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GEOLOGY OF THE RAINY LAKE-WHITE EAGLE FALLS AREA, DISTRICT OF MACKENZIE: EARLY PROTEROZOIC CAULDRONS, STRATOVOLCANOES AND SUBVOLCANIC PLUTONS

R.S. HILDEBRAND

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Cover

Oblique aerial photograph of east shoreline of Great Bear Lake showing typical outcrop. Most of the visible outcrops are andesite of the LaBine Group. (GSC 204112A)

Critical Reader

M. Schau

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Abstract

The 1.875 Ga LaBine Group and associated plutons outcrop along the western margin of the Great Bear Magmatic Zone at Great Bear Lake. The oldest rocks are mature crossbedded quartz arenite, deposited on the Hottah Terrane. Later, large volumes of pillow basalt, associated breccias and aquagene tuff were erupted, possibly during a period of extension. A period of uplift ensued and subaerial ash-flow eruptions of rhyolite led to collapse of Black Bear Cauldron, in which 2 km of tuff ponded. The cauldron then became the site for fluvial and lacustrine sedimentation followed by augite-plagioclase porphyritic andesitic volcanism. Distinctive quartz monzonite-monzodiorite sheet-like plutons, spatially, temporally, and compositionally related to the andesitic lavas, were emplaced next, and altered their wall rocks to distances >1 km as they cooled by hydrothermal convection. Younger ash-flow eruptions of dacite caused collapse of Clut Cauldron accompanied by landsliding and avalanching of the cauldron walls. Abundant andesitic and intrusive debris is intercalated with the propylitized intracauldron facies tuff adjacent to the walls, and some blocks are as large as 1 km across. Clut Cauldron became the site for fluviolacustrine sedimentation after collapse and was likely resurgent. Resurgence was probably related to the emplacement of a quartz monzonite pluton which occupies the core of the cauldron. Volcanoes of augite and pargasite-bearing andesite developed after collapse and were followed by ash-flow eruptions of dacite-rhyolite which filled paleovalleys.

Résumé

Le groupe de LaBine, daté à 1,875 Ga, et les plutons associés affleurent le long de la marge ouest de la zone magmatique de Great Bear dans la région du Grand Lac de l'Ours. Les roches les plus anciennes sont des arénites quartzeuses matures à stratification entrecroissée qui reposant sur le «Hottah Terrane». Postérieurement, des brèches et des tufs aquagènes associés à de nombreux basaltes en coussins se sont formés, probablement durant une période d'extension. Une période de soulèvement a suivi, et des éruptions subaériennes de cendres rhyolitiques ont amené l'affaissement du chaudron de Black Bear, à l'intérieur duquel s'était deposé 2 km de tuf. Une période de sédimentation fluviatile et lacustre suivie d'un épisode volcanique de type andésite à augite, à plagioclase et à texture porphyritique se sont ensuite produits à l'emplacement du chaudron. Ensuite, des plutons, formant des feuillets de monzonite quartzifère et de monzodiorite reliés dans le temps, l'espace et la composition aux laves andésitiques, ont été mis en place et ont altéré les roches encaissantes sur un rayon de 1 km, lors de leur refroidissement par convection hydrothermale. Des éruptions tardives de cendres dacitiques ont causé l'affaissement du chaudron de Clut, et en ont provoqué l'effondrement des murs. Pouvant atteindre 1 km de diamètre, de nombreux débris andésitiques et intrusifs sont intercalés dans le faciès «intra-chaudron» de tuf «propylitizé» adjacent aux murs. Après l'affaissement, une période de sédimentation fluvio-lacustre résurgente a eu lieu à l'emplacement du chaudron de Clut. La résurgence est probablement liée à l'emplacement d'un pluton de monzonite quartzifère au coeur du chaudron. Des volcans, dont les laves sont du type andésite à augite et à pargasite se sont developpés après l'affaissement et ces dernières ont été suivies par des coulées de cendres dacitiques et rhyolitiques qui ont rempli les paléovallées.

INTRODUCTION

A classic problem in geology concerns the relationship of volcanic rocks to plutonic rocks. On a grand scale, are the giant batholiths of continental arcs related to the volcanic rocks which form their roofs? If so, then what are the compositional and temporal relationships? On a smaller scale, geologists are concerned with the nature of plutons beneath stratovolcanoes and cauldrons (see for example, Thorpe and Francis, 1979; Lipman et al., 1981). Are they, in fact, comagmatic? Do ring complexes, such as those of Peru (Bussell et al., 1976) represent subcauldron plutonic complexes? Many of these problems might be resolved by careful study of older deformed volcano-plutonic terranes.

This paper reports the results of a detailed mapping and petrographic study of parts of the Great Bear Magmatic Zone, an early Proterozoic continental volcanic arc (Hildebrand, 1982) located along the east shore of Great Bear Lake. Rocks of the zone are folded, and sections thousands of metres thick are exposed on individual fold limbs. This, coupled with greater than 60 per cent outcrop, superb lake shore exposures, and only minor weathering since deglaciation, combine to make the area excellent for studying the 3-dimensional make up of a continental volcano-plutonic complex.

Present Investigation

This report summarizes the results of eight months fieldwork in the Camsell River-Conjuror Bay area during the summers of 1978 through 1980 and follow-up petrographic studies. In this report emphasis is placed on the LaBine Group and associated intrusive rocks. Geological mapping of the entire White Eagle Falls (86F/12), Rainy Lake (86E/9) 1:50 000 sheets was done on 1:62 000 scale black and white aerial photographs except for the area of the LaBine Group which was mapped at 1:16 000 on colour aerial photographs or on 1:16 000 enlargements made from the standard 1:62 000 black and white aerial photographs. This work was compiled on 1:50 000 topographic maps.

In general, the terminology used for ash-flow tuffs is that of R.L. Smith (Smith, 1960a, b; Ross and Smith, 1961) and volcanic stratigraphic nomenclature is that of Fisher (1966). Modal analyses of intrusive rocks were estimated in the field and terminology follows that recommended by Streckeisen (1967, 1973). The volcanic rocks have been divided on the basis of their SiO_2 contents as follows:

basalt	< 52% SiO_2
andesite	53-63% SiO_2
dacite	64-70% SiO_2
rhyolite	> 70% SiO_2

This classification agrees reasonably well with that used in the field (Streckeisen, 1967) which suggests that in most rocks there have been only minor changes in SiO_2 contents during alteration. Chemical analyses are not presented here but can be found in Hildebrand (1982).

Previous Work

The earliest geological investigation in the Great Bear Lake area was that of Bell (1901) who first located secondary copper and cobalt minerals in the Echo Bay area.

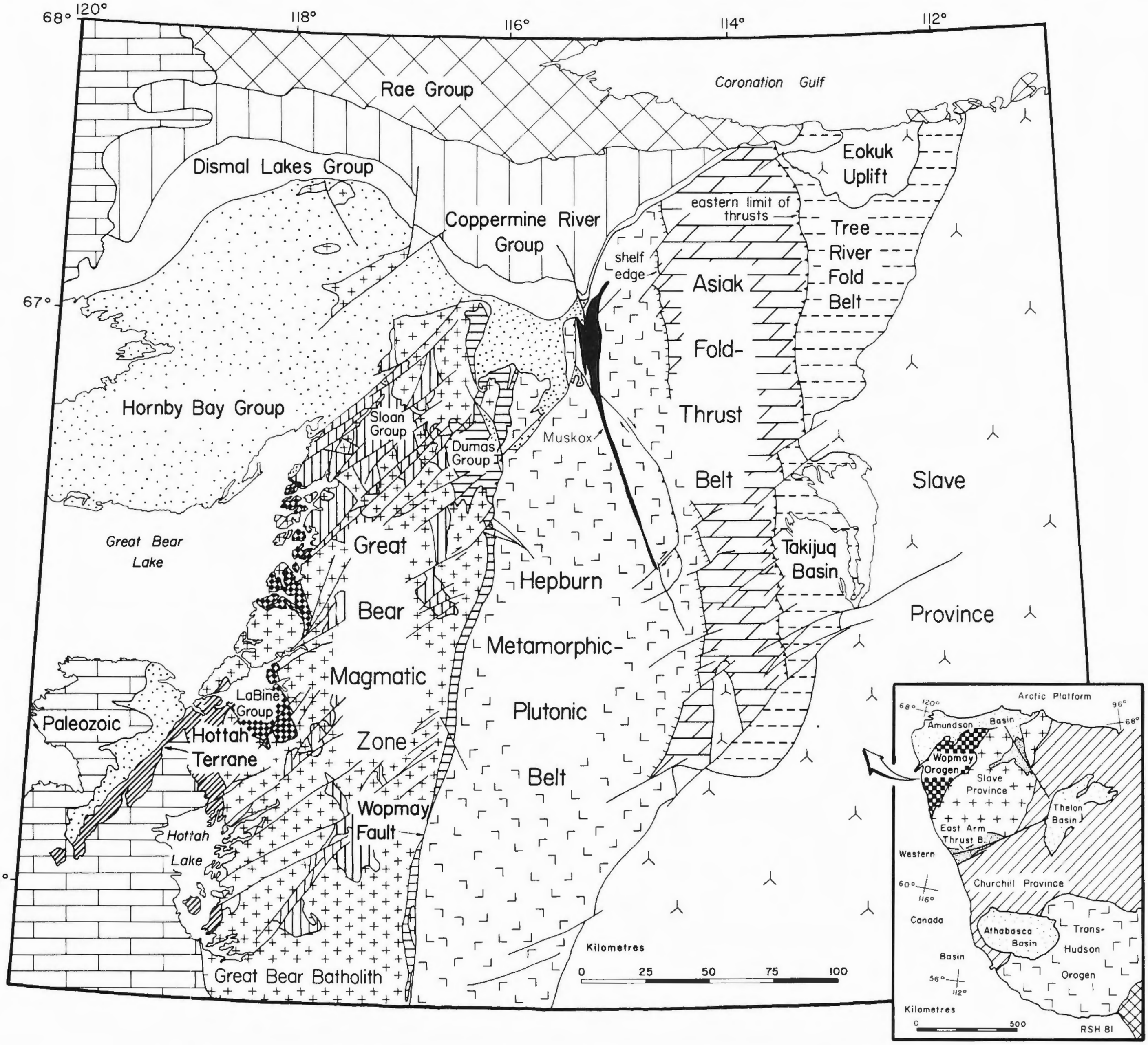

Figure 1. Major tectonic and geological subdivisions of Wopmay Orogen and adjacent area.

However, the geology of the region remained unknown until uranium-silver mineralization was discovered by Gilbert LaBine in 1929. The discovery prompted further geological examination of the region by the Geological Survey of Canada (Kidd, 1932, 1933) and Kidd (1936) subsequently mapped a narrow strip of land from Great Bear Lake to Great Slave Lake in reconnaissance fashion.

No further geological work was carried out in the Camsell River-Conjuror Bay area until the late 1940s when Lord and Parsons (1947) mapped parts of the Calder River sheet (86F). Although the area was intermittently prospected for uranium during the 1950s and 60s it was not until the late 60s when Terra Mining and Exploration Ltd. of Edmonton opened their Silver Bear mine on the south shore of the Camsell River that further scientific studies ensued. This work, done during the 1970s, was mainly concerned with the mineralization (Badham, 1972, 1973b, 1975; Gandhi, 1978; Shegelski, 1973; Shegelski and Scott, 1975; Thorpe, 1974; Withers, 1979) but some maps were made (Shegelski and Murphy, 1973; Padgham et al., 1974).

Hoffman, who was mapping a narrow strip across the northern part of Wopmay Orogen, was the first to propose a subduction-related origin for the entire Great Bear Volcano-Plutonic Belt (Hoffman, 1972, 1973; Fraser et al., 1972). Shortly thereafter, Badham (1973a) reached a similar conclusion based on 18 chemical analyses from rocks in the Camsell River-Conjuror Bay area.

Hoffman and others (1976) and McGlynn (1974, 1975, 1976) mapped the area and were the first to undertake a comprehensive treatment of the regional stratigraphy and structural relationships (Hoffman and McGlynn, 1977). However, the geological space-time relationships, were not known in enough detail to work out the evolution and genesis of the various magmas, so in 1977 I undertook a more detailed mapping project of the LaBine Group as the initial phase of a larger study aimed at understanding the tectonic setting and petrogenesis of the area (Hildebrand, 1981, 1982, 1983a).

Regional Geology

The Labine Group is widely exposed in the western part of Wopmay Orogen (Fig. 1), an early Proterozoic north trending orogen which developed on the western margin of the Archean Slave Craton between 2.1 and 1.8 Ga (Hoffman, 1973, 1980a). The orogen is one of the best-exposed early Proterozoic orogenic belts in the world and it appears to contain many of the features found in Cenozoic orogens. For this reason Hoffman (1973, 1980a) has suggested that plate tectonic models for the Cenozoic Earth are applicable to the early Proterozoic. The orogen can be divided into three major tectonic elements whose boundaries parallel the trend of the belt as a whole. From east to west they are: Asiak Fold and Thrust Belt, Great Bear Magmatic Zone, and the Hottah Terrane (Fig. 1).

Asiak Fold and Thrust Belt is an area 140 km wide where passive continental margin sedimentary (Grotzinger and Hoffman, 1983) and initial rift volcanic rocks (Easton, 1982), along with overlying foredeep deposits of northwesterly provenance, were thrust eastward towards the craton (Tirrul, 1983). In the western part of the belt continental rise-prism rocks were metamorphosed and intruded by numerous syntectonic peraluminous plutons (Hepburn metamorphic-plutonic belt). The plutons form a continuous series in which the oldest are protomylonitic granites and the youngest are relatively undeformed diorites and gabbros (Hoffman et al., 1980; Hoffman and St-Onge, 1981). U-Pb ages of the plutons cluster about 1.885 Ga (Bowring and Van Schmus, 1982).

The Hottah Terrane (Fig. 1) forms the basement for much of the Great Bear Magmatic Zone as it is unconformably overlain by the LaBine Group (Hildebrand, 1982) and locally by the Sloan Group (Bowring, 1982). The terrane comprises deformed and metamorphosed sedimentary and volcanic rocks which are cut by a variety of deformed and undeformed intrusions. Ages of deformed plutons range from 1.948 to 1.90 Ga (Bowring and Van Schmus, 1982; Hildebrand et al., 1983). The supracrustal rocks (Holly Lake metamorphic suite) are of unknown age and provenance. Their metamorphic grade appears to range up to amphibolite facies (McGlynn, 1976; Hildebrand et al., 1983). Hottah Terrane is considered to be a microcontinent, exotic with respect to Asiak Fold and Thrust Belt and Slave Craton, beneath which attempted subduction of the leading edge of the Slave Craton took place (Hildebrand et al., 1983).

The Great Bear Magmatic Zone (Fig. 1) comprises a multitude of gregarious plutons, mostly biotite- and hornblende-bearing, which intrude their own volcanic cover. It is separated from Asiak Fold and Thrust Belt by the poorly understood Wopmay fault zone, but rocks of the Great Bear Magmatic Zone locally overstep the fault zone and lie unconformably on deformed rocks of the fold and thrust belt. Rocks in the extreme western and eastern parts of the magmatic zone unconformably overlie polydeformed and metamorphosed rocks of the Hottah Terrane (Hildebrand, 1981; Bowring, unpublished data; Hildebrand et al., 1983).

All of the non-plutonic rocks in the Great Bear Magmatic Zone were termed the McTavish Supergroup by Hoffman (1978, 1982). The supergroup is divided into three groups separated by unconformities: the LaBine Group, Sloan Group and Dumas Group in ascending order (Hoffman, 1978).

The LaBine Group, which forms the principal subject of this paper, is a diverse aggregation, up to 7 km thick, of siliceous to intermediate lava flows and pyroclastic rocks, plus associated sedimentary rocks (Hoffman and McGlynn, 1977). This group outcrops only along the western margin of the volcano-plutonic belt (Fig. 1) where it unconformably overlies the Hottah Terrane (McGlynn, 1976; Hildebrand, 1981). U-Pb ages of the group fall around 1.87 Ga (Bowring and Van Schmus, 1982).

The stratigraphy of the LaBine Group in the Echo Bay-MacAlpine Channel area was described in detail by Hildebrand (1981). The pertinent points to be extracted from that work are as follows: The oldest rocks are mainly andesitic lavas, breccias, and pyroclastic rocks, at least 3 000 m thick, interpreted to be the remains of a number of large stratovolcanoes. Overlying, and in part interfingering with the stratovolcanoes are seven major ash-flow tuff sheets which are locally intercalated with andesite, dacite, rhyolite flows and domes, and a diverse assemblage of fluvial and lacustrine sedimentary rocks. At least three, and perhaps as many as five, cauldrons have been identified and can be related to specific ash-flow tuff sheets.

The LaBine Group is disconformably overlain by the Sloan Group, which consists mostly of thick sequences of densely welded intermediate ash-flow tuff and intermediate and mafic lava flows (Hoffman and McGlynn, 1977; Bowring, 1982). Outcrops of the Sloan Group are confined to the central portion of the Great Bear Magmatic Zone (Fig. 1). To the east (Figure 1), the Sloan Group is unconformably overlain by the Dumas Group which also unconformably lies on the internal parts of Asiak Fold and Thrust Belt, and is a sequence of mudstone, intermediate to siliceous ash-flow tuff and intermediate to mafic lava flows (Bowring, 1982).

Table 1. Table of Formations

Age / Zone	Group	Complex / Suite	Unit	Member	Lithology
late Proterozoic					
			Gunbarrel Gabbro		coarse grained gabbro
			intrusive contact		
early Proterozoic					
			Cleaver Diabase		altered diabase dykes
			intrusive contact		
GREAT BEAR MAGMATIC ZONE			Hooker Megacrystic Granite		k-feldspar megacrystic granite
GREAT BEAR MAGMATIC ZONE			intrusive contact		
GREAT BEAR MAGMATIC ZONE			Grouard Porphyries		plagioclase-hornblende-quartz-biotite-k-feldspar porphyritic dykes
GREAT BEAR MAGMATIC ZONE			intrusive contact		
GREAT BEAR MAGMATIC ZONE			plagioclase porphyry		
GREAT BEAR MAGMATIC ZONE			intrusive contact		
GREAT BEAR MAGMATIC ZONE			quartz diorite		fine grained quartz diorite
GREAT BEAR MAGMATIC ZONE			intrusive contact		
GREAT BEAR MAGMATIC ZONE			kqp porphyry		k-feldspar -quartz-plagioclase porphyry
GREAT BEAR MAGMATIC ZONE			intrusive contact		
GREAT BEAR MAGMATIC ZONE	LABINE GROUP		"younger ash-flow tuffs"		simple cooling units of dacite rhyolite ash-flow tuff
GREAT BEAR MAGMATIC ZONE	LABINE GROUP		Animal Andesite		andesite lavas and breccias
GREAT BEAR MAGMATIC ZONE	LABINE GROUP		relations uncertain		
GREAT BEAR MAGMATIC ZONE	LABINE GROUP	*CLUT CAULDRON COMPLEX*	Calder Quartz Monzonite		hornblende-biotite quartz monzonite
GREAT BEAR MAGMATIC ZONE	LABINE GROUP	*CLUT CAULDRON COMPLEX*	intrusive contact		
GREAT BEAR MAGMATIC ZONE	LABINE GROUP	*CLUT CAULDRON COMPLEX*	Uranium Point Formation		sandstone, conglomerate, lapilli tuff, mudstone, ashstone
GREAT BEAR MAGMATIC ZONE	LABINE GROUP	*CLUT CAULDRON COMPLEX*	White Eagle Tuff		lithic and crystal-rich dacite ash-flow tuff
GREAT BEAR MAGMATIC ZONE	LABINE GROUP	*CLUT CAULDRON COMPLEX*	White Eagle Tuff	mesobreccia member	breccia
GREAT BEAR MAGMATIC ZONE	LABINE GROUP		unconformity		
GREAT BEAR MAGMATIC ZONE	LABINE GROUP	*"EARLY INTERMEDIATE INTRUSIVE SUITE"*	Balachey Pluton		mainly quartz monzonite
GREAT BEAR MAGMATIC ZONE	LABINE GROUP	*"EARLY INTERMEDIATE INTRUSIVE SUITE"*	Rainy Lake Intrusive Complex		monzodiorite, monzonite, pseudosyenite
GREAT BEAR MAGMATIC ZONE	LABINE GROUP		intrusive contact		
GREAT BEAR MAGMATIC ZONE	LABINE GROUP	*BLACK BEAR CAULDRON COMPLEX*	Camsell River Formation		andesitic lavas, breccias, ash-flow tuff, sandstone, mudstone, conglomerate
GREAT BEAR MAGMATIC ZONE	LABINE GROUP	*BLACK BEAR CAULDRON COMPLEX*	Terra Formation		mudstone, sandstone, limestone, breccia, rhyolite flows, ashstone
GREAT BEAR MAGMATIC ZONE	LABINE GROUP	*BLACK BEAR CAULDRON COMPLEX*	Moose Bay Tuff	ash-flow tuff member	rhyolitic ash-flow tuff, andesite, sandstone
GREAT BEAR MAGMATIC ZONE	LABINE GROUP	*BLACK BEAR CAULDRON COMPLEX*	Moose Bay Tuff	lower member	sandstone,mudstone, breccia, andesite, limy argillite
GREAT BEAR MAGMATIC ZONE	LABINE GROUP		unconformity		
GREAT BEAR MAGMATIC ZONE	LABINE GROUP		unnamed sills		gabbro, diabase,
GREAT BEAR MAGMATIC ZONE	LABINE GROUP		intrusive contact		
GREAT BEAR MAGMATIC ZONE	LABINE GROUP		unnamed dykes		plagioclase, quartz, k-feldspar porphyritic dykes
GREAT BEAR MAGMATIC ZONE	LABINE GROUP		intrusive contact		
GREAT BEAR MAGMATIC ZONE	LABINE GROUP		Bloom Basalt		pillow basalt, breccia, tuff,dolomite
GREAT BEAR MAGMATIC ZONE	LABINE GROUP		Conjuror Bay Formation	upper member	mudstone, ashflow tuff, breccia
GREAT BEAR MAGMATIC ZONE	LABINE GROUP		Conjuror Bay Formation	lower member	quartz arenite
			unconformity		
HOTTAH TERRANE			unnamed granitoid intrusions		deformed diorite, granodiorite, quartz monzonite
HOTTAH TERRANE			Holly Lake metamorphic suite		deformed metasedimentary rocks

Plutonic rocks of the Great Bear Magmatic Zone are mainly hornblende- and biotite-bearing. They have been roughly divided into four age suites (G1-G4: Hoffman and McGlynn, 1977; Hoffman, 1978), each with similar compositions. The oldest are sheets and laccoliths of quartz diorite, quartz monzonite, monzonite, and monzodiorite (G1) here informally termed the "early intermediate intrusive suite." They intrude piles of andesite occurring in the LaBine Group. These plutons were generally followed by emplacement of dome-shaped biotite-hornblende quartz monzonite and granodiorite plutons (G2), some of which can be shown to occupy the cores of cauldrons (Hildebrand, 1981). Large discordant biotite granites (G3), without known extrusive equivalents, were intruded after eruption of the Dumas Group and after the belt was folded. The final plutons to be emplaced were a suite of small, ovoid tonalite to diorite bodies (G4), found sporadically throughout eastern parts of the zone. U-Pb zircon ages in the belt range from 1.876 Ga to 1.84 (Van Schmus and Bowring, 1980; Bowring and Van Schmus, 1982).

The entire Great Bear Magmatic Zone, except the G3 and G4 plutons, is folded about shallowly plunging axes which trend northwest except near the extreme eastern and western margins of the belt where they trend north (Hoffman and McGlynn, 1977). The folds appear en echelon which led Hoffman (1980a) and Hildebrand (1981) to suggest that they are the product of oblique convergence.

The folds, and even the youngest plutons (G4) of the magmatic zone, are cut be a swarm of northeast trending transcurrent faults (used in the sense of Freund, 1974). Most of these faults are steeply dipping and have right-lateral separation in the order of kilometres. They are part of a larger set of conjugate transcurrent faults found throughout Wopmay Orogen (Hoffman, 1980b). Freund (1970, 1974) has shown that in regions undergoing transcurrent faulting, each fault plane rotates about a vertical axis away from the axes of principal compressive stress. In the Great Bear Magmatic Zone such rotations are counter-clockwise. Thus, as pointed out by Hoffman (1980b), all studies of directional properties such as paleomagnetism or paleocurrent studies, as well as all pre-fault reconstructions, require a clockwise correction.

Acknowledgments

It is a pleasure to thank P.F. Hoffman, for suggesting this study and helping to see it through to completion. Assistance in the field was provided by Karen S. Pelletier and Bradford J. Johnson in both 1979 and 1980, Tracy Cooke and Lisa Campbell during 1979, and Joseph Conway and X.Y. Zhang in 1980.

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GENERAL GEOLOGY

The geology of the area is complex and varied, resulting from a history of volcanism, plutonism along with related hydrothermal alteration, and sedimentation followed by folding and transcurrent faulting. Geographic names used in this paper are shown in Figure 2 (in pocket), which is a geological sketch map showing the major lithostratigraphic units of the area. The geological maps upon which this figure is based are available as Geological Survey of Canada Open File 930 (Hildebrand, 1983b) and will be published in colour as Geological Survey of Canada Map A1589 (Hildebrand, in press). A table of formations is shown in Table 1.

Hottah Terrane

Holly Lake metamorphic suite

The oldest rocks of the study area are deformed and metamorphosed (greenschist to amphibolite) sedimentary rocks of the Holly Lake metamorphic suite. The term Holly Lake metamorphic suite is an informal one proposed by Hildebrand (1981) to include all nongranitoid rocks of the Hottah Terrane. In the map area the Holly Lake metamorphic suite is exposed only in the Conjuror Bay area and at Fishtrap Lake.

Rocks of the Holly Lake metamorphic suite near Fishtrap Lake are composed of layers, 0.5 mm-2 cm thick, of partially pinnitized cordierite porphyroblasts and biotite, alternating with bands of quartz and biotite. The layering is openly folded about nearly vertical axes but local crosscutting quartz veins and microveins are ptygmatically folded.

In the Conjuror Bay area rocks of the Holly Lake metamorphic suite are biotite grade psammite and semipelite. They typically have a steeply dipping NNE-SSW cleavage and are tightly folded about shallowly plunging axes which trend nearly north. Locally the cleavage is spaced several centimetres apart and is therefore probably of pressure solution origin (Beach, 1979). In places the spaced cleavage is kinked.

Myriads of quartz veins (25 cm wide) form en echelon groups that parallel the nearly vertical axial planes of the folds (Figure 3), while numerous smaller veins (1-2 cm) are oriented either parallel to bedding or randomly. In most places the small veins are folded (Figure 4) and/or broken by faults. On the mainland south of Conjuror Bay shear zones up to 20 m wide and striking NNE are cut by metre-wide quartz veins that trend parallel to the shear zones.

On Bloom Island the rocks are not intensely sheared, and abundant sedimentary structures such as ripple laminations, load features and graded bedding are preserved (Figure 5). Thickness of beds ranges from thin laminations to 30 cm, and individual beds are generally continuous over outcrop lengths of 20 or 30 m.

Intrusions

Metasedimentary rocks of the Holly Lake metamorphic suite south of the map area were intruded, prior to deformation, by quartz diorite-quartz monzonite-granite plutons. Remnants of the plutons occur south of Hloo Channel, on Richardson Island, on islands in western Conjuror Bay, and in the Fishtrap Lake area (Figure 2). They are variably foliated and commonly contain aligned potassium feldspar megacrysts and enclaves of country rock (Fig. 6). In several places potassium feldspar megacrysts cut across aplite dyke margins and are also commonly found in enclaves and xenoliths within the plutons. These relations suggest a subsolidus metasomatic origin for the megacrysts (Pitcher and Berger, 1972). A U-Pb zircon age of 1.902 Ga was obtained from a granitoid, similar in texture, composition, and deformation to the above, southwest of the map area (Hildebrand et al., 1983).

In most places the fabric of the deformed granitoids is abruptly truncated by nonfoliated granitoid plutons of the Great Bear Magmatic Zone. For example, on Richardson Island foliated granitoid forms the roof for two younger

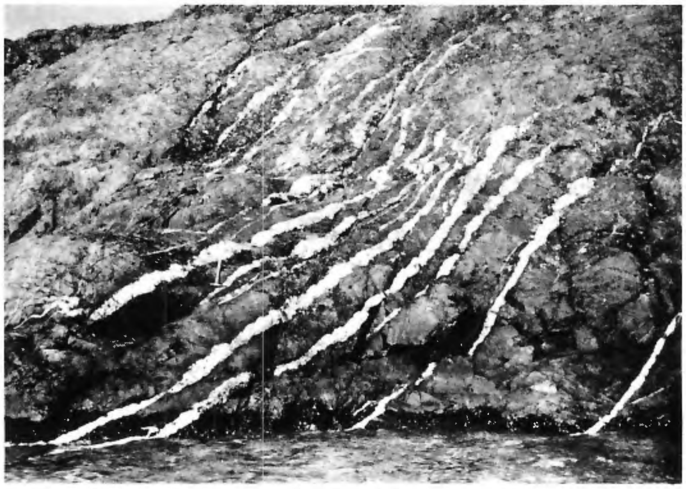

Figure 3. *En echelon quartz veins cutting folded metasedimentary rocks of the Holly Lake metamorphic suite, southern Bloom Island. (GSC 190563)*

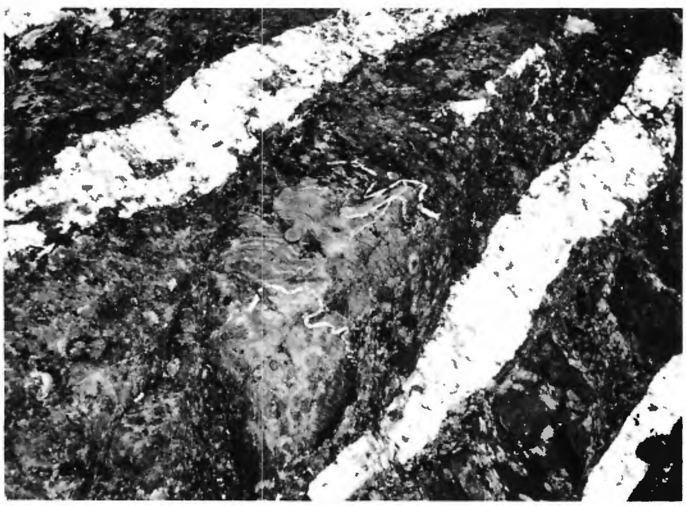

Figure 4. *Detail of Figure 3 showing folded quartz veins. Coin is 2 cm diameter. (GSC 190562)*

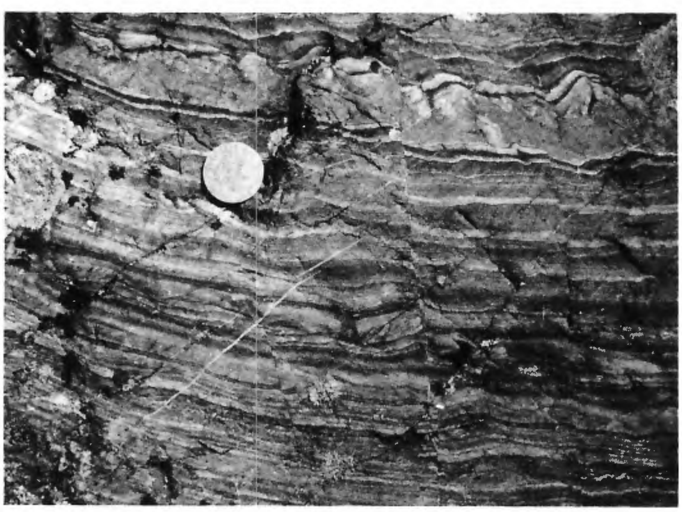

Figure 5. *Deformed metasediments showing well preserved sedimentary structures, Holly Lake metamorphic suite. South end of Bloom Island. Coin is 2 cm diameter. (GSC 190566)*

Figure 6. *Enclaves of metavolcanics in granitoid rocks of the Hottah Terrane, south side of Hloo Channel. Pen in the top centre for scale. Pen used for scale in this, and subsequent photos, is 15 cm long. (GSC 190561)*

Figure 7. *Unconformity between Hottah Terrane and Conjuror Bay Formation, small island south of Cobalt Island. Tree in left centre is 3 m high. (GSC 190559)*

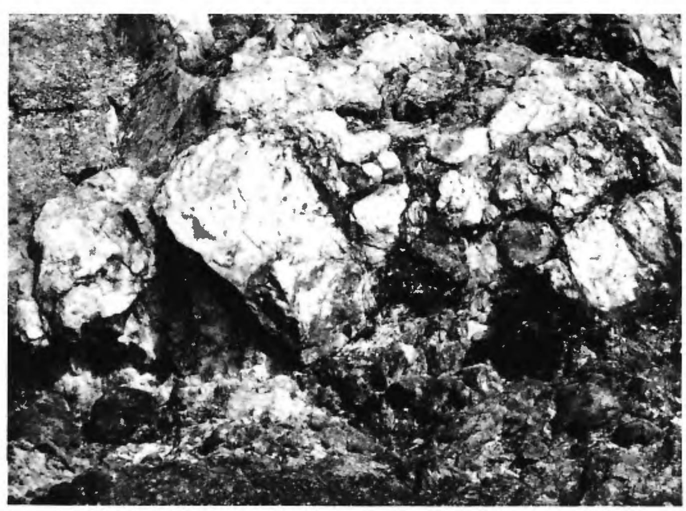

Figure 8. *Detail of possible solution breccia at base of Conjuror Bay Formation; location as in Figure 7. (GSC 190557)*

undeformed plutons (Figure 2). The youngest known rocks of the Hottah Terrane appear to be gabbro and diabase. These intrusive bodies, which are foliated, occur as boudins in the most deformed granitoids and as dykes in the lesser deformed granitoids. A complete gradation exists between the two. Therefore they postdate emplacement of the Hottah Terrane granitoid rocks and predate the latest penetrative deformation.

LaBine Group

Conjuror Bay Formation

Unconformably overlying the Hottah Terrane in the Conjuror Bay area is a complex succession of sedimentary and pyroclastic rocks about 150 m thick, here termed the Conjuror Bay Formation. The formation is conformably overlain by several kilometres of basaltic lavas and breccia of the Bloom Basalt.

The Conjuror Bay Formation is exposed on several islands in Conjuror Bay, on the mainland east of Tla Bay, and south of Rainy Lake (Fig. 2). The best exposures and most complete sections occur on the islands in Conjuror Bay and east of the bay but there is nowhere a completely exposed section. The section exposed on Bloom Island, however, is nearly complete with only the unconformity and basal few metres of section inferred.

The formation is divided into two members: a lower member of mature crossbedded quartz arenite and an upper member comprising concretionary mudstone, ashstone, lapilli tuff, sandstone, conglomerate, and breccia.

Basal Unconformity

The unconformity between the Holly Lake metamorphic suite and the Conjuror Bay Formation is well exposed on the small island south of Cobalt Island and less well exposed, due to younger intrusions and Quaternary cover, on the mainland south of Conjuror Bay (Fig. 1). On Bloom Island the unconformity is not actually exposed but sedimentary rocks of the Conjuror Bay Formation are separated from the Hottah Terrane by a valley 20 m wide.

On the small island south of Cobalt Island vertically dipping and foliated metasedimentary rocks of the Hottah Terrane are overlain by gently northward-dipping quartz arenite (Fig. 8). There is about 20 m of relief on the unconformity at this locality and rounded hills of Hottah Terrane appear to be preserved beneath the quartz arenite.

A peculiar feature found above the unconformity is a breccia 3 to 4 m thick consisting of semirounded, phacoidal blocks of the overlying quartz arenite with ferrodolomite void filling and replacement (Fig. 9). The breccia grades upwards into unbrecciated quartz arenite. At the margins of the fragments are darkened zones of unknown composition. Locally within the breccia anomalous uranium values are encountered (S.S. Gandhi, personal communication, 1980). The breccia is interpreted to be a solution feature which developed when water percolated along the unconformity. The darkened zones rimming fragments may be insoluble residues.

Lower Member

The lower quartz arenite member of the Conjuror Bay Formation is generally well bedded (4 cm to 1 m), medium- to fine-grained, and trough crossbedded with laminations rich in heavy minerals (Fig. 10). Paleocurrents indicate south-southwest transport. In some areas herringbone crossbedding occurs (Fig. 10), but outcrops are not sufficient to determine whether or not crossbedding is bipolar. Coarse sand lenses are locally present and contain dolomite concretions.

Near the top of the sandstone are lenses of vein-quartz pebble conglomerate (Fig. 11) up to 4 m thick with irregular, probably scoured, basal contacts and sharp planar upper contacts. Pebbles are clast supported with minor mudstone matrix. Clasts contained within the lenses are dominantly rounded to subrounded vein quartz pebbles along with minor subangular to angular clasts of mudstone, quartz arenite, quartzite granulestone, and rounded vesicular basalt cobbles.

Upper Member

Conformably overlying the lower member is an assemblage, of variable thickness, from 40 to 100 m, comprising intercalated fine sandstone, basaltic ashstone, siltstone, concretionary mudstone, chert, lapilli tuff, conglomerate and breccia. The thickest preserved sections are east of Tla Bay and the unit thins rapidly to about 40 m on the islands in Conjuror Bay.

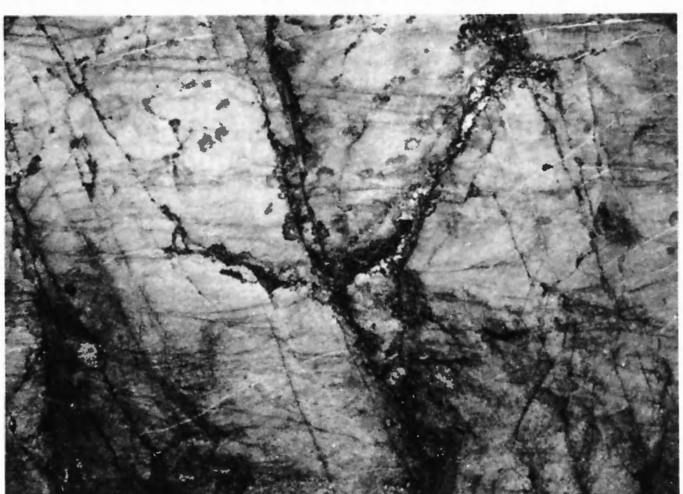

Figure 9. *Crossbedded quartz arenite, Conjuror Bay Formation, southeast side of Bloom Island. Pen in top centre for scale. (GSC 190555)*

Figure 10. *Herringbone crossbedding, Conjuror Bay Formation, south side Conjuror Bay. (GSC 190554)*

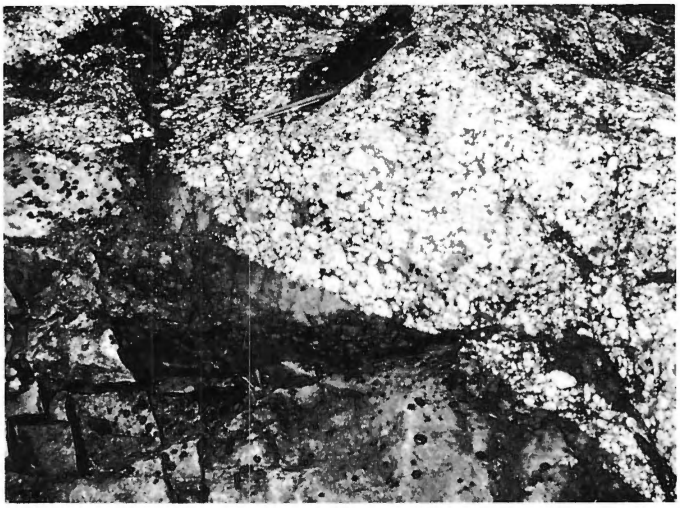

Figure 11. *Quartz-pebble conglomerate in upper part of Conjuror Bay Formation, southeast Bloom Island. (GSC 190553)*

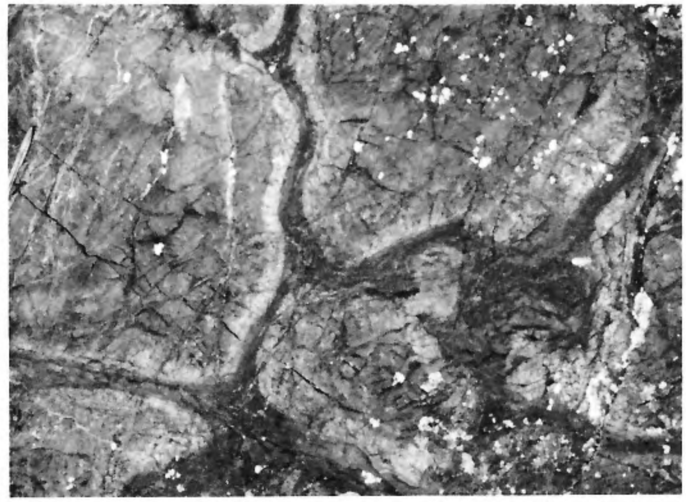

Figure 12. *Altered pillow basalts, Bloom Basalt, Bloom Island. (GSC 190539)*

Bedding ranges from fine laminations to about 1 m thick and is generally planar. However, some low-angle crossbedding, load features, and scoured channels are present in the sedimentary rocks.

Many tuffaceous units only 4 to 10 cm thick, contain abundant flattened fragments of siliceous pumice, devitrified shards, and about 20 per cent broken phenocrysts of plagioclase. They do not appear to be welded and therefore flattening of the pumice is attributed to compaction.

Sandstones of this member are typically immature pebbly arkoses containing a variety of volcanic and sedimentary fragments. They are commonly crossbedded or graded and are generally less than 1 m thick. Clast-supported polymictic conglomerates, containing mostly volcanic and plutonic clasts of unknown provenance, often appear to fill channels and are sometimes graded.

Interpretation

The uniform lithology, substantial thickness (150 m), sedimentary structures, and mineralogically mature nature of the formation suggest that deposition was subaqueous. The presence of herringbone crossbedding suggests tidal dominance and therefore relatively shallow marine water. Thus, the formation is interpreted as marginal marine.

Bloom Basalt

Two to three kilometres of pillow basalt, associated breccia and aquagene tuff, along with intercalated oolitic and stromatolitic dolomite are exposed in the Conjuror Bay area (Fig. 2). It is here named Bloom Basalt after its exposures on Bloom Island.

The contact with the underlying Conjuror Bay Formation is placed at the base of the lowest lava flow. The original top of the formation is not exposed in the mapped area. However, the formation is overlain along an angular unconformity by Moose Bay Tuff and in a few places by the "younger ash-flow tuffs." Bloom Basalt occupies a similar stratigraphic position as pillow basalts found at Hottah Lake, and the two units were correlated by Hoffman and McGlynn (1977).

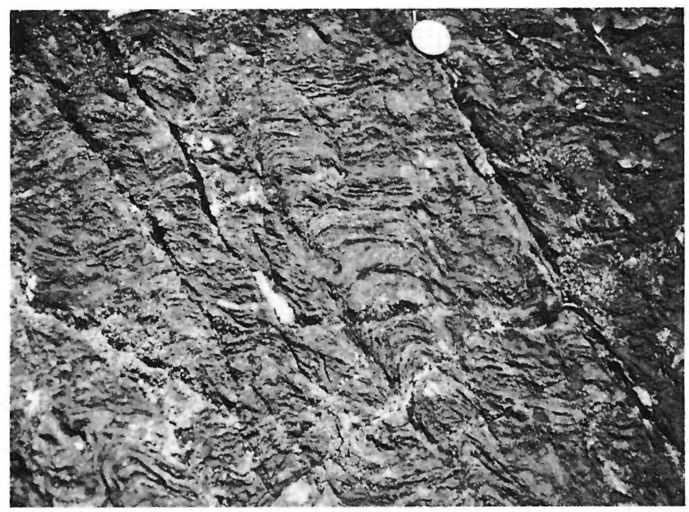

Figure 13. *Stromatolitic dolomite of Bloom Basalt, east side of Bloom Island. (GSC 190551)*

The formation is dominantly composed of pillow lavas. The pillows range in size from 0.3 to 3 m across. Most have well developed vesicular selvages and contain abundant chlorite-carbonate amygdules in their central parts. Amygdules are commonly concentrated near the tops of the pillows. All the pillows are intensely altered and carbonate-epidote-chlorite veins and replacement are ubiquitous (Fig. 12). For this reason no samples were analyzed for chemical composition but similar, less altered rocks from the Hottah Lake area, in a similar stratigraphic position, were analyzed by Wilson (1979) and are iron-rich, low titanium basalts. By analogy the pillow lavas in the Conjuror Bay area may be of similar composition.

In thin section the pillow lavas contain completely saussuritized plagioclase microphenocrysts up to 1 mm long in an altered groundmass of epidote, chlorite, carbonate, tremolite-actinolite, sphene, and opaque Fe-Ti oxides. Much of the tremolite-actinolite appears to replace original pyroxene. The texture is best described as intersertal.

Lenses of pillow breccia are locally present in the formation. They comprise variably sized pillow fragments in a fragmental mafic matrix. Sparse aquagene tuff also occurs as lenses in the pillow basalt piles but these were not studied in detail due to the intense alteration and consequent obliteration of all original mineralogy and most textures.

Oolitic and stromatolitic dolomite (Fig. 13), up to 30 m thick, occurs locally in the formation. The best exposures are on Cobalt Island where the dolomite unit consists of crossbedded and rippled oolitic grainstone overlain by the distinctive branching stromatolite **Jacutophyton** (identification by P.F. Hoffman, 1981).

Interpretation

The thick sections of pillow basalt and associated pillow breccia in the Bloom Basalt indicate deposition under water. The presence of intercalated **Jacutophyton**-bearing and oolitic dolomite, most easily interpreted as patch reefs, suggests that the environment was shallow marine as **Jacutophyton** is known only from environments interpreted to be marine. The common occurrence of the stromatolite **Jacutophyton** stratigraphically above the oolitic dolomite indicates a slight deepening of water depth with time (Hoffman, 1976).

Because Bloom Basalt is over 2 km thick in the Conjuror Bay area and absent in sections south of Rainy Lake, there may have been a period of normal faulting during eruption of the basalt. This would explain the presence of Conjuror Bay Formation and lack of Bloom Basalt in the eastern section. Another possibility may be uplift and erosion after eruption of Bloom Basalt. This would require considerable uplift, perhaps several kilometres. As the overlying Moose Bay Tuff is interpreted to be subaerial this is certainly a good possibility, but there is no stratigraphic record of considerable erosion (i.e., conglomerates, talus) preserved.

Porphyritic Dykes and Sills

Quartz-feldspar porphyritic dykes and sills intrude the Holly Lake metamorphic suite, Conjuror Bay Formation, and Bloom Basalt but are themselves cut by mafic sills that lie unconformably beneath Moose Bay Tuff. Therefore, the porphyries were emplaced prior to the eruption and deposition of the Moose Bay Tuff.

The porphyritic intrusions are common on the mainland south of Conjuror Bay where most form sills intruded into intensely sheared rocks of the Holly Lake metamorphic suite. The sills are not sheared. A few intrusions occur on the islands in Conjuror Bay. There they form dykes up to 10 m across.

The intrusions are spectacularly porphyritic with centimetre-size phenocrysts of cryptoperthite, plagioclase, and quartz in a fleshy red or grey aphanitic matrix. The relative proportions of the various phenocrystic phases varies from body to body but K-feldspar always constitutes the majority.

Tabular plagioclase crystals, up to 1 cm long, are generally saussuritized but some are replaced by chessboard albite. Locally they form glomeroporphyritic clots. Cryptoperthite after sanidine, commonly occurring as Carlsbad twins, range in size up to 2 cm long. In some of the intrusions they are not only tabular but may also be ovoid to rounded. Some of the perthites are charged with inclusions which are found to be axiolitic intergrowths of plagioclase, quartz, chlorite, and carbonate. Quartz (4 mm) mostly occurs as bipyramids, rounded and embayed by resorption, but in a few dykes clots of quartz up to 1 cm across occur. Less than 1 per cent partially chloritized biotite occurs as small (<2 mm) flakes, while original pyroxenes (<4 per cent), now replaced by chlorites, opaques, and uralitic amphibole, form prisms up to 3 mm long. Less than 1 per cent accessory zircon and apatite also occur. The matrix is a microfelsitic intergrowth of quartz and feldspar, commonly dusted with hematite.

Mafic Sills

Rocks included in this section comprise mafic sills, up to 70 m thick, that intrude the porphyries and older units but are unconformably overlain by Moose Bay Tuff on islands in Conjuror Bay. There are two basic varieties: fine grained diabase without phenocrysts, and diabase with glomeroporphyritic plagioclase clots up to 2 cm across (Fig. 14).

In thin section they are holocrystalline with subophitic texture comprising slender saussuritized plagioclase laths in a matrix of subhedral uralitized pyroxene and skeletal grains of opaque oxides. Where present, the large plagioclase phenocrysts are rounded, intensely fractured, and completely saussuritized.

Moose Bay Tuff

This formation comprises a sequence, in ascending order, of sedimentary rocks, andesite, and densely welded, lithic-rich rhyolite ash-flow tuff intercalated with minor intermediate lavas, tuffs and arkosic sandstone. The units beneath the ash flow tuff are here designated as the lower member, while the overlying ash-flows and intercalated rocks are termed the ash-flow tuff member. The Moose Bay Tuff is named for its excellent exposures around Moose Bay where it attains its maximum exposed thickness of nearly 3 km.

Exposures of the Moose Bay Tuff occur in a broad, broken band on the southwest side of Norex syncline from 5 km south of Terra Ridge to the large point which juts out into Conjuror Bay west of the mouth of the Camsell River (Fig. 2). A few scattered exposures occur on islands in Conjuror Bay.

Relationships with older rocks at the base of the lower member are unknown because the unit is everywhere intruded by younger rocks. West of the Camsell River the lower member is absent and the ash-flow tuff member is inferred to lie unconformably on Bloom Basalt but the contact is obscured by a distinctive K-feldspar-quartz-plagioclase porphyry. The upper or ash-flow tuff member, unconformably overlies Bloom Basalt and the mafic sills on islands in Conjuror Bay and the unconformity is well-exposed on the northeast side of Cobalt Island and on the east side of the island to the south. South and east of the Gunbarrel Gabbro the ash-flow tuff member is overlain by the Terra Formation but the contact is never seen due to younger intrusions. To the west the tuff is overlain by White Eagle Tuff.

Lower Member

The lower member contains a sequence of sedimentary rocks, minor dacite ash-flow tuff, and at least one andesitic lava flow which underlies the upper ash-flow tuff member of the Moose Bay Tuff. The lower 40 m of the unit consists of interbedded sandstone, siltstone, and ashstone. Beds of mudstone and siltstone are generally 1-10 cm thick and ashstone beds are typically between 5 and 10 cm in thickness. Sandstones are mostly well bedded wackes comprising angular to subrounded sand grains in a silty or muddy matrix. They commonly contain abundant mudchips.

South of Moose Bay the sedimentary rocks interfinger with polymictic breccias containing angular to rounded fragments ranging from sand size to 30 m or more, across.

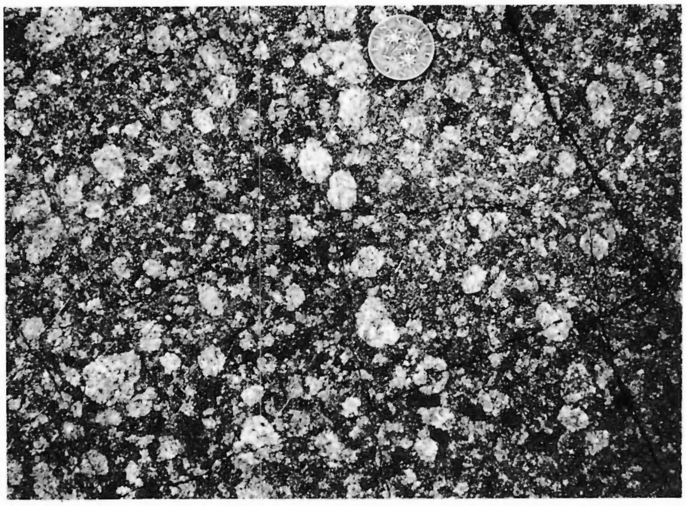

Figure 14. *Plagioclase glomeroporphyritic sill. (GSC 190570)*

Figure 15. *Lithic-rich densely-welded rhyolite ash-flow tuff of ash-flow tuff member, Moose Bay Tuff north of Moose Bay. Note abundant, small, flattened pumice fragments. (GSC 190521)*

Clast lithologies include rhyolitic ash-flow tuff and porphyries, andesite, ashstone, mudstone, siltstone and sandstone. At some localities the breccia is matrix supported while elsewhere there is a paucity of matrix so that the breccia is clast supported. Some of the larger blocks are themselves intensely brecciated. The matrix is typically a greenish, strongly altered, siliceous ashstone which in places contains fragments identical to the fine grained matrix.

The breccia normally passes up into arkosic sandstone similar to stratigraphically lower sandstones, but in one fault block south of Moose Bay it is overlain by a calcareous ashstone, that is in part brecciated and in part folded, containing occasional large blocks (2-5 m) of silicified sediment. Overlying the ashstone is 10 m of white weathering, green, siliceous ashstone which in turn is capped by several metres of finely laminated red and purple concretionary mudstone with a corrugated appearance on weathered surfaces.

Above the sandstone, in most other sections north of Black Bear Lake, there is a plagioclase porphyritic andesitic lava flow, about 20 m thick, with quartz-filled amygdules about 5 mm across and well developed trachytic texture. The flow weathers red and grey, and is platy jointed in its lower parts.

In exposures on the peninsula which juts out from the northwest side of Black Bear Lake the flow is overlain by 20 m of massive pebbly sandstone. Clasts are subrounded to rounded and consist of chert, mudstone, rhyolite and orthoquartzite.

Ash-flow Tuff Member

The predominant lithology of the ash-flow tuff member of the Moose Bay Tuff is densely welded, lithic-rich, rhyolite ash-flow tuff which reaches a maximum thickness of nearly 1.5 km. Generally, the ash flows were deposited so quickly that they welded together without visible partings. However, north of Moose Bay the tuff shows characteristics of compound cooling such as interfingering relationships with sandstone and intermediate-mafic extrusive rocks.

The tuff directly overlies Bloom Basalt northwest of a transcurrent fault that passes from the west side of Moose Bay out into Conjuror Bay (Fig. 2) and it thins rapidly until it pinches out at the mainland point south of Cobalt Island. East of the fault the upper part of the tuff is intercalated with 0.5 km of intermediate lava flows, breccia, and lapilli tuff which thin rapidly to the east, so that they are not present in sections east and south of the Camsell River. Beneath the lavas are a few hundred metres of interbedded airfall tuff, ash-flow tuff, and sandstone. The sandstones are very similar in composition to the ash-flow tuff and are therefore considered to be its reworked arkosic equivalents.

Large blocks of dacite welded tuff occur at the base of the member south of Black Bear Lake. The blocks are up to 15 m across and have no preferred orientation.

Lithic fragments in the tuff are abundant, locally making up to 50 per cent of the rock. They are generally porphyritic siliceous volcanic rocks, but fragments of metamorphic rock are also common. In stratigraphically higher parts of the tuff most lithic fragments are pebble to granule size. Their average size increases downsection with cobbles becoming more abundant.

The upper parts of the tuff are characterized by small (<2 cm) flattened pumice fragments, often green to black (Fig. 15). In stratigraphically lower parts of the tuff they are not commonly preserved due to propylitic alteration and recrystallization.

The upper kilometre of the tuff weathers red to flesh whereas the lower parts weather shades of white and green due to more intense alteration and silicification. Quartz veining is common in the areas where the tuff weathers white.

In thin section the ash-flow tuff is seen to contain 4-10 per cent broken and embayed quartz phenocrysts (to 3 mm) along with 10-15 per cent shattered 1-2 mm phenocrysts of turbid microperthite, probably after sanidine, and tiny anhedral flakes of chloritized biotite in an ultrafine-grained groundmass of quartz, feldspar, and sericite.

Interpretation

The tremendous thickness of the Moose Bay Tuff indicates that the tuff ponded in a topographic depression. The dramatic thickness change of the tuff across the transcurrent fault which passes along the western side of Moose Bay suggests that the depression was fault-bounded on the west. The disparity in thickness of the tuff across the fault, and the presence of coarse breccias in the lower member just southeast of the fault, suggest that it was active just prior to, and during, eruption of the ash-flow tuff member. This interpretation implies that the fault, as a zone of weakness, was later reactivated during transcurrent faulting, because the fault presently separates stratigraphic units younger than the Moose Bay Tuff.

Restored stratigraphic and structural relations such as the above are typical of those found in Cenozoic calderas (Steven and Lipman, 1973, 1976; Lambert, 1974; Lipman, 1975; Bailey et al., 1976; Bailey and Koeppen, 1977; Smith et al., 1970; Byers et al., 1976; Seager, 1973; Elston et al., 1976). Therefore, the possible synvolcanic fault may have been the main ring fault along which subsidence of the central block of a cauldron took place. The rapid thinning and pinchout of the tuff along the unconformity with the Bloom Basalt is a type of buttress unconformity which could represent the original topographic wall of a cauldron, created as material collapsed from the oversteepened cauldron wall, itself generated by subsidence along the ring fracture zone.

If the above interpretations are correct than all exposures of the Moose Bay Tuff are intracauldron deposits. The postulated cauldron is here named the Black Bear Cauldron after Black Bear Lake.

The trace of the eroded topographic margin appears to pass into Conjuror Bay and is found on Cobalt Island, the island south of Cobalt Island, and on Bloom Island (Fig. 16). In those exposures both the ash-flow tuff member and "younger ash-flow tuffs" lie unconformably on Bloom Basalt.

The topographic margin was intruded by a distinctive potassium feldspar-quartz-plagioclase porphyry ("kap" porphyry) which also can be traced through the islands of Conjuror Bay. While the porphyry may appear to be a type of ring pluton it is considered to be unrelated to Black Bear Cauldron as it intrudes the "younger ash-flow tuffs" and is therefore much younger than the Moose Bay Tuff.

The small normal and reverse faults south of Moose Bay are possibly related to differential subsidence of the central block. Because the proposed ring fracture dips slightly inward the faults probably developed as the central block collapsed. It is interesting that at least one of the fault blocks (Fig. 2) appears to have remained as a high during the subsidence. This suggests that one mechanism for decreasing the size of the central block, so that it is able to subside along a ring fault whose radius is decreasing downward, might be to leave large slivers remaining in the cauldron fill deposits.

Terra Formation

The Terra Formation, as defined here, comprises up to 200 m of sedimentary and volcanic rocks which lie between the Moose Bay Tuff and the first overlying intermediate lava flow (Camsell River Formation). It is exposed only on the southwest limb of Norex syncline from Clut Lake to Conjuror Bay (Fig. 2) and is named for exposures on Terra Ridge. The formation pinches out abruptly at the proposed cauldron margin fault of Black Bear Cauldron.

There are no complete sections of the formation because it is a locus for intrusions. Most exposures form the roof of the Rainy Lake Intrusive Complex and so are

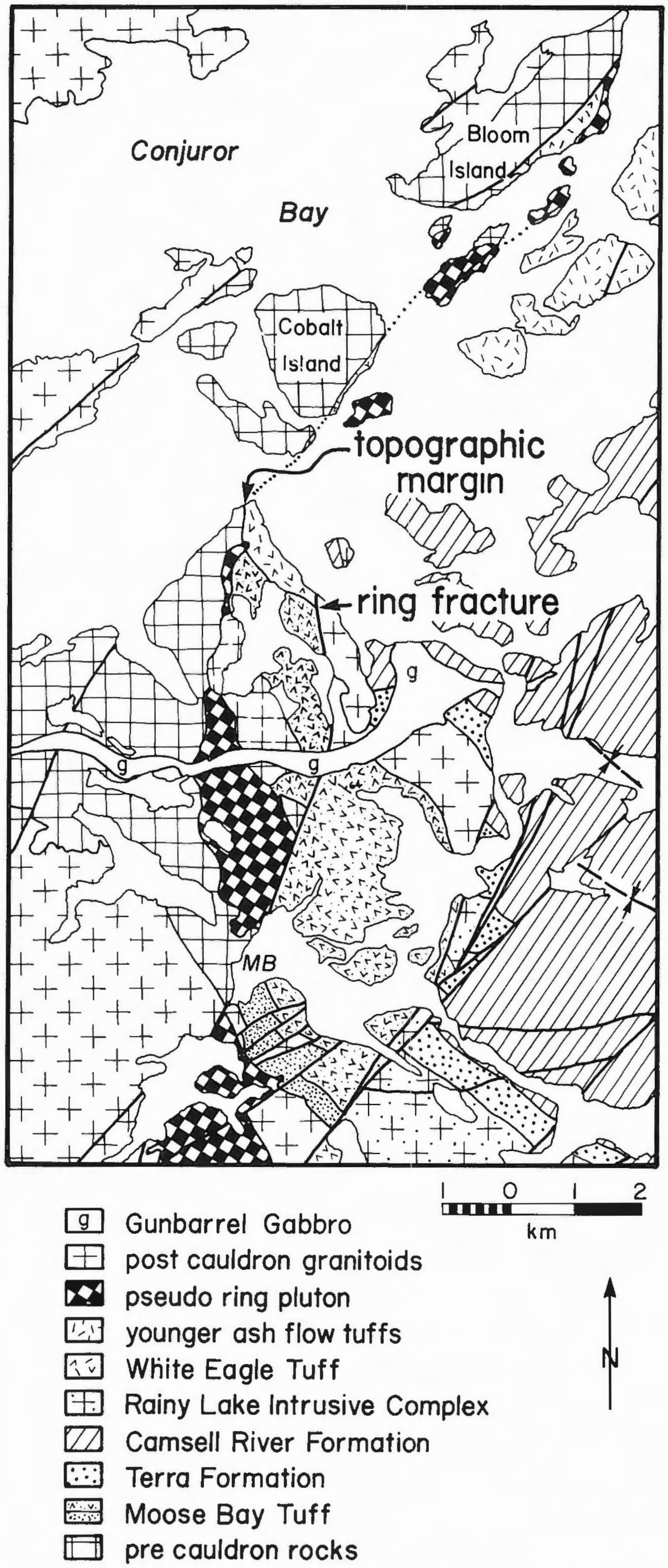

Figure 16. *Sketch map of southern Conjuror Bay area showing possible ring fracture of Black Bear Cauldron and trace of topographic margin.*

considerably altered. The remaining exposures are north of Terra Ridge (Fig. 2), where the base of the formation is intruded by a biotite-quartz microporphyritic sill which also alters the formation but to a lesser degree than the Rainy Lake Intrusive Complex. In addition, half of the exposures above the Rainy Lake were intruded by a plagioclase porphyry and at least one diorite body (Fig. 2).

Rapid lateral facies changes are characteristic of the formation as a whole but lithic arkose generally dominates the upper half of the formation. The lower half is a more varied assemblage of mudstone, breccia, limy argillite and ashstone.

Lithology

Lithic arkose is the major lithology of the Terra Formation and dominates the upper parts of the formation. The sandstones are typically volcanogenic, immature, granular to pebbly, fine- to coarse-grained and weather various shades of brown, purplish brown, rust brown and green-grey. Commonly there are interbedded purplish-brown mudstones (Fig. 17). Many of the sandstones contain abundant mudstone rip-ups. Locally, foresets are draped with mudstone. Beds of sandstone are lenticular and nearly always less than 1 m thick, with 0.2-0.3 m being a typical thickness. Sedimentary structures are common and include trough and planar crossbedding, ripple lamination and, where interbedded with mudstone, load features. In places there are paleochannels filled with clast-supported conglomerate comprising rounded to subrounded pebbles and cobbles of chert, andesite, silicified mudstone, siliceous porphyry, and vein quartz in an arkosic matrix containing up to 5 per cent hematite grains. Beds of lithic pebbly sandstone locally contain abundant rhyolitic fragments.

The lower part of the section just west of Clut Lake is composed of siltstone and fine sandstone with minor mud drapes. The sandstones are generally well sorted, arkosic, crossbedded, and rippled with minor climbing ripples. These grade upwards into coarser grained trough-crossbedded sandstones with linear carbonate concretions (1 m x 5 cm).

Figure 17. *Intercalated sandstone-mudstone, Terra Formation, Terra Ridge. (GSC 190574)*

Figure 19. *Intercalated limy argillite and rhyolitic ashstone, Terra Formation. Pen in top centre for scale. (GSC 190511)*

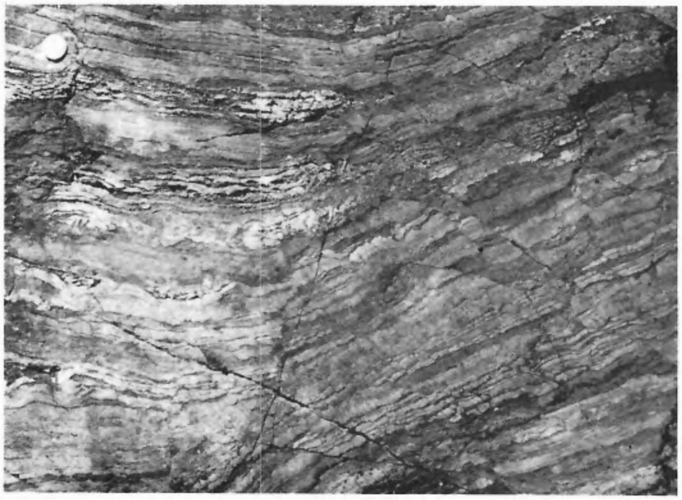

Figure 18. *Altered and fractured mudstone and siltstone, Terra Formation, Terra Ridge. (GSC 190537)*

Figure 20. *Sedimentary breccia, Terra Formation, Terra Ridge. (GSC 190545)*

Elsewhere the lower half of the formation comprises varicoloured, laminated mudstones and ashstones. They are everywhere strongly altered and recrystallized to hornfels (Fig. 18) as they form the roof of the Rainy Lake Intrusive Complex, and are dominantly red, green, and black. In thin section, green and black rocks are found to be dominated by tremolite-actinolite and chlorite while reddish laminations generally consist predominantly of albite with finely disseminated hematite.

Pyroclastic units are also common throughout the Terra Formation. They are most commonly fine siliceous and intermediate ashstones ranging in thickness from a few centimetres to half a metre. They generally weather shades of pink but where strongly altered weather white. In thin section, these units are seen to contain broken microphenocrysts of quartz and potassium feldspar. Locally, normal and reverse size-graded beds of lapilli tuff are found.

About 20 m of interbedded carbonate and argillite occur in the middle of the formation north of Terra Ridge west of the Camsell River. Laminations are crinkly, somewhat irregular, and average about 1 cm thick. Interbedded with these units are beds and lenses of pink weathering rhyolitic ashstone, up to 0.5 m thick (Fig. 19). Near the top of this succession are 0.3 m thick beds of fine grained sandstone and crystal tuff, both typically graded.

In the middle parts of the formation lenticular beds of completely unsorted breccia occur. They are thickest (15 m) and most abundant in the northwest. Typically, they contain angular to subrounded fragments of carbonate-argillite and rhyolitic ashstone in a sparse black or dark green silty matrix (Fig. 20). The fragments, which range up to 4 m across, are identical to the limestone-argillite and rhyolite assemblage described above (Fig. 21). Badham (1972) interpreted the breccias to have resulted from emplacement of the Rainy Lake Intrusive Complex, but because they are everywhere concordant with beds above and below them, the breccias are here interpreted to be of sedimentary origin.

A stubby, quartz-porphyritic rhyolite flow occurs in the Terra Formation about 5 km southeast of Terra Ridge. It overlies mafic ashstone. The lower 3 to 4 m of the lava flow weather white and grade up into 12 m of dark grey to green massive rhyolite. Most of the flow (30 m) is flow banded and autobrecciated. Individual flow bands (less than 15 cm) are either pink or grey with both sharp and diffuse, gradational contacts. They are folded and microfaulted.

Interpretation

The fine grained and thinly laminated nature of the lower part of the Terra Formation and interbedded limy argillite-rhyolitic ashstones without scours and current structures indicate that deposition was in relatively quiet, shallow water. The rapid lateral facies changes of the formation, its local distribution and the presence of subaerial units both directly above and below the unit suggest that the formation is nonmarine, and probably lacustrine. The upper lithic arkose with its abundant current-generated structures and conglomeratic lenses is interpreted to be of fluvial origin.

Because the Terra Formation directly overlies intracauldron facies Moose Bay tuff and pinches out abruptly at the possible cauldron margin fault northwest of Mule Bay it is interpreted to have accumulated within the topographic depression of Black Bear Cauldron. Lakes have developed inside most calderas following collapse, and younger examples include the giant Toba caldera (van Bemmelen, 1949), Creede caldera (Steven and Ratté, 1965, 1973), the Kari Kari caldera (Francis et al., 1981), and Kutcharo caldera (Katsui et al., 1975).

The coarse, locally derived breccias of limy argillite-rhyolite suggest that local areas were subject to syndepositional uplift and erosion. Whether this resulted from resurgence or local block faulting near the ring fracture system could not be determined because the formation is exposed in a strip.

Camsell River Formation

The Camsell River Formation is named for its exposures along the Camsell River at Rainy Lake. It is a 2 km thick assemblage of intercalated andesitic to dacitic lava flows, laharic breccia, explosion breccia, andesitic ash-flow tuff, sandstone, conglomerate, ashstone, lapilli tuff and mudstone, that conformably overlies the Terra Formation. The lower contact is placed at the base of the lowest andesite flow or breccia. The top of the formation is not exposed.

Most exposures are in a broad northwest-southeast band from Conjuror Bay to Clut Lake (Fig. 2) between the Balachey Pluton and Rainy Lake Intrusive Complex, but many also occur north of the Balachey Pluton, such as on Clut Island. Like the Terra Formation it is not present in sections west of the proposed ring fracture zone of the Black Bear cauldron. A sketch map illustrating the complex facies relationships of the formation in the Norex syncline area is shown as Figure 22.

Figure 21. *Large clast of interbedded dolomite and argillite in sedimentary breccia of Terra Formation, Terra Ridge. (GSC 190567)*

Lava Flows

Andesitic to dacitic lava flows of the Camsell River Formation are characterized by abundant large platy plagioclase phenocrysts (Figure 23) that are often flow-aligned (Fig. 24). Individual flows are generally 10 to 30 m thick. They are commonly columnar jointed above platy jointed bases, but many flows have autobrecciated margins. In cases where basal flow breccias overlie mudstone it is common to find blocks of lava up to 0.5 m across "floating" in a mudstone matrix.

The lavas are predominantly dark grey. However, parts of many flows are oxidized to a brick-red and some are altered to white, pink, and green. Most flows are amygdaloidal with amygdule content varying from less than 10 per cent to nearly 50 per cent of the rock by volume. The amygdules commonly comprise quartz, calcite, epidote, and chlorite.

All lavas of the Camsell River Formation are altered to some degree as they were intruded by the Balachey Pluton and the Rainy Lake Intrusive Complex. A few flows have

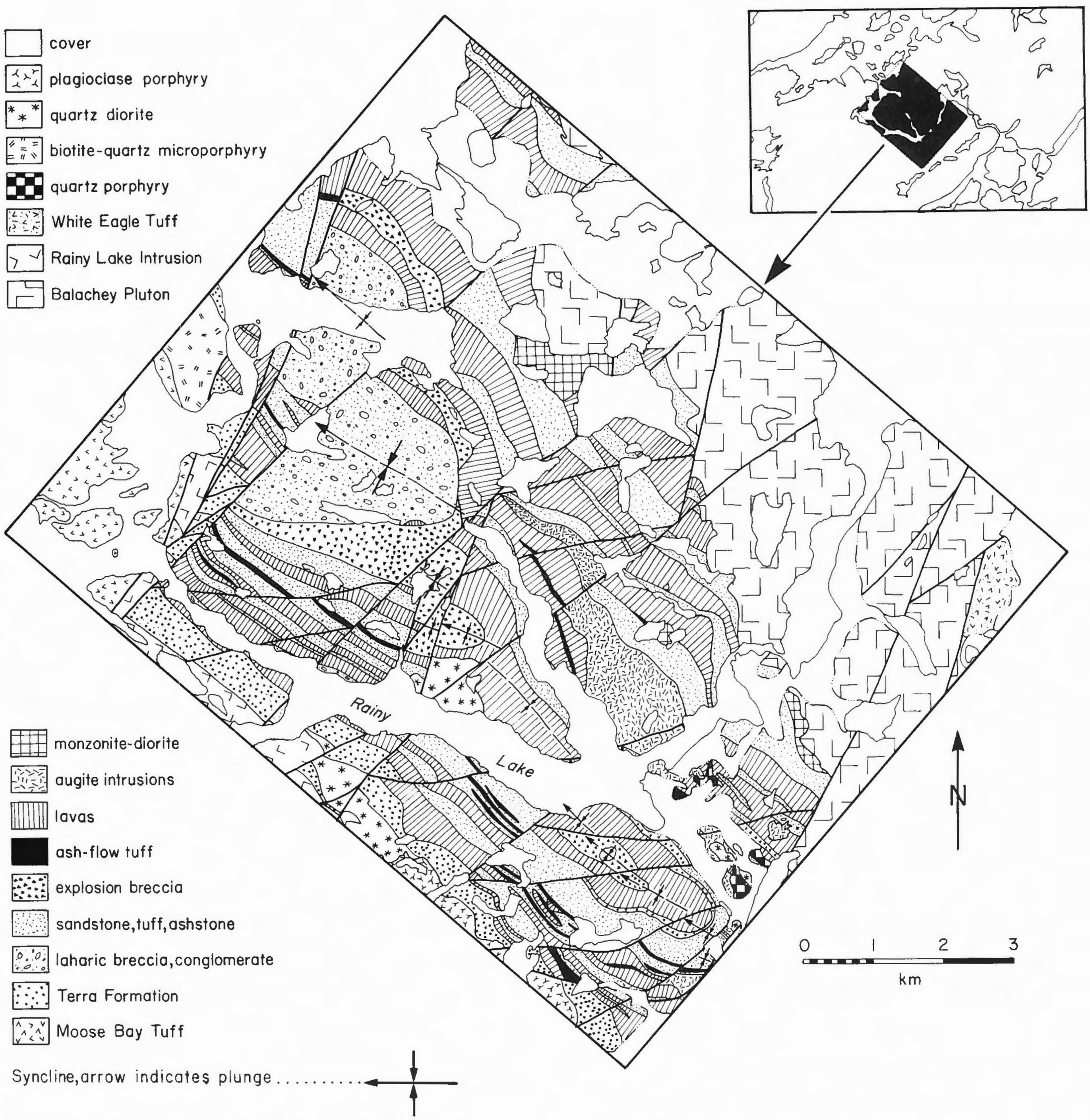

Figure 22. *Generalized sketch map of Norex syncline area showing the complex facies relationships between various rock types in the Camsell River Formation.*

Figure 23. *Porphyritic andesite flow Camsell River Formation, north east side of Terra Ridge. (GSC 190578)*

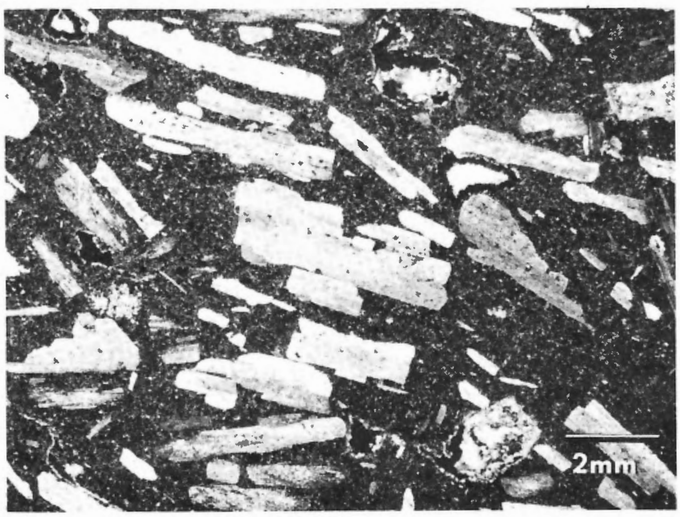

Figure 24. *Photomicrograph of flow-oriented plagioclase phenocrysts in andesitic lava flow, Camsell River Formation. (GSC 190595)*

Table 2. Modal analyses of Camsell River Formation andesite flows

Sample no.	% groundmass	% plagioclase	% pyroxene	% oxide
H-79-296	59	41	< 1	--
P-79-97	72	15	11	2
H-79-135	55	44	1	--
H-79-124b	75	23	1	1
H-79-194	76	22	1	1
H-79-126	78	20	2	--
H-80-7	57	43	--	--

original mineralogy preserved while others are completely recrystallized to mixtures of albite, epidote, chlorites, tremolite-actinolite, sphene and magnetite. A brief description of the alteration related to the two intrusions is found with the descriptions of those bodies.

In the flows where vestiges of original mineralogy are preserved, phenocrysts of calcic andesine, up to 1 cm long, and augite or salite (to 5 mm) are engulfed in a dense pilotaxitic matrix made up of subparallel microlites of plagioclase, intergranular chlorite and magnetite and undetermined interstitial material. Plagioclase always dominates the modes (see Table 2).

Ash-flow Tuffs

Andesitic ash-flow tuffs of the Camsell River Formation are generally less than 10 m thick. They are found at many horizons in the formation, are very discontinuous along strike, and appear to fill paleovalleys. The tuffs are most common in the southeast and often thin to the northwest.

Most are densely welded simple cooling units containing variable proportions of lithic fragments, broken crystals of plagioclase and altered ferromagnesium minerals, pumice, shards, and dust. All are completely devitrified, and many have well developed eutaxitic structure. However, a few cooling units do not contain pumice or shards but are an aggregation of broken crystals, andesitic fragments, and dust.

Laharic and Explosion Breccias

The term laharic breccia is used here for rocks composed of blocks of a wide variety of size and shape engulfed in a muddy or silty matrix. Such rocks are rare in the Camsell River Formation but where found are generally dominated by andesitic fragments, many of which are larger than 1 m in diameter. The best and most accessible exposures of laharic breccia (Fig. 25) in the Camsell River Formation occur on the north side of Terra Ridge.

Another type of breccia found in the Camsell River Formation is composed of angular andesitic fragments of various sizes in a fine grained microbrecciated matrix of andesitic material (Fig. 26). The matrix is identical to most of the fragments except that plagioclase crystals are broken and fractured in the matrix. Locally, a few foreign rock fragments can be found, but at most they make up only a few per cent of the rock. These breccias are interpreted to be explosion breccias created by Vulcanian-type eruptions.

Explosion breccias occur at several stratigraphic horizons in the Camsell River Formation but are most common near the top. One major unit of explosion breccia (Fig. 22) near the top of the formation thins to the northwest and as fragments decrease in size in this direction, it is considered to have been erupted from a source which lay to the east.

Ashstone-Lapilli Tuff-Sandstone-Conglomerate

The rock types under this heading occur throughout the Camsell River Formation. They are described under one heading because they are intimately intercalated, grade into one another laterally, and because in many cases, due to alteration, it is difficult to determine whether or not a given bed of volcanic material has been reworked by sedimentary processes.

Figure 25. *Laharic breccia, lower part of Camsell River Formation, Terra Ridge. (GSC 190581)*

Figure 26. *Explosion breccia, Camsell River Formation, southwest side of Norex Syncline. (GSC 190571)*

Figure 27. *Volcanic congomerate, Camsell River Formation. Note imbricated cobbles and abundant plagioclase crystals, north side of Camsell River, Terra syncline. (GSC 190564)*

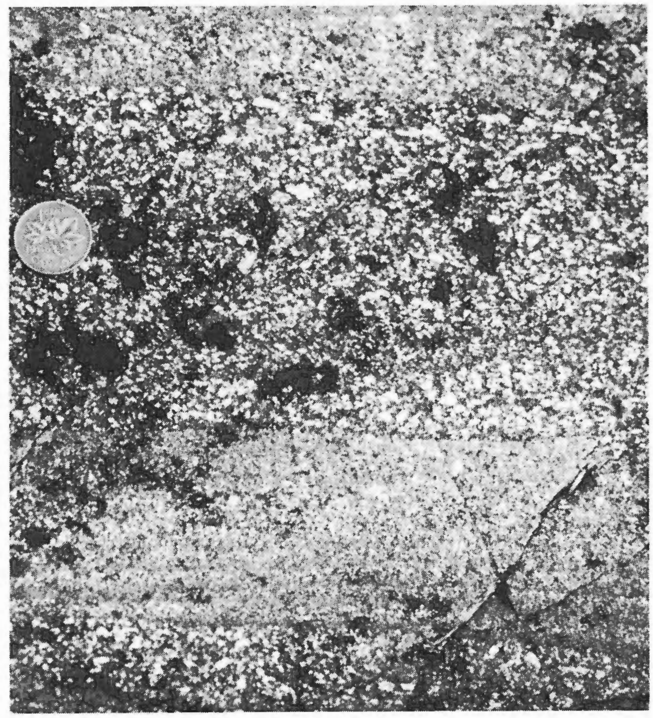

Figure 28. *Plagioclase crystal sandstone, Camsell River Formation. Photo location same as Figure 27. (GSC 190568)*

Figure 29. *Interbedded sandstone and conglomerate of upper clastic unit, Camsell River Formation, north side of bay at the mouth of Camsell River. (GSC 190612)*

Ashstones of the formation are planar-bedded rocks consisting of whole and broken phenocrysts of plagioclase and pyroxene in a fine grained matrix of sphene, plagioclase, chlorites, tremolite-actinolite, and opaque oxides. Beds range from thin laminations to a few centimetres thick. They occur as normally and reversely graded beds, some with razor-sharp contacts and others with gradational contacts. Some beds contain sparse lapilli-size fragments of andesite. Most are strongly altered and contain abundant disseminated sulphides (locally up to 25 per cent).

Lapilli tuffs are generally thicker bedded than the ashstones but a continuum exists between the two. Beds are typically greater than 5 cm, but less than 0.5 m thick. Most contain sparse lapilli of andesite and plagioclase in an ashstone matrix, but some beds have closely packed subrounded lapilli of andesite. As with the ashstones, both normally and reversely graded beds occur.

Sandstones and conglomerates are more common in the Camsell River Formation than either ashstone or lapilli tuff. Most contain andesitic debris in beds ranging in thickness from thin laminations to several metres. The sandstones are commonly planar and trough crossbedded. Many individual beds have bouldery or cobbly zones near their bases interpreted to be lag deposits (Fig. 27). The clasts in those zones are often imbricated. Many of the sandstones, particularly in the lower parts of the formation, comprise rounded augite grains and imbricated tabular plagioclase crystals with abraded corners (Fig. 28).

The uppermost unit of the Camsell River Formation, exposed only in the core of Norex syncline, is a bouldery conglomerate over 100 m thick. It contains mostly well rounded cobbles and boulders of andesite (Fig. 29 and 30) in a sandy to muddy matrix. The unit is best exposed in outcrops along the shore east of the outlet of the Camsell River into Conjuror Bay.

Interpretation

The abundance of lava flows and explosion breccias in the Camsell River Formation is typical of near source facies of intermediate composition stratovolcanoes. However, as no vent regions or feeder dykes were observed and because there is a large amount of epiclastic material intercalated with the volcanic rocks, it is most likely that the formation represents material deposited on the flanks of a volcano, perhaps in an environment similar to the large fluvio-volcanic fans of the Peusangan valley or Mt. Talang, Sumatra (Verstappen, 1973).

The occurrence of the formation above cauldron-fill deposits, along with its abrupt pinch-out at the proposed cauldron-margin fault, suggest that the formation accumulated within the Black Bear Cauldron after collapse. Post-collapse andesitic volcanism is known from several younger cauldrons. For example, post-collapse andesitic lavas and breccias fill both the Oligocene Platoro and Summitville calderas in the San Juan volcanic field of southwestern Colorado (Lipman, 1975); the andesitic stratovolcanoes Atosanupuri and Masu formed after collapse of, and partially fill, the 7 million year old Kutcharo caldera, east Hokkaido (Katsui, 1955; Katsui et al., 1975); and four calderas of Kyushu, Japan (Aso, Aira, Ibusuki, and Kikai) each contain stratovolcanoes of pyroxene andesite (Matumoto, 1943).

In most of the cases cited above, there appears to be a compositional continuum between the ash-flow tuffs, which are mostly dacitic in composition, and the post-collapse andesites. For this reason Lipman (1975) suggested that post-collapse andesites might represent the lower parts of the same magma chambers from which the ash-flow tuffs were derived.

This is not a likely explanation for andesites of the Camsell River Formation because there is a large compositional gap between them and the rhyolitic ash-flow tuff of Black Bear Cauldron. Therefore, the andesites of the Camsell River Formation are thought to represent a different batch of magma than that which erupted the Moose Bay Tuff.

The thinning of explosion breccias to the northwest coupled with the decrease in ash-flow tuffs and thickening of epiclastic rocks in that direction suggest that the eruptive source lay to the southeast. Although the original extent of the Black Bear Cauldron is unknown, the lack of eruptive vents for the andesites and the probable nongenetic relationship between them and the tuff, suggest that the eruptive centre may have been outside the cauldron and the lavas spilled into the topographic depression remaining after collapse.

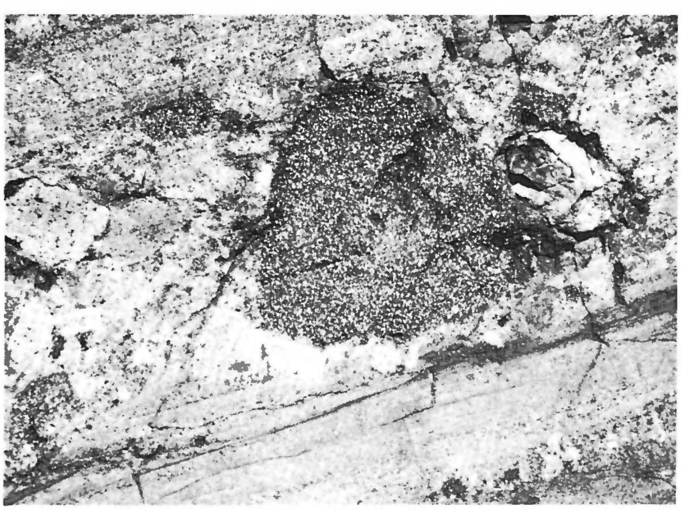

Figure 30. *Detail of outcrop in Figure 29. The dark andesite boulder shown is just to the left of the assistant's left knee in Figure 29. Note the mudstone drapes and imbricated cobbles. (GSC 190613)*

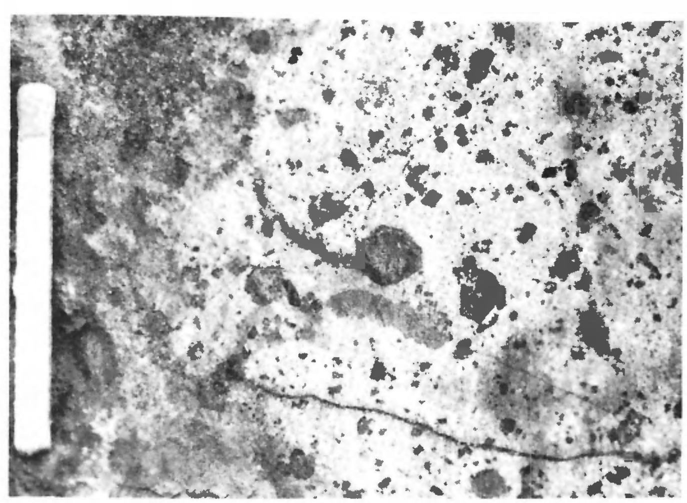

Figure 31. *Detail of augite porphyritic intrusion showing euhedral pyroxene, northeast side of Jason Bay. (GSC 190525)*

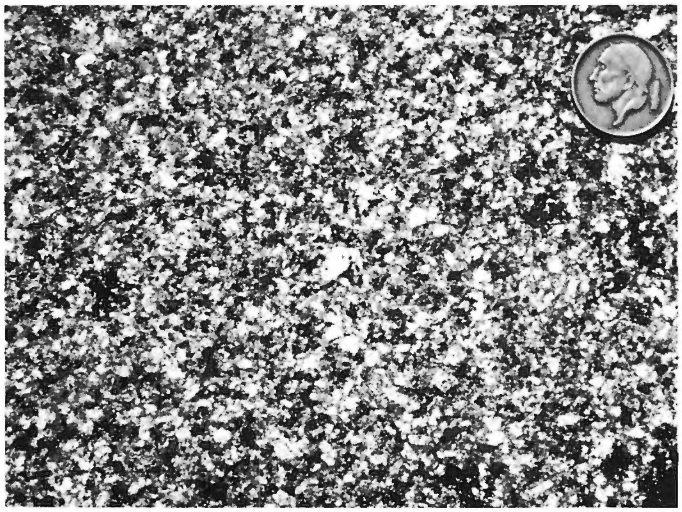

Figure 32. *Detail of quartz monzonite, Balachey Pluton. Note the wide variation in size of plagioclase phenocrysts characteristic of seriate texture, southside of Balachey Lake. (GSC 190514)*

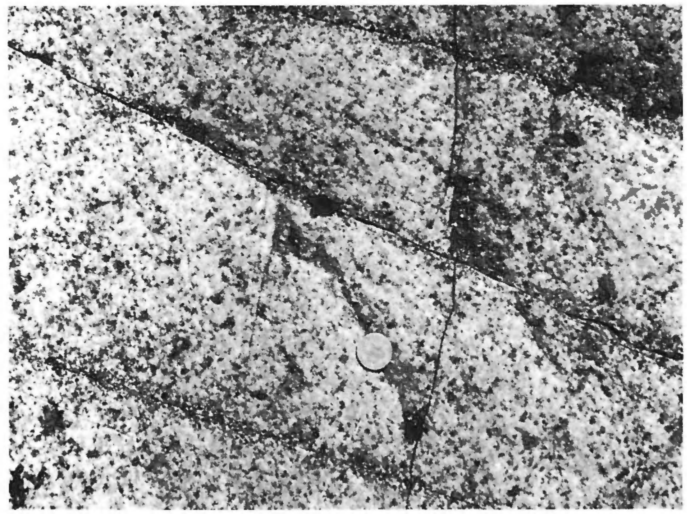

Figure 33. *Amphibole concentrations along fractures, Balachey Pluton, south side of Balachey Lake. (GSC 190549)*

Augite Porphyritic Intrusions

Rocks under this heading are irregular-shaped augite porphyritic bodies common in the area around the eastern end of Rainy Lake. They typically contain uralitized euhedral to subhedral augite crystals up to 0.5 cm across (Fig. 31) in a fine grained matrix of altered plagioclase, sphene, amphibole, chlorites and epidote.

Badham (1972) and Withers (1979) considered these units basalt flows. However, north of Smallwood Lake irregular fingers tens of metres long clearly intrude breccias and andesite lava flows of the Camsell River Formation (Fig. 22) and have chilled margins. Although a few vesicles are present locally, most outcrops contain none of the features expected in basalt flows.

The bodies predate intrusion of the Balachey Pluton but whether they are related to volcanism of the Camsell River Formation is not known with any degree of certainty. Blocks of similar rocks in breccias of the formation do, however, suggest that some were exposed at the surface during that time and therefore may be genetically related to the andesites.

Balachey Pluton

This is a pluton comprising mainly seriate quartz monzonite, monzonite, and quartz monzodiorite. It outcrops continuously for over 20 km in a north trending belt, 1 to 6 km wide, in the central part of the study area (Fig. 2). The pluton is named for its extensive polished and lichen-free outcrops on Balachey Lake. Age relations between the Balachey Pluton and Rainy Lake Intrusive Complex are unknown.

General Lithology

The major rock types of the pluton are medium- to coarse-grained hornblende quartz monzonite (Fig. 32) in the northwest, and quartz monzodiorite in the southeast. Other rock types such as hornblende monzonite and hornblende monzodiorite are relatively minor phases. Locally, there is a plagioclase porphyritic phase adjacent to external contacts. Contacts between internal phases are everywhere gradational and moderate mineralogical variations were seen on scales ranging from kilometres down to hand specimen.

The Balachey Pluton contains a multitude of xenoliths and enclaves which are especially numerous in the northwest parts of the body and vary in size up to 7 m long. All of the xenoliths appear to be pieces of nearby wall rock, are intensely altered, and have been more or less digested. Lithologies include andesite and epiclastic rocks with shapes ranging from angular to rounded, and there is a general tendency for the smaller xenoliths to be more rounded than the larger ones. A common, and important feature, present in many outcrops of the intrusion is the occurrence of abundant fractures along which amphiboles are concentrated (Fig. 33). The amphiboles are similar to those seen elsewhere in the intrusion.

West of the Camsell River numerous chalcopyrite-pyrite veins, up to 10 cm wide, are found to cut the intrusion as do smaller stringers of quartz and specular hematite (Fig. 34). These veins and stringers trend approximately north, parallel to many small faults showing right-lateral separation. Both the faults and the veins are probably contemporaneous with, and related to, post-Labine transcurrent faulting.

Contacts

Contacts of the Balachey Pluton with surrounding country rocks are always sharp and trend northwest (Fig. 2). Along the entire southwestern margin, and part of the northeastern margin, rocks of the complex intrude, and strongly alter, up to 2 km from the contact, lavas, tuffs, and sedimentary rocks of the Camsell River Formation, as well as earlier intrusions of monzonite and diorite. In these areas the contact dips away from the pluton at about the same inclination as the bedding of wall rocks (about 30°).

From Uranium Point to Grouard Lake, a distance of 15 km, the northeastern margin of the intrusion is nearly always vertical, but locally is roughly horizontal so that the contact is step-like in cross-section (Fig. 35). Where the contact is flat, or nearly so, there is a peculiar breccia comprising angular fragments of the intrusion within a hematitic matrix. Overlying the breccia, and buttressed against the steeper portions of the contact nearly everywhere is another breccia (mesobreccia member – White Eagle Tuff), unaltered and characterized by a wide variety of fragments, 30 to 100 per cent of which are identical to phases of the

Figure 34. *Hematite veins cutting Balachey Pluton, west side of Camsell River between Rainy and Balachey Lakes. (GSC 190512)*

Balachey Pluton, sitting in a crudely bedded muddy to sandy matrix. Quartz monzonite fragments, up to 1 m across, range from well rounded to angular and some even appear to be bounded by original joint surfaces. Although a more detailed description of this unit and its genetic significance will be presented later, there is little doubt that this contact is an unconformity (Lord and Parsons, 1947; Hoffman et al., 1976) – an extremely important one because it tightly constrains the emplacement age of the Balachey Pluton.

Shape of the Pluton

If the interpretation of relations along much of the northeastern margin as evidence of an unconformity is correct, then there are many stratigraphic units younger than the Balachey Pluton. Because the younger rocks are folded about similar axes as pre-Balachey rocks, then the Balachey must predate the folding and is itself folded. Furthermore, as there are northwesterly plunging synclines on both the northeast and southwest sides of the intrusion, and because the contacts of the pluton themselves, where intrusive, dip away from the intrusion, it appears that the pluton occupies the core of a northwesterly plunging anticline.

The intrusive contacts have similar dips as bedding in the country rocks (about 30°), and also have similar strikes. This implies that the roof of the intrusion is concordant with the country rocks and was rather flat prior to folding.

There are several other intrusions which also intrude andesitic rocks of the LaBine Group and display striking similarities to the Balachey in texture, composition, and wall rock alteration type. They are the plutons of the Mystery Island Intrusive Suite found in the Echo Bay area (Hildebrand, 1981, 1982) and the Rainy Lake Intrusive Complex (Tirrul, 1976) of the Camsell River area. All but one of these intrusions, the Tut pluton of the Echo Bay area which was itself de-roofed early on, are exposed in cross-section and are seen to be concordant, sheet-like bodies. Thus, it is reasonable to assume a similar sheet-like form for the Balachey Pluton.

Petrography

Thin section examination of the main body of the intrusion shows that it is a massive rock consisting of euhedral, sericitized plagioclase phenocrysts, 1 to 4 mm long, in a matrix of quartz and microperthite, typically forming granophyric intergrowths. Concentric shells of sericite define original zoning in the plagioclase phenocrysts. Quartz always displays undulatory extinction. Both it and the microperthite locally appear to replace plagioclase. Fibrous green amphibole, probably tremolite-actinolite, is subhedral to anhedral, replaced by chlorite along cleavage planes, and form clots 2 to 4 mm across. A few small patches of amphibole are replaced by epidote. Anhedral grains of opaque iron-titanium oxides are concentrated in the amphibole clots but sparse hexagonal plates of hematite occur scattered throughout the rock. Hexagonal prisms of apatite less than 0.5 mm in diameter are a common accessory but total less than 1 per cent of the rock, as do euhedral zircon crystals.

In thin sections made from samples collected close to the roof of the pluton, plagioclase phenocrysts are seen to be replaced by an interlocking mosaic of quartz and albite. Vestiges of original plagioclase phenocrysts occur, but most have been completely replaced by albite and are no longer euhedral. Instead, they have margins which grade into and interlock with the quartz and albite matrix. The few intensely sericitized cores of plagioclase that do remain are completely albitized around their margins. Amphibole is present in these rocks as felted mats and irregular clots pseudomorphing earlier ferromagnesium minerals. The borders of the clots and aggregates are ragged and fuzzy. Opaque oxides are much sparser in these rocks than in the main body of the pluton; only a few tiny anhedral grains occur. Thousands of minute apatite grains are seen in individual thin sections but are so small that their total abundance is probably not much greater than 1 per cent. As in the central parts of the intrusion all quartz grains display undulatory extinction.

The fact that even late replacement quartz has been strained might suggest that the deformation may not have taken place during emplacement of the pluton but instead occurred as the sheet-like body was folded. However, a block of the intrusion in the White Eagle Tuff, known to have been erupted prior to folding, also contains strained quartz, yet quartz phenocrysts in the tuff itself are not strained. Quartz diorite bodies which predate the folding also do not contain strained quartz. Therefore, the deformation is ascribed to the later stages of emplacement and not to folding.

Alteration of Wall Rocks

The Balachey Pluton strongly alters its wall rocks for a distance of at least 1 km, assuming that the contact continues to dip at 30° beneath the surface. At present a detailed study of the alteration and its relation to the intrusion is under way. Accordingly, only a brief description is given here.

Three zones of alteration were mapped in the field: an inner zone of intense bleaching and albitization; a central zone of magnetite-apatite-actinolite; and an outer zone of pyrite-chalcopyrite. The criteria used to define the zones were as follows: (1) the boundary between the inner and central zones was placed at the first appearance of the assemblage magnetite-apatite-actinolite; (2) the boundary between the central and outer zones was mapped as the disappearance of the magnetite-apatite-actinolite assemblage; and (3) the outer margin of the sulphide zone was placed at the disappearance of visible gossan. Mapped in this way albite is present in all three zones and sulphides occur in the outer part of the magnetite-apatite-actinolite zone.

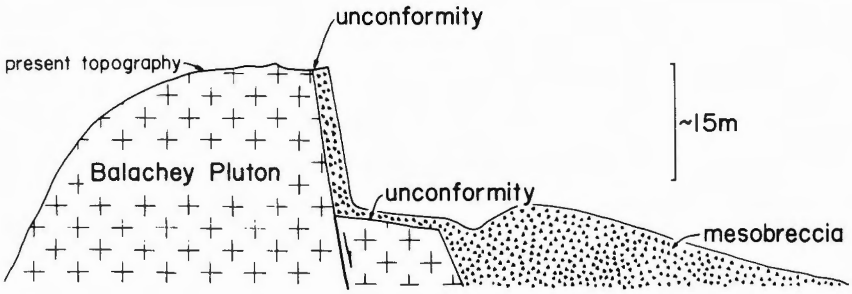

Figure 35

Sketch illustrating relationships on southeast-facing cliff at Uranium Point. Scale approximate.

The zones of alteration are widest in the northwest (Fig. 2) and pinch-out towards the southeast. They are truncated by the unconformity along the northeast side of the intrusion.

The inner albite zone is characterized by nearly complete albitization of the andesitic lavas and sedimentary rocks. Most original textures are obliterated and the rocks weather white to very pale pink. Nearly all bedded rocks are intensely brecciated but vestiges of bedding can still be seen within the fragments. A fine grained, pre-Balachey, monzonitic intrusion located north of Jason Bay (Fig. 22) is completely albitized only adjacent to fractures, which gives the rock a mottled pink and white appearance in outcrop. Andesite flows within this zone are commonly completely replaced by granoblastic-polygonal albite with only a few specks of chlorite and weather white in outcrop.

The zone of magnetite-apatite-actinolite is characterized by the presence of those minerals as pods, veins, disseminations, and as rosettes with albite. Most commonly there are small veins a centimetre or two wide in which fibrous green amphibole grows perpendicular to the vein walls with interstitial, anhedral pink apatite and octahedra of magnetite or martite. Pods of magnetite-apatite-actinolite up to 2 m across also occur and these typically contain coarse blades of amphibole up to 30 cm long, magnetite octahedra to 5 or 6 cm, and patches of apatite of variable size up to 20 cm. Rosettes of bladed albite, up to 15 cm across, with interstitial chlorite, amphibole, and magnetite are commonly found as alteration products of andesite flows (Fig 36). Epidote is a common mineral within this zone and a few cavities within lava flows are lined with it and contain partially filled cores of apatite.

The contact of the magnetite-apatite-actinolite zone with the sulphide zone is gradational but was mapped as the disappearance of magnetite-apatite-actinolite. Sulphides within the zone are mainly pyrite although minor chalcopyrite and secondary (?) pyrrhotite also occur. Typically the sulphides form gossany patches of variable size, but generally tens of metres across, of up to 20-25 per cent fine disseminations in the country rocks. They are easily recognizable in the field from great distances. It is this zone that contains polymetallic veins of native silver and bismuth and Ni-Co arsenides located along the north side of the Camsell River (see Economic Geology).

Interpretation

The late stage replacement of plagioclase phenocrysts in the Balachey Pluton by quartz and albite, the concentration of amphibole adjacent to fractures in the pluton, and the wide alteration halo, sometimes with fracture controlled albitization such as found in the pre-Balachey monzonite, attest to the activity of high temperature hydrothermal fluids. At present, without oxygen isotope data, it is not possible to determine the relative role of

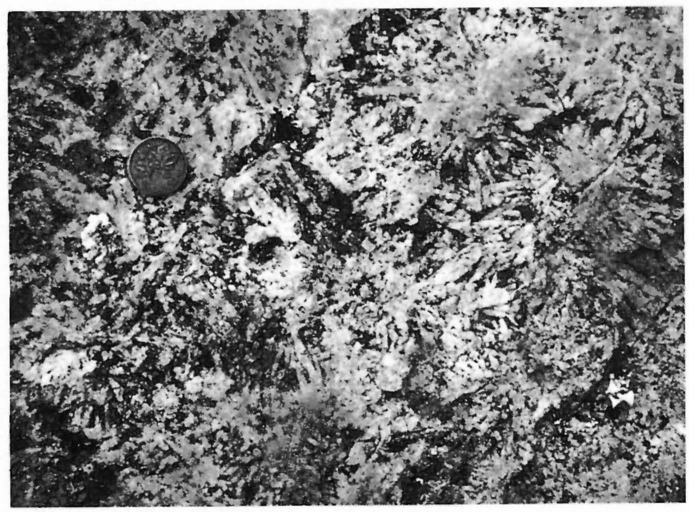

Figure 36. *Albite rosettes in magnetite-apatite-actinolite zone of Balachey Pluton alteration halo north of Jason Bay. Original rock type was an andesitic lava flow. (GSC 190523)*

magmatic versus ground water, but the incredible volume of altered rock suggests large scale ground water-rock interactions.

Although it is not possible to know how much Camsell River Formation was eroded prior to eruption of the White Eagle Tuff, the upper conglomerate of the Camsell River Formation may mark the original top of the pile. If so, then the Balachey Pluton was intruded 2-3 km beneath the surface. Even if substantial volumes of andesite were stripped away, the pluton was nevertheless emplaced at only a few kilometres depth – a remarkable occurrence considering its size (20 km across).

The close temporal, spatial, and compositional relationships (Hildebrand, 1982) of the Balachey Pluton to the Camsell River Formation suggest that the two are genetically related, although the Balachey Pluton apparently did not vent at the surface. Probably the intrusion represents the type of magma chamber which at deeper levels fed the surface volcanism of the Camsell River Formation. Eventually the body migrated upwards and invaded volcanic ejecta much in the manner envisioned by Hamilton and Myers (1967).

Rainy Lake Intrusive Complex

The Rainy Lake Intrusive Complex (Tirrul, 1976) is a compositionally and mineralogically zoned sheet-like pluton about 1500 m thick and 10-11 km across. The pluton was folded after intrusion and is now exposed in cross-section on the southwest limb of Norex Syncline (Fig. 2). Only a brief description of the pluton is made here because work on this complex, but interesting, body is still in progress.

The intrusion has a flat roof that is roughly concordant with bedding of the roof rocks. However, down dip in the Terra Mine workings the upper contact is seen to cut up section. The floor of the body is convex downward with the thickest parts near the centre of the intrusion. Both the upper and lower contacts strike northwest and dip from 50-90° to the northeast. In the southeast the pluton was intruded by a younger syenogranite and the original lower contact of the Rainy Lake Intrusive Complex is therefore not exposed in that area.

General Lithology

Tirrul (1976) recognized that the pluton was compositionally zoned parallel to its flat roof, and mapped five major lithological units within the body. From top to bottom they are: upper border monzonite, fine grained syenite, coarse grained syenite, monzonite, and monzodiorite (Fig. 2). In addition, there is also a lower border monzonite. The mineralogy of the intrusion is summarized in Figure 37.

Border Phase. Where the upper margin of the intrusion is exposed (Fig. 38) there is typically a well developed border phase, up to 20 m thick, comprising 30-35 per cent intensely sericitized plagioclase phenocrysts (Fig. 39) up to 1 cm long and ragged mafic clots (3 mm) of chlorites, amphibole, carbonate, and opaque oxides sitting in a much finer groundmass of chlorites, carbonate, chessboard albite, sphene, epidote, and a trace of quartz. Concentric shells of sericite outline original zoning in some of the plagioclase phenocrysts. Under the microscope all original plagioclase appeared altered but the microprobe revealed tiny domains of unaltered andesine. Most of the phenocrysts are rimmed with unaltered albite that intimately interlocks with the matrix.

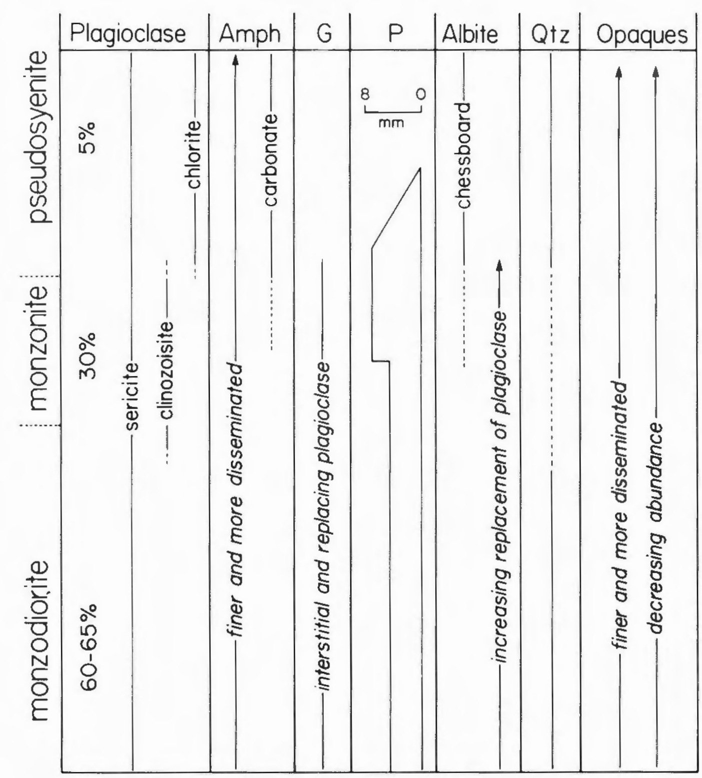

Figure 37. *Diagram summarizing mineralogy of the Rainy Lake Intrusive Complex. Amph = amphibole, G = granophyre, P = perthite, Qtz = quartz.*

Large numbers of slender needles of apatite, up to 2 mm long, occur throughout the matrix. Veins of magnetite-apatite-actinolite, up to 30 cm across, cut the monzonite (Fig. 40) and most trend normal to the outer contact, locally cutting across it. In the veins fibrous amphibole grows normal to the vein walls with central zones of coarse anhedral apatite and magnetite octahedra.

The lower border phase is similar to the upper border monzonite except that it does not contain mafic clots or magnetite-apatite-actinolite veins. It generally weathers pink.

Lower Monzodiorite. The lower half of the pluton is, in its lowest parts, a seriate monzodiorite (Fig. 41) consisting of euhedral, sericitized plagioclase phenocrysts from 1 or 2 mm to 1 cm long with interstitial pale green amphibole, opaques, perthite, granophyre, and a few specks of chlorite. The plagioclase crystals occur as euhedral tablets of oscillatory zoned andesine. They are heavily sericitized and closely packed. Only locally have crystals grown together. Some of the phenocrysts have been replaced at their margins by unaltered albite. In the field the plagioclase crystals locally define a weak foliation. These features led Tirrul (1976) to suggest that the lower monzodiorite was a cumulate rock derived from gravitational settling of the plagioclase.

The pale green amphibole occurs mostly as interstitial clots (3 mm) consisting of fibrous material with random optical orientations but a few light brown to green actinolitic hornblendes show uniform crystallographic orientation. The actinolitic hornblendes are about 2-3 mm across and also fill interstices between plagioclase phenocrysts. Anhedral opaque oxides are ubiquitous in the clots but uncommon in the actinolitic hornblende crystals with uniform optical orientation.

Anhedral perthite, about 4 mm across in maximum diameter, also occurs as interstitial material and is often intimately intergrown with the amphibole. In places it appears to have replaced marginal portions of the plagioclase phenocrysts. Granophyric intergrowths of quartz and microperthite have a similar mode of occurrence as the perthite in that they are mainly interstitial, intergrown with

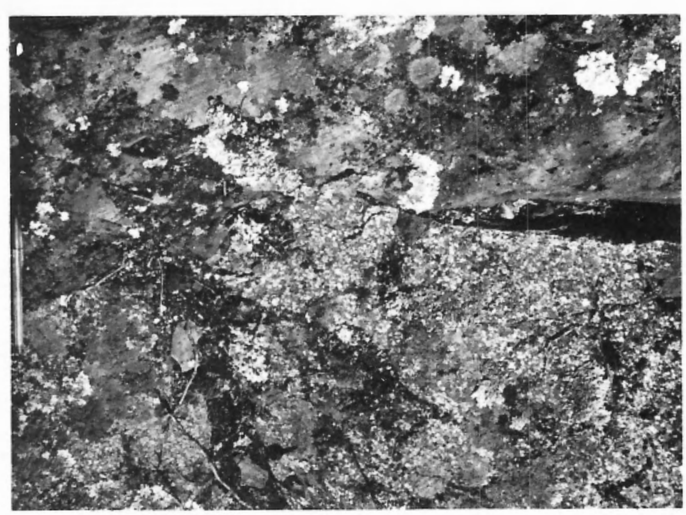

Figure 38. *Sharp upper contact of Rainy Lake Intrusive Complex, Terra Ridge. (GSC 190535)*

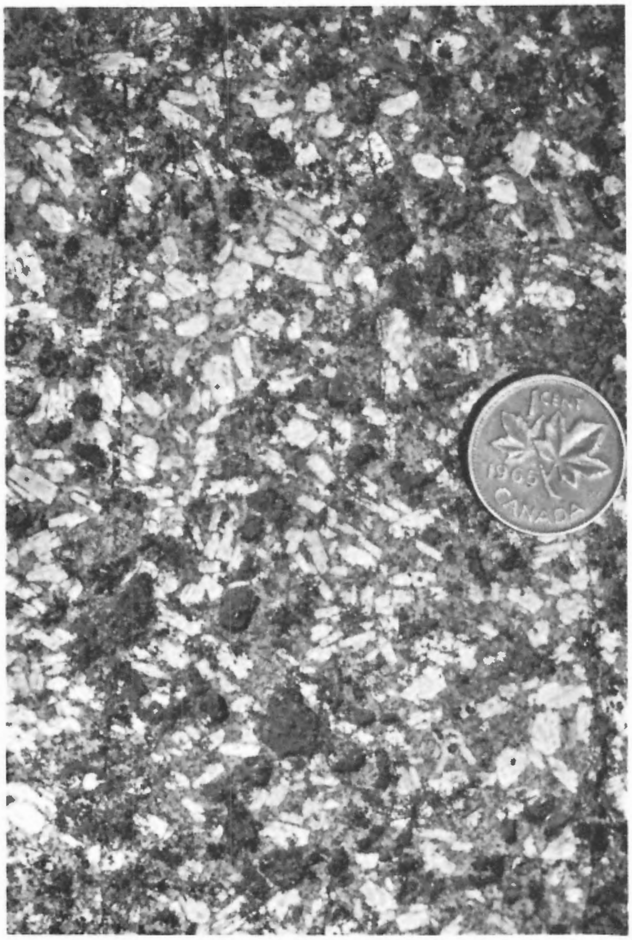

Figure 39. *Detail of upper border monzonite, Rainy Lake Intrusive Complex, Terra Ridge. Note the similarities of plagioclase phenocrysts to those of andesites of the Camsell River Formation. (GSC 190538)*

amphibole, and appear to have replaced plagioclase. Locally, quartz occurs without potassium feldspar. Tiny hexagonal prisms of apatite are a common feature in the interstitial areas between plagioclase phenocrysts.

Upwards in the basal monzodiorite the following changes are seen: plagioclase phenocrysts become more heavily sericitized, have wider rims of albite, cores of finely disseminated zoisite or clinozoisite, and are replaced along cleavage traces by albite; the clots of amphibole become smaller and the amphiboles themselves become more ragged and felted; quartz becomes sparser and locally absent.

Monzonite. The transition from monzodiorite to monzonite is gradational and takes place over a distance of several metres. Mineralogically, the change is characterized by an increase in the size of perthite to 7 mm and the appearance of minor amounts of chessboard albite. Quartz is absent. Apatite becomes especially common and nests of tiny needles occur throughout the matrix. Epidote clots become common and appear to be after amphibole. Chlorite and fine amphibole occur in the cores of plagioclase phenocrysts.

Texturally, both unaltered albite and perthite replace significant portions of the plagioclase phenocrysts so that only ovoid sericitized cores remain. Felted ferromagnesiam minerals form ragged clots with abundant opaque oxides.

Figure 40. *Magnetite-apatite-actinolite vein cutting upper border monzonite, Rainy Lake Intrusive Complex, 2 km southeast of Terra Ridge. (GSC 190534)*

In general, the monzonite appears much less altered in thin section than the lower monzodiorite. This is mainly due to the destruction of altered plagioclase and replacement by rather fresh albite and perthite, but there are fewer plagioclase phenocrysts in the monzonite than in the monzodiorite.

Syenite. The upper contact of the monzonite is also gradational over several metres. The syenite is characterized by a sudden decrease in size of perthite from 7 mm to 4 mm, the growth of abundant chessboard albite, and the development of abundant carbonate in the ferromagnesiam clots. The clots are smaller and much sparser in this phase than in lower parts of the intrusion. The destruction of plagioclase is such that only sparse elliptical relics of intensely chloritized cores remain (Fig. 42). Apatite is either very common or virtually absent and there does not appear to be a gradation between the two. Quartz makes up at most 2 per cent of the rock but granophyre is completely absent. Opaque oxides are still concentrated in the ferromagnesiam clots but like the clots they become smaller and more disseminated upwards.

As higher levels of the intrusion are reached, perthite decreases in size until it is absent altogether. Chessboard albite increases in abundance as perthite decreases. Tiny blebs of quartz become common where perthite is sparse or absent. By this level there is only one, or perhaps two, relict cores of plagioclase per thin section. They are always heavily chloritized and contain tiny wisps of amphibole.

The syenitic portions of the intrusion weather pink, probably due to the presence of finely disseminated hematite. Numerous dykes of fine grained albitite, up to 30 cm across, and typically with gradational contacts, cut the body. They appear to be randomly oriented but were not systematically measured during mapping. Overall, the syenitic phases appear remarkably fresh in thin section except for the relict cores of plagioclase.

A remarkable feature found in the top 10 m of the syenite is the occurrence of pink apatite coating fracture surfaces. The fractures typically trend at high angles to the roof of the intrusion.

The contact of the syenitic phase with the upper border phase is sharp. Locally the syenite transgresses the border monzonite so that it is absent, or nearly so, and syenite occurs at the upper contact of the intrusive.

Water Content and Magma Temperature

Plagioclase was the liquidus phase in the Rainy Lake magma and therefore it is likely that the Rainy Lake magma contained 2 per cent or less H_2O (see Marsh, 1976). If it is the same age as the Balachey Pluton, the depth of emplacement was probably about 3 or 4 km as the Rainy Lake Intrusive Complex intrudes the base of the Camsell River Formation.

Once the pressure and water content of an andesitic magma are known it is easy to estimate the liquidus temperature of the magma by using published experimental data. With 2 per cent water at less than 5 kb the liquidus temperature for andesitic magmas is slightly less than 1100°C (Hamilton et al., 1964; Eggler and Burnham, 1973).

Most of the crystallization of an andesitic magma takes place over a short temperature interval 50 to 100° below the liquidus (Marsh, 1981). As the Rainy Lake magma was about one-third crystalline when intruded, it can be inferred that the temperature of the magma was about 1050-1000°C when emplaced.

Alteration

The Rainy Lake Intrusive Complex has a similar alteration halo to that of the Balachey Pluton but the zones are not as well defined. They have been modified by the emplacement of younger intrusions and the albite and magnetite-apatite-actinolite zones appear to be telescoped into the intrusion itself (Fig. 43). There are, however, larger bodies of magnetite-apatite-actinolite (Fig. 44) above the roof of the Rainy Lake Intrusive Complex than occur around the Balachey Pluton.

The bodies of magnetite-apatite-actinolite led Badham and Morton (1976) to speculate that an iron phosphate liquid separated from the Rainy Lake Intrusive Complex as an immiscible liquid. This appears unlikely for the following reasons:

1. Many veins contain only amphibole and/or apatite. Magnetite can be absent. Thus there is commonly more silica than iron in the veins.
2. The veins are commonly zoned with margins of amphibole and magnetite and cores of apatite – a texture incompatible with their derivation from a single iron phosphate melt.
3. Granular magnetite-apatite-actinolite replaces individual beds of sedimentary rock (Fig. 45, 46) and selectively replaces matrices of ash-flow tuffs of the Camsell River Formation.
4. Apatite coats fractures in the upper syenite which indicates that it was solid enough to fracture when the apatite crystallized.
5. The composition of amphiboles (Fig. 47) in the veins suggests low temperature crystallization (Hildebrand, 1982) not the temperatures of over 1000°C that are needed to maintain an iron phosphate melt (C. Thompson, personal communication, 1981).
6. Lastly, an iron phosphate liquid will sink, due to greater density, in a silicate liquid (Daly, 1915) and therefore magnetite-apatite-actinolite bodies separated from a silicate liquid by immiscibility should occur at the bottom of the intrusion, not at the top, as is the case in the Rainy Lake Intrusive Complex.

All of the above are, however, compatible with a hydrothermal origin.

Interpretation

The Rainy Lake Intrusive Complex appears compositionally related to the Camsell River Formation. The pluton did not rise as close to the surface as the Balachey Pluton did but its effect on the country rocks was similar.

When first intruded, the pluton was probably a relatively homogeneous body of andesitic magma containing 30-35 per cent large andesine phenocrysts. Magma adjacent to the walls was rapidly chilled to form the porphyritic border phase. As the plagioclase crystals occurring in the lower monzodiorite are nearly the same size as those of the upper and lower border phases there was not much plagioclase growth after emplacement. The major difference between the two zones is that the lower monzodiorite contains 60-65 per cent plagioclase phenocrysts whereas the border phases contain only 30-35 per cent. Apparently some mechanism mechanically concentrated plagioclase phenocrysts in the lower part of the intrusion.

While it is not possible to reliably predict the viscosity of the Rainy Lake magma, experimental work and subsequent thermal modelling suggest that when a body of magma this size with the composition, temperature, and water content of

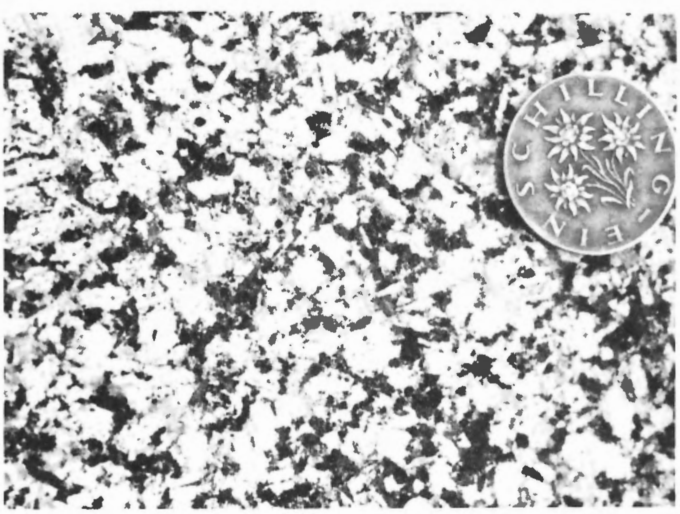

Figure 41. *Lower monzodiorite, Rainy Lake Intrusive Complex, 1 km east of Black Bear Lake. (GSC 190530)*

Figure 42. *Upper syenite, Rainy Lake Intrusive Complex 2 km south of Rainy Lake. Note sparse plagioclase phenocrysts. (GSC 190533)*

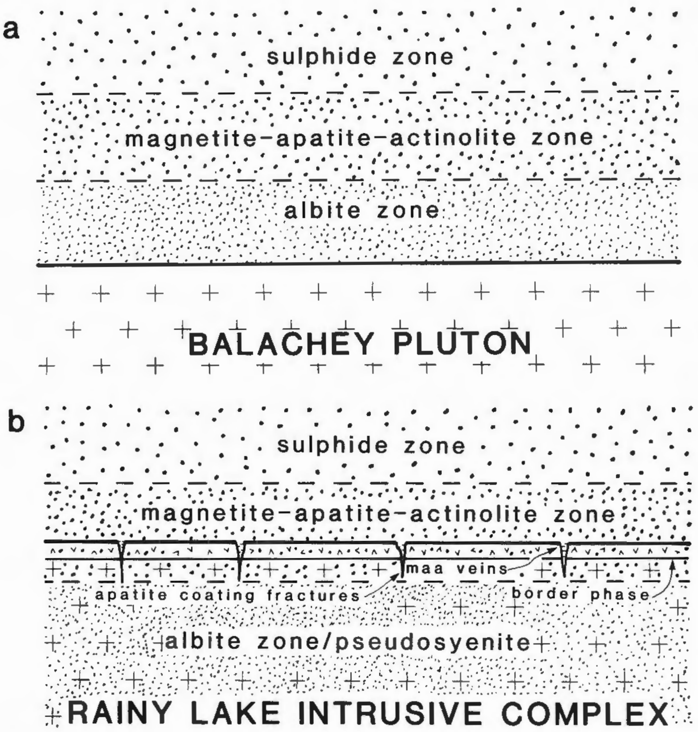

Figure 43. *Comparison of alteration zoning between the Balachey Pluton (a) and the Rainy Lake Intrusive Complex (b). Note that the magnetite-apatite-actinolite zone occurs partly within the upper part of the Rainy Lake Intrusive Complex.*

Figure 44. *Body of granular magnetite-apatite-actinolite above roof of Rainy Lake Intrusive Complex, Terra Ridge. (GSC 190508)*

the Rainy Lake is intruded, it will convect (Shaw, 1965; Bartlett, 1969; Murase and McBirney, 1973; McBirney and Noyes, 1979). Since convective rates are many orders of magnitude greater than crystal settling rates calculated by using Stokes Law (Rice, 1980) it is unlikely that the plagioclase crystals settled slowly to the bottom, but instead were carried downward by convection currents and deposited near the floor of the magma chamber.

The upper parts of the intrusion as seen today do not reflect the original composition of the differentiated magma. Calculations by Tirrul (1976) and by me clearly demonstrate

Figure 45. *Granular magnetite-apatite-actinolite replacing sedimentary rocks of the Arden Formation, Terra Ridge. (GSC 190530)*

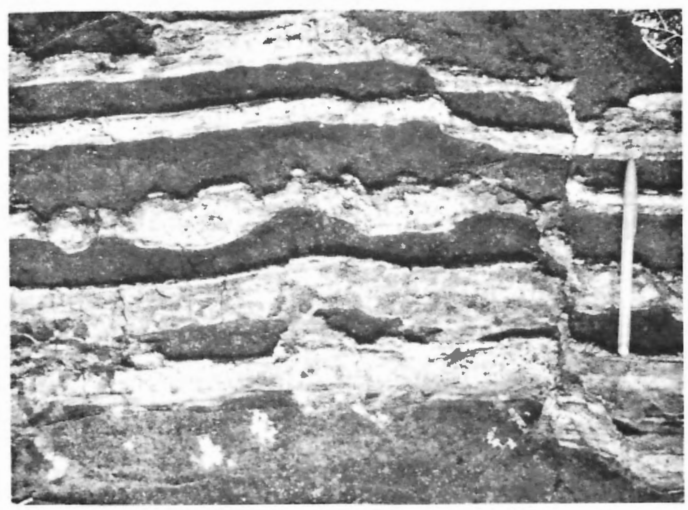

Figure 46. *Granular magnetite-apatite-actinolite replacing alternate beds of sedimentary rock of the Terra Formation above roof of Rainy Lake Intrusion, Terra Ridge. (GSC 190532)*

the inability of plagioclase and amphibole-clinopyroxene fractionation to yield liquids of the composition (65% SiO_2) found in the upper parts of the Rainy Lake from any reasonable original bulk composition. Instead, it is suggested that the upper part of the intrusion is a metasomatic rock generated by hydrothermal convection, and/or retrograde boiling, and should probably be termed pseudosyenite rather than syenite as it would not be an igneous rock.

While retrograde boiling may have generated the fractures in the roof of the intrusion (see Burnham, 1979; Burnham and Ohmoto, 1980) which are now filled with magnetite-apatite-actinolite and may have even altered the upper part of the body, the water to rock ratio would not, in all likelihood, have been large enough to pervasively alter the entire pluton and its wall rocks to their present state. The only mechanism capable of doing so appears to be cooling by hydrothermal convection. By this mechanism vast quantities of meteoric water circulate through the cooling intrusion and heat is transferred outward into the country rocks

(Taylor, 1979; Parmentier and Schedl, 1981). Furthermore, virtually identical alteration types are seen in the country rocks around the Balachey Pluton and it would be difficult to argue that this alteration is anything but hydrothermal (Fig. 43).

Therefore, one might make the argument, based on similarities with the Balachey Pluton that the upper syenite, composed mostly of albite, is equivalent to the inner albite zone of the Balachey halo and that the magnetite-apatite-actinolite zone is represented by the fracture coatings of apatite in the syenite, the veins of magnetite-apatite-actinolite in the border phase, and the larger bodies of magnetite-apatite-actinolite above its roof (see Fig. 43). Similarly, the large sulphide zones which host the polymetallic ore veins of Terra Mine, located on Terra Peninsula, could be the sulphide halo.

The iron, calcium, phosphorous, and magnesium of the magnetite-apatite-actinolite bodies could have been derived from the albitite veins, which are depleted in those elements relative to the rest of the syenite (Hildebrand, 1982). Volumetrically there was enough iron, calcium, magnesium, and phosphorous lost from the veins to easily produce the volume of those elements present in the magnetite-apatite-actinolite bodies. It is hypothesized that the albitite veins were the main fluid pathways during hydrothermal alteration and represent the zones of greatest alteration and consequent depletion.

The tremendous increase in sodium in the upper half of the intrusion relative to the lower half requires a source for that element other than the pluton or the country rocks because neither is depleted in sodium. NaCl-rich brines may have remained as intergranular fluids in marine sandstones of the Conjuror Bay Formation, present just beneath the intrusion. Fluid inclusion work, not yet done, should test this hypothesis.

Bookstrom (1977) interpreted magnetite-actinolite deposits at El Romeral, Chile as products of hydrothermal alteration while Fiske et al. (1963) attributed magnetite-apatite-actinolite bodies above the roof of the Tatoosh Pluton, Washington, to volatile streaming. The bodies at Great Bear Lake are similar to magnetite-apatite-actinolite deposits at Kiruna, Sweden (Geijer and Odman, 1974) and in the St. Francois Mountains, Missouri (Snyder, 1969). Both the Rainy Lake Intrusive Complex and Balachey Pluton have many features in common with the Tatoosh and other epizonal plutons described in the literature (Table 3).

White Eagle Tuff

The White Eagle Tuff is a densely welded ash-flow sheet and associated breccias named for exposures near White Eagle Falls along the Camsell River between Clut Lake and Balachey Lake. It generally lies unconformably on the Camsell River Formation, but on the mainland south of Conjuror Bay it lies on Moose Bay Tuff. Northeast from Clut Lake to north Balachey Lake the formation is overlain by clastics of the Uranium Point Formation. It is overlain by Animal Andesite north of Balachey Lake, while in the south-east Conjuror Bay area and east of Clut Lake the tuff is found beneath the "younger ash-flow tuffs".

Distribution and Thickness

The White Eagle Tuff is exposed almost continuously in a 2 to 4 km wide north trending belt from Grouard Lake nearly to Conjuror Bay (Fig. 2), a distance of about 20 km. There the tuff is exposed in a series of open northwest trending folds with axes that plunge shallowly northwestward so that the base of the tuff is exposed only in the southeast, on Clut Island and on the eastern isthmus between Clut Lake and Grouard Lake. There is no complete section exposed throughout the entire belt, which makes accurate measurement of its thickness impossible. Continuous sections in excess of 1.5 km thick are, however, exposed in fold limbs.

All along the southwest margin of this belt the tuff interfingers with and grades into the coarse sedimentary breccia which unconformably overlies the Balachey Pluton. This breccia is here termed the mesobreccia member of the White Eagle Tuff.

The tuff is also well exposed south and west of Animal Lake. About 30-40 m of nearly flat lying tuff occur south of the lake but the top of the unit is not exposed. To the west of the lake White Eagle Tuff is a maximum of 500 m thick.

Exposures of the tuff are also found on islands in eastern Conjuror Bay and on the mainland south of the bay. At those localities the tuff is nowhere thicker than 200 m but sections are not complete.

General Lithology

The bulk of the White Eagle Tuff is a composite ash-flow sheet, composed of densely welded and devitrified andesitic to dacitic ash flows (Hildebrand, 1982). Partially welded tuff is present only at the top and bottom of the unit in the thinner preserved sections west of Balachey Lake. Also included within this unit are minor beds of conglomerate and crystal tuff found only northwest of Balachey Lake.

Exposures of ash-flow tuff at the southeast end of Clut Lake contain altered and fractured blocks of Camsell River Formation up to 1 km in diameter and a few blocks of Balachey Pluton ranging up to 100 m across. Several large blocks with brecciated margins have many smaller fragments of the same rock type around them. In a crude way the size of the blocks becomes larger in stratigraphically higher sections of the tuff (Hildebrand, 1983b). Where blocks are

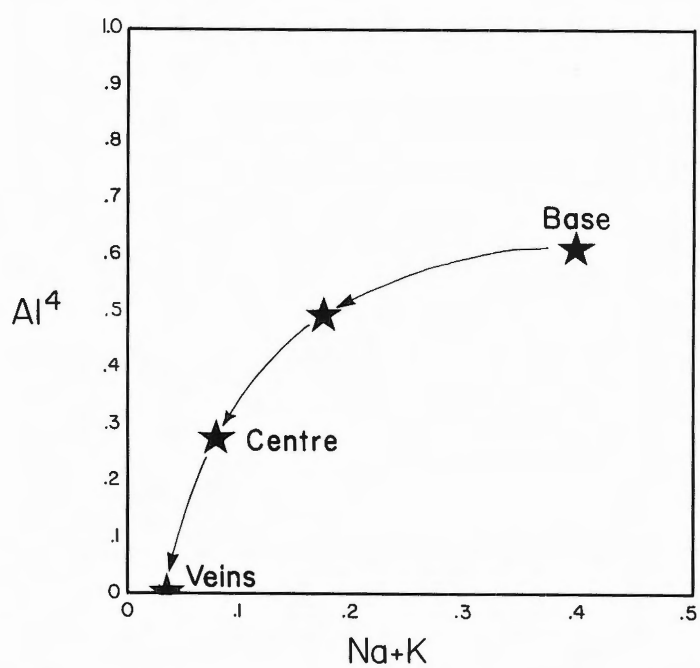

Figure 47. *Composition of amphiboles in the Rainy Lake Intrusive Complex plotted in terms of atoms of tetrahedrally co-ordinated aluminum versus atoms of sodium and potassium (data from Hildebrand, 1982).*

Table 3. Comparison of epizonal plutons (modified after Schweickert, 1976)

	Cloudy Pass Batholith[1]	Tatoosh Pluton[2]	China Garden Pluton[3]	Rainy Lake Intrusive Complex[4]	Balachey Pluton[4]
Chief rock type:	grano-diorite	grano-diorite	quartz monzonite	monzo-diorite	quartz monzonite
Euhedral plagioclase:	common	common	common	common	common
Interstitial quartz and K-feldspar:	yes	yes	yes	yes	yes
Plagioclase replaced by late feldspar and quartz:	yes	?	yes	yes	yes
Rocks altered:	yes	yes	yes	yes	yes
Chilled borders:	yes	yes	yes	yes	yes
Porphyritic facies:	yes	yes	yes	yes	yes

[1]Cater (1969); [2]Fiske and others (1963); [3]Schweickert (1976); [4]This report

numerous the tuff contains abundant xenocrysts of green amphibole similar to green amphiboles found filling vesicles in andesite flows of the Camsell River Formation.

Elsewhere the tuff varies in lithic content but is typically lithic-rich with lithics generally making up 10-20 per cent of the rock. In a few areas lithic fragments of foliated granitoids occur and are similar to rocks forming plutons of the Hottah Terrane.

Phenocryst abundance and size in the White Eagle Tuff were not studied in detail but total phenocryst content typically ranges from 25-35 per cent of the rock (Fig. 48). The phenocrysts in the rock are broken crystals of plagioclase, amphibole, biotite, and quartz, along with subhedral to euhedral microphenocrysts of magnetite. In general the phenocrysts are less than 3 mm in diameter but a few are as large as 5 mm.

In stratigraphically deeper levels of exposure the tuff contains 1-2 per cent quartz whereas quartz is generally very sparse, if present at all, in the upper parts.

Pumice, typically highly flattened, is present in nearly all exposures but in some thick sections is partially obscured by welding, devitrification, and/or post-depositional alteration. West of Balachey Lake and in the Conjuror Bay area black fiamme 10-15 cm in diameter and 1 cm thick are very conspicuous.

Petrography

Thin section examination of the White Eagle Tuff shows that it chiefly contains broken crystals of plagioclase up to 3 mm long, now ubiquitously replaced by carbonate and epidote, in a massive groundmass of finely intergrown quartz, feldspars, sphene, chlorites, and optically unresolvable alteration minerals that typically mask original textures. However, in a few specimens collected high in the sheet, well preserved vitroclastic textures were seen. Ragged plates of biotite (to 1 mm) completely altered to epidote, chlorite, and opaque oxides make up no more than 5 per cent of the bulk. Amphibole, as large as 3.5 mm, makes up another 1 or 2 per cent of the total and it too is typically altered to assemblages of epidote and carbonate. There are typically a few small (0.5 mm) quartz chips present but they only make up slightly more than 1 per cent of the bulk in the stratigraphically lowest parts of the tuff. Opaque iron-titanium oxides most commonly occur as tiny grains in altered biotite, but are also present as anhedral microphenocrysts less than 1 mm across.

Mesobreccia Member

The informal term mesobreccia member is here applied to the thick local assemblage of breccias along the northeastern margin of the Balachey Pluton (Fig. 2). The mesobreccia member interfingers with the ash-flow tuff and in many places is gradational with it. In the field the units were mapped on the basis of matrix type. That is, if the matrix was muddy or silty it was mapped as mesobreccia, but if tuffaceous it was assigned to the ash-flow tuff. Relationships between the two units are illustrated in Figure 2. From this it can be seen that the mesobreccia occurs as northeastward thinning wedges. The stratigraphically lowest part of the breccia is not exposed but presumably it rests on Camsell River Formation as does the ash-flow tuff. The breccia is overlain by the Uranium Point Formation. The unconformity (see section on Balachey Pluton contacts) with the Balachey Pluton is nearly always vertical, but locally is roughly horizontal so that the contact is steplike in cross-section (Fig. 33).

The mesobreccia is generally an unsorted mixture of clasts (1 cm to 2 m in diameter) and matrix, in places clast supported and in others matrix supported (Fig. 49 and 50). The breccia is poorly bedded and typically massive but in places there are graded beds and discrete zones which contain only pebbles and blocks of Balachey Pluton. The dip of these units is presently less than 15° to the northeast.

The clast population varies considerably from place to place. Generally, exposures closer to the Balachey Pluton contain a higher proportion of Balachey Pluton clasts than do those farther from the contact. Other common clast types are altered fragments of Camsell River Formation, pebbles of magnetite and sulphides, and cobbles of a distinctive quartz-plagioclase porphyry of unknown provenance.

Clast shapes span the entire range from rectangular to spheroid and both extremes are commonly found adjacent to one another in the same breccia tongues. Some Balachey clasts are nearly perfect quadrilaterals suggesting that they are still bounded by original joint surfaces.

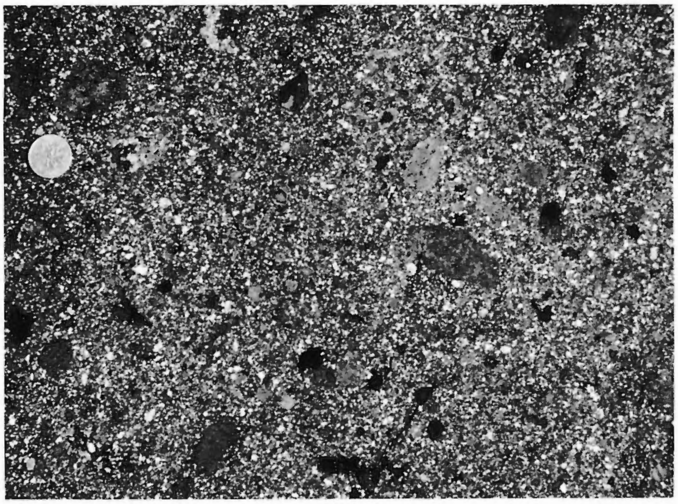

Figure 48. *Crystal, lithic-rich tuff typical of intracauldron facies of White Eagle Tuff, 2 km east of Uranium Point. (GSC 190516)*

Figure 49. *Detail of mesobreccia member of White Eagle Tuff showing angular fragments of Balachey Intrusive Complex, Uranium Point. (GSC 190617)*

Interpretation

The abrupt pinch-out of tremendously thick sections of the tuff, coupled with the zones of megabreccia, indicate that most exposures of the White Eagle Tuff represent intracauldron facies tuff. The thin simple cooling units exposed south and west of Animal Lake and in the Conjuror Bay area are not propylitized, contain abundant pumice, and have unwelded, or poorly welded bases. Therefore, they are most easily and logically interpreted as remnants of the outflow sheet. The name, Clut Cauldron, is proposed for the cauldron because it is so well exposed near Clut Lake.

The gargantuan blocks of Camsell River Formation and Balachey Pluton that occur in the tuff south of Clut Lake probably represent material which spalled from the steep caldron walls during collapse of the cauldron. This, along with the order of magnitude thickness difference between the intracauldron and outflow facies tuff, clearly demonstrates that subsidence occurred simultaneously with ash-flow eruptions. The crude inverse grading of blocks may indicate that relief on the wall increased with time. This suggests that ash-flow volcanism was not able to keep pace with subsidence.

The occurrence of the mesobreccia member as northeastward thinning wedges, coupled with the nearly ubiquitous clasts of Balachey Pluton which become more common towards the intrusion, indicate that the breccia was derived from the southwest. The interfingering relationships of the breccia with the White Eagle Tuff indicate that deposition of the breccia went on contemporaneously with eruption and deposition of the tuff.

As mentioned in the section on the Balachey Pluton, the unconformity between the breccia and the Balachey Pluton is presently a nearly vertical buttress facing northeast. When the shallow northeastward dips of the breccia are returned to a horizontal position the unconformity still dips steeply to the northeast indicating that the contact remained as a steep scarp during deposition of both the breccia and the White Eagle Tuff.

The above relations are interpreted to indicate that the mesobreccia represents material shed from the southwest wall of Clut Cauldron during collapse of the central block of the cauldron. Similar deposits have been described in Tertiary cauldrons by several workers (Lipman, 1976; Ratté and Steven, 1967; Lambert, 1974).

Uranium Point Formation

This is a unit, dominantly composed of interbedded sandstone, siltstone, mudstone, and pyroclastic rocks, which conformably overlies both the mesobreccia and intracauldron facies White Eagle Tuff. It is overlain by Animal Andesite. The lower contact of the formation is defined as the first sandstone or siltstone bed above the White Eagle Tuff while the upper contact is placed at the base of the first lava flow.

The Uranium Point Formation outcrops northeast of the Balachey Pluton (Fig. 2) and is a maximum of 80 m thick. It is not present outside Clut Cauldron.

Beds of sandstone-siltstone range in thickness up to 1 m and are composed of angular to subangular volcanic debris. They are generally planar bedded but locally ripple drift and low angle cross-lamination were seen. Siltstones and sandstones are often draped with laminations of purplish mudstone. Convolutions are common where there is abundant mudstone. Beds of mudstone range from paper-thin laminations to 15 mm thick and are typically continuous on an outcrop scale.

Some of the sandstones are pebbly with a wide variety of typically subrounded to angular volcanic clasts of unknown provenance. Angular chips and flat pebbles of carbonate are common in some beds (Fig. 51). Two outcrops of pebbly conglomerate were found but they were not of sufficient size to determine the bed geometry.

Commonly interbedded with the clastic units, especially in the northwest, are ashstones and devitrified crystal and lapilli tuffs. These beds are laterally continuous and average about 15 cm thick. Whereas most are probably of airfall origin some are crossbedded and rippled indicating that they were reworked. At the northwest end of Balachey Lake the top of the unit contains ash-flow tuff with well-developed eutaxitic structure. The tuff is a simple cooling unit that weathers orange-red or purple. It is about 30 m thick. The upper portion of the tuff is extremely lithic-rich and contains about 50 per cent aphanitic volcanic rock chips.

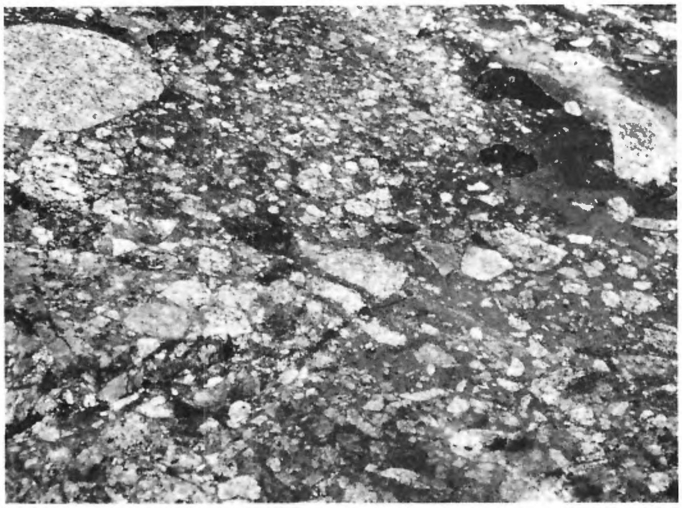

Figure 50. *Rounded and angular clasts of Balachey Intrusive Complex in muddy matrix, mesobreccia member, White Eagle Tuff, west side of Clut Lake. (GSC 190583)*

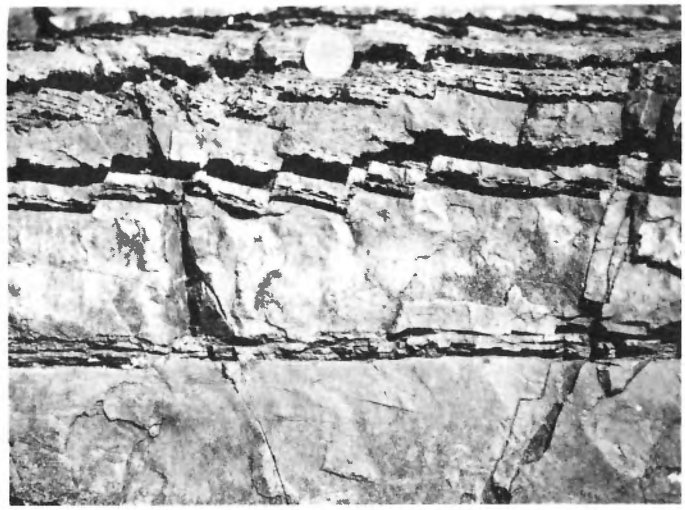

Figure 52. *Synsedimentary normal faults in interbedded sandstone and mudstone, Uranium Point Formation, Uranium Point. (GSC 190520)*

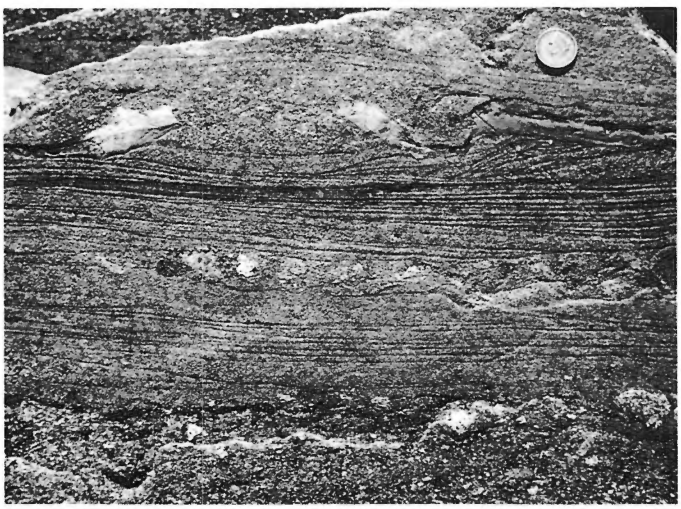

Figure 51. *Crossbedded and ripple-laminated volcanogenic sandstone holding angular carbonate fragments, Uranium Point Formation, north side of Balachey Lake. (GSC 190546)*

Figure 53. *Slump fold in alternating mudstone-ashstone, Uranium Point Formation, Uranium Point. (GSC 190519)*

Two common features of the finer units, both clastic and pyroclastic, are the occurrence of synsedimentary normal faults (Fig. 52) and slump folds (Fig. 53). Measurements of both features indicate that slumping was toward the southwest, that is, toward the wall of Clut Cauldron (see Fig. 51).

Bouldery and cobbly clastic dykes up to 1 m wide and commonly carrying clasts of Balachey Pluton occur locally. They have a sandy to muddy matrix.

Interpretation

The abundance of fine clastic detritus coupled with the general lack of current structures suggests that Uranium Point Formation was deposited in relatively quiet water. The stratigraphic position of the unit above and below subaerial units and its local distribution make a marine origin unlikely. Thus, a lacustrine environment is favoured for the deposition of the formation.

The presence of the unit only inside Clut Cauldron suggests that lake(s) developed in the topographic depression remaining after collapse of the cauldron. Periodic volcanic eruptions from unknown sources occasionally deposited pyroclastic units within the lake.

The southwest-directed slumping and synsedimentary normal faulting suggest that the central part of the cauldron was uplifted during or shortly after deposition of the Uranium Point Formation. This uplift or resurgence is thought to be related to the emplacement of the Calder Quartz Monzonite more or less in the central parts of Clut Cauldron.

Calder Quartz Monzonite

Hornblende-biotite quartz monzonite and minor monzogranite are exposed in a 100 km^2 wedge-shaped area extending west from the Calder River to Ghosty Lake and south at least as far as Grouard Lake. The unit is here named Calder Quartz Monzonite after its exposures west of the Calder River.

The southwestern contact of the body is intrusive, cuts only the White Eagle Tuff, and roughly parallels the southwestern margin of Clut Cauldron at a distance of about 8 km. The original extent of the pluton to the north-northeast is unknown as it was intruded by the Hooker Megacrystic Granite.

Seriate quartz monzonite is characteristic of the unit (Fig. 54). Subhedral tablets of plagioclase (to 5 mm) are surrounded by potassium feldspar, quartz and ferromagnesiam minerals. Commonly the plagioclase forms glomeroporphyritic clots containing from 3 to 6 crystals. Biotite is always more common than hornblende with the combined total ranging from 8 to 15 per cent of the rock. Both often form clots.

Xenoliths of volcanic rocks are generally sparse but where they do occur they are typically less than 0.5 m across and strongly altered. Compositionally the Calder Quartz Monzonite is very similar to the White Eagle Tuff (Hildebrand, 1982), although exact matching is ruled out due to loss of vitric ash during eruption, post-eruptive alteration, and alteration of the pluton resulting from interaction with ground water during cooling.

Interpretation

The compositional similarity of the Calder Quartz Monzonite to the White Eagle Tuff and the fact that the southwest contact of the pluton parallels the margin of Clut Cauldron suggest that it may be a subcauldron pluton. The emplacement of the pluton might then be responsible for the doming or resurgence of the central part of the cauldron suggested by the direction of slumping in the Uranium Point Formation as shown in Figure 55.

Animal Andesite

Animal Andesite is an accumulation (>1 km) of pargasitic and augite porphyritic andesite lava flows, breccia and tuff which occur in the core of a broad syncline north of the Balachey Pluton (Fig. 2). The formation overlies the Uranium Point Formation and is overlain by the "younger ash-flow tuffs." It is named for exposures north of Animal Lake.

Lavas of the formation are easily separated from those of the Camsell River Formation by their stratigraphic position and their lesser degree of alteration. They are also less plagioclase porphyritic, sometimes nearly aphyric, and have fewer amygdules than andesites of the Camsell River Formation. In the field, amphibole, pyroxene and plagioclase phenocrysts are commonly visible. Large quartz and potassium feldspar xenocrysts are also characteristic of some of the lavas.

The lower contact of the formation is often well exposed and sedimentary rocks of the Uranium Point Formation are baked and altered. In places the sedimentary rocks are caught up in the basal few metres of the lowest flow in the pile.

In general, lava flows of Animal Andesite are massive with minor columnar joints, although one flow-banded lava was found (Fig. 56). Platy jointed bases are common in most flows but some flows have autobrecciated margins. The flows are shades of dark grey and reddish purple on fresh surfaces and a light brown or grey on weathered surfaces.

Due north of Balachey Lake the lava flows are intercalated with andesitic breccias and tuff. Beds are generally massive to poorly graded. Block and bombs within them are often oxidized to a purplish red and are scoriaceous. An oval-shaped pipe of intrusive andesite, which may represent a feeder for the pyroclastic units and/or lava flows, is exposed in this area. This local assemblage probably constitutes a small, composite cone created by Strombolian eruptions and quiet effusions of less gas-charged lava.

Petrography

Lavas of the Animal Andesite are aphanitic to porphyritic dark rocks containing variable proportions of plagioclase, clinopyroxene, and amphibole. A summary of the modal composition of various lavas is given in Table 4.

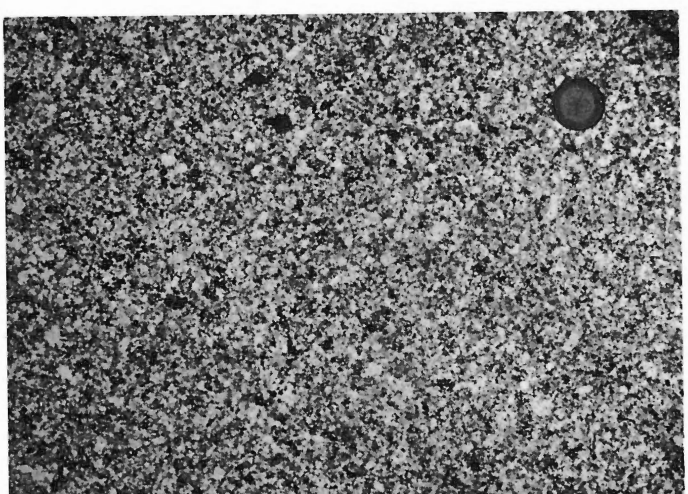

Figure 54. *Seriate quartz monzonite of Calder Quartz Monzonite. North side of Clut Lake. (GSC 190510)*

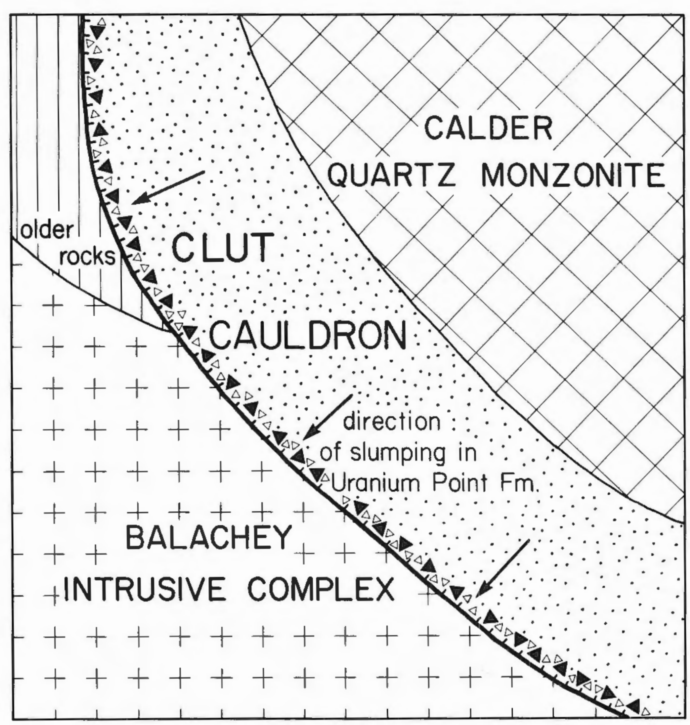

Figure 55. *Palinspastic reconstruction of southwestern Clut Cauldron showing relationship of Calder Quartz Monzonite to cauldron margin.*

Figure 56. *Flow banding, Animal Andesite lava flow, 1 km east of Animal Lake. (GSC 190614)*

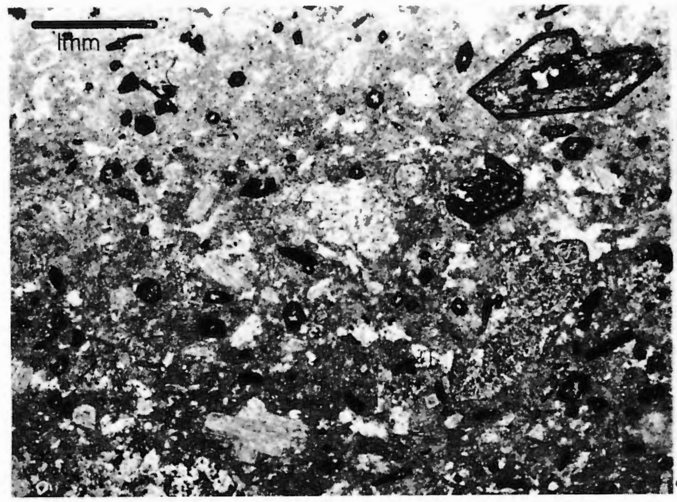

Figure 58. *Photomicrograph of amphibole porphyritic andesite flow, Animal Andesite, north of Animal Lake. Note opacitic rims. (GSC 190601)*

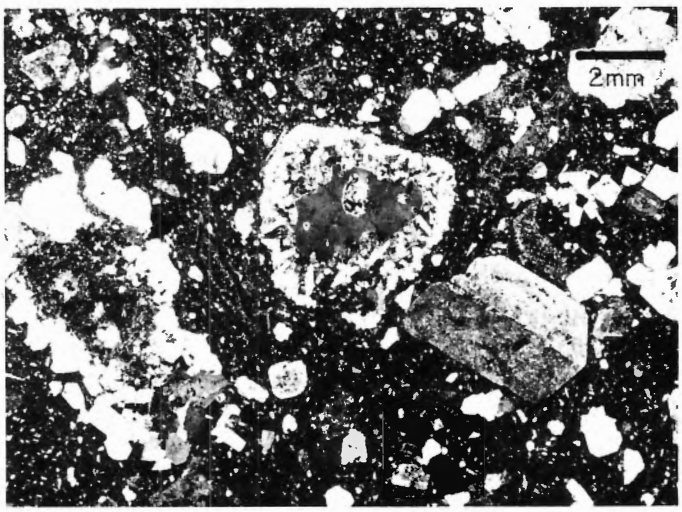

Figure 57. *Clinopyroxene armoured quartz xenocrysts (centre), altered K feldspar xenocryst, and clinopyroxene clots, Animal Andesite. (GSC 190611)*

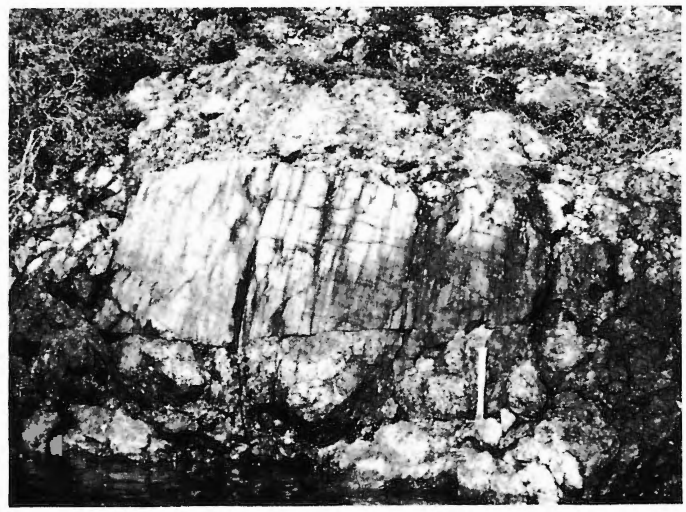

Figure 59. *Large block in basal lag of ash-flow tuff, younger ash-flow tuffs, Conjuror Bay. (GSC 190579)*

Every flow is altered to some degree. Some are relatively fresh with only incipient alteration of feldspar phenocrysts. Others are strongly propylitized with complete saussuritization of plagioclase and replacement of amphiboles and/or pyroxenes by carbonate and chlorite. In those rocks original groundmass textures are partially or completely destroyed by the formation of anhedra of feldspar and quartz. In less altered samples phenocrysts are commonly set in either an orthophyric or pilotaxitic matrix. A few flows are microdiktytaxitic while others are intersertal.

Plagioclase phenocrysts, up to 5 mm long, are commonly zoned with cores ranging from andesine to medium labradorite (An_{55}-An_{61}) and rims of oligoclase (An_{15}-An_{25}). In many of the altered flows plagioclase may be completely albitized or have albite rims. Several flows contain poorly terminated plagioclase phenocrysts with tiny inclusions of chlorite, clinopyroxene, and quartz, perhaps after glass. In some of the phenocrysts inclusions are so numerous that the phenocrysts have a skeletal appearance. In many rocks distinction between phenocrysts and groundmass microlites is arbitrary because crystals intermediate in size are also present.

Pyroxene forms stubby prisms as long as 7 mm and anhedral grains or subhedral prisms in the groundmass. The phenocrysts are calcic clinopyroxene, mostly augite (Hildebrand, 1982). They are dark green to black in hand specimen. Round and irregular-shaped crystal clots of subhedral-anhedral augite are a common constituent. The largest one observed was irregular in shape and 8 mm in diameter. Similar clots have been described in calc-alkaline andesites by Stewart (1975) and by Garcia and Jacobson (1979).

Strongly resorbed quartz xenocrysts, up to 5 mm, are common in lavas north of Balachey Lake. The xenocrysts are typically armoured by coronas of augite microphenocrysts (Fig. 57). The microphenocrysts are often arranged so that their long axis is orthogonal to the surface of the xenocryst. Nests of slender apatite needles are a common accessory in the coronas. Coronas of clinopyroxene are commonly found around quartz xenocrysts in various regions of the world in both extrusive and intrusive rocks of intermediate to mafic composition (Muir, 1953; Kuno, 1950; Doe et al., 1969; Sato, 1975).

Table 4. Modal analyses of Animal Andesite, lava flows

Sample no.	%groundmass	%pyroxene	%plagioclase	%amphibole	%opaques	%quartz xenocrysts
H-80-91	94	5	---	1	---	
H-80-96	69	22	1	---	8	---
H-79-164	56	28	---	12	4	---
H-79-104	56	9	30	---	5	---
H-79-105	66	10	20	---	4	---
H-79-142	68	---	24	5	3	---
J-80-75	78	11	9	1	1	---
J-80-76	89	6	1	---	2	2
P-79-109	67	9	19	---	5	---
P-79-82	82	1	12	3	2	---
H-80-90	89	6	2	2	1	1
H-80-89	76	20	1	---	2	1
H-80-92	89	4	5	1	1	---
H-80-93	79	15	2	2	1	1
H-80-86	81	12	---	5	2	---
H-80-88	70	21	5	3	1	1
P-79-72	67	---	23	8	2	---
P-79-95	80	---	6	12	2	1

Models based on 1000 points/thin section. Figures rounded to nearest per cent.

Prisms of amphibole (less than 3 mm) are typically pargasitic (Hildebrand, 1982) and nearly always display some type of reaction relationship (Fig. 58). Some are completely pseudomorphed by opacite and are highly corroded. In others there is only a thin rind of pyroxenes, plagioclase, and opaque oxides. In one flow there are opacitic rims around resorbed pargasite phenocrysts which indicates that the amphiboles were out of equilibrium with the melt prior to dehydration. Opacitic amphiboles are especially common in calc-alkaline volcanic rocks and are usually attributed to a drastic reduction in water pressure during, or just prior to eruption (Kuno, 1950; Stewart, 1975; Garcia and Jacobson, 1979).

Interpretation

The local accumulations of blocks and bombs, 1 km thick sections of lavas, and lack of intercalated sedimentary rocks are characteristic of near-source areas of andesitic stratocones. Animal Andesite is preserved both inside and outside Clut Cauldron which may indicate that vents were located in both areas, or perhaps that there was little relief on the cauldron margin during eruption of the andesites.

The most siliceous samples of Animal Andesite have similar silica contents to the least siliceous samples of White Eagle Tuff yet the lavas have higher concentrations of Rb, Zr, and Ba (Hildebrand, 1982). Therefore, the two units do not appear to have been genetically related by mixing, crystal fractionation of observed phases, or assimilation of quartz and potassium feldspar, because none of those mechanisms can increase Rb, Zr and Ba downward in a magma chamber and maintain the same silica value. Soret or thermogravitational diffusion, as advocated by Grout (1932) and Hildreth (1981), could reproduce the chemical variation for most of the elements but not for Rb or SiO_2, both of which appear to be concentrated upwards by that mechanism. Therefore, magma erupted as Animal Andesite was probably a different batch than that which erupted the White Eagle Tuff.

"Younger ash-flow tuffs"

The youngest stratigraphic unit of the area is a compositionally diverse sequence of apparent simple cooling units of ash-flow tuff and minor intercalated sedimentary rocks here informally termed the "younger ash-flow tuffs". They range in composition from andesite to rhyolite but the more siliceous compositions dominate (Hildebrand, 1982). The younger ash-flow tuffs appear to rest on White Eagle Tuff in the Conjuror Bay area and in the extreme south-eastern part of the map area. There is a small area on the mainland east of Conjuror Bay where they overlie Animal Andesite. Relations with the Calder Quartz Monzonite are not exposed. Nowhere in the map area was the top of this unit found.

Distribution and Thickness

Extensive erosion has left only a fragmentary record of the distribution of the younger ash-flow tuffs; they outcrop in just two regions of the map area: on islands in Conjuror Bay and on the mainland east of Clut Lake (Fig. 2). The two areas were not studied in enough detail to correlate individual cooling units between them but overall lithologies and stratigraphic position above older units are generally similar. It is, however, possible that the cooling units in the two areas are not the same age.

In the Conjuror Bay area the thickness of the unit is perhaps 1.5 km but faulting and lack of continuous exposure due to the water of Conjuror Bay make exact thickness estimates unreliable. The thickness of the pile east of Clut Lake is even greater but there much of the pile is not very eutaxitic and the top of the unit is not exposed.

Lithological Description

The younger ash-flow tuffs are an assemblage of cooling units whose individual thicknesses are generally in the order of 100-250 m. Cooling units were distinguished in the field on the basis of sedimentary intercalations and unwelded zones.

Many of the ash-flow units of the younger ash-flow tuff generally contain modal potassium feldspar which helps to distinguish them from White Eagle Tuff which generally does not contain modal potassium feldspar. Three of the cooling units, and their intercalated sedimentary rocks, located in the Conjuror Bay area are discussed here.

Cooling unit 1. The lowest cooling unit in the Conjuror Bay area is a rhyolitic tuff about 200 m thick which has a 20 m thick basal bouldery zone. Boulders in this part of the tuff range up to 3 or 4 m in diameter and are closely packed in a tuffaceous matrix (Fig. 59). In a recent paper Walker et al. (1981) have attributed basal bouldery zones of ash flows to differential settling during flow.

The basal zone grades up into a 10-15 m thick zone which contains large sheath folds (Fig. 60) (see Cobbald and Quinavis, 1980). The folds are primary flow folds (Chapin and Lowell, 1979) which have rotated into the flow direction during the final stages of flow. The fold axes now parallel the lineation. Above the flow-folded zone, and gradational with it, the tuff is brick red and contains abundant flattened pumice fragments with a weak lineation. Those parts of the cooling unit above the flow-folded zone display well developed columnar jointing. This jointing is especially evident in upper parts of the tuff where it weathers crumbly due to poor welding.

In general, the tuff is lithic-rich with angular chips and pebbles of a wide variety of rock types locally making up to 10 per cent of the rock, except in the aforementioned basal zone where lithics are more abundant than tuffaceous material.

The top of this tuff is poorly exposed but appears to be covered by a metre of laminated rhyolitic ashstone, which may represent airfall material related to the eruption which produced the youngest ash flow in the cooling unit.

One-half kilometre west, this horizon is represented by slightly cobbly, planar bedded, lithic arkose with fine partings, minor rippled tops, and in places mudcracks. Beds are generally 5 cm to 1 m thick. Ripple crests indicate that the sandstones were derived from either the north or the south and the angularity of nearly all grains suggests that provenance was local.

Cooling unit 2. Overlying the thin sedimentary interval is another cooling unit of rhyolitic ash flow tuff about 150 m thick. This tuff also has a bouldery base but fragments (less than 0.5 m) are not nearly as large as those of the lower cooling unit.

Above the unwelded bouldery base the tuff is incipiently welded and is crystal poor. It weathers light grey. Lapilli, most of which are pumice, constitutes 10 to 20 per cent of the unit and pebble-size lithic fragments make up another 10 per cent.

Within 10 m upsection the tuff is densely welded and weathers brick red with well developed columnar jointing. Crystal fragments increase in abundance upsection.

The top of the tuff is marked by another epiclastic interval. At least one large (15 m) intensely fractured block of rhyolitic to dacitic ashstone and crystal tuffs intercalated with hematitic red mudstone beds, 10 to 30 cm thick, occurs in this interval. Locally there are minor conglomerates and devitrified ashstone beds. The conglomerates are clast supported and contain subrounded to rounded boulders and cobbles of andesite, white chert, and rhyolite in a fragmental matrix of angular sand grains.

One hundred metres to the west are spectacular outcrops of densely welded ash-flow tuff. This tuff is very eutaxitic with flattened pumice fragments up to 50 cm long. Up section black fiamme are conspicuous (Fig. 61) and lithophysael cavities of vapour phase origin are found beneath lithic fragments. Phenocrysts in this tuff are plagioclase, quartz, potassium feldspar, chloritized biotite and altered pyroxene. The tuff was folded prior to eruption and deposition of the next highest cooling unit in the section. The folding may be due to slumping.

Cooling unit 3. The above sequence is unconformably overlain by the basal unwelded zone of the next cooling unit in the sequence which may be 400 m thick but parts are underwater and not exposed. Although the tuff is generally phenocryst-poor at the base, quartz appears as the dominant phenocryst in the field about 20 m above the lower contact. It is conspicuous for only a few tens of metres. Biotite appears in hand specimen midway through the cooling unit. The tuff is strongly eutaxitic (Fig. 62) except near the base and the top of the cooling unit. Lithic fragments make up to 15 per cent of the bulk.

Figure 60. *Sheath fold above basal lag breccia, younger ash-flow tuffs, Conjuror Bay. (GSC 190582)*

Figure 61. *Densely welded ash-flow tuff showing dark black fiamme, cooling unit 2, younger ash-flow tuffs, Conjuror Bay. (GSC 190548)*

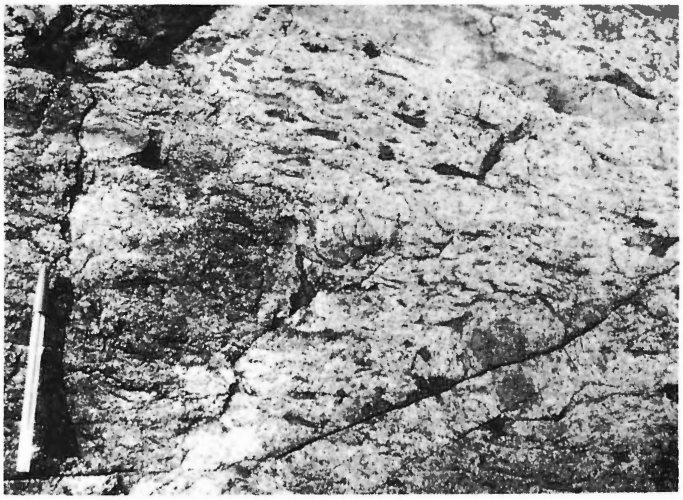

Figure 62. *Eutaxitic foliation in cooling unit 3, younger ash-flow tuffs, Conjuror Bay. (GSC 190515)*

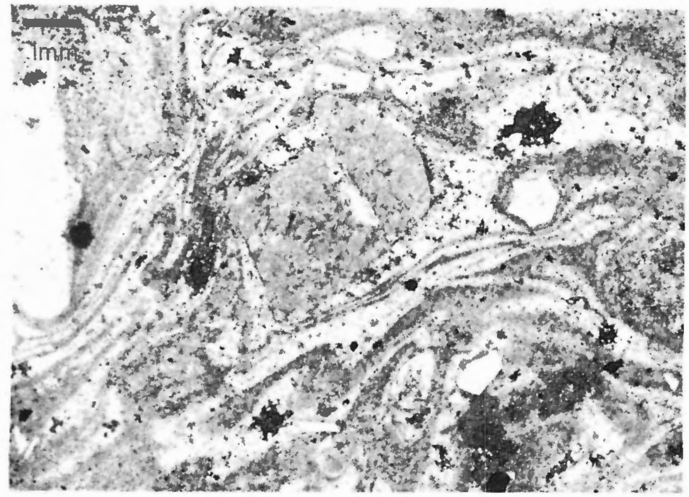

Figure 63. *Photomicrograph of densely welded ash-flow tuff showing well preserved vitroclastic texture, younger ash-flow tuffs. (GSC 190615)*

Petrography

All of the original glass in the "younger ash-flow tuffs" has devitrified to cryptofelsite, yet vitroclastic textures are remarkably well preserved (Fig. 63). Every ash flow of the unit is porphyritic. Modal analyses of several units are presented in Table 5. Only cooling unit 1 in the Conjuror Bay section which is mineralogically typical of the younger ash-flow tuffs is described here. The unit contains phenocrysts of quartz, orthoclase, plagioclase, and altered pyroxene in a reddish oxidized matrix crowded with devitrified shards, many of which are bent around phenocrysts giving the rock a pronounced fluidal banding. Nearly all shards are rimmed by opaques. Approximately 5 per cent of the tuff is made up of shattered, cracked and embayed bipyramidal euhedra of quartz, some of which reach 5 mm across. Tabular phenocrysts of orthoclase, measuring up to 3 mm, are cracked, corroded and make up about 10 per cent by volume. Broken and twinned tabular plagioclase, from minute specks to chips measuring 4 mm, constitute 5 percent of the bulk and contain tiny red euhedra of hematite. Relict pyroxenes (less than 2 mm) make up less than 1 per cent of the rock. All are replaced by chlorite and opaque oxides.

In the middle part of the cooling unit quartz is slightly more abundant and orthoclase phenocryst fragments are larger (4 mm). The matrix is completely recrystallized to microfelsite dusted with hematite.

Altered mafic minerals increase in number upwards in the tuff and reach 4 per cent in the stratigraphically highest thin section examined. The percentage of small crystal chips increases to about 30 per cent of the bulk.

Interpretation

The younger ash-flow tuffs are all simple cooling units of medium thickness. Therefore, they are probably remnants of outflow facies tuff. The tuffs appear to fill topographic depressions, probably stream valleys, as evidenced by the intercalated sandstone and conglomerate. Most cooling units are mineralogically zoned and therefore probably erupted from compositionally zoned magma chambers but the chemical variations within single cooling units were not studied. The sources for the tuffs are unknown and probably lay outside the map area.

"KQP" Porphyry

This is a porphyritic intrusion comprising potassium feldspar, quartz, and plagioclase phenocrysts in a pinkish aphanitic matrix. It is a sill-like body that intrudes the base of the Moose Bay Tuff from Black Bear Lake to Conjuror Bay (Fig. 2). The sill is also present on islands in Conjuror Bay where it intrudes the younger ash-flow tuffs. There, the body follows the topographic margin of Black Bear Cauldron. The porphyry itself is intruded by the quartz diorite suite and is therefore older than that suite.

On islands in Conjuror Bay the intrusion contains abundant xenoliths of Bloom Basalt. Most of the basalt blocks are intensely brecciated and altered.

Examination of thin sections of the porphyry show that it contains rounded and embayed quartz phenocrysts (5 mm), chloritized biotite (1 mm), euhedral to subhedral, sericitized plagioclase, and euhedral-subhedral microperthite in a

Table 5. Modal analyses of "younger ash-flow tuffs"

Sample no.	%plagioclase	%quartz	%K-spar	%pyroxene	amph.+ %biotite	%opaque	%groundmass
H-79-182	9	19	9	4	--	<1	60
H-79-143	14	5	4	--	11	<1	67
P-79-129	21	7	--	3	4	<1	67
H-79-136	4	4	5	--	<1	<<1	86
H-79-137	7	11	8	1	--	<<1	72
H-79-138	2	5	10	2	--	<1	80

granophyric groundmass of quartz and alkali feldspar. Both the plagioclase and microperthite tend to form glomeroporphyritic clots up to 6 mm in diameter.

Interpretation

The granophyric groundmass of the intrusion indicates that it was emplaced relatively near the surface. The intrusion follows the topographic margin of Black Bear Cauldron and might be considered a ring pluton genetically related to the Moose Bay Tuff. However, it is clearly younger than even the Clut Cauldron and therefore probably not related to the older Black Bear Cauldron. This indicates that extreme caution must be exercised when interpreting ring dykes or plutons to be related to even a spatially related cauldron, for here is a case where the only relation between the two appears to be that the cauldron provided a zone of weakness for a much younger intrusion.

Quartz Diorite

These intrusive bodies are ovoid to laccolith-shaped quartz diorites generally less than 4 km in diameter. They occur south of the Balachey Pluton (Fig. 2). If all members of the suite are the same age then their emplacement must be later than the younger ash-flow tuffs because one member of the suite intrudes the potassium feldspar-quartz-plagioclase porphyry (Fig. 2) which itself cuts the younger ash-flow tuffs. As the quartz diorites are intruded by the Grouard dykes they must predate the late biotite syenogranites and thus are not part of the hornblende tonalite suite (G4) of Hoffman and McGlynn (1977).

In general, the bodies are texturally and mineralogically similar. They are fine-to medium-grained rocks consisting of sericitized plagioclase phenocrysts (<0.5 cm) in a fine grained matrix of quartz, albite, uralitic amphibole, chlorites, opaques and sphene.

Plagioclase Porphyry

Intruding the quartz diorite above the roof of the Rainy Lake Intrusive Complex is a pink to flesh plagioclase porphyry that is exposed in cross-section. It is roughly oval with a semiconcordant roof and floor. Contacts with all country rocks are razor sharp.

This unit was mapped by Badham (1972) as extrusive, but contact relations, such as local apophyses which cut and metamorphose the country rocks, clearly indicate its intrusive nature (Fig. 2). Country rocks, including the quartz diorites, are often brecciated adjacent to the contacts.

The body is texturally homogeneous. It consists throughout of albitized plagioclase euhedra 1-3 mm in length and irregular mafic clots, now altered to assemblages of chlorite, epidote, sphene, opaques, and carbonate, sitting in a fine grained mosaic of equigranular albite, orthoclase, and quartz.

Both the map pattern (Fig. 2) and evidence at individual outcrops indicate that the porphyry postdates the diorite bodies. Since, as argued earlier, the quartz diorites postdate the Rainy Lake Intrusive Complex, then the porphyry must also postdate the emplacement of the Rainy Lake Intrusive Complex.

Grouard Porphyries

North trending porphyritic dykes occur throughout the map area and are here termed the Grouard Porphyries after exposures at the north end of Grouard Lake. They postdate folding and cut all rock types except Cleaver Diabase and syenogranite plutons but are generally too small to show on Figure 2.

The dykes vary in width from 1 m to many tens of metres and are often continuous along strike for several kilometres. Variable amounts of plagioclase, hornblende, biotite, quartz, and potassium feldspar phenocrysts in a pink to brick-red aphanitic matrix characterize the dykes. Some contain all five phases whereas others contain only two or three. In some the margins are plagioclase-hornblende porphyritic while the more interior portions contain all five phases.

In some specimens euhedral bipyramids of quartz (5 mm) constitute 10-15 percent of the rock but in other samples the quartz is rounded and embayed by resorption. Plagioclase (to 10 per cent), often completely sericitized, forms subhedral to euhedral crystals up to 5 mm across. Microperthitic alkali feldspars (<2 cm) are subhedral-euhedral but are often broken. Prisms of hornblende (<2 mm) are occasionally fresh but more typically are altered to assemblages of sphene, chlorites, epidote, carbonate, and opaque oxides. Biotite, occurring as subhedral flakes up to 2 mm across, is partly or wholly altered to chlorite. In a few dykes, phenocrysts of magnetite occur as anhedral grains less than 1 mm in diameter. The groundmass is typically cryptocrystalline felsite which locally displays a mottled texture.

North Trending Mafic Dykes

These fine-grained dykes, not shown on Figure 2, occur mainly west of Smallwood Lake north and south of Rainy Lake. They trend nearly north and postdate the intrusion of the Grouard dykes. Their age relation relative to the Cleaver dykes is unknown but they are considerably more altered than those dykes and therefore probably older. Although these dykes are mostly less than 3-4 m across and are not especially numerous they are mentioned here because one of them cuts mineralized veins at Norex mine, located between Smallwood and Rainy lakes. This is an important relationship because this dyke is not the same age as diabase on Terra Ridge and because the vein it cuts contains Ni-Co arsenides on both sides of the dyke yet is silver-bearing on only one side (H. Sanche, personal communication, 1980).

Hooker Megacrystic Granite

Hornblende-biotite-alkali feldspar megacrystic syenogranite which cuts across folds in the area, underlies nearly 200 km^2 in the northeastern corner of the map area. It is here named Hooker Megacrystic Granite after its exposures at Hooker Lake, which lies to the north outside of the map area.

The contacts with wall rocks are always sharp. Adjacent to the contact there is commonly a border phase several metres wide consisting of patches of quartz-potassium feldspar porphyry, aplite, pegmatite, and graphic granite. Calder Quartz Monzonite appears little altered at the contact but is intruded by aplite dykes. Other rock types, such as White Eagle Tuff and Animal Andesite are visibly altered within 3-4 m of the contact and tend to weather pinkish, probably due to albitization. The dip of the contact is variable. In places it dips gently away from the pluton at about 30°, while in others it is nearly vertical. Locally the contact is horizontal and Hooker Megacrystic Granite overlies Calder Quartz Monzonite.

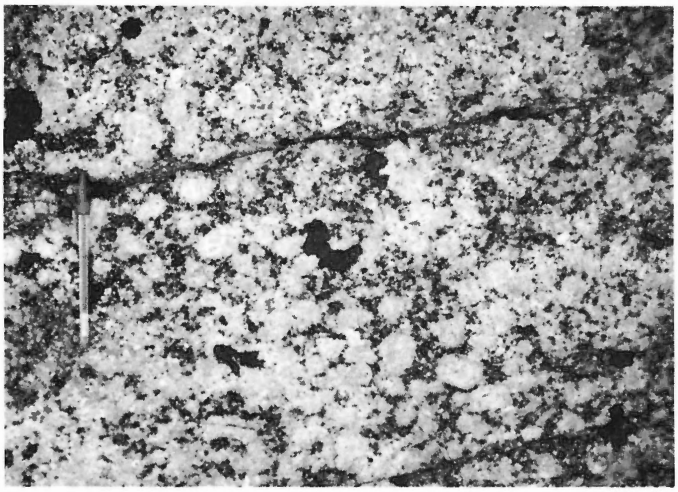

Figure 64. *Hooker Megacrystic Granite, 5 km southeast of Ghosty Lake. (GSC 190616)*

The presence of potassium feldspar megacrysts up to 5 cm long is distinctive (Fig. 64). They constitute from as little as 5, to as much as 40 per cent of the rock. Quartz (15-20 per cent) commonly occurs as irregular blobs and clots 8-10 mm across. Anhedral flakes of biotite also tend to form clots (<10 mm) and make up 8-16 per cent of the bulk. Subhedral plagioclase (to 10 mm) is heavily seriticized.

Locally near the margins of the intrusion prismatic green amphibole (to 7 mm) predominates over biotite. A pecular feature of the amphibole is the occurrence of lenticular zones of quartz parallel to longitudinal cleavage traces. Chlorite and opaque oxides have a similar occurrence but do not occur together with the quartz. In places with abundant amphibole, granophyric intergrowths of quartz and microcline make up to 5 per cent of the rock. Locally the amphibole is intimately intergrown with the granophyre which occasionally has finely disseminated hematite along the boundaries between the feldspar and quartz.

Interpretation

The Hooker Megacrystic Granite, like other syenogranite plutons of the Great Bear Magmatic Zone (Hoffman and McGlynn, 1977) postdates folding in the area. As many of the folds in the zone have steep, nearly vertical limbs, the crust was significantly shortened by this event. Consequently, it was also thickened. Such an event may have thickened the crust to such an extent that its base was partially melted. This could have given rise to the Hooker Megacrystic Granite and the other G-3 plutons of the Great Bear Magmatic Zone. The possibility that the G-3 plutons were merely slow rising bodies related to the rest of the Great Bear Magmatic Zone is effectively ruled out by the magmatic gap of 10 to 20 million years (Bowring, and Van Schmus, 1982) between most of the Great Bear magmatism and the emplacement of the G-3 plutons.

Other Plutons

Only brief mention is made here regarding other granitoid plutons of the area.

Yen (G-2): This pluton is a composite body of medium grained hornblende-biotite and biotite-hornblende granodiorite, quartz monzonite, and monzogranite. It generally contains 20-25 per cent ferromagnesiam minerals, often forming clots.

Richardson (G-3): Mainly coarse grained biotite-hornblende monzogranite characterized by centimetre-size clots of quartz and locally by megacrysts of potassium feldspar.

Unnamed syenogranites (G-3): Typically a coarse grained biotite syenogranite containing only minor hornblende.

Tla (G-3): This intrusive is also composite. It comprises medium grained hornblende-biotite monzogranite and quartz monzonite often with fine grained patches containing potassium feldspar megacrysts. In general, ferromagnesian minerals are much smaller than those in the Yen.

Cleaver Diabase

An east-west swarm of diabase dykes which postdate transcurrent faulting was mapped by Hildebrand (1983a) in the Echo Bay area. Hoffman (1982) termed them Cleaver Diabase. Similar diabase dykes with similar trends also occur in the Camsell River area and are much more numerous there than in the Echo Bay belt. They are considered part of the same suite and so the name Cleaver Diabase is also used. They are generally too small to show on Figure 2.

The dykes are variably altered; none are fresh. They have an ophitic to subophitic texture with 35 to 40 per cent subhedral to anhedral augite, typically partially altered to mixtures of green amphibole, chlorites, opaque oxides, and plagioclase. Plagioclase phenocrysts are typically euhedral laths of labradorite which may make up as much as 50 per cent of the bulk. The remainder of the rock is interstitial material comprising primary material (granophyre, magnetite) and alteration products such as epidote, carbonate, leucoxene, and sphene. Many of the dykes contain euhedral cubes of pyrite.

Gunbarrel Gabbro

This intrusion is a large sheet-like body which slices through all rocks of the area including Cleaver Diabase. It is exposed from the mouth of the Camsell River to the north end of Yen Lake (Fig. 2). Badham (1972) mapped this unit as an esker, perhaps due to its sinuous appearance on air photographs.

The gabbro is a coarsely crystalline rock with well developed ophitic texture comprising 50-60 per cent labradorite to andesine phenocrysts and 35-40 per cent subhedral to anhedral augite. Anhedral grains of opaque iron-titanium oxides constitute another 3 to 5 per cent of the rock. Interstitial material comprises feldspar, granophyre and opaques.

STRUCTURAL GEOLOGY

Folds

All of the rocks older than the Grouard Porphyries are folded about shallowly plunging axes which trend northwest. The folds have wavelengths ranging from 1-7 km and are part of the regional set of folds found throughout the Great Bear Magmatic Zone (Hoffman and McGlynn, 1977). In general, the folds have steep limbs and no associated cleavage. Due to the lack of widespread stratigraphic units of constant thickness it is not possible to describe the folds more precisely. The lack of visible penetrative strain suggests, however, that they are flexural-slip folds.

The major folds of the area are, from southwest to northeast: Norex Syncline; the anticline cored by the Balachey Pluton; and an unnamed syncline cored by Animal Andesite (Fig. 2) Eutaxitic foliation in the White Eagle Tuff indicates the presence of other folds to the northeast, but it was not possible to trace them from one fault block to another due to local obliteration of the foliation by alteration, intrusion by plutons, and cover.

A few smaller scale folds, with wavelengths ranging from 10 cm to 15 m were found above the roof of the Rainy Lake Intrusive Complex on Terra Ridge. They are cut by the magnetite-apatite-actinolite bodies and therefore may be related to the emplacement of the complex.

Transcurrent Faults

Numerous northeast trending transcurrent faults, typical of those found throughout the Great Bear Magmatic Zone and the rest of the circum-Slave Province area, postdate all rocks except Cleaver Diabase and Gunbarrel Gabbro. The faults are nearly always vertical and are reasonably straight for long distances (Fig. 2). They are commonly linked to one another by east trending faults which have much smaller separations. It is the east-west faults that host the economic ore veins of the area.

The fault zones themselves are nearly always filled with quartz veins and stockwork, some of which are 50 m wide. Brecciation and annealing relationships of the quartz in the stockworks indicate that most faults had several periods of movement (see Furnival, 1935). Wall rocks adjacent to the fault zones are intensely altered for distances up to 150 m away from the fault zones.

It may have been this hydrothermal alteration that played havoc with the Rb-Sr systematics of the area (Hildebrand, 1982) because much smaller veins and faults, possibly related to the transcurrent faults, are present in nearly every outcrop. As the transcurrent fault system occurs throughout Wopmay Orogen and East Arm Thrust Belt it is interesting to speculate even further and suggest that such a process has operated over a much wider area because Rb-Sr systematics from rocks in both areas have been similarly disturbed. Nearly all rocks analyzed from Wopmay Orogen and Athapuscow Aulocogen yield points which form reasonably good linear arrays whose regression lines have slopes about 100 ma younger than U-Pb zircon ages (Baadsgaard et al., 1973; Goff et al., 1982; Easton, 1982; Van Schmus and Bowring, 1980; Bowring and Van Schmus, 1982) implying large scale, low grade alteration over huge areas.

ECONOMIC GEOLOGY

Systems of polymetallic veins containing native Ag, Bi, Ni-Co arsenides ± pitchblende occur in the mapped area. Several of the veins were first discovered during the flurry of prospecting that followed the discovery of silver and pitchblende by Gilbert LaBine and E.C. St. Paul at the present townsite of Port Radium in 1930 but they had only limited production at that time. Recent mining activity in the area has focused on veins located on Terra Ridge (Silver Bear Mine) and east of Rainy Lake (Norex and Smallwood mines). To date, production has totaled over 13 000 000 ounces of silver (H. Sanche, personal communication, 1980).

There have been numerous papers and theses written on the mineralogy of the veins (see Previous Work) and the interested reader is referred to those works for additional information. However, a few comments on the general setting and possible origin of the deposits follow.

Most of the known deposits are located within fractures adjacent to, and roughly parallel with, east trending faults probably related to the northeast-trending transcurrent fault system. Much of the production has come from areas where the faults cut the sulphide zones of the Balachey Pluton and the Rainy Lake Intrusive Complex. As a lot of the sulphide zone along the southwest side of the Balachey Pluton weathers recessively, and consequently has been poorly prospected, it is possible that new ore veins remain to be discovered in that area.

There are also numerous showings of Ni-Co arsenides scattered throughout the area (i.e. Clut Island, Bloom Island) but all showings that were noticed during this study had already been trenched. However, a few veins of chalcopyrite, up to 10 cm wide, were found in the Camsell River Formation at the northwest end of the Balachey Pluton. In addition, several veins containing bornite were found along the southeast shore of central Richardson Island (65°43'30"N, 118°17'30"W) and minor molybdenite occurs in the Camsell River Formation at 65°32'N, 118°01'W.

Several workers (Shegelski, 1973; Hoffman et al., 1976) have suggested, on the basis of spatial relationships and ore zonation, that the Ag, Bi, and Ni-Co arsenides were derived from either the Rainy Lake Intrusive Complex or the Balachey Pluton. All known deposits are located adjacent to those plutons as is the case in the Echo Bay-Port Radium area where similar ore veins are spatially located near the Mystery Island Intrusive Suite, a suite of plutons similar in composition, petrology, and alteration to the plutons of the Conjuror Bay-Camsell River area (see Hildebrand, 1981; 1983a).

There is also another group of petrologically and compositionally similar intrusions (Compton Laccoliths) located within the East Arm Thrust Belt (Hoffman et al., 1977). They are of the same age as the Great Bear Magmatic Zone (Bowring and Van Schmus, 1982) and have associated magnetite-apatite-actinolite veins, albitization, and locally, minor veins containing Ni-Co arsenides and native Ag (Hildebrand, 1981; Gandhi and Prasad, 1982). The intrusions are laccolithic and intrude the contact between limestone-argillite rhythmites (Pekanatui Point Formation) and an overlying solution collapse breccia (Stark Formation) composed of carbonate blocks, up to 1 km across, sitting in a pervasively brecciated red mudstone matrix.

Because the rock types of the Great Bear Magmatic Zone and the East Arm Thrust Belt are so different it is difficult to understand how such similar mineralization could have been derived from the country rocks in each area. The common denominator between the two areas appears to be the intrusions themselves. Therefore, it is postulated that the intrusions were the original sources for the metals now found in the veins.

Since both the East Arm Thrust Belt and Wopmay Orogen contain numerous transcurrent faults of the same age (Hoffman et al., 1977; Hoffman, 1978, 1980b; Hoffman and St-Onge, 1981) and because the mineralization is located either in the fault zones themselves or in fractures apparently related to them, the deposition of the metals may have been related to the same hydrothermal systems postulated to have reset the Rb-Sr systematics (see Structural Geology) throughout both the orogen and the thrust belt.

SUMMARY OF GEOLOGICAL HISTORY

Mature, crossbedded quartz arenite, 30 m thick, was deposited unconformably on the Hottah Terrane. As subsidence continued, finer grained sediments accumulated below wave base and periodic eruptions of pyroclastic ejecta, from unknown sources, deposited lapilli tuff into the basin.

Later, perhaps during a period of extension, large volumes of pillow basalt, associated breccias and aquagene tuff were erupted and accumulated to thicknesses exceeding 2 km. Subsidence kept pace with volcanism and in places carbonate patch reefs developed where piles of basalt built up close to sea level. These rocks were intruded by porphyritic sills and dykes of a siliceous nature, and still later by gabbro and diabase sheets.

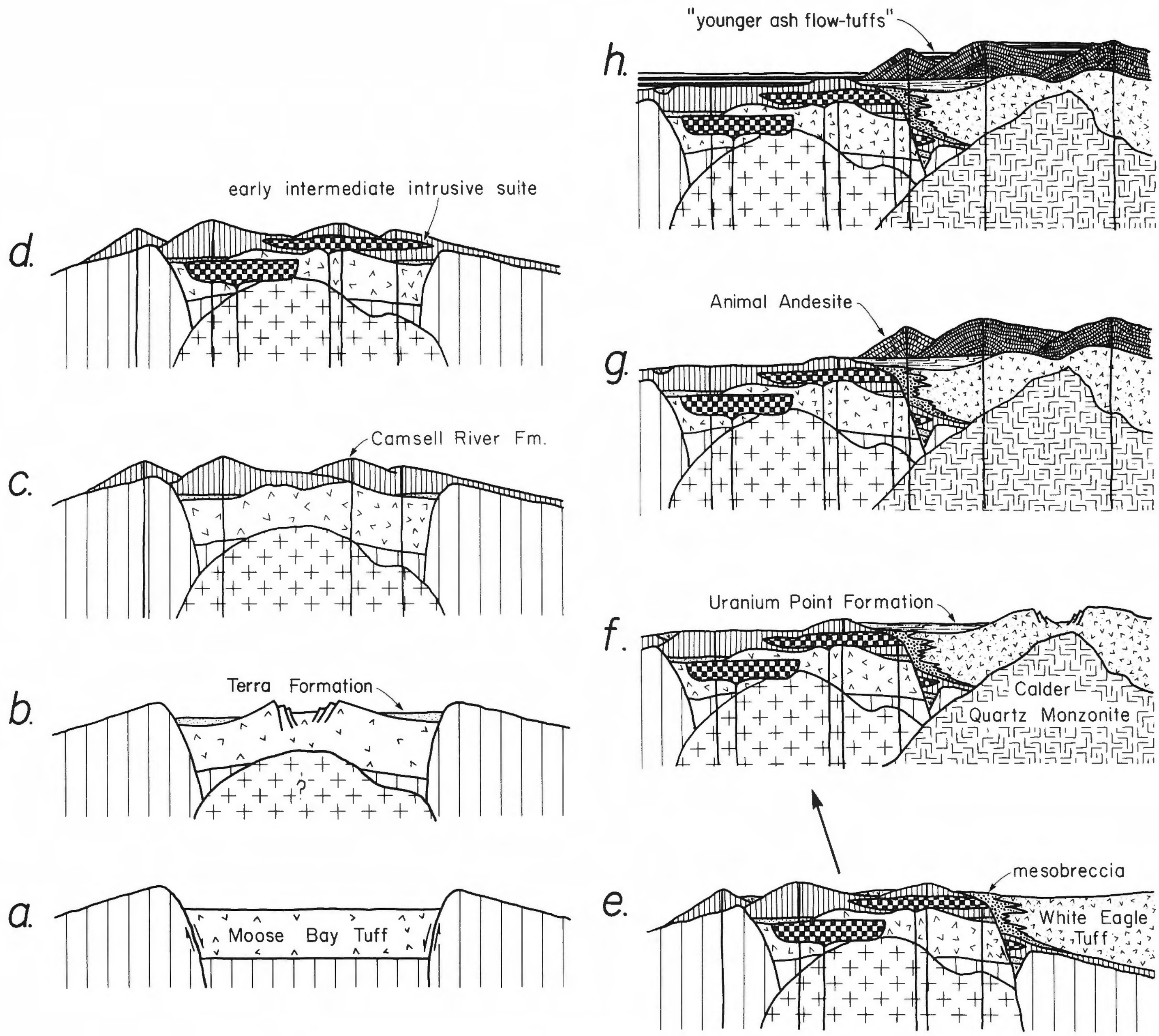

Figure 65. *Cartoon illustrating evolution of the LaBine Group in the map area. See text (Summary of Geological History) for explanation.*

A period of uplift ensued and subaerial ash-flow eruptions of rhyolite led to collapse of Black Bear Cauldron, in which 2 km of tuff ponded (Fig. 65a). The topographically low-standing core of the cauldron then became the locus for fluvial and lacustrine sedimentation as streams drained nearby highlands (Fig. 65b). Silicic volcanism, perhaps erupted from the same magma body responsible for the earlier ash flows, continued and rhyolite flows and ashstone were intercalated with the sedimentary rocks.

Shortly thereafter, at least one large stratovolcano of augite-plagioclase porphyritic andesite developed near the cauldron and large amounts of andesite spilled into the depression (Fig. 65c). The large compositional gap between the ash-flow tuff and the andesite suggest that the two were not erupted from the same magma chamber. Instead, there were two magma batches.

Distinctive quartz monzonite-monzodiorite sheet-like plutons, similar to the magma bodies likely to have fed the andesitic eruptions, were emplaced at shallow levels into the andesite pile (Fig. 65d). They intensely altered themselves and their wall rocks as they cooled, mainly by hydrothermal convection.

Younger ash-flow eruptions of crystal-rich dacite caused collapse of Clut Cauldron, which was accompanied by landsliding and avalanching of the steep cauldron walls. This resulted in coarse breccias of andesite and intrusive debris which intertongue with the propylitized intracauldron facies tuff adjacent to the walls (Fig. 65e).

Clut cauldron also became the site for fluviolacustrine sedimentation (Fig. 65f) after ash-flow eruptions had ceased but periodic pyroclastic eruptions from unknown sources deposited material into the shallow lakes. The emplacement of the Calder Quartz Monzonite into the central part of the cauldron probably caused resurgence of the central block (Fig. 65f). During this uplift unconsolidated lacustrine sediments slumped away from the domed core toward the cauldron margins.

Volcanoes of augite and pargasite-bearing andesite developed after collapse (Fig. 65g). The timing of this volcanism relative to resurgence of Clut Cauldron is unknown. The andesites could have been erupted from a deeper level of the same magma chamber as the White Eagle Tuff but this is not likely as they are richer in elements likely to be concentrated towards the roof of a magma chamber.

Shortly after andesitic eruptions ceased, compositionally varied ash flows were erupted from unknown sources and filled topographic depressions (Fig. 65h). Next, varied high-level intrusions, ranging from small ovoid bodies of diorite and plagioclase porphyry to pseudo-ring dykes were emplaced into the volcanic piles.

There was a pause in igneous activity and the entire belt was folded about northwest trending axes. This folding may have resulted in severe crustal shortening and possibly thickened the crust so that its base was partially melted. As a consequence large bodies of granitic melt were formed and rose nearly to the surface. Just prior to their final emplacement, during a period of east-west extension swarms of siliceous porphyry dykes were intruded.

After solidification of the dikes and the granite plutons, the area was subjected to east-west compressional stresses which resulted in brittle fracturing at high structural levels. The end result was the myriad of northeast trending transcurrent faults that cut the entire Great Bear Magmatic Zone. The fault zones acted as conduits for hydrothermal fluids, and rocks within and adjacent to the faults were intensely altered.

Much younger events include intrusion of east trending diabase dykes and large sheets of gabbro.

REFERENCES

Baadsgaard, H., Morton, R.D., and Olade, M.A.D.
1973: Rb-Sr isotopic age for the Precambrian lavas of the Seton Formation, East Arm of Great Slave Lake, Northwest Territories; Canadian Journal of Earth Sciences, v. 10, p. 1579-1582.

Badham, J.P.N.
1972: The Camsell River-Conjuror Bay area, Great Bear Lake, N.W.T.; Canadian Journal of Earth Sciences, v. 9, p. 1460-1468.

1973a: Calc-alkaline volcanism and plutonism from the Great Bear Batholith, N.W.T.; Canadian Journal of Earth Sciences, v. 10, p. 1319-1328.

1973b: Volcanogenesis, orogenesis and metallogenesis, Camsell River, N.W.T.; unpublished Ph.D. thesis, University of Alberta, Edmonton, 334 p.

1975: Mineralogy, paragenesis and origin of the Ag-Ni, Co arsenide mineralization, Camsell River, N.W.T., Canada; Mineralium Deposita, v. 10, p. 153-175.

Badham, J.P.N. and Morton, R.D.
1976: Magnetite-apatite intrusions and calc-alkaline magmatism, Camsell River, N.W.T.; Canadian Journal of Earth Sciences, v. 13, p. 348-354.

Bailey, R.A., Dalrymple, G.B., and Lanphere, M.A.
1976: Volcanism, structure, and geochronology of Long Valley Caldera, Mono County, California; Journal of Geophysical Research, v. 81, no. 5, p. 725-744.

Bailey, R.A. and Koeppen, R.P.
1977: Preliminary Geologic Map of Long Valley Caldera, Mono County, California; United States Geological Survey, Open File 77-468 (2 sheets).

Bartlett, R.W.
1969: Magma convection, temperature distribution, and differentiation; American Journal of Science, v. 267, p. 1067-1082.

Beach, A.
1979: Pressure solution as a metamorphic process in deformed terrigenous sedimentary rocks; Lithos, v. 12, p. 51-58.

Bell, J.M.
1901: Report of the topography and geology of Great Bear Lake and of a chain of lakes and streams thence to Great Slave Lake; Geological Survey of Canada, Annual Report 1901, p. 5c-35c.

Bookstrom, A.A.
1977: The magnetite deposits of El Romeral, Chile; Economic Geology, v. 72, p. 1104-1130.

Bowring, S.A.
1982: Preliminary geologic map of the Kamut and Adam lakes map areas (86K/9, 86K/8); Department of Indian Affairs and Northern Development, Yellowknife, Economic Geology Series, Map 1982.

Bowring, S.A. and Van Schmus, W.R.
1982: Age and duration of igneous events, Wopmay Orogen, Northwest Territories, Canada; in Abstracts with Programs, Geological Society of America, v. 14, no. 7, p. 449.

Burnham, C.W.
1979: Magmas and hydrothermal fluids; in Geochemistry of Hydrothermal Ore Deposits, ed.; H.L. Barnes, Wiley-Interscience, New York, p. 71-136.

Burnham, C.W. and Ohmoto, H.
1980: Late processes of felsic magmatism; in Granite Magmatism and Related Mineralization, Ed. S. Ishihara, and S. Takenovchi; The Society of Mining Geologists of Japan, Mining Geology Special Issue, no. 8, p. 1-11.

Bussell, M.A., Pitcher, W.S., and Wilson, P.A.
1976: Ring complexes of the Peruvian Coastal Batholith: a longstanding subvolcanic regime; Canadian Journal of Earth Sciences, v. 13, p. 1020-1030.

Byers, F.M., Carr, W.J., Orkild, P.O., Quinlivan, W.D., and Sargent, K.A.
1976: Volcanic suites and related cauldrons of Timber Mountain-Oasis Valley Caldera Complex, southern Nevada; United States Geological Survey, Professional Paper 919, 70 p.

Cater, F.W.
1969: The Cloudy Pass epizonal batholith and associated subvolcanic rocks; Geological Society of America Special Paper 116, 54 p.

Chapin, C.E. and Lowell, G.R.
1979: Primary and secondary flow structure in ash-flow tuffs of the Gribbles Run paleovalley, central Colorado; in Ash-Flow Tuffs, ed. C.E. Chapin, and W.E. Elston, eds.; Geological Society of America Special Paper 180, p. 137-154.

Cobbold, P.R. and Quinquis, H.
1980: Development of sheath folds in shear regimes; Journal of Structural Geology, v. 2, p. 119- 126.

Daly, R.A.
1915: Origin of the iron ores at Kiruna; Vetenskapliga Och Praktiska Undersokningar I Lappland, Geology 5, 31 p.

Doe, B.R., Lipman, P.W., Hedge, C.E., and Kurasawa, H.
1969: Primitive and contaminated basalts from the southern Rocky Mountains, U.S.A.; Contributions to Mineralogy and Petrology, v. 21, p. 142-156.

Easton, R.M.
1982: Tectonic significance of the Akaitcho Group, Wopmay Orogen, N.W.T., unpublished Ph.D. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 395 p.

Eggler, D.H. and Burnham, C.W.
1973: Crystallization and fractionation trends in the system andesite-H_2O- CO_2-O_2 at pressures to 10 kb; Geological Society of America, Bulletin, v. 84, p. 2517-2532.

Elston, W.E., Rhodes, R.C., Coney, P.J., and Deal, E.G.
1976: Progress report on the Mogollon Plateau volcanic field, no. 3, surface expression of a pluton; in Cenozoic Volcanism in Southwestern New Mexico, ed. W.E. Elston and S.A. Northrop; New Mexico Geological Society Special Publication no. 5, p. 3-28.

Fisher, R.V.
1966a: Rocks composed of volcanic fragments and their classification; Earth Science Reviews, v. 1, p. 287-298.

Fiske, R.S., Hopson, C.A., and Waters, A.C.
1963: Geology of Mount Rainer National Park, Washington; United States Geological Survey Professional Paper 444, 93 p.

Francis, P.W., Baker, M.C.W., and Halls, C.
1981: The Kari Kari caldera, Bolivia, and the Cerro Rico stock; Journal of Volcanology and Geothermal Research, v. 10, p. 113-124.

Fraser, J.A., Hoffman, P.F., Irving, T.N., and Mursky, G.
1972: The Bear Province; in Variations in Tectonic Styles in Canada, ed. R.A. Price, and R.J.W. Douglas; Geological Association of Canada Special Paper 11, p. 454-503.

Freund, R.
1970: Rotation of strike-slip faults in Sistan, southeast Iran; Journal of Geology, v. 78, p. 188-200.

1974: Kinematics of transform and transcurrent faults; Tectonophysics, v. 21, p. 93-134.

Furnival, G.M.
1935: The large quartz veins of Great Bear Lake, Canada; Economic Geology, v. 30, p. 843-850.

Garcia, M.O. and Jacobson, S.S.
1979: Crystal clots, amphibole fractionation and the evolution of calc-alkaline magmas; Contributions to Mineralogy and Petrology, v. 69, p. 319-327.

Geijer, P. and Odman, O.H.
1974: The emplacement of the Kiruna iron ores and related deposits; Sveriges Geologie Undersokning, Serial C, no. 700, 48 p.

Ghandi, S.S.
1978: Geological observations and exploration guides to uranium in the Bear and Slave structural provinces and the Nonacho Basin, District of Mackenzie; in Report of Activities, Part B, Geological Survey of Canada Paper 78-1B, p. 141-150.

Ghandi, S.S. and Prasad, N.
1982: Comparative petrochemistry of two cognetic monzonitic laccoliths and genesis of associated uraniferous actinolite-apatite-magnetite veins, east arm of Great Slave Lake, District of Mackenzie; in Uranium in Granites, ed. Y.T. Maurice; Geological Survey of Canada, Paper 81-23, p. 81-90.

Goff, S.P., Baadsgaard, H., Muehlenbachs, K., and Scarfe, C.M.
1982: Rb-Sr isochron ages, magmatic $^{87}Sr/^{86}Sr$ initial ratios and oxygen isotope geochemistry of the Proterozoic lava flows and intrusions of the East Arm of Great Slave Lake, Northwest Territories, Canada; Canadian Journal of Earth Sciences, v. 19, p. 343-356.

Grotzinger, J.P. and Hoffman, P.F.
1983: Aspects of the Rocknest Formation, Asiak Thrust-Fold Belt, Wopmay Orogen, District of Mackenzie: in Current Research, Part B, Geological Survey of Canada, Paper 83-18, p. 83-92.

Grout, F.F.
1932: Petrography and Petrology; McGraw Hill Book Company, Inc., New York, 522 p.

Hamilton, D.L., Burnham, C.W., and Osborn, E.F.
1964: The solubility of water and effects of oxygen fugacity and water content on crystallization in mafic magmas; Journal of Petrology, v. 5, p. 21-39.

Hamilton, W. and Myers, W.G.
1967: The nature of batholiths; United States Geological Survey, Professional Paper 554-C, p. C1-C30.

Hildebrand, R.S.
1981: Early Proterozoic LaBine Group of Wopmay Orogen: Remnant of a continental volcanic arc developed during oblique convergence; in Proterozoic Basins of Canada, ed. F.H.A. Campbell; Geological Survey of Canada, Paper 81-10, p. 133-156.

1982: A continental arc of early Proterozoic age at Great Bear Lake, Northwest Territories; unpublished Ph.D. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 237 p.

1983a: Geology Echo Bay-MacAlpine Channel area, District of Mackenzie, Northwest Territories; Geological Survey of Canada Map 1546A.

1983b: Geological map of the Rainy Lake and White Eagle Falls map areas, District of Mackenzie; Geological Survey of Canada, Open File 930. Geology, Rainy-Lake White Eagle Falls, District of Mackenzie; Geological Survey of Canada, Map 1589A. (in press)

Hildebrand, R.S., Bowring, S.A., Steer, M.E., and Van Schmus, W.R.
1983: Geology and U-Pb geochronology of parts of the Leith Peninsula and Rivière Grandin map areas, District of Mackenzie; in Current Research, Part A, Geological Survey of Canada, Paper 83-1A, p. 329-342.

Hildreth, W.
1981: Gradients in silicic magma chambers: implications for lithospheric magmatism; Journal of Geophysical Research, v. 86, no. B11, p. 10153-10192.

Hoffman, P.F.
1972: Cross-section of the Coronation Geosyncline (Aphebian), Tree River to Great Bear Lake, District of Mackenzie (86 J, K, O, P); in Report of Activities, Part A, Geological Survey of Canada, Paper 72-1, p. 119-125.

1973: Evolution of an early Proterozoic continental margin: the Coronation geosyncline and associated aulacogens of the northwestern Canadian Shield; The Royal Society of London, Philosophical Transactions, Series A, v. 273, p. 547-581.

1976: Environmental diversity of middle Precambrian stromatolites; in Stromatolites, ed.; M.R. Walter Elsevier, New York, p. 599-611.

1978: Geology of the Sloan River map-area (86K), District of Mackenzie; Geological Survey of Canada, Open File Map 535.

1980a: Wopmay Orogen: Wilson Cycle of early Proterozoic age in the northwest of the Canadian Shield; in The Continental Crust and Its Mineral Deposits; ed. D.W. Strangway; Geological Association of Canada, Special Paper 20, p. 523-549.

1980b: Conjugate transcurrent faults in north-central Wopmay Orogen (early Proterozoic) and their dip-slip reactivation during post-orogenic extension, Hepburn Lake map-area District of Mackenzie; in Current Research, Part A, Geological Survey of Canada, Paper 80-1A, p. 183-185.

1982: The Northern Internides of Wopmay Orogen; Geological Survey of Canada, Open File Map, 832.

Hoffman, P.F. and McGlynn, J.C.
1977: Great Bear Batholith: volcano-plutonic depression; in Volcanic Regimes in Canada, ed. W.R.A. Baragar, L.C. Coleman and J.M. Hall; Geological Association of Canada, Special Paper 16, p. 170-192.

Hoffman, P.F., Bell, I.R., and Tirrul, R.
1976: Sloan River map-area (86K), Great Bear Lake, District of Mackenzie; in Report of Activities, Part A, Geological Survey of Canada, Paper 76-1A, p. 353-358.

Hoffman, P.F. Bell, I.R., Hildebrand, R.S., and Thorstad, L.
1977: Geology of the Athapuscow Aulacogen, east arm of Great Slave Lake, District of Mackenzie; in Report of Activities, Part A, Geological Survey of Canada, Paper 77-1A, p. 117-129.

Hoffman, P.F. and St-Onge, M.R.
1981: Contemporaneous thrusting and conjugate transcurrent faulting during the second collision in Wopmay Orogen: implications for the subsurface structure of post-orogenic outliers; in Current Research, Part A, Geological Survey of Canada, Paper 81-1A, p. 251-257.

Hoffman, P.F., St-Onge, M.R., Easton, R.M., Grotzinger, J., and Schulze, D.L.
1980: Syntectonic plutonism in north-central Wopmay Orogen (early Proterozoic), Hepburn Lake map area, District of Mackenzie; in Current Research, Part A, Geological Survey of Canada, Paper 80-1A, p. 171-177.

Katsui, Y.
1955: Geology and petrology of the volcano Mashu, Hokkaido, Japan; Journal of the Geological Society of Japan, v. 61, p. 481-495.

Katsui, Y., Ando, S., and Inaba, K.
1975: Formation and magmatic evolution of Mashu volcano, east Hokkaido, Japan; Journal of the Faculty of Science, Hokkaido University, Serial IV, v. 16, p. 533-552.

Kidd, D.F.
1932: A pitchblende-silver deposit, Great Bear Lake, Canada; Economic Geology, v. 27, p. 145.

1933: Great Bear Lake area, Northwest Territories; Geological Survey of Canada, Summary Report 1932, Part C, p. 1-36.

1936: Rae to Great Bear Lake, Mackenzie District, N.W.T.; Geological Survey of Canada, Memoir 187.

Kuno, H.
1950: Petrology of Hakone volcano and the adjacent areas, Japan; Geological Society of America Bulletin, v. 61, p. 957-1020.

Lambert, M.B.
1974: The Bennett Lake Cauldron Subsidence Complex, British Columbia and Yukon Territory; Geological Survey of Canada, Bulletin 227, 213p.

Lipman, P.W.
1975: Evolution of the Platoro Caldera Complex and related volcanic rocks, southeastern San Juan Mountains, Colorado; United States Geological Society of America Bulletin, v. 87, p. 1397-1410.

1976: Caldera-collapse breccias in the western San Juan Mountains, Colorado; Geological Society of America Bulletin, v. 87, p. 1397-1410.

Lipman, P.W., Boethke, P., and Taylor, H.
1981: Penrose Conference report: silicic volcanism; Geology, v. 9, p. 94-96.

Lord, C.S. and Parsons, W.H.
1947: The Camsell River map area; Geological Survey of Canada, Map 1014A.

Marsh, B.D.
1976: Some Aleutian andesites: their nature and source; Journal of Geology, v. 84, p. 27-45.

1981: On the crystallinity, probability of occurrence, and rheology of lava and magma; Contributions to Mineralogy and Petrology, v. 78, p. 85-98.

Matumoto, T.
1943: Four gigantic calderas in Kyushu; Japanese Journal of Geology and Geography, v. 19, p. 36-37.

McBirney, A.R. and Noyes, R.M.
1979: Crystallization and layering of the Skaergaard intrusion; Journal of Petrology, v. 20, p. 487-554.

McGlynn, J.C.
1974: Geology of the Calder River map area (86F), District of Mackenzie; in Report of Activities, Part A, Geological Survey of Canada Paper 74-1A, p. 383-385.

1975: Geology of the Calder River map area (86F), District of Mackenzie, in Report of Activities, Part A, Geological Survey of Canada Paper 75-1A, p. 339-341.

1976: Geology of the Calder River (86F) and Leith Peninsula (86E) map areas, District of Mackenzie; in Report of Activities, Part A, Geological Survey of Canada Paper 76-1A, p. 359-361.

Muir, I.D.
1953: Quartzite xenoliths from the Balluchulish Granodiorite; Geological Magazine, v. 90, p. 409-428.

Murase, T. and McBirney, A.R.
1973: Properties of some common igneous rocks and their melts at high temperatures; Geological Society of America, Bulletin, v. 84, p. 3563-3592.

Padgham, W.A., Shegelski, R.J., Murphy, J.D., and Jefferson, C.W.
1974: Geology, White Eagle Falls (86F/12), District of Mackenzie, N.W.T.; Department of Indian Affairs and Northern Development Open File 199.

Parmentier, E.M. and Schedl, A.
1981: Thermal aureoles of igneous intrusions: some possible indications of hydrothermal convective cooling; the Journal of Geology, v. 89, p. 1-22.

Pitcher, W.S. and Berger, A.R.
1972: The Geology of Donegal: A study of Granite Emplacement and Unroofing; Wiley-Interscience, New York, 435 p.

Ratté, J.C. and Steven, T.A.
1967: Ash-flows and related volcanic rocks associated with the Creede Caldera, San Juan Mountains, Colorado; United States Geological Survey Professional Paper 524-H, 58 p.

Rice, A.
1980: Convective fractionation: a mechanism to provide cryptic zoning (macrosegregration), layering, crescumulates, banded tuffs, and explosive volcanism in igneous processes; Journal of Geophysical Research, v. 86, no. B1, p. 405-417.

Ross, C.S. and Smith, R.L.
1961: Ash-flow tuffs: their origin, geologic relations and identification; United States Geological Survey, Professional Paper 366, 81p.

Sato, H.
1975: Diffusion coronas around quartz xenocrysts in andesite and basalt from Tertiary volcanic region in northeastern Shikoku, Japan; Contributions to Mineralogy and Petrology, v. 50, p. 49-64.

Schweickert, R.A.
1976: Shallow-level plutonic complexes in the eastern Sierra Nevada, California, and their tectonic implications; Geological Society of America, Special Paper 176, 58p.

Seager, W.R.
1973: Resurgent volcano-tectonic depression of Oligocene age, south-central New Mexico; Geological Society of America, Bulletin, v. 81, p. 3611-3636.

Shaw, H.R.
1965: Comments on viscosity, crystal settling, and convection in granitic magmas; American Journal of Science, v. 263, p. 120-152.

Shegelski, R.J.
1973: Geology and mineralogy of the Terra silver mine, Camsell River, N.W.T.; unpublished M.Sc. thesis, University of Toronto, Toronto, 169 p.

Shegelski, R.S. and Murphy, J.D.
1973: Geology of the Camsell River silver district, Great Bear Lake area; Department of Indian Affairs and Northern Development, Open File Map 135.

Shegelski, R.J. and Scott, S.D.
1975: Geology and mineralogy of the silver-uranium-arsenide veins of the Camsell River District, Great Bear Lake, N.W.T.; Geological Society of America Abstracts with Programs, v. 7, no. 6, p. 857-858.

Smith, R.L.
1960a: Ash-flows; Geological Society of America, Bulletin, v. 71, p. 795-842.

1960b: Zones and zonal variations in welded ash flows: United States welded ash-flows; United States Geological Survey, Professional Paper 354F, p. F149-F159.

Smith, R.L., Bailey, R.A., and Ross, C.S.
1970: Geologic map of the Jemez Mountains, New Mexico; United States Geological Survey, Map I-571 (reprinted 1976).

Snyder, F.G.
1969: Precambrian iron deposits in Missouri; Economic Geology, Monograph 4, p. 231-238.

Steven, T.A. and Lipman, P.W.
1973: Geological map of the Spar City Quadrangle; United States Geological Survey, Map GQ-1052.

1976: Calderas of the San Juan volcanic field, southwestern Colorado; United States Geological Survey, Professional Paper 958, 35 p.

Steven, T.A. and Ratté, J.C.
1965: Geology and structural control of ore deposition in the Creede District, San Juan Mountains, Colorado; United States Geological Survey, Professional Paper 487, 90 p.

1973: Geological map of the Creede Quadrangle; United States Geological Survey, Map GQ-1053.

Stewart, D.C.
1975: Crystal clots in calc-alkaline andesites as breakdown products of high-Al amphiboles; Contributions to Mineralogy and Petrology, v. 53, p. 195-204.

Streckeisen, A.L.
1967: Classification and nomenclature of igneous rocks; Nves Jahrhuch Mineralogishe Moh, v. 107, p. 144-150.

1973: Plutonic Rocks. Classification and nomenclature recommended by the IUGS Subcommission on the Systematics of Igneous Rocks; Geotimes, October 1973, p. 26-30.

Taylor, G.A.
1959: Notes on Savo volcano, 1959; the Geological Survey of the British Solomon Islands, Geological Record 1959-62, p. 168-173.

Taylor, H.P., Jr.
1979: Oxygen and hydrogen isotope relationships in hydrothermal mineral deposits; in Geochemistry of Hydrothermal Ore Deposits, ed. H.L. Barnes, Wiley-Interscience, New York, p. 236-277.

Thorpe, R.
1974: Lead isotope evidence on the genesis of the silver-arsenide vein deposits of the Cobalt and Great Bear Lake areas, Canada; Economic Geology, v. 69, p. 777-791.

Thorpe, R.S. and Francis, P.W.
1979: Petrogenetic relationships of volcanic and intrusive rocks of the Andes; in Origin of Granite Batholiths: Geochemical Evidence, ed. M.P. Atherton, and J. Tarney, Shiva Publishing Ltd., Orpington, 65-75.

Tirrul, R.
1976: The Geology of the Rainy Lake Igneous Complex, District of Mackenzie, Northwest Territories; unpublished B.Sc. thesis, Queen's University, Kingston, Ontario, 115 p.

Tirrul, R.
1983: Structure cross-sections across Asiak Foreland Thrust and Fold Belt, Wopmay orogen, District of Mackenzie; in Current Research, Part B, Geological Survey of Canada, Paper 83-1B, p. 253-260.

van Bemmelen, R.W.
1949: The Geology of Indonesia; Martinus Nijhoff, The Hague, 732 p.

Van Schmus, W.R. and Bowring, S.A.
1980: Chronology of igneous events in the Wopmay Orogeny, Northwest Territories, Canada; Geological Society of America, Abstracts with Programs, v. 12, no. 7, p. 540.

Verstappen, H. Th
1973: A geomorphological reconnaissance of Sumatra and adjacent islands (Indonesia); Wolters-Noordhoff, Groningen, The Netherlands, 182 p.

Walker, G.P.L., Self, S., and Froggatt, P.C.
1981: The ground layer of the Taupo ignimbrite: striking example of sedimentation from a pyroclastic flow; Journal of Volcanology and Geothermal Research, v. 10, p. 1-11.

Wilson, A.
1979: Petrology and geochemistry of the Upper Hottah Lake Sequence, Hottah Lake, District of Mackenzie, Northwest Territories; unpublished B.Sc. thesis, McMaster University, Hamilton, Ontario.

Withers, R.L.
1979: Mineral deposits of the Northrim Mine and a brief enquiry into the genesis of veins of the (Ag, Bi, Ni, Co, As) type; unpublished M.Sc. thesis, University of Alberta, Edmonton, Alberta, 271 p.