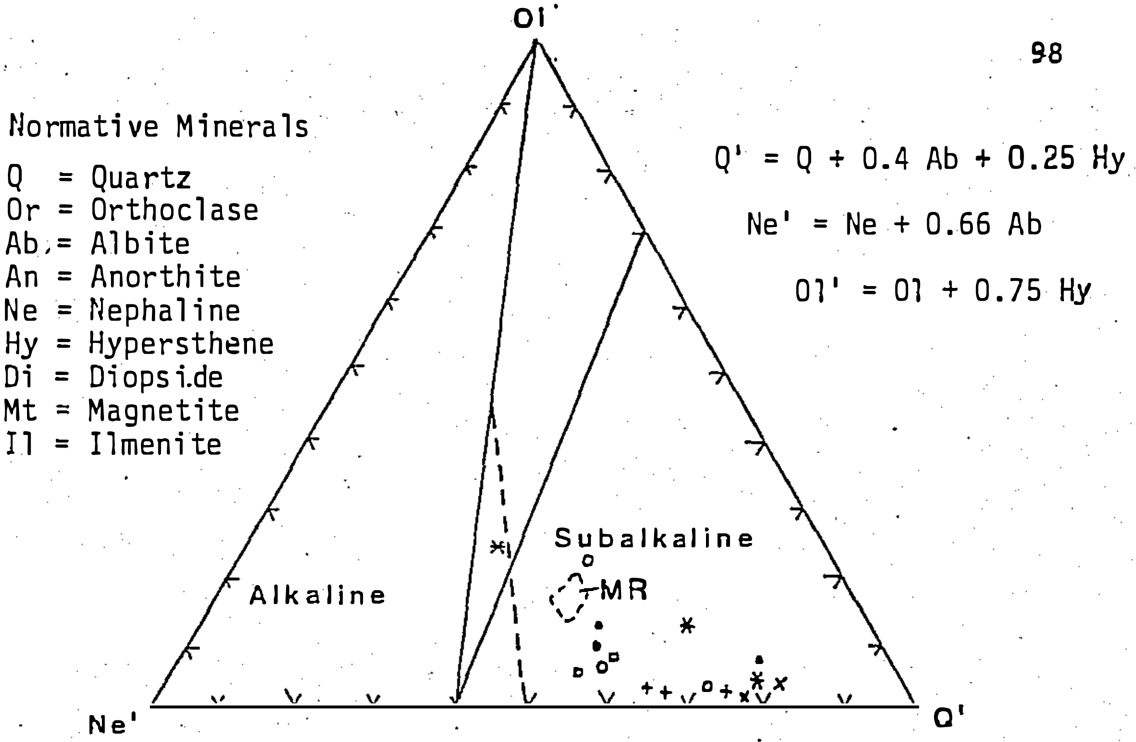


Figure 21. Ne'-Ol'-Q' projections of alkaline and subalkaline rocks, showing positions of samples from Montana Mountain. MR = Miners Range suite (Grond, 1980).

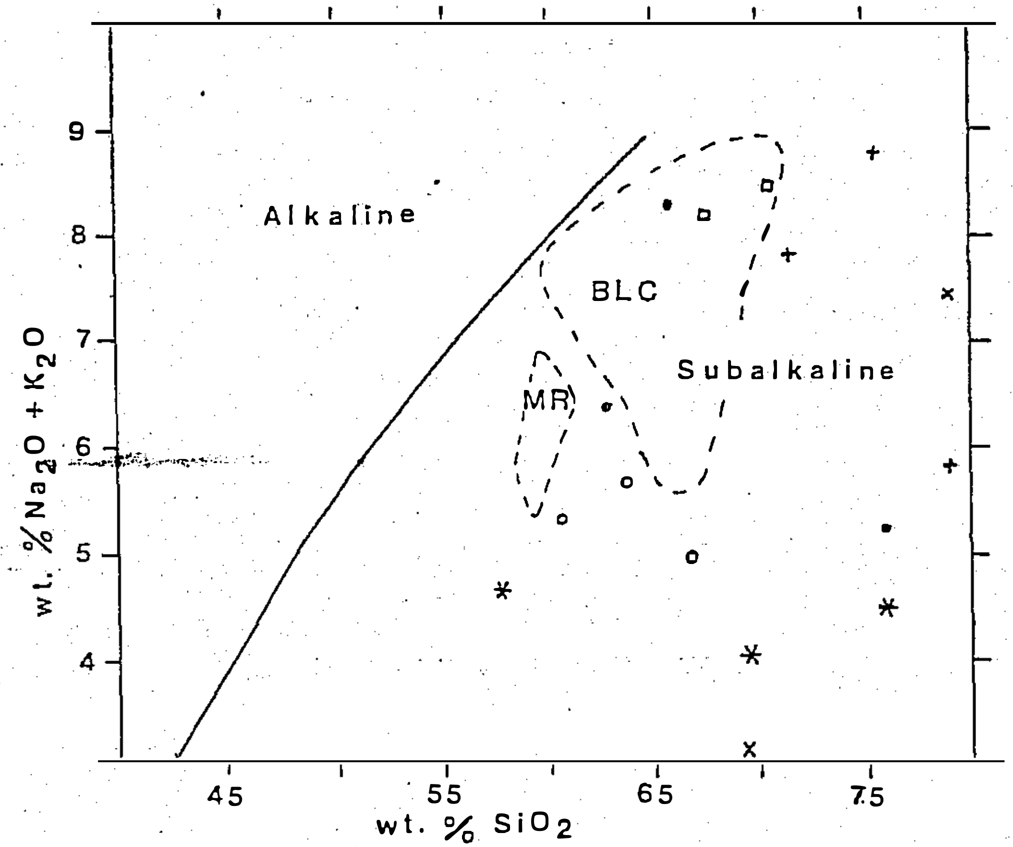


Figure 22. Alkalies-silica plot for alkalic and sub-alkalic rocks. Dividing line shown was proposed by Irvine and Baragar (1971). Large envelope encloses Bennett Lake suite (Lambert, 1974); smaller area defines 3 samples from Mount Nansen flows in the Miners Range (Grond, 1980).

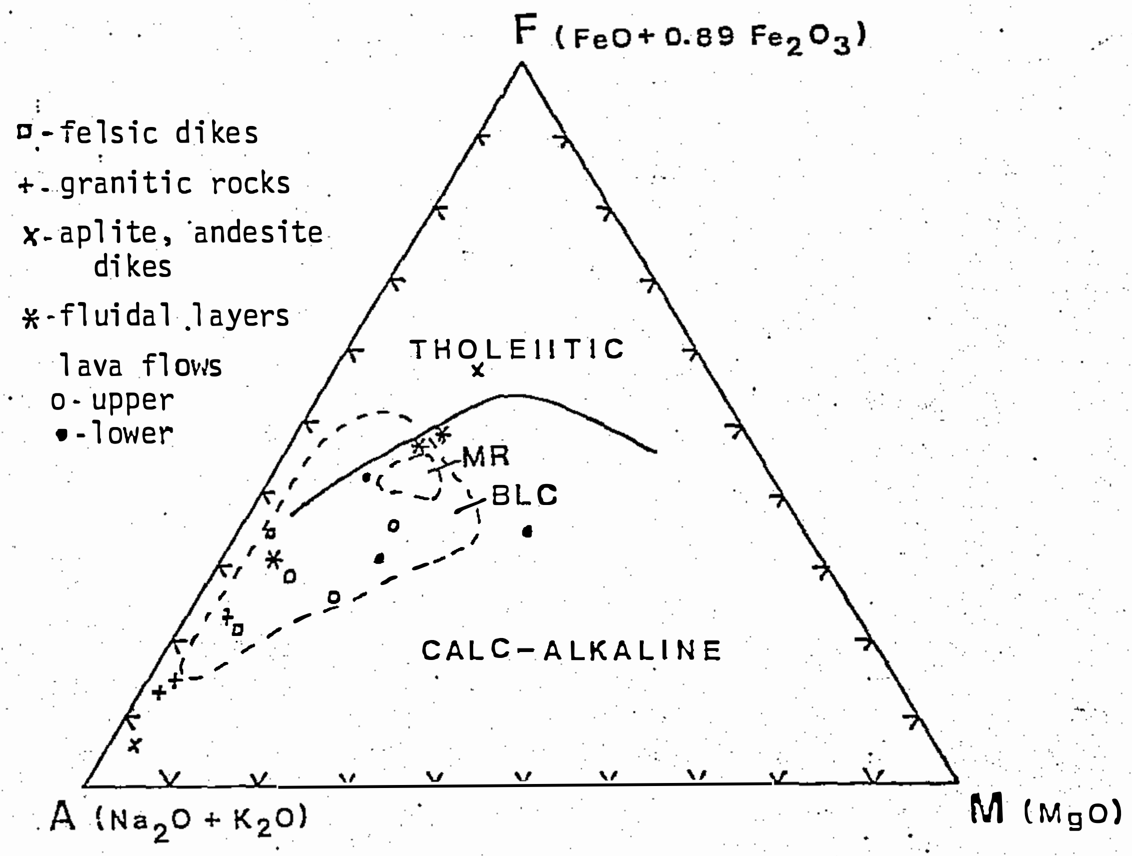


Figure 23. A-F-M plot of variation in rocks from the Montana Mountain area. Dividing line is from Irvine and Baragar (1971). Oxides, calculated on a volatile-free basis, are in weight percent. BLC = Bennett Lake complex (Lambert, 1974); MR = Miners Range (Grond, 1980).

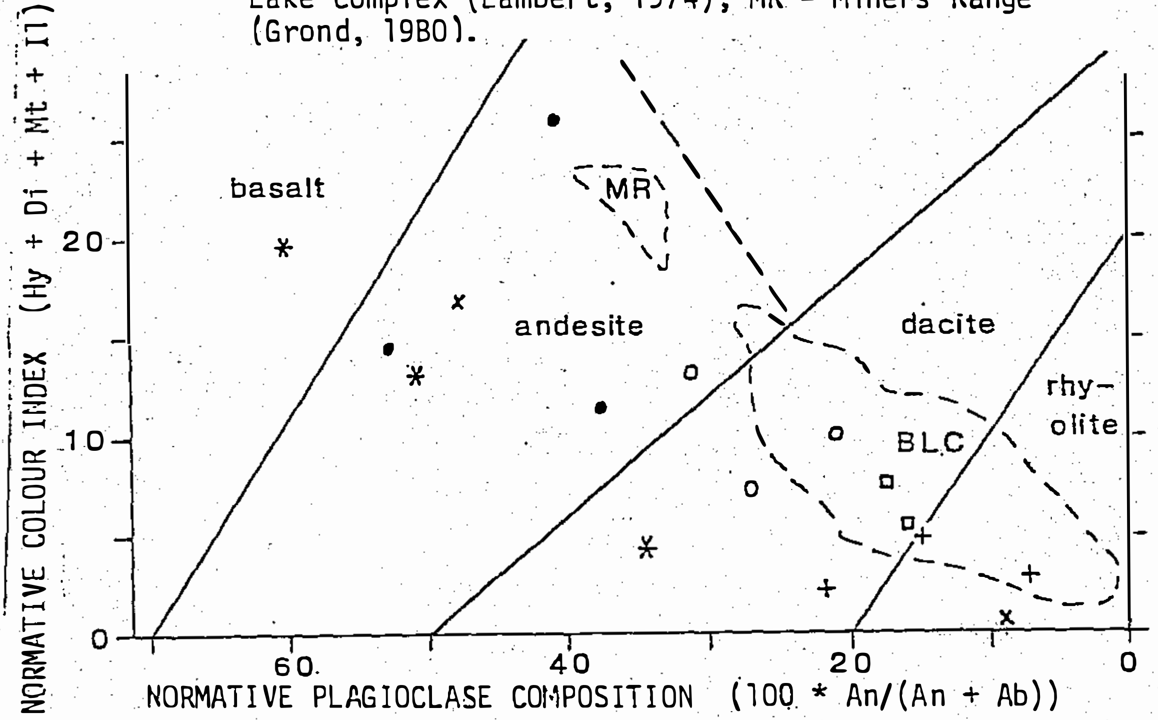


Figure 24. Normative composition of volcanic and plutonic rocks from the Montana Mountain complex. Rock type divisions were outlined by Irvine and Baragar (1971).

from the silicified rocks, because some dacitic rocks contain secondary silica enrichment.

Silica-variation diagrams are plotted for each major oxide and minor element (Figures 25-27). Some oxides show uniform patterns, although most are widely scattered because samples were chosen to be representative, and were not intended to show systematic changes. In general the plutonic rocks match trends of felsic rocks, which may imply a related magmatic source.

Interpretations from geochemical data must await more consistent sampling and further study. It is probable however, that the Montana Mountain complex is similar in composition to other centres in the Sloko Volcanic Province, and belongs to the calc-alkaline suite. Lavas and breccias near the edge of of the complex (lower units) are andesitic; but the 'upper flows' in the central part, which probably are younger, are dacites. The chemistry thus supports field observations that volcanism may have become more siliceous with time. Compositional cycles, commonly observed in rhyolitic and dacitic complexes (Lambert, 1974 and Berman, 1981) do not appear to be present in the Montana Mountain complex.

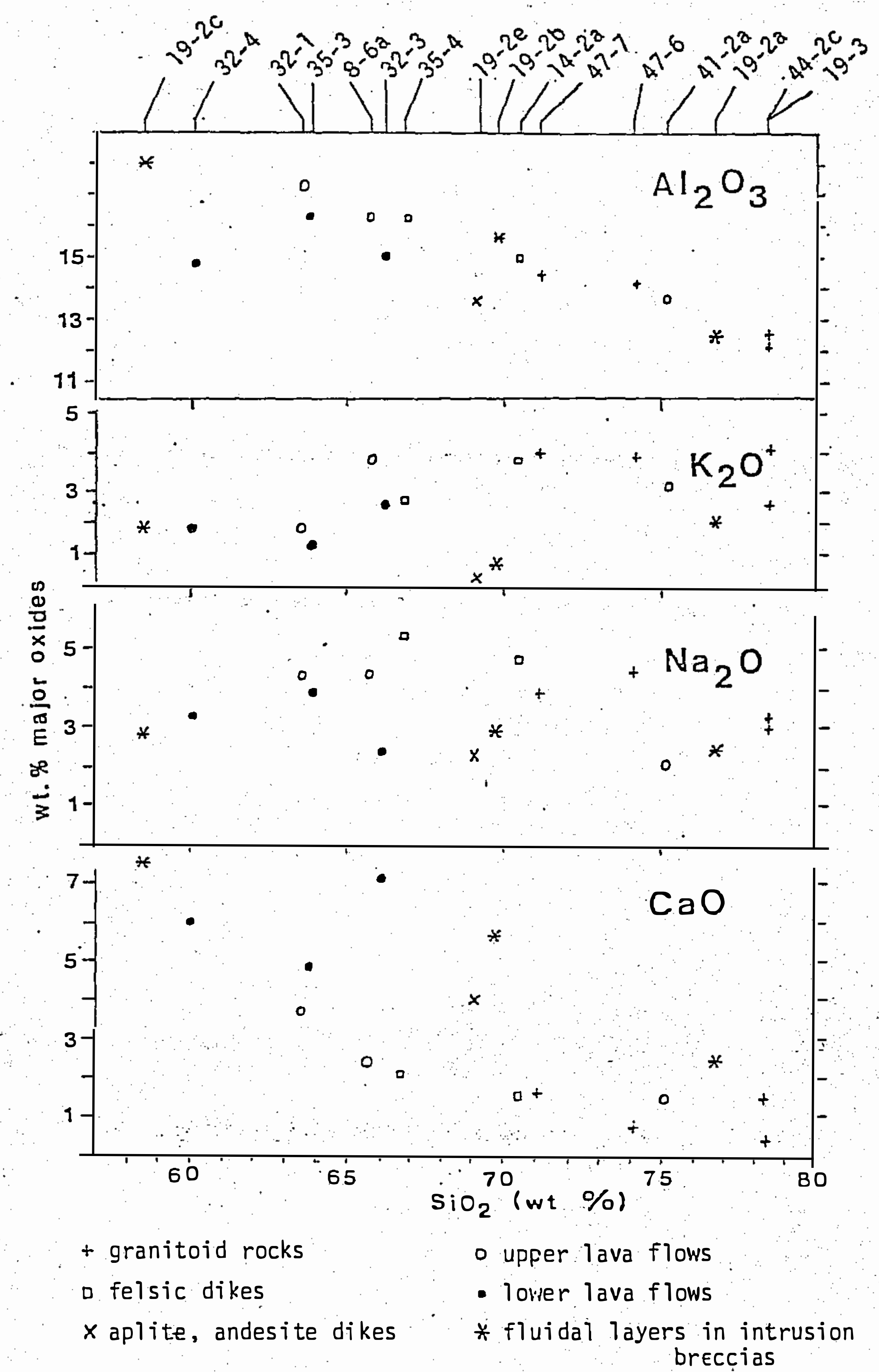


Figure 25. SiO_2-variation diagrams for major oxides of volcanic and plutonic rocks of the Montana Mountain complex. Chemical analyses were recalculated on a volatile-free basis.

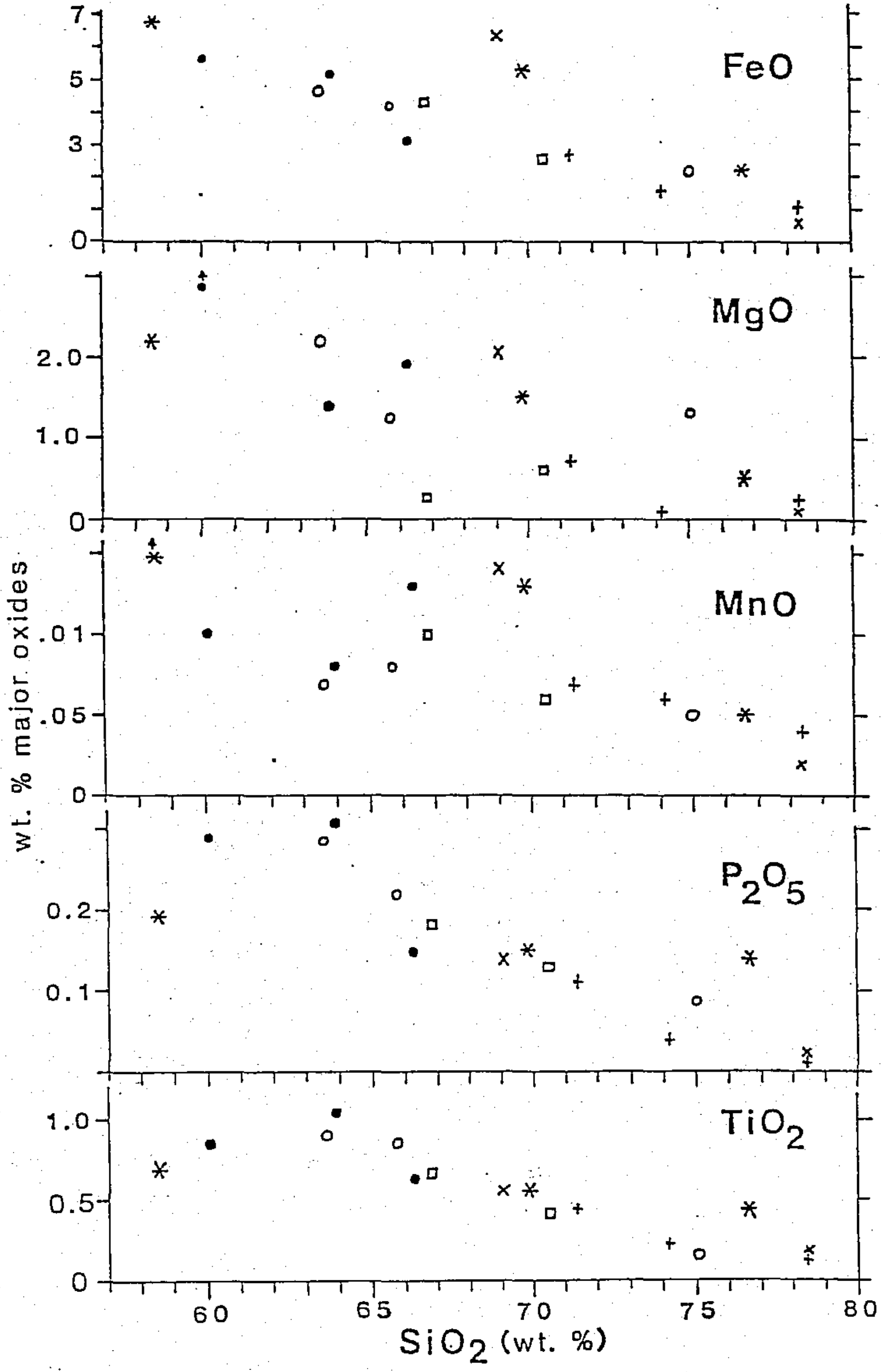


Figure 26. SiO_2-variation diagrams for major oxides of plutonic and volcanic rocks in the Montana Mountain complex.

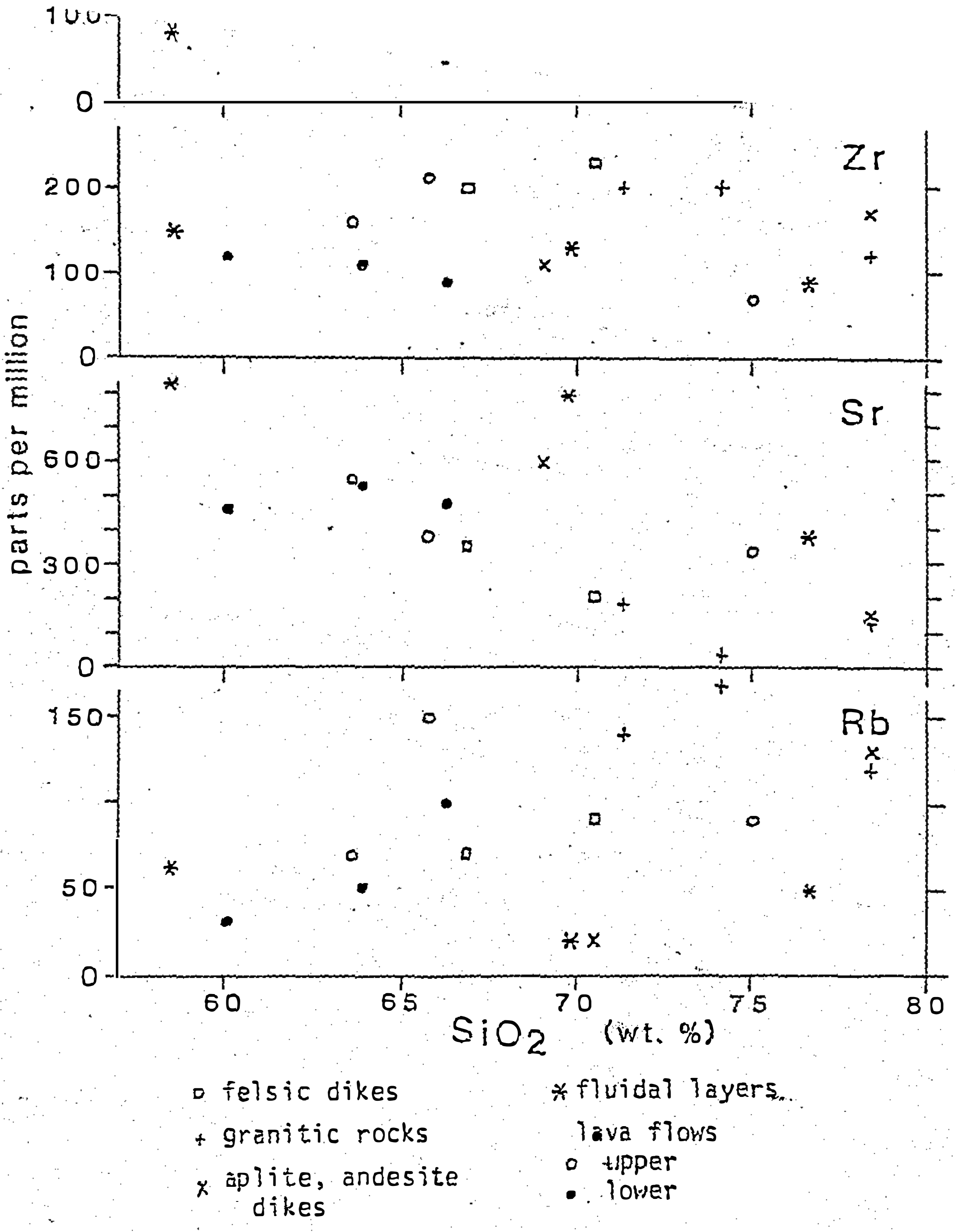


Figure 27. SiO_2-variation diagrams of Cr_2O_3 and minor elements in volcanic and plutonic rocks of the Montana Mountain complex.

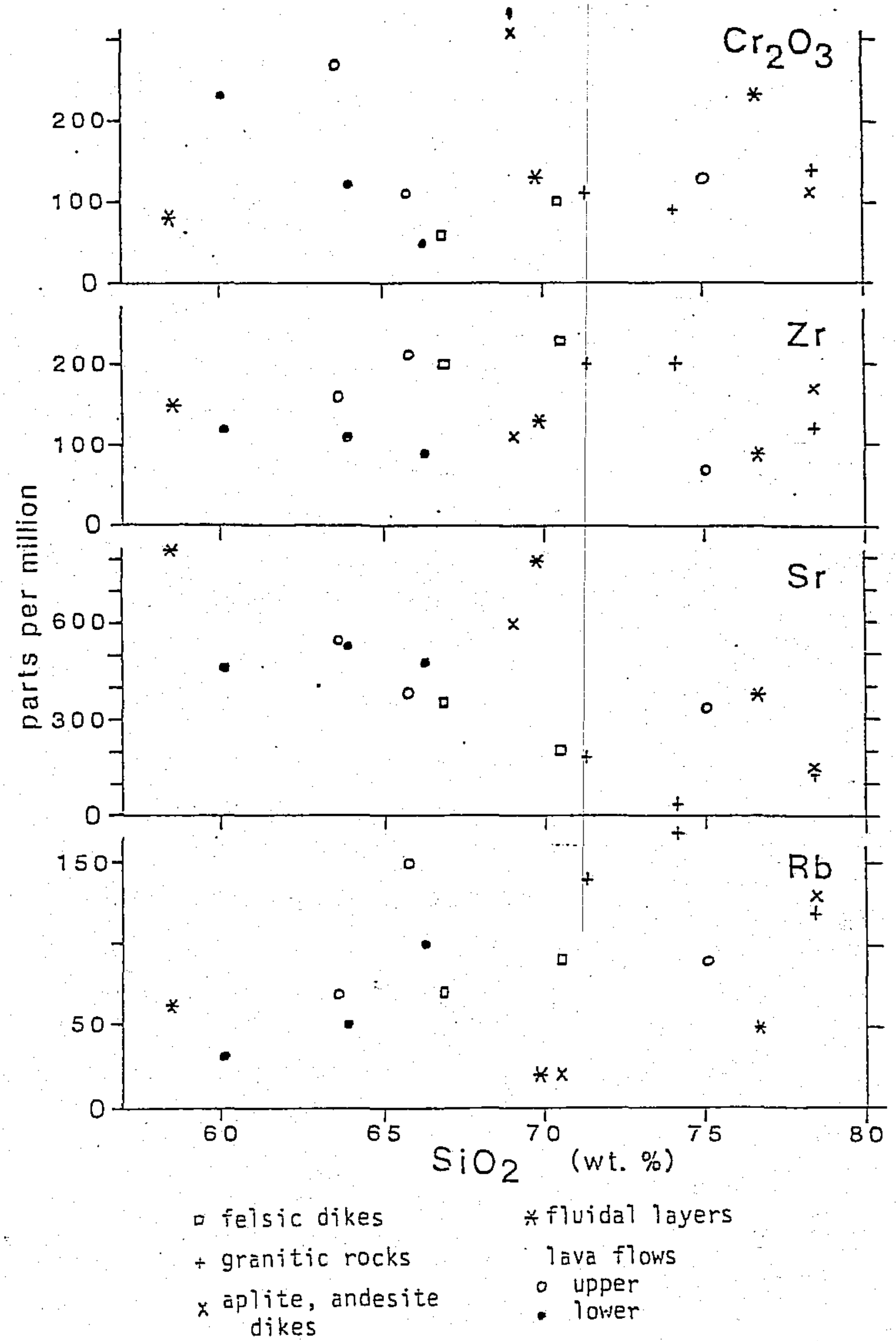


Figure 27. SiO_2-variation diagrams of Cr_2O_3 and minor elements in volcanic and plutonic rocks of the Montana Mountain complex.

CHAPTER VIII

CONCLUSION: EVOLUTION OF THE COMPLEX

The Montana Mountain complex belongs to the suite of volcanic rocks typified by the Mount Nansen and Sloko Lake localities, which in the study area consist mainly of andesitic to dacitic flows and breccias. It is one of a chain of intermediate to felsic volcanic centres that intruded and were deposited upon an eroded land surface.

The following account summarizes interpretations of the complex. Figure 28 depicts the main stages of evolution.

Initial effusive volcanism built a broad cone with gentle slopes (A). The earliest deposits probably are not exposed, but eruptions appear to have been subaerial. Blocky to massive andesitic lava flows may have extended more than 20 km from the complex.

The volcano probably reached a height of more than 1000 m before internal pressures increased sufficently to cause eruptions to become more explosive. Pyroclastic and felsic rocks were deposited at the top of the stratified volcanic pile.

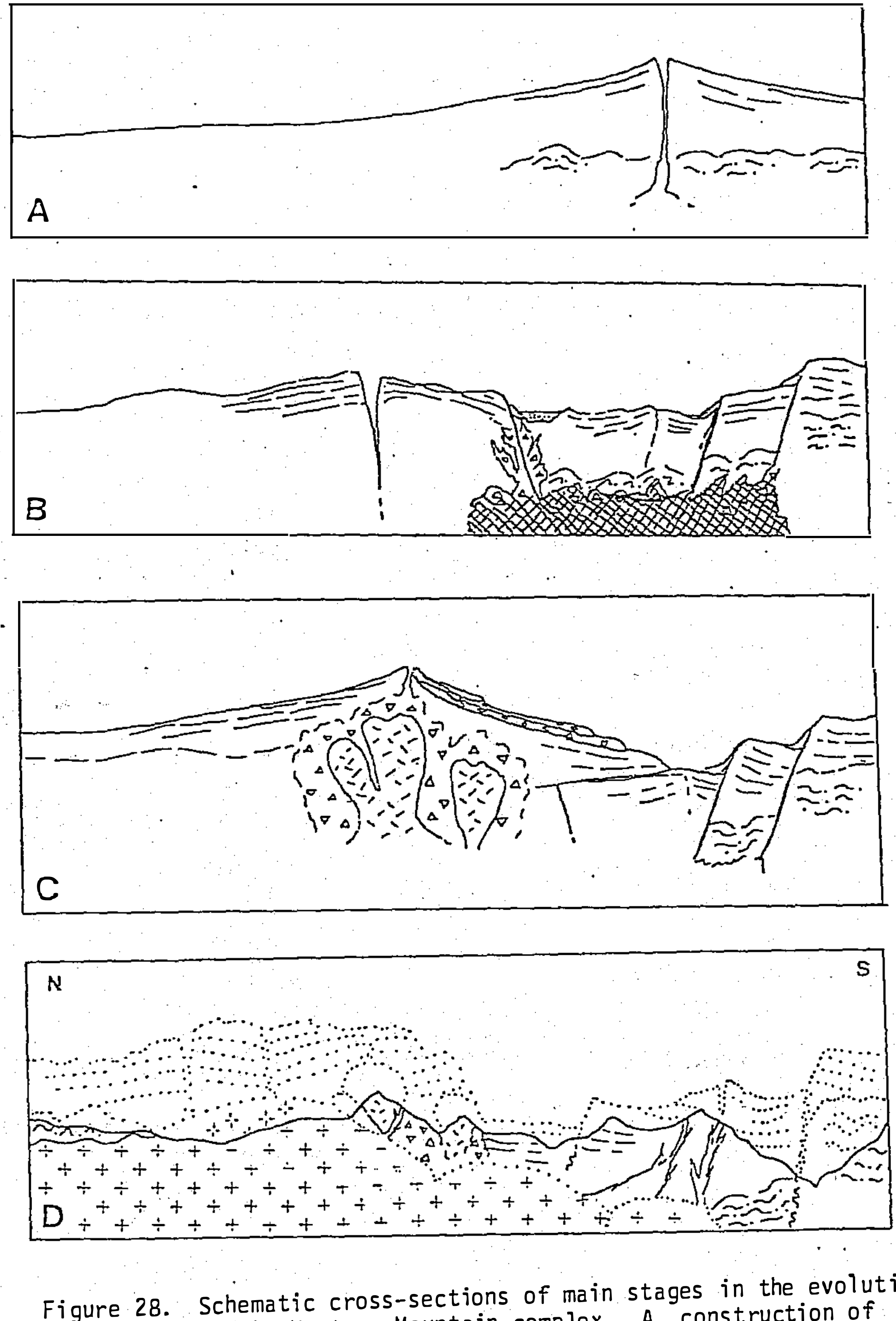


Figure 28. Schematic cross-sections of main stages in the evolution of the Montana Mountain complex. A, construction of a broad volcano. B, partial collapse. C, andesite plugs and breccia formation. D. intrusion of the pluton and erosion.

One or more periods of subsidence interrupted development of the volcanic cone (B). The original feeder pipe, not recognized in the complex, has been obliterated by the collapse or subsequently covered. Subsidence may have driven gases trapped in the top of the magma chamber out along boundary fracture zones to create breccia dikes.

The rock record appears to be more complicated in the central region than on the adjacent flanks. Tephra, lava flows and volcaniclastic sediments appear to have filled a depression to a depth of several hundred metres. Settling of some areas caused tilting of others.

Possibly later, andesitic magma intruded beneath a large (inferred) volcanic structure situated over the northern part of the present complex (C). Plug domes may have caused churning of large volumes of host volcanic and sedimentary rocks, forming the massive intrusion breccias. Magmatic froth surged through the breccias, which then settled and cooled to preserve the distinctive fluidal layers. From vents the froth may have been released as pyroclastic flows. The presence of active hydrothermal systems is suggested by quartz chips in the laharic breccias.

Following the rise of the andesite plugs, the magma became more granitic, and ultimately intruded the pre-existing volcanic pile (D). Felsic dikes occupied previous subsidence faults and fissures opened by upward arching of the complex. Some dikes may have reached the surface, resulting in deposition of vesicular agglutinate in the vicinity of Dail Peak.

The lack of extrusive rocks on the north side of the complex suggests that the volcanic centre once extended over the 'Carcross pluton'.

CHAPTER IX

REGIONAL AND ECONOMIC CONSIDERATIONS

AGE OF THE VOLCANIC COMPLEX

The underlying Laberge Group is fossiliferous and well dated as lower and middle Jurassic (Wheeler, 1961). Because the volcanic rocks intrude the Laberge strata, the complex cannot be older than lower Jurassic. The Mount Nansen rocks do not show the tight folding present in the Laberge Group, indicating a deformational event (and deep erosion) took place prior to volcanism.

The volcanic complex is intruded and metamorphosed by the 'Carcross pluton', dated by Morrison et al (1979) at 64.3 +/- 2.2 Ma (K-Ar method). This determination is intermediate between the late Cretaceous (75 Ma) and Eocene (55 Ma) plutonic suites identified by Morrison and others in the Whitehorse map-area.

Mount Nansen volcanic rocks in the Miners Range were dated at 72.4 +/- 2.5 Ma by Grond (1980) using the K-Ar method. Other ages determined for the

Mount Nansen Group include: 67.9 +/- 2.3, 73.1 +/- 2.5 and 68.0 +/- 2.2 Ma (all by Churchill, 1980; K-Ar method), and 72.0 +/- 2 Ma (Rb-Sr, Armstrong; unpublished) in the Carmacks map-area, and 58.4 Ma (K-Ar; Tempelman-Kluit and Wanless, 1975) in Snag map-area to the west. Although Mount Nansen volcanic rocks were erupted at different times and their source areas probably developed over several millions of years, the results indicate that they are broadly late Cretaceous in age. Most of the complexes have been intruded by leucogranite stocks which may have reset ages indicated by the potassium- and argon-bearing minerals.

Nisling Range alaskite bodies and dikes are recognized by Tempelman-Kluit (1974, 1980) as subvolcanic equivalent and feeders for Mount Nansen occurrences in the Dawson Range. Their ages fall into two groups: 50-55 Ma where they occur within the Ruby Range granodiorite (part of the Coast Plutonic belt), and 65-68 Ma in biotite granite stocks northeast of that range (Tempelman-Kluit and Wanless, 1975; K-Ar method). These intrusive correlatives of Mount Nansen Group probably cooled later and have younger isotopic ages than the extrusive rocks.

The Montana Mountain complex, with similar rock types and relations to others of the Mount Nansen

Group, is probably contemporaneous. The 'Carcross pluton' may belong to a group of biotite granite stocks with related felsic dikes that are mainly exposed in south-central Yukon. These are equivalent in age to the Nisling Range Alaskite (Tempelman-Kluit, 1981).

Massive andesite plugs attest to the great thickness of the volcanic pile. If they were built at the end of volcanic activity, plutonic rocks beneath them probably cooled more slowly, and isotopic ages may be younger. Furthermore, intrusion of the granite into the complex has probably reset the original radioactive ages of the volcanic rocks.

QUARTZ VEINS AND RELATED MINERALIZATION

Quartz veins are distributed on the east side and north central part of the volcanic complex, as well as along the south margin of the 'Carcross pluton' (Figure 4). The mineralized Venus vein is the largest and has been traced on surface more than 2 km with widths up to 3.5 m and a down-dip extent of at least 800 m. Other veins are 5 to 250 m long, and most have subparallel quartz stringer zones. Those along Windy Arm dip moderately west; other veins in the center of the complex and nearby pluton dip north and northwest respectively.

The quartz veins fill fractures and faults, some of which have open spaces and slickensides on the hanging wall. Most contain white quartz, although sulfides are a major component of some of the widest veins. Quartz is coarsely crystalline or massive, and in places saccharoidal. The Venus vein shows characteristic symmetrical mineral zoning about the vein center, with arsenopyrite on both walls, followed by quartz and pyrite nearer the center, which contains galena and sphalerite with quartz. Blue-grey, streaked quartz is irregularly distributed and in places well-mineralized.

Gold is contained in arsenopyrite; silver is predominantly in galena and minor cadmium in sphalerite. Less common are tetrahedrite, chalcopyrite and stibnite, as well as pyrargarite and other silver sulfide minerals. Element geochemistry studies by Ralfs (1975) and Morin (1981) showed that concentrations of gold, antimony and arsenic are greatest in the vein near the top of the Venus mine workings. Silver, cadmium, lead and zinc concentrations increase with depth (over 420'/130 m down dip). The mineral zoning suggests that this section of the vein is of the mesothermal type (defined by Park and MacDermid, 1970).

The quartz veins have hydrothermal haloes of oxide and clay minerals in the surrounding rocks that resemble the alteration around porphyry copper deposits (propylitic, argillic and phyllic alteration zones). Volcanic rocks near Venus vein weather orange-brown, are sericitic and commonly silicified, in contrast to the altered host plutonic rocks which are rich in white clay minerals, chlorite and muscovite.

Near the Venus mine workings, the oxidized envelope extends at least 20 m to either side of the quartz vein and 30-50 m below the surface. If alteration resulted from fluid saturation of the host rocks close to the original surface, the present distribution suggests that the vein has not been deeply eroded. Moreover, a near-surface environment is implied by the abundance of chalcedony, a low-pressure precipitate, along the Venus and Montana veins. Studies of inclusions in the quartz could conclusively test this hypothesis.

The quartz veins occur principally in faulted rocks forming the east side of the volcanic complex and the southern extent of the pluton. They are not present in Nakina or Laberge rocks in the intervening 6 km between the Venus mine and those of the pluton, and are thus most likely to have been emplaced during igneous events. Asymmetric mineralized bands and slickensides in the quartz veins attest to repeated faulting, which created open spaces for circulating fluids.

Association with felsic dikes (Figure 17), and orientations suggestive of radial and concentric patterns within the complex imply that the veins are related to granitic intrusion and possibly arching of the volcanic rocks. The quartz veins probably were emplaced after volcanic activity in the complex ceased, perhaps during structural adjustments.

REFERENCES

Aitken, J.D.
1959: Atlin map-area, British Columbia (104N); Geol. Surv. Can., Memoir 307. 89 p.

Berman, R.G.
1981: Differentiation of calc-alkaline magmas; evidence from the Coquihalla volcanic complex, B.C.; J. Volcanol. Geoth. Res. 9, pp. 151-179.

Berman, R.G. and Armstrong, R.L.
1980: Geology of the Coquihalla volcanic complex, southwestern B.C.; Can. J. Earth Sci. 17, pp. 985-995.

Bostock, H.S.
1936: Carmacks District, Yukon; Geol. Surv. Can., Memoir 189. 67 p.

Bostock, H.S. and Lees, E.J..
1938: Laberge map-area, Yukon; Geol. Surv. Can.; Memoir 217.

Cairnes, D.D.
1907: Exploration in a portion of the Yukon south of Whitehorse; Geol. Surv. Can., Summary Rept. for 1906. pp. 22-30.

1909: Reports on a portion of the Conrad and Whitehorse mining districts, Yukon; Geol. Surv. Can., Dept. of Mines, Publ. 982. pp. 14-18.

1917: Lode mining in the Windy Arm portion of the Conrad mining district, southern Yukon; Geol. Surv. Can., Summary Report for 1916. pp. 34-49.

Christie, R.L.
1959: Bennett map-area, British Columbia; Geol. Surv. Can., Map 19-1957.

Churchill, S.J.
1980: Geochronology and chemistry of the Cretaceous Carmacks Group, Yukon; Unpubl. B.Sc. Thesis, Univ. of B.C.

Cloos, H.
1941: Bau und Tatigeit von Tuffschloten. Untersuchungen an den Schwabichen vulkan; Geol. Rundschau, 32, pp. 709-800.

Fisher, R.V.
1966: Breccias composed of volcanic fragments and their classification; Earth Sci. Rev. 1, pp. 287-298.

Gates, O.
1959: Breccia pipes in the Shoshone Range, Nevada; Econ. Geol. 54, pp. 790-815.

Grond, H.
1980: New K-Ar dates and geochemistry of Mount Nansen volcanics, Yukon; Unpubl. B.Sc. Thesis, Univ. of B.C. 36 p.

Hammond, P.E.
1980: Mount St. Helens box score: a compilation of activity; Volcano News 4, (July, 1980); Edited by C.A. Wood, Silver Spring, MD 20910, USA

Hughes, C.J.
1973: Spilites, keratophyres and the Igneous Spectrum; Geol. Mag. 109 (6), pp. 513-527.

Hyndman, D.W.
1972: Petrology of Igneous and Metamorphic Rocks; McGraw-Hill Book Co. 553 p.

Kents, P.
1964: Special breccias associated with hydrothermal developments in the Andes; Econ. Geol. 59, pp. 1551-1563.

Kindle, E.D.
1952: Dezadeash Map-area, Yukon; Geol. Surv. Can., Memoir 268.

Irvine, T.N. and Baragar, W.R.A.
1971: A guide to the chemical classification of common volcanic rocks; Can. J. Earth Sci., 8, pp. 523-547.

Lajoie, J.
1979: Volcaniclastic rocks: Facies Models 17; Edited by R.G. Walker, Geol. Assn. Can., Geoscience Canada, Reprint Series 1. pp. 191-200.

Lambert, M.B.
1974: The Bennett Lake cauldron subsidence complex, British Columbia and Yukon; Geol. Surv. Can., Bulletin 227. 213 p.

LeMaitre, R.
1976: A new approach to the classification of igneous rocks, using the basalt-andesite-dacite-rhyolite suite as an example; Contrib. Mineral. Petrol. 56, pp. 191-203.

Macdonald, G.A.
1972: Volcanoes. Prentice-Hall Inc. 510 p.

MacLean, T.A.
1914: Windy Arm district. In Lode mining in Yukon: an investigation of quartz deposits in the Klondike division; Can. Mines Br. Publ. 222, pp. 185-199.

McConnell, R.G.
1906: Windy Arm district, northwestern B.C.; Geol. Surv. Can., Summary Rept. for 1905, pp. 30-32.

Monger, J.W.H.
1975: Upper paleozoic rocks of the Atlin Terrane, northwestern B.C. and south-central Yukon; Geol. Surv. Can., Paper 74-47, 63 p.

Monger, J.W.H. and Price, R.A.
1979: Geodynamic evolution of the Canadian cordillera: progress and problems; Can. J. Earth Sci. 16, pp. 770-791.

Morin, J.A.
1981: Element distribution in Yukon gold-silver deposits; In Yukon Geology and Exploration 1979-1980, Geology Section, Dept. of Indian and Northern Affairs, Whitehorse. pp. 68-84.

Morrison, G.W., Godwin, C.T. and Armstrong, R.I.
1979: Interpretation of isotopic ages and strontium initial ratios for plutonic rocks in the Whitehorse map-area, Yukon; Can. J. Earth Sci. 16, pp. 1988-1997.

Muller, J.E.
1967: Kluane Lake map-area, Yukon; Geol. Surv. Can., Memoir 340.

Mulligan, R.
1963: Geology of the Teslin map-area, Yukon (105C); Geol. Surv. Can., Memoir 326.

Park, C.F.,jr. and MacDermid, R.A.
1970: Ore Deposits; 2nd Ed., Freeman Publ., San Fransisco. 522 p.

Parsons, W.H.
1967: Manner of emplacement of pyroclastic andesite breccias; Bull. Volcanol. 2 (30), pp. 177-187.

1969: Criteria for the recognition of volcanic breccias: a review; Geol. Soc. Am. Memoir 115, pp. 263-304.

Ralfs, K.
1975: A study of the mineralogy, paragenesis, zoning and wall-rock alteration, Venus vein, Montana Mountain, southwest Yukon; Unpubl. B.Sc. Thesis, Univ. of B.C. 48 p.

Reid, R.P.
1981: Report of field work on the upper Triassic reef complex of Lime Peak, Laberge map-area, Yukon; In Yukon Geology and Exploration 1979-1980: Geology Section, Dept. of Indian and Northern Affairs, Whitehorse, pp. 110-114.

Reynolds, D.L.
1954: Fluidization as a geologic process, and its bearing on the problem of intrusive granites; Am. J. of Sci. 252, pp. 577-614.

Roots, C.F.
1981: Geological setting of gold-silver veins on Montana Mountain; In Yukon Geology and Exploration 1979-1980; Geology Section, Dept. of Indian and Northern Affairs, Whitehorse, pp. 116-122.

Sabina, A.P.
1972: Rocks and minerals for the collector: The Alaska Highway - Dawson Creek B.C. to the Yukon/Alaska border; Geol. Surv. Can., Paper 72-32.

Sawyer, J.P.B. and Dickinson, R.A.
1976: Mount Nansen; In Porphyry copper and molybdenum deposits of the calc-alkaline suite; Can. Inst. of Mining and Metall. Sp. Vol. 15, pp. 336-343.

Souther, J.G.
1967: Acid volcanism and its relationship to the tectonic history of the cordillera in B.C. Canada; Bull. Volcanol. 30 pp. 167-177

1971: Geology and mineral deposits of the Tulsequah map-area, B.C. (104K); Geol. Surv. Can., Memoir 362, 83 p.

1977: Volcanism and tectonic environments in the Canadian cordillera - a second look; In Volcanic Regimes in Canada, Edited by W.R.A. Baragar, L.C. Coleman and S.M. Hall; Geol. Assn. Can., Special Paper 16, pp. 3-24.

Stauffer, M.R., Mukherjee, A.C. and Koo, J.
1975: The Amisk Group: An Aphebian (?) island arc deposit; Can. J. Earth Sci. 12, pp. 2021-2035.

Streckeisen, A.L.
1973: Classification and nomenclature of igneous rocks; Geotimes, Oct. 1973, p. 26.

Tempelman-Kluit, D.J.
1974: Reconnaissance geology of Aishihik Lake, Snag and part of Stewart River map-areas, west-central Yukon; Geol. Surv. Can., Paper 73-41, 97 p.

1978: Reconnaissance geology, Laberge map-area, Yukon; Geol. Surv. Can., Paper 78-1A, pp. 61-66.

1979: Transported cataclasite, ophiolite and granodiorite in Yukon: Evidence of arc-continent collision; Geol. Surv. Can., Paper 79-14, 27 p.

Tempelman-Kluit, D.J. (con't.)

1980: Highlights of field work in the Laberge and Carmacks map-areas, Yukon; Geol. Surv. Can., Paper 80-1A, pp. 357-362.

1981: Geology and mineral deposits of southern Yukon; In Yukon Geology and Exploration 1979-1980; Geology Section, Dept. of Indian and Northern Affairs, pp. 7-31.

Tempelman-Kluit, D.J. and Wanless, R.K.
1975: Potassium-argon age determinations of metamorphic and plutonic rocks in the Yukon Crystalline Terrane; Can. J. of Earth Sci. 12, pp. 1895-1909.

Wheeler, J.O.
1961: Whitehorse map-area, Yukon Territory; Geol. Surv. Can., Memoir 312, 156 p.

Williams, H.
1957: Glowing avalanche deposits of the Sudbury basin; Ont. Dept. of Mines Ann. Rept. 65 (3), pp. 57-89.

Williams, H. and McBirney, H.R.
1979: Volcanology. Freeman Cooper and Co. 381 p.

Wright, A.E. and Bowes, D.R.
1963: Classification of volcanic breccias: a discussion; Geol. Soc. Am. Bull. 74, pp. 79-86.

APPENDIX A : Chemical composition of volcanic and intrusive rocks of the Montana Mountain area.

TABLE A-1.

DESCRIPTIONS OF ROCKS FOR CHEMICAL ANALYSIS

Breccias and lava flows near Pooly Canyon
(average elevation 4000'/2200 m)

• 32-3 - Light grey matrix of silicified breccia
• 32-4 - Dark green, vesicular lava flow
• 35-3 - Light green, fine-grained matrix of agglomerate breccia

Lava flows from upper Pooly Creek
(elevations 5100'-6400'/1550-1950 m)

○ 32-1 - Light green, massive dacite
○ 41-2 - Dark, aphanitic rock with white, fluidal-textured laminae
○ 8-6 - Dark green lava flow; with 20% oligoclase phenocrysts to 3 mm long.

Fluidal layers; 500 m north of Montana Mountain
(elevation 6500'/1980 m)

$\ast_f$ 19-2a - Mauve-weathering, siliceous, aphanitic laminae
$\ast_m$ 19-2b - Dark green, fine-grained flow layers
$\ast_c$ 19-2c - Dark green flow layer with coarse-weathering textures

Felsic dikes

□ 14-2 - Light grey quartz latite; orthoclase (?) and quartz phenocrysts - 30%
□ 35-4 - Trachyte dike; potassic feldspar phenocrysts - 20%

Other dikes

X 19-2e - Mauve-weathering, quartzofeldspathic dike
X 19-3 - White aplite (30 cm dike in andesite 50 m from contact with pluton)

Plutonic Rocks

+ 44-2c - Oxidized alsakite (10 m below volcanic contact)
+ 47-6 - medium-grained granite: 'mauve alteration type'
+ 47-7 - Fresh hornblende biotite granite

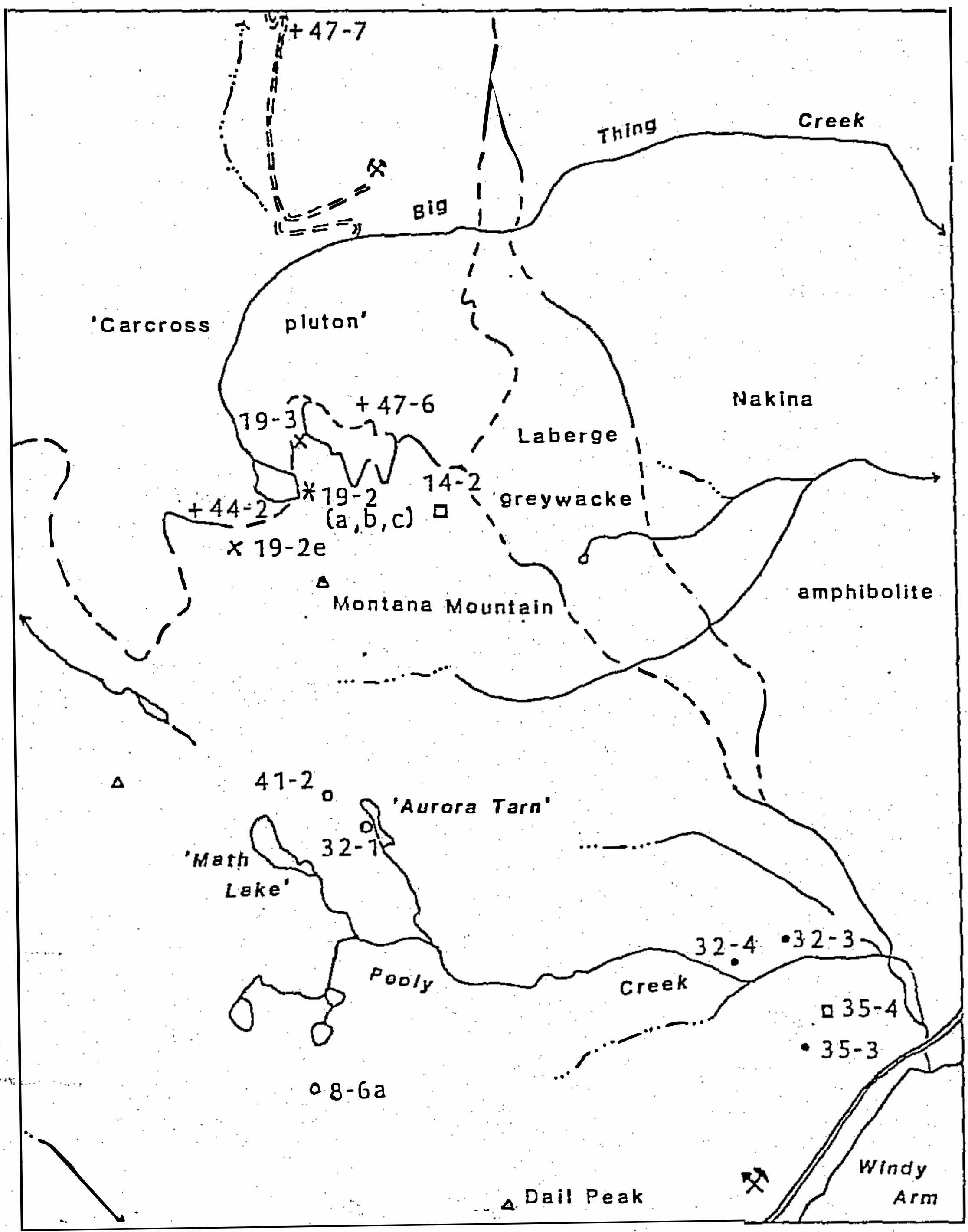


Figure A-1. Location of samples for chemical analysis.

Symbols for rock types are explained on Table A-1.

TABLE A-2

CHEMICAL COMPOSITION OF VOLCANIC ROCKS OF THE MONTANA MOUNTAIN COMPLEX

Sample No:	● 32-3	● 32-4	● 35-3	○ 32-1	○ 41-2	○ 8-6a	$*_f$ 19-2a	$*_m$ 19-2b	$*_c$ 19-2c
MAJOR OXIDES (weight percent)									
SiO_2	59.3	55.0	59.2	62.3	73.3	64.3	75.7	65.2	57.6
Al_2O3	13.5	13.6	15.2	16.9	13.5	16.1	12.4	15.6	17.8
CaO	6.40	5.46	4.38	3.64	1.45	2.25	2.32	5.55	7.35
Na_2O	2.07	3.03	3.75	4.25	2.03	4.22	2.35	2.93	2.81
K_2O	2.41	1.91	1.61	2.04	3.10	3.88	2.19	1.18	2.00
FeO	3.01	5.56	5.19	4.81	2.27	4.11	2.32	5.40	6.88
MgO	1.72	5.00	1.30	2.16	1.32	1.24	0.52	1.43	2.19
MnC	0.12	0.10	0.08	0.07	0.05	0.08	0.05	0.13	0.21
TiO_2	0.57	0.78	0.97	0.89	0.18	0.81	0.42	0.58	0.69
P_2O_5	0.14	0.27	0.29	0.29	0.09	0.22	0.14	0.15	0.19
Loss on Ign.	7.77	6.38	4.46	1.77	1.23	1.23	0.62	0.85	1.08
Total	97.3	97.7	97.1	99.6	98.8	98.9	99.3	99.7	99.6
Cr_2O_3 and MINOR ELEMENTS (parts per million)									
Cr_2O3	50	230	120	270	130	110	230	130	80
Zr	90	120	110	160	70	210	90	130	150
Sr	540	460	530	540	340	390	380	790	840
Rb	100	30	50	70	90	150	50	20	60
NORMATIVE COMPOSITIONS (weight percent)[1]									
Quartz	26.2	12.0	20.7	18.2	44.4	17.9	48.1	31.3	12.4
Corundum	0.0	0.0	0.04	1.74	4.47	1.44	2.35	0.0	0.0
Orthoclase	15.9	12.3	10.2	12.3	18.7	23.4	13.1	7.03	11.9
Albite	19.5	28.0	34.2	36.7	17.6	36.5	20.1	25.0	24.1
Anorthite	22.9	19.6	21.4	16.5	6.75	9.97	10.7	26.0	30.3
Diopside	9.33	6.52	0.0	0.0	0.0	0.0	0.0	0.68	4.61
Hypersth.	2.47	16.1	7.29	9.36	6.60	6.17	3.28	10.2	12.3
Olivine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Magnetite	1.36	1.84	2.26	1.95	0.39	1.81	0.91	1.26	1.52
Ilmenite	1.19	1.61	1.97	1.71	0.34	1.57	0.79	1.01	1.33
Apatite	0.35	0.68	0.73	0.68	0.21	0.52	0.33	0.35	0.45

[1] Norms calculated by Carleton University computer, program LEMNORM9.

TABLE A-3

CHEMICAL COMPOSITION OF INTRUSIVE ROCKS OF THE MONTANA MOUNTAIN COMPLEX

Sample No.	□ 14-2	□ 35-4	× 19-2e	× 19-3	+ 44-2	+ 47-6	+ 47-7
MAJOR OXIDES (weight percent)							
SiO_2	63.9	65.0	67.8	76.6	76.4	72.6	70.0
Al_2O_3	14.7	15.9	13.4	12.3	12.0	13.8	14.2
CaO	1.60	2.05	3.89	0.54	1.54	0.64	1.73
Na_2O	4.53	5.16	2.28	2.98	3.23	0.12	3.72
K_2O	3.84	2.73	0.73	4.33	2.56	4.32	4.03
FeO	2.60	4.42	6.40	0.51	1.11	4.46	2.60
MgO	0.66	0.26	2.05	0.10	0.21	1.60	0.77
MnO	0.60	0.10	0.14	0.02	0.04	0.06	0.07
TiO_2	0.42	0.69	0.55	0.14	0.12	0.21	0.42
P_2O_5	0.13	0.18	0.14	0.02	0.01	0.04	0.11
Loss on Ign.	1.70	2.93	1.16	0.77	2.00	0.31	0.63
Total	99.4	99.8	99.3	98.4	99.4	98.3	98.6
Cr_2O_3 and MINOR ELEMENTS (parts per million)							
Cr_2O_3	100	60	1180	110	170	90	110
Zr	230	200	110	170	120	200	200
Sr	210	250	600	140	140	40	180
Rb	90	70	20	130	120	170	140
NORMATIVE COMPOSITIONS (weight percent)[1]							
Quartz	23.2	18.9	37.4	42.3	44.75	28.7	29.2
Corundum	0.46	1.24	2.12	1.83	1.18	0.81	1.60
Orthoclase	23.2	16.6	4.37	26.2	15.5	26.9	24.3
Albite	39.2	44.9	19.6	25.8	28.0	37.3	32.1
Anorthite	7.29	9.24	18.7	2.59	7.77	2.96	6.03
Diopside	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hypersth.	4.16	5.06	14.3	0.43	1.96	2.15	3.56
Olivine	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Magnetite	0.91	1.49	1.52	0.30	0.26	0.45	1.39
Ilmenite	0.79	1.31	1.04	0.26	0.27	0.39	0.82
Apatite	0.31	0.43	0.33	0.47	0.02	0.94	0.26

[1] Norms calculated by Carleton University computer, program LEMNORM9.

APPENDIX B: Investigations of Abandoned Workings on Quartz Veins

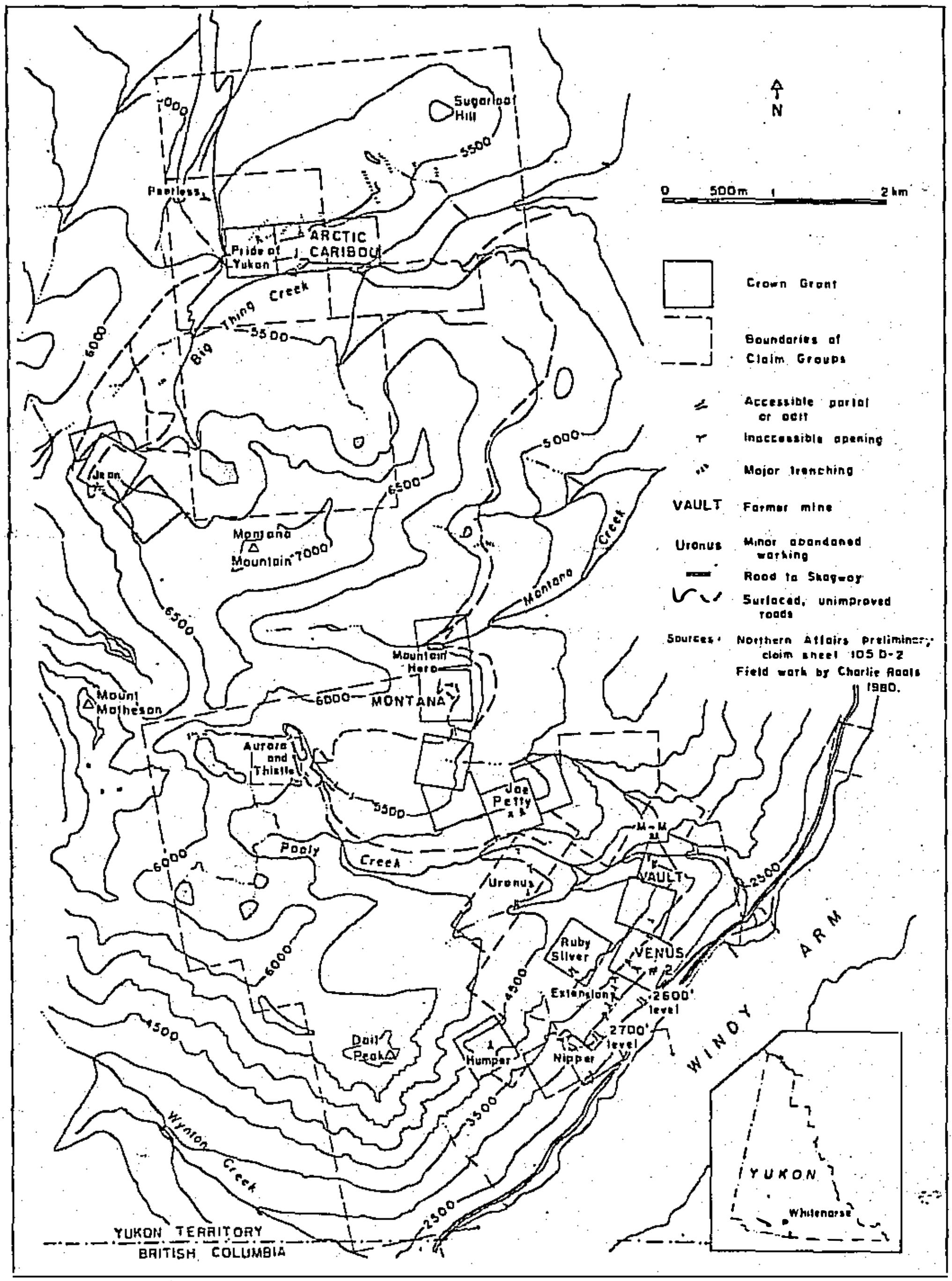


Figure B-1. Mineral claims and major workings on Montana Mountain.

	Elevation A.S.L.	Conditions of Workings	History, Development, production, if reported	Economic Sulphide Minerals	Nature of Vein	Nature of Host Rock	Remarks
[illegible] adits	5500' 5400' 5250'	Adits caved, last by bulldozer trenching	1907 – 10 m adit [illegible] hand trenching 1973 – bulldozer clearing of portals with large dump	minor aspy, gn in dump	Adit at 5500' into fault-vein 2-3 cm, [illegible]	[illegible] light green flows, [illegible]	[illegible] mentioned in private report as more northerly. [illegible] S of 5500' [illegible]
[illegible] mines	5100' 5100'	2 partly [illegible] portals, bulldozer trenching	1905 – [illegible] 1960 – lower portal [illegible] in 33,903 tons	aspy, minor [illegible], [illegible]	Several veins discovered; [illegible] 30 m [illegible] fault. Blue-grey quartz [illegible] with mineralization	[illegible] altered granite, with 10 m wide envelope of white clay, pyrite alteration	[illegible] in alteration envelope. Blue-grey [illegible] more richly mineralized, replaces white quartz
[illegible] adits, trenches	4750'	[illegible] caved adits, [illegible] trenches	1910 – 1930 approx. inclined shafts [illegible]	stibnite on dump, [illegible] reported	Blue and grey quartz vein, 30 cm wide, [illegible] over 200 m. Dark grey gouge along middle of vein	light grey siliceous flow, porphyry quartz dike envelope 2.0 m wide, [illegible] alteration	[illegible] of cliffs
[illegible] adit and bulldozer cut	5370' to 5500'	Caved adit, [illegible]	Staked 1938, trenching 1963, [illegible] m crosscut, [illegible] bulldozer [illegible] 1970 [illegible] D.D.	in dump, aspy, [illegible]	White quartz minor blue-grey quartz, calcite, [illegible] surface trace [illegible]	altered granite, yellowish [illegible] alteration chlorite-clays, [illegible] very sericitic, py in alteration	
[illegible] trenching, [illegible]	[illegible]	[illegible]	[illegible] 1950's [illegible] trenching, drill stations [illegible]	minor [illegible] in [illegible]	No [illegible]	chlorite-alteration granite, yellow clay [illegible], with [illegible] in [illegible]	may be the [illegible] Claim described by [illegible] (1963)
[illegible] trenches [illegible]	[illegible]	[illegible]	[illegible] 1905. Adit 15 m, [illegible]	aspy, [illegible] on dump	Minor white quartz	Intrusion breccia type, w/ chlor, [illegible] 200 m S of granite contact	not previously reported; [illegible]. Only workings on [illegible] side of volcanic complex
Joe Petty adit	[illegible]	Accessible	1905: adit of 15 m drift; [illegible] inclined shaft, trenches. Prod: several tons. 1960 bulldozer nearby hillside	only malachite noted, gn, "Ag minerals" reported	White quartz, [illegible], width of vein in general 10-30 cm, [illegible] traceable 200 m	grey intermediate flows, of breccia and vesicular horizons; 2 m oxidized envelope	Vein appears parallel to flow [illegible]. Blue-grey quartz in sheared portions
[illegible]	[illegible]	Accessible, in [illegible] cliffs	1905, [illegible] trenching, and 3 adits, [illegible] Prod. 5.6 tons	aspy, [illegible] on dump, [illegible]	[illegible] vein 10-30 cm	porphyry intermediate flow [illegible] breccia [illegible], with felsic dike [illegible]	Vein splays at [illegible] and into [illegible] faults. Yellow and black oxidation [illegible]
[illegible] adit and mine	[illegible]	Both [illegible], vein [illegible] in trench.	1905-1912 inclined shaft, [illegible] drift. Prod: minor. 1961: [illegible] drift, bulldozer trenching	aspy, [illegible] on dump, [illegible]	White qtz, [illegible] surface [illegible] 40 m. [illegible] of vein. Mineralization reported on hanging wall	[illegible], dark [illegible] flows, [illegible] breccia, porphyritic rhyolite dike at N end	[illegible] alteration envelope [illegible]; contacts of 1.2 m [illegible] jarosite clay
Mountain [illegible] adit	[illegible] 6000'	Portal caved	1905-1912 – 90 m crosscut, [illegible] development. Several pits at 6000' now rubble covered; large dumps	none at adit. aspy, [illegible] on hillside	No vein apparent, reported [illegible]; dark brown oxidized alt. in higher [illegible]	light grey "[illegible]" breccia, porphyritic andesitic rocks	under terminus of [illegible], windy [illegible], [illegible] equipment
[illegible] adits	[illegible] 7400'	2 adits accessible	1906 – 27 (upper), 10 m crosscut [illegible] side, 17 m drift [illegible] side 27 (lower) large dump; reported 33 m crosscut, 38 m winze	banded aspy, gn with in lower dump	Grey qtz, [illegible] 5-10 cm, [illegible], 60 m [illegible], with qtz, [illegible], [illegible] 15-20 cm wide	grey silicified andesite, [illegible] oxidized, 1-2 [illegible], jarosite clay, py, qtz stringers	
[illegible] adit	[illegible]	Reported [illegible] in tunnel	1905-1911 – [illegible] in [illegible] [illegible], 1965 – 200 m adit driven at [illegible]	aspy, gn, [illegible] on large dump	Small veins reported encountered in crosscut; [illegible] Blue-grey qtz- [illegible] of white clay w/ py, aspy	granite, [illegible] alt. chlorite, [illegible] replace mafic minerals	[illegible] cabin. [illegible] near entrance. [illegible] nearby
Pride of [illegible] mine	5700'	Inclined [illegible], bulldozer [illegible]	1905 prod: 1910-1912 – 2600 oz. [illegible] in 2575 tons. Total 275 m internal workings. Dump removed	[illegible] or [illegible] stibnite	Reported [illegible] vein and [illegible] thick, dipping [illegible]	Surface: oxidized, [illegible] altered granite with chlorite clots	
[illegible] Red Deer adit	4400'	Adit accessible	1905(?) – private interests, adit at [illegible]. [illegible] Red Deer(s) 1927(?) Rich ore removed from dump	gn, aspy on dump high assay values of vein	White qtz, [illegible] 15-40 cm, [illegible]. Red Deer vein [illegible] may be extension	[illegible] probably dike	very high grade silver vein
[illegible] adit	[illegible] (Paddy Cr.) to [illegible]	4 adits caved, 1 reported accessible	1905-7, [illegible] adit [illegible]. 1908 adit [illegible] Co. [illegible] near creek. Hand trenching on [illegible]	aspy, gn in dump, [illegible] reported	White qtz, reported 30-110 cm, [illegible] 400 m. Dolomite (?) in vein. [illegible]	Breccia and [illegible] silicified intermediate to felsic flows.	early reports [illegible], as with Joe Petty
[illegible] mine	[illegible]	2 adits accessible	1906-1912 – extensive development [illegible]. Adits 110 m	[illegible] vein: aspy, gn, sph, with minor [illegible]. Reported: [illegible]	Sugary and crystalline banded white qtz, 7-50 cm, [illegible] at tunnel entrance, qtz stringer [illegible] near creek.	pink weathering grey trachyte, other felsic dike rocks common, 5 m wide oxidized, [illegible]	[illegible] in [illegible] concentrates. [illegible] reported, vein oxidized near surface. Alteration contains [illegible]
[illegible] No. 2	[illegible] appr. [illegible] [illegible]	Shaft caved, [illegible] house, [illegible] portals O.K.	Extensive underground dev., [illegible] m of workings. Prod: 1905-1910, [illegible] oz. Au [illegible] oz. Ag in [illegible] tons.	[illegible]	Qtz vein well banded, persistent, 20-110 cm wide, [illegible]. Slickensided, with gouge	dark green andesite, [illegible] breccia, with felsic dikes sub-parallel to surface trace.	
[illegible] extension	[illegible]	Shaft caved, partial [illegible]	1915 – drift 100 m, 1977 – shaft	[illegible] zoning from centre of vein to wallrock: [illegible], pyrite & [illegible], quartz, crystals, pyrite & [illegible], wall alteration.	Vein [illegible] cm, [illegible] at surface, reported [illegible] at depth 10 cm clay [illegible], [illegible] coated.	[illegible] silicified andesite, also breccia	[illegible] portals, trenches [illegible] along trace of [illegible] vein. [illegible] workings; [illegible] on dump [illegible] alteration described in [illegible], 1975.
[illegible] mine 2400, 2700 levels	2400' 2700'	Main entrances, [illegible] Mines Limited	1914 by [illegible] Mines Limited, Prod: [illegible] oz. Au [illegible] oz. Ag in [illegible] tons. Workings on 2400, 2550, 2700, [illegible] levels over 1 km of vein		Vein 1-2 m width, dip changes from [illegible] to [illegible] surface [illegible] to bend and disappears W	green intermediate volcanics partly silicified breccias [illegible] rock, possibly [illegible]	[illegible] 27,600 tons, [illegible] Pb: [illegible] Zn [illegible]

Abbreviations: N=north, S=south E=east, W=west; Prod.=Production D.D.=diamond drilling; Sulfide Minerals: py=pyrite gn=galena aspy=arsenopyrite sph=sphalerite tet=tetrahedrite [illegible]=[illegible] (ruby silver) [illegible]=[illegible] (black silver) cp=chalcopyrite; min=mineralization seric=sericite alt=alteration; [illegible] qtz=quartz [illegible]

TABLE B-1

Geological notes and development on major workings, Montana Mountain area

REFERENCES

Archer, Cathro and Associates Ltd., 1972. Northern Cordillera Mineral Inventory. (revised 1982)

Boyle, R. W. 1979. The Geochemistry of Gold and its Deposits, Geol. Surv. Can. Bulletin 280.

Bostock, H. S. 1957. Yukon Territory, Selected Field Reports of the Geological Survey of Canada 1898 to 1933, Geol. Surv. of Can. Memoir 284.

Cairnes, D. D., 1912. Wheaton District, Yukon Territory; Geol. Surv. of Can. Memoir 31.

Debicki, R. L., 1983. Yukon Mineral Industry, 1941 to 1959; Dept. of Indian and Northern Affairs.

Dept. of Indian and Northern Affairs. Yukon Geology and Exploration, 1982.

Gabrielse, H., et al. 1980. Macmillan River, Yukon-District of Mackenzie-Alaska, Sheet 105, 115. Map 1398A; Geol. Surv. of Can.

Geological Survey of Canada. Summary Reports and Report of Activities, 1906 to 1965.

Grapes, K. J., Morin, J. A., 1983. Yukon Mining and Exploration Overview - 1983; D.I.A.N.D.

Lambert, M. B. 1974. The Bennett Lake Cauldron Subsidence Complex, British Columbia and Yukon Territory; Geol. Surv. of Can. Bull. 227.

Macdonald, G. 1983. Initial Report to the Members for Tally-Ho Exploration Co. Ltd.

Monger, J. W. H., 1975. Upper Paleozoic Rocks of the Atlin Terrane, northwestern B. C. and south-central Yukon; Geol. Surv. of Can. Paper 74-47.

Morin, J. A. 1984. Significant Developments and General Mineral Exploration Highlights - Yukon, 1984; D.I.A.N.D.

Morin, J. A., Grapes, K. J., Debicki, R. L., 1982. Yukon Mineral Industry 1982 - an overview, p. 4-17 in Yukon Exploration and Geology, 1982. D.I.A.N.D.

Morrison, G. W., 1979. Metallogenic Map, Whitehorse Map Area, Yukon, 105D. Dept. of Indian and Northern Affairs, Open File, EGS 1979-6.

North American Gold Mining Industry News. Issue April 27, 1984.

Roots, C. F., 1982. Geology of the Montana Mountain area, Yukon. M.Sc. Thesis Carlton University.

Smith, M. J., 1982. The Skukum Volcanic Complex, 105D SW: Geology and Comparison to the Bennett Lake Cauldron Complex, p. 68-72 in Yukon Exploration and Geology, 1982, D.I.A.N.D.

Smith, M. J. 1983. Petrology and Geology of High Level Rhyolite Intrusives of the Skukum area, 105D SW, Yukon Territory, p. 62-73 in Yukon Exploration and Geology, 1981; D.I.A.N.D., 1983.

Roots Thesis

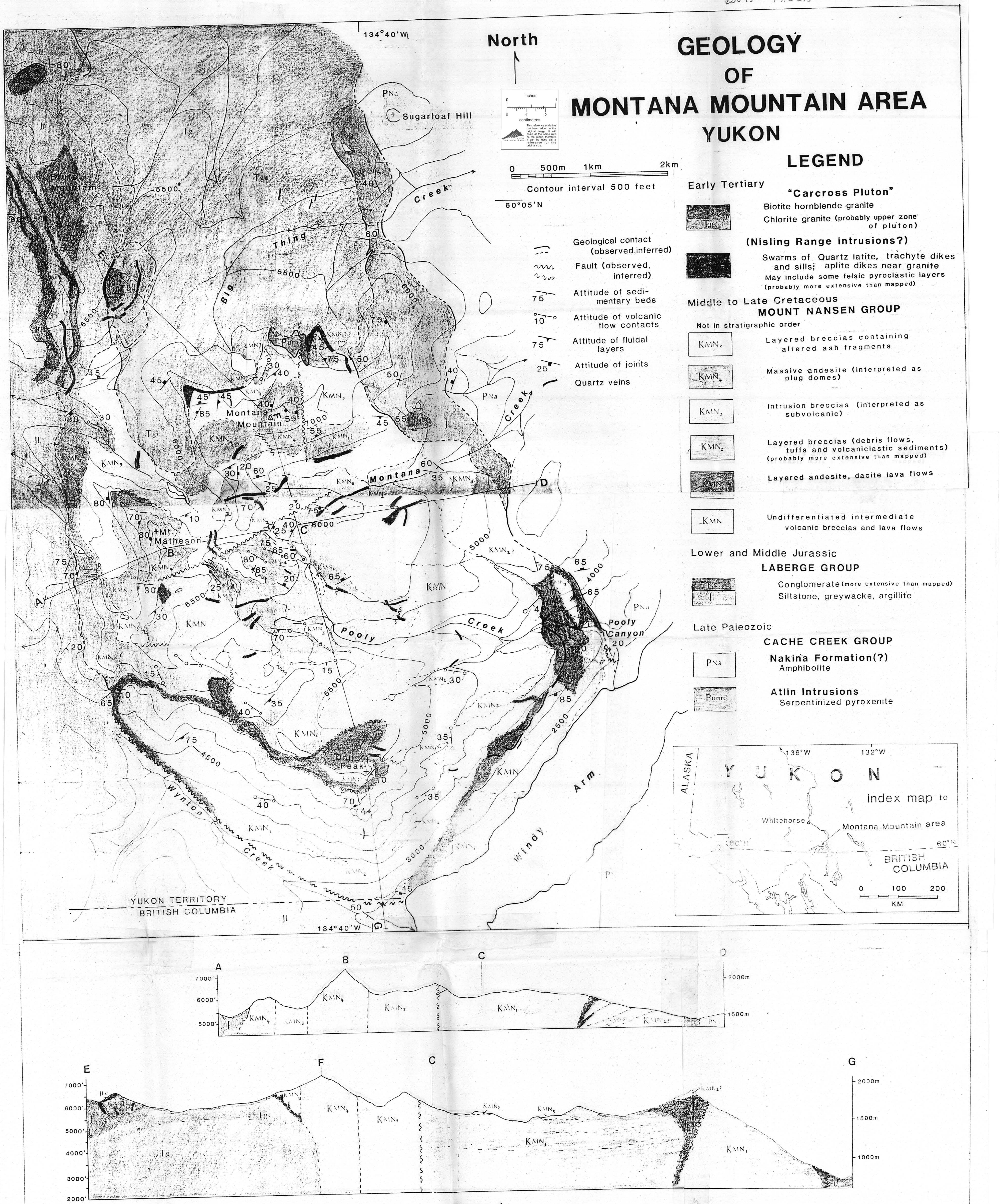


Figure 4