Province of British Columbia
Ministry of Energy, Mines and
Petroleum Resources

MINERAL RESOURCES DIVISION
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CARBONATITES, NEPHELINE SYENITES, KIMBERLITES, ULTRAMAFIC LAMPROPHYRES AND RELATED ROCKS

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INTRODUCTION

A previously poorly documented alkaline igneous province is present in the eastern Canadian Cordillera. It comprises carbonatites, agpaitic nepheline and sodalite syenites, some ijolite series rocks (?), one kimberlite locality and numerous ultramafic and lamprophyric diatreme breccias, all of which intruded the Cordilleran miogeoclinal succession prior to the deformation and metamorphism associated with the Jura-Cretaceous Columbian orogeny. The purpose of this report is to describe these occurrences.

Carbonatites are ultrabasic igneous rocks composed of more than 50 per cent carbonate minerals. They may contain significant amounts of olivine, magnetite, pyroxene, sodic amphibole, biotite, vermiculite, apatite, columbite, zircon, rare earth carbonate minerals and pyrochlore. Carbonatites occur most commonly as intrusive bodies, generally associated with other alkaline igneous rocks (Pecora, 1956; Heinrich, 1966) such as nepheline syenites, ijolites, urtites, melteigites (nepheline + mafic silicates ± feldspathoids in various proportions) and jacupirangites (alkaline pyroxenites). Metasomatic rocks (fenites), which are generally enriched in sodium and ferric iron and depleted in silica, are also commonly associated with carbonatites, often marginal to the intrusive complexes. Extrusive carbonatites are less common, but have been described in western Uganda (von Knorring and du Bois, 1961), northern Tanzania (Dawson, 1962, 1964; Hay, 1983), Kenya (Le Bas and Dixon, 1965; Le Bas, 1977; Deans and Roberts, 1984) and Germany (Keller, 1981).

Many carbonatite bodies are valuable sources of a number of commodities. Niobium has been produced at Oka and St. Honoré, Quebec and at Araxa, Brazil; the Mountain Pass carbonatite in California is the largest producer of rare earth elements in the western world; and copper and by-product apatite, magnetite, vermiculite and zirconium oxide are produced at Palabora, South Africa (Heinrich, 1966; Currie, 1976a). Nepheline syenite is an important raw material used in the glass and ceramics industries. Small amounts have also been used in paints and as fillers in plastics. The Blue Mountain region of Ontario is the largest free world producer of nepheline syenite (Currie, 1976a).

Kimberlites are volatile-rich, potassic, ultrabasic igneous rocks which occur as small volcanic pipes, dykes and sills. They have a distinctly inequigranular texture resulting from the presence of macrocrysts (olivine ± phlogopite, picroilmenite, chrome spinel, magnesian garnet, clinopyroxene and orthopyroxene) set in fine-grained matrix. The matrix contains phenocrystic and/or groundmass olivine ± phlogopite, carbonate, serpentine, clinopyroxene, and many other minerals (Clement *et al.*, 1984). Kimberlites may contain diamond, but only as a rare constituent. The term kimberlite was introduced into the geological literature in 1887 to describe the host rocks of diamonds at Kimberley, South Africa. Since that time many rocks carrying olivine + phlogopite + carbonate ± clinopyroxene ± feldspathoid ± spinel have erroneously been referred to as kimberlites, rocks which should be placed in the lamprophyre group (Clement *et al.*, 1984). Inaccurate or incorrect classification only complicates the understanding of petrogenetic and economic implications.

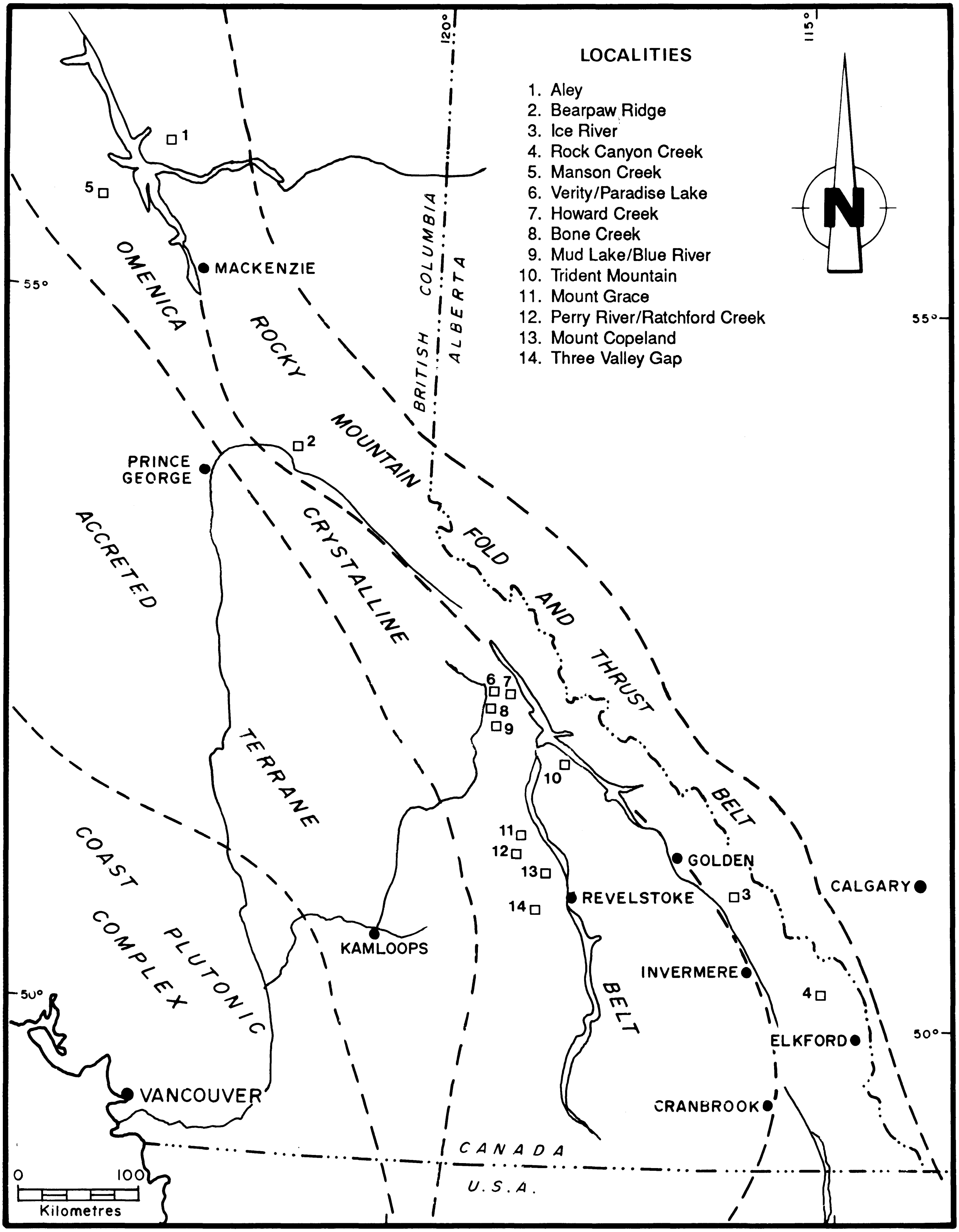


Figure 1. Index map showing locations of carbonatite and nepheline syenite gneiss complexes.

Kimberlite has traditionally been considered the only important primary source of diamond. Recent studies (Scott-Smith and Skinner, 1984a, 1984b; Jacques *et al.*, 1986; Scott-Smith *et al.*, 1986) have shown that diamonds may also be present in economic concentrations in lamproites. Lamproites are ultrapotassic rocks that are chemically and mineralogically distinct from kimberlites, characterized by the presence of phenocrystic and/or groundmass leucite, Ti-rich phlogopite, clinopyroxene, amphibole (Ti and K-rich richterite), olivine and sanidine, ± glass (Scott-Smith and Skinner, 1984b). Diamonds have occasionally been reported from carbonatites and peridotites, but, to date, the only known economic primary sources remain kimberlites and lamproites.

The parental magmas of alkaline igneous rocks are melts which form deep in the mantle. These melts most commonly intrude cratonic or "shield" areas with a long history of tectonic stability (Heinrich, 1966; Dawson, 1980) and their emplacement is often indirectly associated with normal faults, grabens or failed rifts. In British Columbia, the carbonatites and related rocks were intruded into the sedimentary prism deposited along the rifted continental margin, making this a somewhat anomalous alkaline province in a structural setting which differs from most others worldwide.

DISTRIBUTION AND GENERAL CHARACTERISTICS OF CARBONATITES AND NEPHELINE SYENITES

In British Columbia, carbonatites, nepheline and sodalite syenite gneisses and related alkaline rocks are found in a broad zone which is parallel to, and encompasses the Rocky Mountain Trench. Three northwest-trending belts can be defined within this broad zone.

The eastern belt (Belt 1A, Figure 1) lies in the Main and Western Ranges of the Rocky Mountains (east of the Rocky Mountain Trench) and contains the Aley carbonatite complex (Pell, 1986a; Mäder, 1987), Bearpaw Ridge sodalite syenite (Pell, 1985), the Ice River syenite and carbonatite complex (Currie, 1975, 1976a) and the Rock Canyon Creek fluorite - rare earth showing, a carbonatite-related deposit (Hora and Kwong, 1986; Pell and Hora, 1987). Most of these intrusions tend to be subcircular to elliptical in plan, have extensive metasomatic alteration halos and are hosted in Middle Cambrian to Middle Devonian miogeoclinal rocks. The Rock Canyon Creek showing, however, is an elongated zone of fluorite - rare earth metasomatic alteration, possibly related to a buried carbonatite (Pell and Hora, 1987). During the Columbian orogeny the intrusions were subjected to sub-greenschist facies metamorphism. The obvious effects of deformation are minor, the intrusions appear to have behaved as rigid bodies during orogenesis and were simply rotated, tilted and/or transported eastwards in thrust slices.

The central carbonatite belt (Belt 1B, Figure 1) is located predominantly within the Omineca Belt of the Canadian Cordillera. It stretches from the Rocky Mountain Trench westerly for 50 kilometres or more. All the intrusions in this belt are hosted in Late Precambrian (Hadrynian) to Early Cambrian metasedimentary rocks. They are foliated,

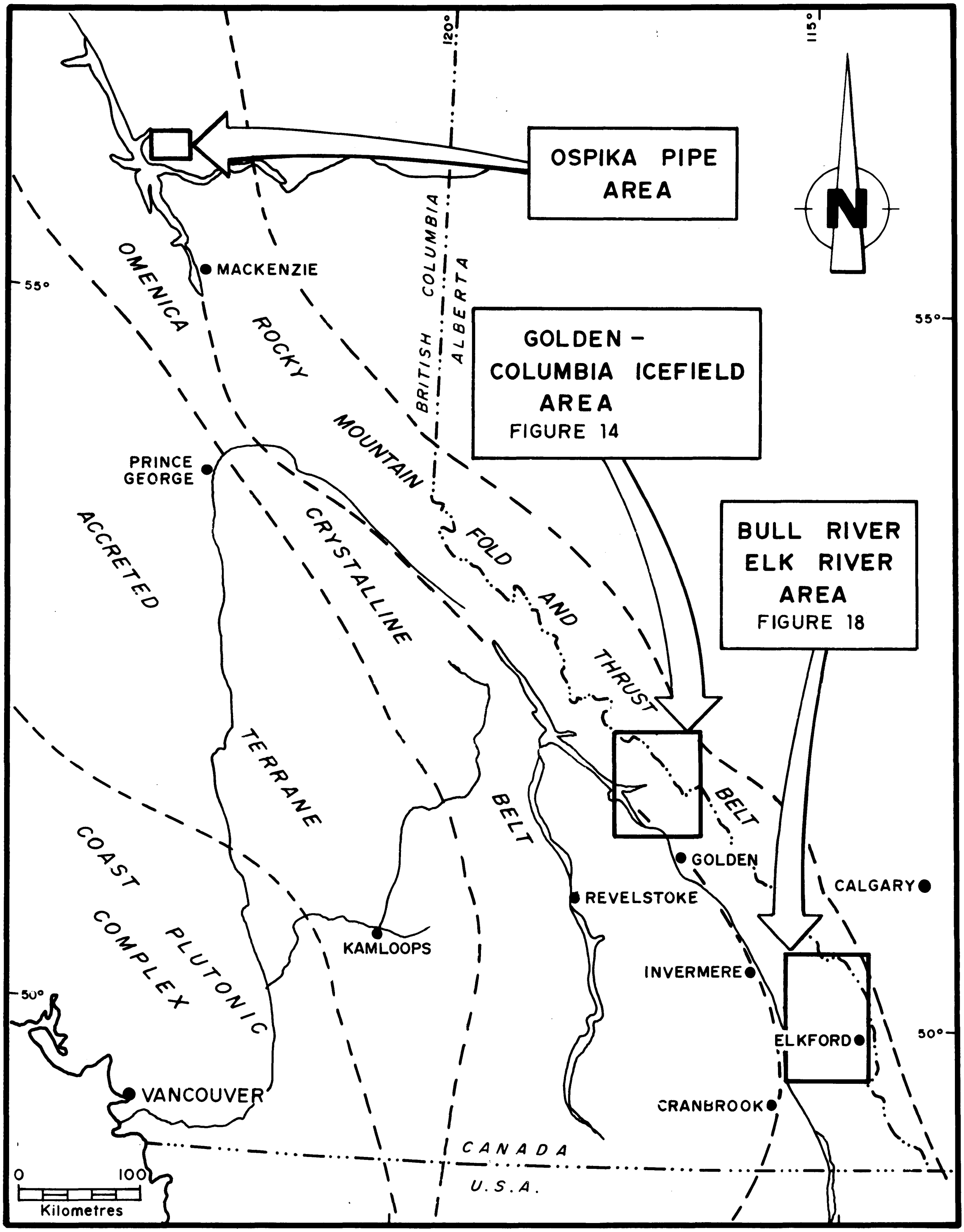


Figure 2. Index map showing locations of alkaline ultrabasic diatreme swarms (from Pell, 1987). For details on the Ospika Pipe *see* Figure 3 or Mäder (1987).

sill-like bodies that have been multiply deformed and metamorphosed, together with the host sedimentary rocks, to amphibolite facies. All the carbonatites have thin sodic pyroxene and amphibole-rich fenitic margins. The belt comprises carbonatites associated with monzonites and some syenites in the Manson Creek area (Lonnie and Vergil showings, Rowe, 1958; Currie, 1976a; Pell, 1985), carbonatites with nepheline and sodalite syenites, urtites to melteigites in the Blue River area (Verity, Paradise and Howard Creek localities, Rowe, 1958; Currie, 1976a; Pell, 1985) and nepheline and sodalite syenites at Trident Mountain and Kinbasket Lake (Currie, 1976a; Perkins, 1983; Pell, 1986b).

Extrusive and intrusive carbonatites, and syenite gneiss bodies, which occur within a mixed paragneiss succession along the margins of the Frenchman Cap gneiss dome north of Revelstoke (McMillan, 1970; McMillan and Moore, 1974; Höy and Kwong, 1986; Höy and Pell, 1986), comprise the most westerly belt (Belt 2, Figure 1). It also lies within the Omineca Belt, approximately 100 kilometres west of the Rocky Mountain Trench. As in Belt 1B, all the alkaline igneous rocks in Belt 2 are sill-like bodies which were multiply deformed and metamorphosed to upper amphibolite facies during the Columbian orogeny.

The Frenchman Cap gneiss dome is one of several late domal structures located near the eastern margin of the Shuswap Complex (Wheeler, 1965). The core of the dome comprises mixed gneisses of probable Aphebian age and is unconformably overlain by "mantling gneiss", an autochthonous cover sequence of unknown age, which hosts most of the carbonatites and syenites. The Mount Copeland syenite gneiss (Fyles, 1970; Currie, 1976b) occurs along the southern margin of the gneiss dome. The extrusive Mount Grace carbonatite tuff, intrusive carbonatites with thick fenitized margins, and syenite gneisses occur along the northern and western flanks of the dome (McMillan, 1970; McMillan and Moore, 1974; Höy and Kwong, 1986; Höy and Pell, 1986).

Several tens of kilometres to the south of the Frenchman Cap Dome, near Three Valley Gap, another carbonatite is hosted in migmatitic gneisses of uncertain affinity (Pell, 1985). It exhibits many similarities in field relationships and geochemical signatures to the intrusions of the Blue River and Manson Creek area (Belt 1B).

DISTRIBUTION AND GENERAL CHARACTERISTICS OF KIMBERLITES AND ALKALINE ULTRABASIC DIATREME BRECCIAS

Alkaline ultrabasic diatremes and dykes are known to occur in the Western and Main Ranges of the Rocky Mountains in three areas of British Columbia (Figure 2). With one exception (the Cross diatreme), all are hosted in Cambrian to Ordovician/Silurian miogeoclinal rocks (Roberts *et al.*, 1980; Grieve, 1981; Pell 1986c, 1987). The Cross diatreme, located in a more easterly structural position, is hosted in carbonate rocks of the Pennsylvanian/Permian Rocky Mountain Group (Hovdebo, 1957; Grieve, 1982). All the diatremes intruded the miogeoclinal sequence of platformal carbonate and clastic rocks prior to the deformation and metamorphism associated with the Columbian orogeny. The effects of deformation and metamorphism are manifested in a weak to strongly developed foliation, some flattening and the development of chlorite. The diatremes were transported eastwards in thrust sheets during orogenesis and, therefore, have presumably been cut off from their roots.

Three petrologically and geographically distinct suites of ultrabasic diatremes are present in British Columbia. The first is found in the Cranbrook - Bull River area (Figure 2). Examples of crater facies and extrusive rocks have been recognized (Pell, 1987). The upper parts of the diatremes are characterized by the abundance of vesiculated glass lapilli in a chaotic fragmental breccia, overlain by bedded epiclastic/pyroclastic material. Towards the periphery of the crater, thin layers of igneous material are apparently interbedded with carbonate rocks of the Ordovician/Silurian Beaverfoot Formation. In one locality, small mafic flows and dykes are exposed near the top of the crater zone. They are porphyritic and comprise abundant clinopyroxene and less abundant olivine phenocrysts, clinopyroxene, oxide and plagioclase microphenocrysts in a fine-grained groundmass (Pell, 1987). Deeper levels within the crater are characterized by juvenile lapilli-rich breccias with rare macrocrysts of chrome spinel, altered pyroxenes and altered olivines sporadically distributed throughout. Sedimentary rock fragments, granitoids and a variety of pyroxenite and periodotite xenoliths have been recovered from these pipes. These rocks are tentatively assumed to have an alkaline basalt affinity, possibly related to limburgites.

The second suite, examples of which are found north of Golden and in the Ospika River area (Figure 2), is characterized by macrocryst-rich breccias and dykes. The macrocryst population consists of titaniferous augite or salite, phlogopite, green chrome diopside, spinel and olivine, with either augite or phlogopite most abundant (Ijewliw, 1987; Pell, 1987). Sedimentary fragments are the most abundant in the breccias, but gabbroic, granitoid and rare peridotite xenoliths as well as cognate material and pelletal lapilli may also be present. These pipes are multiphase intrusions, with massive and multiple breccia phases cut by related dykes, and probably represent diatreme-facies material. Petrologically, the diatremes appear to bear affinity to ultrabasic mica lamprophyres as defined by Rock (1986). These diatremes and dykes are associated with quartz xenocryst-rich breccias, containing dominantly sedimentary rock fragments and little recognizable igneous material.

The third petrologically distinct rock type is represented by one example, the Cross diatreme, located at Crossing Creek, north of the town of Elkford. It is unique among breccia pipes in the Canadian Cordillera as it is a true kimberlite (Grieve, 1981, 1982; Hall *et al.*, 1986; Ijewliw, 1986, 1987). It contains xenoliths of garnet and spinel lherzolite, serpentinized peridotite, gimmerite and sedimentary material as well as pelletal lapilli and xenocrysts of olivine, pyrope garnet, spinel and phlogopite, in a matrix of serpentine and carbonate. The ratio of ultramafic to sedimentary xenoliths is greater in the Cross diatreme than in any of the other breccia pipes.

CARBONATITE AND SYENITE COMPLEXES IN THE ROCKY MOUNTAINS

THE ALEY CARBONATITE COMPLEX (94B/5)

The Aley carbonatite complex was discovered in 1980 and staked by Cominco Ltd. in 1982 (Pride, 1983) for its niobium potential. It is located approximately 140 kilometres north-northwest of Mackenzie, on the east side of Williston Lake between the Peace Reach and the Ospika River at latitude 56°27' north, longitude 123°45' west. The area is generally above treeline (1450 to 2200 metres) and has excellent exposure. It is fairly remote; access is by helicopter from Mackenzie.

The Aley Creek area is underlain by Cambrian to Silurian carbonate and clastic rocks of the Kechika, Skoki and Road River Groups (Thompson, 1978; Pride, 1983). This miogeoclinal succession, deposited near the shelf/off-shelf boundary, was intruded by the Aley carbonatite complex prior to the main Late Jurassic - Early Cretaceous orogenic event. The youngest unit affected by the intrusion is the mid-Ordovician (?) Skoki volcanic sequence.

The complex is oval in outline with a diameter of 3 to 3.5 kilometres, occupying an area of approximately 7 square kilometres. It is cylindrical, with a near-vertical axis (Mäder, 1986, 1987) and consists of a rauhaugite (dolomitic carbonatite) core zone surrounded by an older, outer ring of amphibolite. Some sovite (calcitic carbonatite) and rare earth carbonate sweats occur in the rauhaugite core. A contact aureole of recrystallized carbonate rocks surrounds the amphibolite margin. Rare-earth-carbonate-rich dykes intrude the contact aureole (Figure 3). Ultrabasic lamprophyre dykes and a diatreme breccia pipe (Ospika pipe; Pell, 1986c) intrude altered and fresh carbonates outside the complex. These will be discussed in this report.

Rauhaugite Core Zone

The core of the Aley complex is approximately 2 kilometres in diameter. It comprises more than 50 per cent of the exposed complex and consists of dolomite (80 to 95 per cent) and apatite (5 to 15 per cent) with minor amounts of phlogopite, pyrite, magnetite and zircon (Pride, 1983). It is generally a massive and homogeneous unit, weathering buff to brownish.

Pyrochlore $[(Na,Ca,Ce)_2(Nb,Ta,Ti)_2O_6(OH,F)]$ may be present in this zone. Fersmite $[(Ca,Ce,Na)(Nb,Ta,Ti)_2(O,OH,F)_6]$ forms fibrous to fine-grained aggregates replacing pyrochlore (Mäder, 1987). Primary fersmite is rare. Columbite $[(Fe,Mn)(Nb,Ta)_2O_6]$ is present as a replacement of fersmite (Mäder, 1987).

Sovite Zones

Sovite zones (dykes?) occur locally near the margin of the rauhaugite core zone and in the surrounding amphibolite zone. The sovites exhibit a more varied mineralogy than the rauhaugites. Calcite with or without dolomite dominates and there are accessory amounts of apatite,

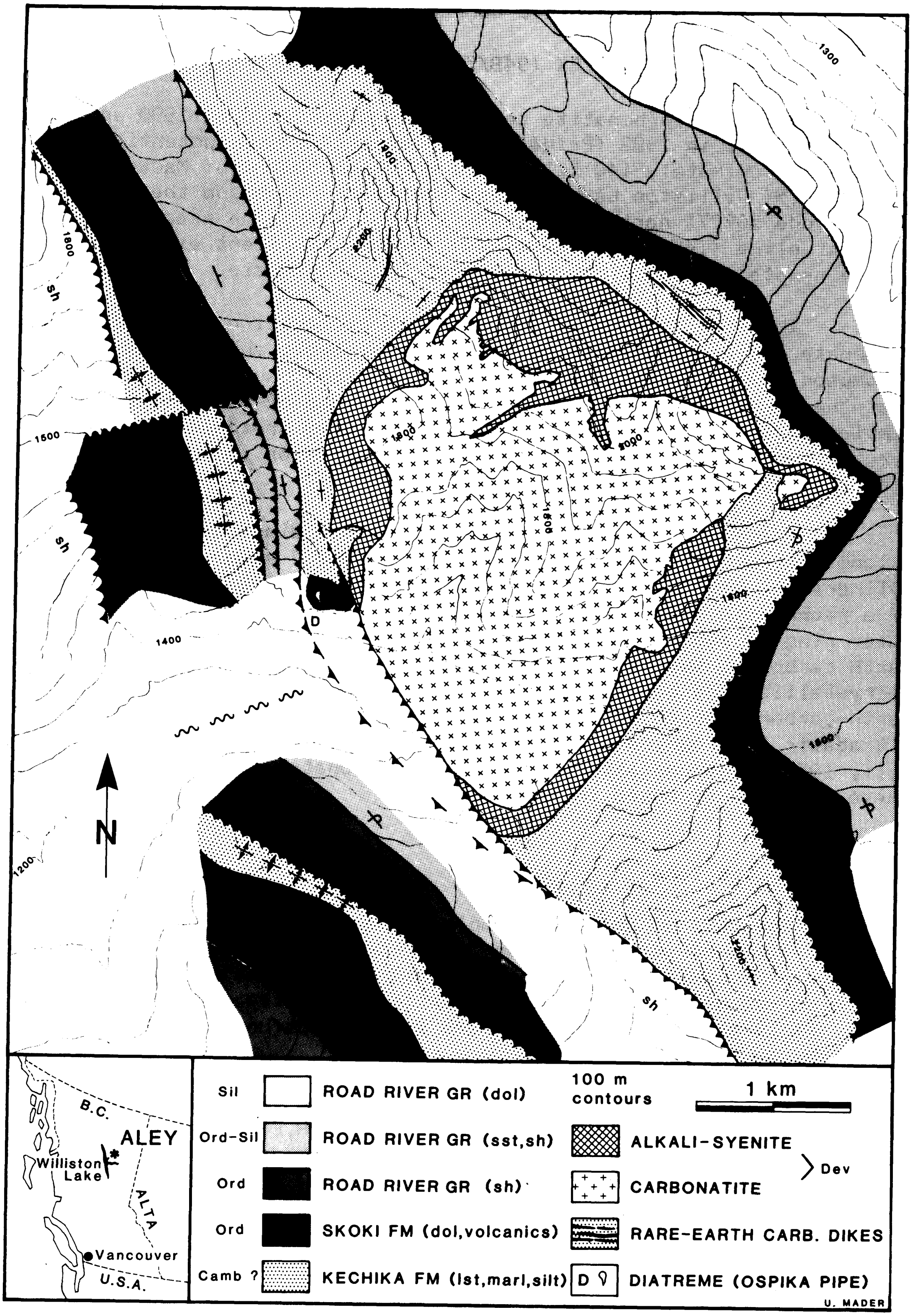


Figure 3. Geological map of the Aley carbonatite complex (from Mäder, 1987).

biotite, magnetite, sodic amphibole (richterite), pyrochlore (Pride, 1983) and fersmite. Zircon and rare baddeleyite associated with zirkelite have also been reported (Mäder, 1987).

Amphibolitic Margin

An amphibolitic margin, approximately 1 kilometre in width, encircles and complexly interfingers with the rauhaugite core. The marginal zone includes massive and breccia phases. No distinct pattern to the spatial distribution of the two phases is evident. Carbonatite dykes cut both members.

The massive phase is a medium to coarse-grained, dark green rock consisting primarily of sodic amphibole (arfvedsonite; Mäder, 1987), quartz, albite and aegirine. It is more extensively developed than the breccia phase and resembles fenites associated with some of the other carbonatite complexes in British Columbia (*see* Pell, 1985, 1986a). Mäder (1987), however, has recognized microsyenite textures in the massive amphibolite, and suggests that it is a primary igneous phase with a metasomatic (fenitic) overprint. The breccia phase contains subrounded clasts of dominantly orthoquartzite, with some siltstone, albitite and syenite fragments in a matrix that is similar to the massive phase. The clast to matrix ratio is highly variable and clast-supported breccias are locally developed. The subrounded nature of the clasts give this unit the appearance of a conglomerate. The massive and breccia phases locally grade into one another.

Alteration Halo

Sedimentary rocks adjacent to the Aley complex have been altered for a distance of approximately 500 metres beyond the amphibolite margin. This alteration halo is characterized by a colour change from grey to buff which is indicative of a limestone to dolomite transition. The altered rocks can look superficially similar to material from the rauhaugite core zone. Apatite, pyrite and magnetite are developed in the alteration zone. White mica and potassium feldspar are the only common metamorphic minerals observed (Mäder, 1987) and the degree of alteration decreases outward from the complex (Pell, 1986a). Trace element abundances (Nb, REE, Th, F) can be correlated with the degree of alteration, also decreasing outward (Mäder, 1987).

Rare-earth-bearing Dykes

Dykes or "sweats" enriched in rare earth elements (REE) occur throughout the complex but are most common in the outer alteration halo. The dykes weather dark reddish brown, are generally intruded parallel to bedding, and average 0.5 to 1.5 metres in thickness. Their primary component is dolomite. Accessory minerals include purple fluorite, pyrite, barite, bastnaesite [$(Ce,La)CO_3F$], and other rare earth carbonate minerals (K. Pride and U. Mäder, personal communications, 1986).

TABLE 1
CHEMICAL ANALYSES, ALEY CARBONATITE COMPLEX

Wt. %	Rauhautite Core				Sovite			Amphibolite			Rare Earth Dykes	
	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	0.50	0.69	5.80	2.42	2.17	1.67	1.02	66.36	53.00	44.00	0.65	7.30
TiO_2	<0.01	0.18	0.02	0.02	0.04	0.02	0.03	0.68	0.35	0.15	0.01	0.04
Al_2O_3	0.26	0.49	0.34	0.15	0.02	0.24	0.18	4.28	1.33	8.69	0.21	0.67
$Fe_2O_3^T$	2.95	5.48	4.91	2.50	2.29	3.59	1.80	11.10	12.91	4.36	10.49	12.00
MnO	0.26	0.22	0.90	0.22	-	0.23	0.40	0.27	0.35	0.49	4.11	3.30
MgO	17.34	16.50	16.60	14.90	5.85	2.60	1.80	2.55	16.00	5.22	11.29	7.91
CaO	32.89	31.20	28.20	31.00	45.69	45.50	46.00	4.05	3.50	14.80	28.14	24.59
Na_2O	0.63	0.06	0.05	0.08	0.48	0.08	0.12	7.79	7.71	3.83	1.13	0.79
K_2O	0.02	<0.10	0.26	0.13	0.05	0.11	0.13	0.24	1.15	3.10	0.04	0.06
LOI	43.52	36.46	39.96	37.08	38.71	35.36	39.69	0.84	-	15.45	42.55	33.31
P_2O_5	1.74	6.07	1.81	5.29	4.60	4.64	1.44	0.70	0.68	0.45	0.14	0.09
Total	95.69	97.45	98.85	93.79	99.90	94.04	92.61	98.86	96.98	100.54	98.76	90.06
ppm												
Ni	-	-	-	-	-	-	-	-	-	-	-	-
Cr	-	-	-	-	-	-	-	-	-	-	-	-
Co	-	-	-	-	-	-	-	-	-	-	-	-
Sr	360	780	3290	1090	5280	2825	4700	300	670	650	5500	700
Ba	39	35	45	<9	315	285	430	1340	540	1870	6900	7.74%
Zr	66	75	150	45	600	210	20	270	390	<20	580	96
Nb	490	-	-	-	3290	-	-	71	280	-	<5	29
Y	41	-	-	-	97	-	-	6	21	-	13	96
La	310	-	-	-	315	-	-	63	235	-	2670	2290
Ce	750	-	-	-	710	-	-	170	110	-	4760	7210
Nd	240	-	-	-	-	-	-	56	-	-	1020	3580
Yb	-	-	-	-	-	-	-	-	-	-	-	-
Sc	-	-	-	-	-	-	-	-	-	-	-	-
Ta	18	-	-	-	<20	-	-	-	-	-	-	-
Th	130	-	-	-	65	-	-	<7	<20	-	28	840
F%	-	0.56	0.34	0.63	-	0.35	0.24	-	-	nd	-	-

Analyses 1, 5, 8, 9, 11, 12 by XRF, from Mäder (1987).
All other analyses by ICAP, alkaline fusion.

Geochemistry

Carbonatites, both rauhaugites and sovites, are very low in silica, aluminum and alkalis, and high in phosphorus, up to 5.29 per cent P_2O_5 (Table 1). They are enriched in the incompatible elements thorium, niobium, zirconium and light rare earths. Barium, strontium and total rare earth elements may reach major element concentrations (Tables 1 and 2) in the rare-earth-bearing dykes. Iron and fluorine are also enriched in the dykes relative to rauhaugites and sovites. The amphibolitic margin has variable major element concentrations (Table 1) and trace element patterns similar to typical carbonatites, but with much lower concentrations.

Dating

Two potassium/argon dates have been obtained from mica separates from the Aley complex (Mäder, 1986), 339±12 Ma and 349±12 Ma. The data suggest an age of emplacement in Latest Devonian to Early Mississippian time.

BEARPAW RIDGE SODALITE SYENITE (93I/4)

A body of sodalite syenite and two flanking syenite sills crop out on Bearpaw Ridge in the Rocky Mountains approximately 60 kilometres east of Prince George, latitude 54°03'00" north, longitude 121°35'30" east. The ridge reaches a maximum elevation of 1700 metres in this area and is largely forested. Best exposure is found in subalpine meadows on north-facing slopes. The lower slopes are easily reached by logging roads from McGregor and Prince George; hiking or helicopter allows access to the ridge crest.

The syenites intrude Silurian Nonda Formation volcaniclastic rocks (Figure 4), which are predominantly alkaline mafic tuffs, locally containing limestone clasts. The syenite is massive, medium grained and white weathering. Three apparently separate bodies crop out; an oval stock, 500 metres by 1000 metres in size, is flanked by two smaller sill-like bodies (Figure 4). The stock contains randomly oriented feldspar laths (1 to 5 centimetres in size) with interstitial mafic silicate, feldspathoid and opaque minerals. The sills have feldspar phenocrysts up to 4 centimetres in size, in a groundmass of felted feldspar laths. The main intrusions are roughly parallel to bedding in the host rocks, however, crosscutting dykelets were observed (Pell, 1985). Intrusion apparently occurred prior to orogenesis. The syenites contain a low-grade metamorphic mineral assemblage (albite-epidote) and are exposed in the core of a synform.

A foliated orthogneiss of unknown age crops out on the western lower slopes of Bearpaw Ridge (Figure 4). It is not shown on previous maps of the area (Taylor and Stott, 1979) and its extent is unknown. Where exposed, the contact between the volcaniclastics and the gneiss is parallel to the bedding in the volcaniclastics, but may be either depositional or faulted.

TABLE 2
RARE EARTH ELEMENT ANALYSES FROM SOME CARBONATITE SUITES

Sample No.	Rock Type	La	Ce	Pr	Nd	Sm	Eu	Tb	Dy	Ho	Tm	Yb	Lu	Th	Sc	Y
Aley Carbonatite Complex																
AL5-12A	REE-enriched carbonatite dyke	>2 000	12 100	<670	2 940	139.0	31	3.0	15	<3	3.7	11.6	0.5	151.0	2.61	-
AL5-12B	REE-enriched carbonatite dyke	>2 000	12 500	<770	3 260	190.0	46	3.5	9	<4	4.5	10.0	<0.2	105.0	2.63	-
AL5-12C	REE-enriched carbonatite dyke	>2 000	4 000	<370	1 080	65.4	17	1.3	7	<2	1.7	3.5	<0.1	61.5	1.67	-
AL5-19B	alakline amphibolite (fenite?)	1 020	2 070	260	941	137.0	86	6.7	51	10	4.5	20.9	2.6	108.0	5.63	-
Rock Canyon Creek																
R85DP-1A	brown-altered carbonate with fluorite	9 800	10 000	-	3 000	300	76.0	-	-	-	-	11.0	1.40	580	57	190
R85DP-1B	brown-altered carbonate with fluorite	3 900	5 100	-	1 200	140	34.0	-	-	-	-	8.2	1.30	250	56	120
R85DP-2A	carbonate breccia with pyrite & fluorite	1 600	3 800	-	2 000	240	60.0	-	-	-	-	7.6	1.40	490	60	190
R85DP-2B	carbonate breccia with pyrite & fluorite	1 900	4 600	-	2 500	260	68.0	-	-	-	-	7.5	0.90	540	40	180
R85DP-3	altered carbonate with fluorite	2 900	5 000	-	2 000	240	55.0	-	-	-	-	9.0	1.04	750	58	210
R85DP-6	massive dark purple fluorite	102	163	-	61	17.3	4.3	-	-	-	-	1.7	0.20	290	3.8	40
R85DP-8	altered carbonate with fluorite	3 500	4 900	-	1 500	273	78.0	-	-	-	-	5.5	0.62	590	100	130
Manson Creek Area - Lonnie and Vergil Claims																
L4-179C	aegirine sovite	347	600	29.0	179	29.7	7.1	2.9	15.5	4.8	1.6	7.7	1.00	0.5	0.50	-
L4-242B	biotite sovite	401	741	57.0	245	39.5	9.1	3.2	16.7	5.3	1.5	6.2	0.74	17.3	0.61	-
L4-184	biotite sovite	371	673	46.0	206	31.0	8.4	3.0	13.0	3.0	1.1	5.2	0.62	6.5	0.15	-
L4-174B	fenite	87.6	172	<49.0	56	8.4	2.0	0.9	3.1	1.8	0.6	2.1	0.38	20.6	12.6	-
L4-197B	syenite	135	286	<35.0	102	17.0	4.5	1.7	7.6	5.6	1.2	3.78	0.55	23.5	0.27	-
L4-240B	syenite	43.2	107	<38.0	35.2	4.9	1.8	0.6	3.6	7.8	0.7	3.46	0.77	40.0	0.43	-
Blue River Area - Verity, Mud Lake, Paradise Lake and Howard Creek Areas																
H4-260	sovite - Howard Creek	254	548	35.0	234	49.2	11.7	3.9	19.5	6.1	1.1	4.18	0.44	14.6	3.3	-
H4-297A	sovite - Howard Creek	241	530	<59.0	233	46.0	11.1	3.8	16.7	6.1	1.1	4.10	0.55	14.7	6.8	-
V4-120	rauhaugite - Verity	171	371	45.0	147	22.7	5.7	1.7	6.1	1.4	2.3	1.40	0.21	2.1	20.3	-
V4-BEF	rauhaugite - Verity	134	279	25.0	119	17.7	4.5	1.6	4.9	1.4	3.5	1.00	0.13	1.4	13.7	-
V4-74D	rauhaugite - Verity	103	208	<16.0	81	14.8	3.7	1.5	7.3	1.0	0.7	1.77	0.17	0.4	19.3	-
V4-31A	rauhaugite - Mud Lake	200	415	<24.0	165	25.6	6.8	1.6	8.2	4.7	2.2	2.00	0.41	5.95	34.8	-
V4-62B	rauhaugite - Mud Lake	174	339	30.0	133	22.5	5.1	2.0	6.6	1.5	1.3	1.40	0.22	5.6	34.7	-
P4-323H	syenite - Paradise Lake	0.9	3.9	<44.0	1.9	<0.2	0.1	<0.2	<0.6	<0.3	0.2	0.60	0.11	2.3	0.14	-
P4-345FL	calcareous segregation in syenite	355	561	<41.0	144	18.1	4.4	1.6	7.9	1.2	1.1	3.22	0.40	14.1	2.97	-
H4-273A	meta-ijolite - Howard Creek	284	664	63.0	273	48.3	13.0	4.99	26.6	4.95	2.3	6.70	0.84	15.8	19.1	-
H4-273B	meta-ijolite - Howard Creek	197	363	<56.0	119	19.4	5.0	2.0	9.6	1.1	0.98	3.39	0.34	8.8	1.40	-
V4-67A	basic sill - Mud Lake	162	302	<16.0	114	20.3	4.8	1.4	7.4	1.99	1.1	2.54	0.32	0.9	22.2	-

TABLE 2 (continued)
RARE EARTH ELEMENT ANALYSES FROM SOME CARBONATITE SUITES

Sample No.	Rock Type	La	Ce	Pr	Nd	Sm	Eu	Tb	Dy	Ho	Tm	Yb	Lu	Th	Sc	Y
Three Valley Gap Carbonatites																
3VG-136A	biotite sovite	212	401	<24.0	151	25.9	6.30	2.4	11.4	0.80	2.22	4.35	0.52	10.1	1.10	-
3VG-135A	biotite sovite	206	396	45.0	140	25.2	6.18	2.4	10.2	3.46	0.90	4.21	0.48	5.2	0.65	-
3VG-137	carbonatite contact	131	275	<25.0	111	20.9	3.99	1.9	8.0	2.39	0.78	2.75	0.32	10.9	1.73	-
Carbonatites, West Flank, Frenchman Cap Dome																
H85P1-5	intrusive carbonatite	1 470	2 010	290	654	73.8	18	5.4	41	9	3.4	17.4	1.7	35.9	8.45	-
H85P1-8	intrusive carbonatite	704	927	<99	271	35.6	9	2.4	18	5	2.0	10.0	1.3	<0.5	0.12	-
H85P4-3B	intrusive carbonatite	>2 000	7 630	<550	3 540	313.0	83	11.0	55	<3	6.7	7.4	0.5	24.8	0.58	-
H85P4-3C	intrusive carbonatite	317	614	<71	279	41.4	11	1.6	13	8	1.2	2.9	0.2	5.0	0.12	-
H85P3-2E	Mount Grace carbonatite	93.9	155	<64	65	8.2	2	0.8	4	<1	<0.5	1.6	0.3	30.6	7.42	-
H85P3-3	Mount Grace carbonatite	957	1 430	<130	469	56.0	13	3.3	20	5	1.6	6.6	0.7	3.2	3.78	-
H85P7	Mount Grace carbonatite	736	1 170	<120	380	33.2	8	1.4	8	2	1.0	3.4	0.2	3.7	7.19	-
H85P9	Mount Grace carbonatite	722	1 190	170	424	42.7	12	2.2	15	3	1.6	4.9	0.5	15.2	6.89	-
H85P10	Mount Grace carbonatite	505	875	110	345	43.6	12	2.3	15	4	1.9	4.9	0.5	15.0	6.70	-
H85P11	Mount Grace carbonatite	937	1 410	<130	433	38.2	9	1.5	10	2	1.0	3.3	0.4	5.7	8.75	-
MG5-7	Mount Grace carbonatite	94.2	198	<65	91	16.1	5	1.5	12	2	0.8	3.3	0.4	0.7	5.37	-
MG5-8	Mount Grace carbonatite	131	235	<68	88	14.6	4	1.4	11	2	0.7	3.3	0.4	0.6	4.42	-
H85P26A	Mount Grace carbonatite	400	670	110	247	34.4	8	2.4	17	8	1.5	8.7	1.0	7.1	2.35	-
H85P26B	Mount Grace carbonatite	362	605	<96	224	28.6	7	1.8	14	5	1.8	6.1	0.9	6.4	2.17	-
H85P26D	Mount Grace carbonatite	479	611	<100	149	13.4	4	0.8	7	<1	0.5	2.6	0.3	31.0	4.67	-
H85P26E	Mount Grace carbonatite	151	289	<60	123	15.1	5	0.8	7	1	0.7	1.6	0.1	0.6	2.14	-
H85P26F	Mount Grace carbonatite	310	512	<89	188	23.2	6	1.3	9	2	0.6	2.5	0.3	1.3	5.51	-
H85P29	Mount Grace carbonatite	242	398	<100	139	17.8	5	1.1	11	1	0.8	4.1	0.5	0.5	5.22	-

All analyses by neutron activation (INAA), listed in ppm.
Rock Canyon Creek data from Graf (1985), Frenchman Cap data from Höy and Pell (1986).
Analyses, with the exception of those from Graf (1985), performed by Bondar-Clegg.

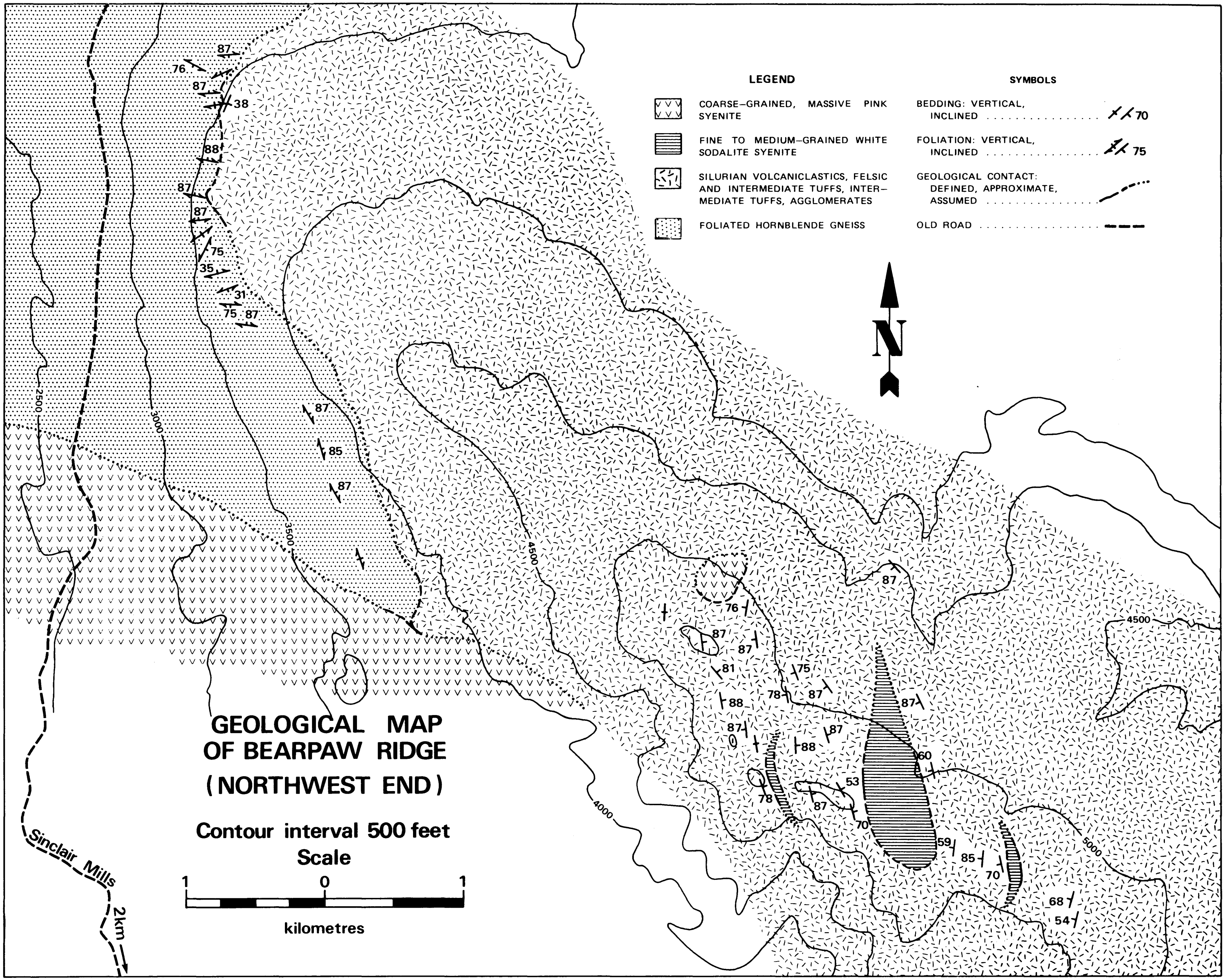


Figure 4. Geological map of Bearpaw Ridge (from Pell, 1985).

A second body of syenite, also previously unmappped, crops out on the southwestern end of Bearpaw Ridge, intruding both the dioritic gneiss and the volcaniclastics (Figure 4). It is a massive, coarse-grained rock with a buff to pink fresh surface containing randomly oriented feldspar laths up to 1.5 centimetres long. Clinopyroxene, amphibole and opaques, predominantly magnetite, comprise up to 10 per cent of the rock. This syenite appears to be post-orogenic and unrelated to the sodalite syenite on the ridge crest. It is however similar petrographically to Cretaceous syenites described elsewhere in the Cordillera.

Sodalite Syenite

The sodalite and related feldspathoid-poor syenites generally comprise 80 to 90 per cent feldspars. Due to metamorphism, much of the feldspar is now altered to albitic plagioclase and original potassic feldspar/plagioclase ratios are difficult to establish. Other metamorphic minerals include epidote (up to 10 per cent), muscovite (generally only a few per cent) and traces of chlorite. In one sample, alteration patches, consisting of fine-grained muscovite and epidote, comprise 30 per cent of the rock. Clay alteration was also noted locally.

Feldspathoid-bearing syenites occur near the centre of the large syenite stock. They may contain up to 10 per cent feldspathoid minerals, generally sodalite + cancrinite or cancrinite alone. No nepheline was noted. Aegirine (strongly pleochroic from marsh to blue-green) and biotite were also locally present in minor amounts. Trace minerals, identified by scanning electron microscopy, include magnetite (Ti-free), allanite, zircon, monazite, apatite, pyrochlore, thorite ($ThSiO_4$) and cheralite [$(Ca,Ce,Th)(P,Si)O_4$].

Nonda Formation Volcaniclastics

The Nonda Formation rocks in this vicinity largely comprise clinopyroxene crystal tuffs, calcareous tuffs and minor basaltic flows. Flow rocks contain clinopyroxene phenocrysts and altered phenocrysts (now chlorite) in a matrix of opaque oxides, plagioclase and clinopyroxene microphenocrysts and chlorite. Some vesicles are present.

Orthogneiss

Folded and foliated gabbroic orthogneiss crops out on the lower slopes of the western end of Bearpaw Ridge. It varies from a banded gneiss containing approximately 70 per cent calcic plagioclase (bytownite) with 5 per cent olivine, 15 per cent titanaugite, 5 to 10 per cent magnetite-ilmenite and a trace of apatite, to a mafic gneiss with 10 per cent calcic plagioclase, 30 per cent olivine, 35 per cent titanaugite, 15 to 20 per cent magnetite-ilmenite and 2 to 3 per cent apatite. In both the feldspar-rich and feldspar-poor phases brown amphibole is present rimming pyroxenes and locally as an intercumulate phase comprising 5 to 7 per cent of the more mafic gneiss.

TABLE 3
CHEMICAL ANALYSES, BEARPAW RIDGE

Wt. %	Syenites (alkaline)						Nonda Formation Volcanics		Other Rocks		
	1	2	3	4	5	6	7	8	9	10	11
SiO_2	53.00	61.00	54.40	54.50	54.80	56.40	42.40	47.70	58.30	45.50	68.80
TiO_2	0.12	0.11	0.09	0.13	0.47	0.10	2.06	0.59	0.80	2.01	0.27
Al_2O_3	22.80	19.40	21.65	22.10	21.80	21.10	15.20	15.80	17.90	15.60	15.70
$Fe_2O_3^T$	2.50	2.68	3.95	2.50	4.38	2.00	14.50	6.88	7.12	11.20	1.50
MnO	0.10	0.10	0.16	0.09	0.11	0.10	0.29	0.08	0.11	0.18	0.01
MgO	0.13	0.12	0.33	0.13	0.33	0.15	9.80	4.58	0.33	5.25	0.16
CaO	0.81	0.85	5.74	0.78	3.13	4.92	11.50	17.50	0.36	12.90	0.97
Na_2O	11.10	6.59	6.02	11.30	6.64	4.91	1.56	0.65	7.68	3.75	4.54
K_2O	6.39	4.60	5.52	6.47	6.87	5.77	1.84	4.33	6.42	1.46	6.28
LOI	2.32	2.55	1.69	2.37	1.23	2.26	1.45	1.96	1.12	2.34	0.89
P_2O_5	<0.09	<0.08	<0.09	<0.09	<0.09	<0.09	0.23	<0.09	0.14	0.89	<0.09
Total	99.36	98.08	99.64	100.46	99.85	97.80	100.83	100.16	100.28	101.08	99.21
ppm											
Ni	<34	<37	-	-	-	<24	-	-	-	-	-
Cr	62	67	-	-	-	44	-	-	-	-	-
Co	1.4	1.9	-	-	-	1.6	-	-	-	-	-
Sr	50*	205	1780*	60*	1050*	290	300*	340*	50*	1080*	310*
Ba	50*	170	1430*	55*	1270*	486	520*	620*	960*	725*	750*
Zr	613	756	2000*	890*	400*	429	<15*	35*	<20*	35*	65*
Nb	-	-	-	-	-	-	-	-	-	-	-
Y	-	-	-	-	-	-	-	-	-	-	-
La	95	108	-	-	-	78	-	-	-	-	-
Ce	135	156	-	-	-	111	-	-	-	-	-
Nd	28	32	-	-	-	22	-	-	-	-	-
Yb	2.7	2.9	-	-	-	1.9	-	-	-	-	-
Sc	0.3	0.2	-	-	-	0.3	-	-	-	-	-
Ta	8.5	10.0	-	-	-	7.5	-	-	-	-	-
Th	36.3	38.3	-	-	-	29.4	-	-	-	-	-

1 - B4211A - sodalite syenite (?); 2 - B4211 - grey to pink granular syenite; 3 - B4203A - white porphyritic syenite dyke; 4 - B4212A - greyish sodalite syenite; 5 - B4216 - syenite sill; 6 - B4212B - sodalite syenite; 7 - B4213 - Nonda Formation mafic volcanic rock; 8 - B4226 - Nonda Formation intermediate to mafic tuff; 9 - B4147 - post-orogenic aegirine syenite; 10 - B4170C - diorite gneiss; 11 - B4163 - granite.

*Trace elements by ICAP.
Major elements analysed by ICAP, alkaline fusion. Trace elements analysed by INAA by Bondar-Clegg, except where indicated.

In some localities the gneiss is remarkably well preserved, in others it is highly altered, consisting of chlorite, epidote, plagioclase, sericite and prehnite.

Post-orogenic Syenite

A second type of syenite outcrops on the southwest end of Bearpaw Ridge (Figure 4). It is massive and coarse grained with randomly oriented feldspar laths up to 1.5 centimetres in size. It comprises 30 to 35 per cent potassic feldspar, 20 to 25 per cent plagioclase and 10 to 20 per cent microperthite with up to 10 per cent clinopyroxene (aegirine-augite to aegirine), 5 per cent hornblende, 5 to 7 per cent magnetite (with titanium) plus ilmenite and minor biotite and apatite. The clinopyroxenes are strongly pleochroic, from yellowish to blue-green and often rimmed by strongly pleochroic blue sodic amphibole (riebeckite). Accessory minerals, identified by scanning electron microscope, include pyrite, barite, monazite and sphalerite.

Geochemistry

The pre-orogenic feldspathoidal syenites on the crest of Bearpaw Ridge are higher in Al_2O_3 and lower in SiO_2, Fe_2O_3, TiO_2 and P_2O_5 than the post-orogenic syenite (Table 3). Other major elements show no systematic variation and trace element analyses are not yet complete.

The Nonda Formation volcanic and volcaniclastic rocks have alkali/silica ratios which allow them to be classified as alkali basalts.

Dating

Taylor and Stott (1979) suggested that the sodalite syenite was a subvolcanic intrusion, related to the formation of the Nonda volcaniclastics. If so, it would be Silurian in age. Zircon separates have been obtained, but analyses are not yet complete.

ICE RIVER COMPLEX (82N/1)

The Ice River complex is an alkaline ultramafic intrusion located 23 kilometres south of Field. It is an arcuate mass, some 18 kilometres in length, with a total exposure of 29 square kilometres (Currie, 1975), most of which lies within Kootenay and Yoho National Parks. Access is difficult due to steep mountainous topography, lack of roads and regulations imposed by Parks Canada.

Within the complex, two distinct suites are present: an early, rhythmically layered, feldspar-free intrusion of jacupirangite, ijolite and urtite, cored by a carbonatite plug and crosscut by carbonatite dykes rich in mafic silicates and oxides; and a later zoned and crosscutting syenitic series, associated with a zeolite and feldspar-bearing carbonatite (Currie, 1975; Peterson, 1983). The alkaline rocks intruded Cambrian and Ordovician shales and carbonates of the Chancellor,

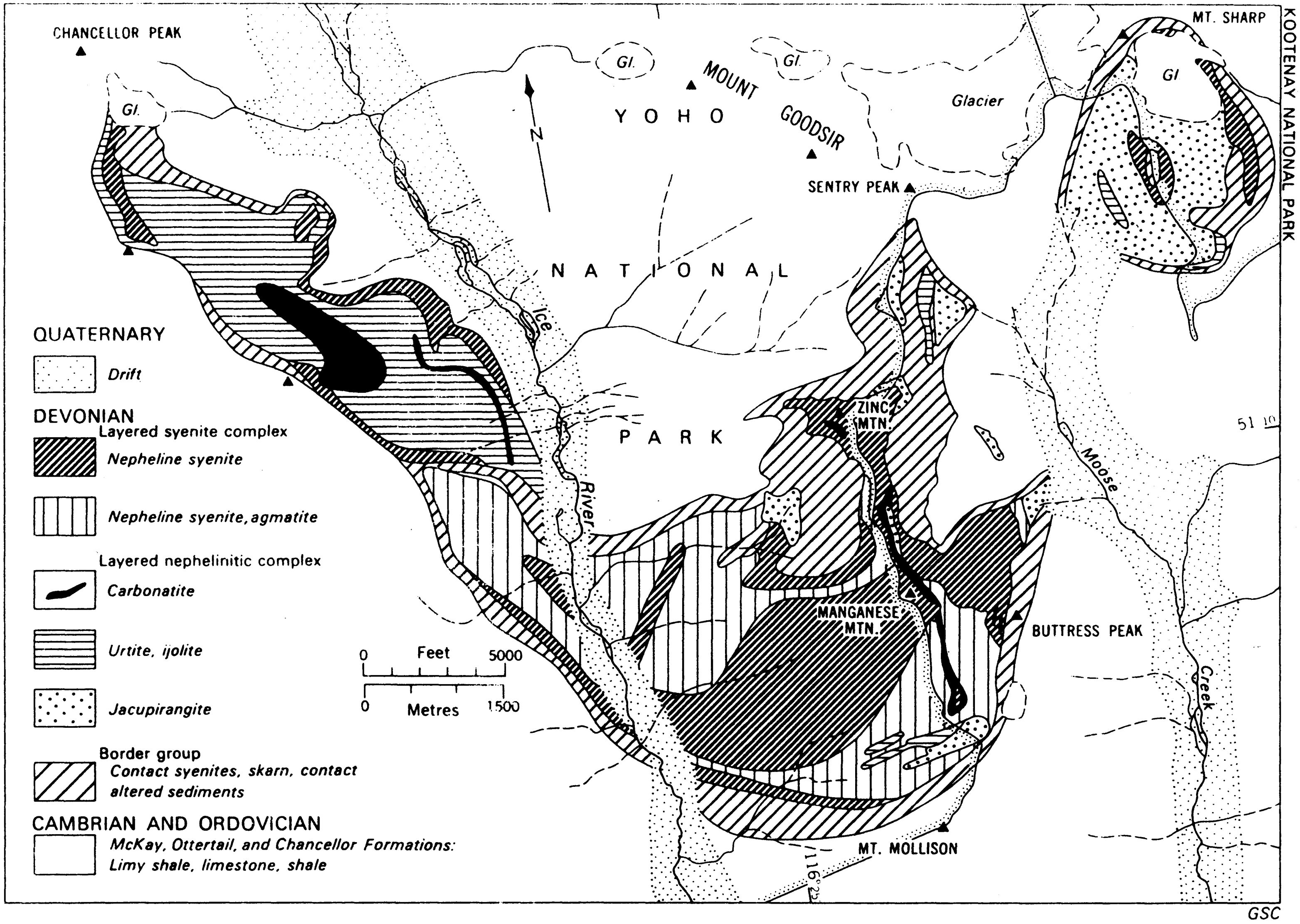


Figure 5. Geology of the Ice River complex (from Currie, 1976a).

Ottertail and McKay Formations (Figure 5). Contact metamorphism of the enclosing sedimentary rocks resulted in the formation of hornfels and skarns. Some limited soda metasomatism also occurred (Currie, 1975). The complex and its host rocks were deformed and subjected to low-grade regional metamorphism during the Columbian orogeny (Currie, 1975).

The Ice River complex was the first alkaline intrusion to be recognized in British Columbia. It was discovered and described around the turn of the century (Dawson, 1885; Barlow, 1902; Bonney, 1902). Work by Allan (1911, 1914) established it as one of the world's major alkaline complexes. During the 1950s and 1960s, there was renewed interest and a number of additional studies undertaken (Jones, 1955; Gussow and Hunt, 1959; Campbell, 1961; Rapson, 1963, 1964; Deans *et al.*, 1966). The most recent comprehensive study is by Currie (1975) and the reader is referred there for additional details. An excellent bachelor's thesis (Peterson, 1983) deals with the mineralogy and petrology of the complex. In view of the many previous studies of the Ice River complex, only a brief description will be given here.

Ultramafic Series

The older part of the complex comprises a semiconcordant, rhythmically layered intrusion of feldspar-free lithologies ranging from jacupirangite through melanite ijolite to melanite urtite (Currie, 1975) and characterized by a repetitive sequence of graded layers, 10 to 200 metres thick, with nepheline increasing in abundance towards the top of each layer (Currie, 1975). Jacupirangite is the most mafic lithology in this series. It contains, in decreasing abundance, titanaugite, titaniferous magnetite, perovskite and phlogopite. Accessory minerals include apatite, calcite, pyrrhotite, cancrinite and natrolite; the latter two minerals are present as alteration of nepheline.

Ijolites are the most common component of the layered series. They vary from a slightly more mafic variety (mela-ijolite) to true ijolite. The mela-ijolites contain clinopyroxene, either titanaugite or hedenbergite, nepheline, phlogopite, magnetite and perovskite or sphene, in order of decreasing abundance. Accessory minerals include calcite, apatite, cancrinite and natrolite. Some varieties contain significant amounts of black melanite garnet and biotite. True ijolites differ in that the pyroxene:nepheline ratio is 1:1 (Currie, 1975) and opaques are uncommon. Locally, kaersutite amphibole replaces pyroxene.

Urtites contain greater amounts of nepheline than pyroxene (generally aegirine) and wollastonite may be present. They are generally coarse grained, with a fabric developed due to the parallel orientation of elongate pyroxene or wollastonite. Kaersutite, melanite, albite, nepheline alteration products, sphene, calcite and apatite may also be present.

Zoned Syenite Complex

The younger portion of the Ice River complex has intruded the older mafic portion and consists of feldspar-rich syenitic rocks. The syenites are unlayered, however, strong alignment and segregation of minerals does occur (Currie, 1975). They form an elliptical pipe-like mass, zoned from a greenish sodalite syenite core through pale grey nepheline syenite to darker coloured mafic-rich rocks at the margin. The complex is surrounded by a thin rim of saturated fine-grained leucosyenite in contact with the country rocks. This phase is commonly full of inclusions.

The syenites are all dominated by the presence of alkali feldspar, generally with subordinate amounts of perthite and albitic plagioclase. Mafic minerals vary from being present in minor amounts to comprising approximately 50 per cent of the rock. Melanocratic varieties are characterized by the presence of titanaugite to hedenbergitic pyroxene ± kaersutite ± biotite. Leucocratic syenites generally contain minor amounts of aegirine; hedenbergitic pyroxene, kaersutite, hastingsite or biotite may also be present. In all varieties, nepheline may comprise up to 30 per cent of the rock. Sodalite may be present in quantities from trace amounts to 20 per cent, and is generally more abundant in leucocratic syenites. Accessory minerals include sphene (no perovskite), apatite, cancrinite and minor opaques (Currie, 1975). Locally, zeolite-rich syenites are present. Fluorite and pyrochlore have also been reported (Peterson, 1983).

Carbonatites

Carbonatites occur in a number of localities in the Ice River complex and display considerable lithologic variation. Complex relationships with other alkaline rocks preclude the unambiguous establishment of an emplacement sequence. Currie (1975) suggests there may be some remobilization of carbonatite during deformation and metamorphism which results in complex crosscutting relationships; alternatively there may be more than one period of carbonatite emplacement.

Carbonatite occurs in the layered ultramafic sequence, west of the Ice River (Figure 5) as layered lenticular masses and as smaller dykes (Currie, 1975). Three types are recognized: a black-weathering, iron-rich variety which is associated with a buff-weathering calcite-rich type, and a red-weathering variety, which crosscuts the buff carbonatite (Peterson, 1983). The black carbonatites commonly occur as dykes containing elemental carbon and tetranatrolite concentrated near the margins, with calcite, siderite and grass-green berthierine [$(Fe^{2+},Fe^{3+},Mg)_{2-3}(Si,Al)_2O_5(OH)_4$, a serpentine mineral] as major components. Other minerals in the black carbonatite are: iron-rich biotite, aegirine, edingtonite (a barium zeolite), perovskite, ilmenite, minor sphalerite and traces of pyrite (Peterson, 1983). The red-weathering carbonatite is similar to the black, but it contains fewer non-carbonate minerals (less than 10 per cent); both siderite and zeolites are absent, serpentine is distinctly yellow-brown rather than grass-green, and pyrochlore and xenotime are present (Peterson, 1983). The buff carbonatite is generally coarse grained and composed of calcite, aegirine, apatite, pyrite and trace pyrochlore (Currie, 1975).

White-weathering carbonatite dykes intrude the ultramafics exposed on Sharp Mountain (Figure 5). They consist predominantly of calcite and fluorapatite with aegirine (occasionally containing hedenbergitic cores), phlogopite, pyrite and ilmenite/magnetite. Some samples contain feldspar-rich zenoliths (microcline plus albite) and garnet (melanite?), analcime, natrolite, cancrinite and sphene.

The carbonatite associated with the syenites is radically different from that occurring within the ultramafic series in that the only silicate minerals present are feldspars (albite and in some localities microcline), zeolites (natrolite, analcime and rarely, edingtonite) and rare phlogopite. In some localities the carbonate is pure calcite (Peterson, 1983), in others ankerite, barytocalcite and strontianite have been identified in addition to calcite. Minor and trace minerals include ilmenite, pyrite, rutile, barite and apatite.

Lamprophyres

Many dark-weathering lamprophyric dykes occur within the Ice River complex and contiguous country rocks. They contain phenocrysts of strongly pleochroic orange-brown phlogopite, zoned crystals of augite/titanaugite, zoned kaersutite and olivine in a groundmass of pyroxene, pale orange phlogopite, calcite, alkali feldspar and opaque oxides. Sphene and apatite have also been reported (Currie, 1975). Field relationships indicate that the lamprophyre dykes were emplaced late in history of the complex.

Geochemistry

Phases of the layered ultramafic complex are generally lower in SiO_2 and higher in CaO and TiO_2 than those of the syenitic series (Table 4). Within the ultramafic series, SiO_2, Na_2O and K_2O increase and CaO, TiO_2, Fe_2O_3 and FeO decrease with decreasing colour index (that is, from jacupirangite to urtite, Table 4). Carbonatites and some of the melanocratic syenites have high concentrations of "incompatible" trace elements (Nb, REE) and strontium (Table 4).

Dating

The age of emplacement of the Ice River complex has long been a topic of debate. Allan (1914) suggested that emplacement was post-Cretaceous. Gussow and Hunt (1959) examined contact relationships and concluded that the complex was a sample of Precambrian basement. Radiometric dates obtained in the early 1960s (Lowdon, 1960; Baadsgaard *et al.*, 1961; Rapson, 1963) suggested a mid-Paleozoic age, *circa* Devono-Mississippian (Table 5). Currie (1975), uncertain of the validity of the early radiometric work, had additional material analysed and obtained Early Triassic ages (*see* Table 5). In evaluating his, and earlier work, Currie (1975) suggested a preferred age of emplacement of *circa* 245 Ma. Recent work on uranium/lead zircon systematics (R. Parrish, personal communication, 1986; *also see* Table 5) indicates that the mid-Paleozoic dates most closely represent the true age of emplacement.

TABLE 4
CHEMICAL COMPOSITIONS OF ICE RIVER COMPLEX ROCKS

	Jacurpirangite			Mela-ijolite			Melanite Ijolite		Ijolite				Urtite		Carbonatite			Lamprophyre			
Major Element Content (wt. %)																					
SiO_2	34.2	37.9	33.6	41.6	42.0	40.0	35.9	39.0	40.2	43.7	43.9	40.3	43.5	44.2	1.2	7.7	1.6	40.6	38.2	38.9	37.3
TiO_2	5.62	5.64	7.14	2.21	3.22	2.42	4.40	2.04	3.48	1.20	2.44	3.58	0.19	0.14	0.02	0.09	0.05	2.29	4.1	4.5	4.3
Al_2O_3	5.6	8.7	9.9	11.6	12.4	12.5	19.1	20.2	19.8	25.8	19.3	21.3	26.2	26.1	0.3	2.6	0.4	13.4	15.6	16.3	16.4
Fe_2O_3	8.9	2.1	6.4	2.9	4.1	2.8	4.8	3.3	2.5	1.6	2.4	2.4	1.1	1.3	0.1	2.0	0.2	2.7	4.1	5.6	4.1
FeO	8.5	6.2	8.2	7.4	7.4	6.9	4.3	8.2	5.7	3.7	5.4	4.9	2.1	3.2	8.9	0.8	0.7	7.1	4.6	5.1	4.3
MnO	0.12	0.06	0.18	0.20	0.20	0.18	0.17	0.28	0.20	0.15	0.20	0.12	0.50	0.51	1.75	0.31	0.40	0.16	0.22	0.22	0.20
MgO	10.6	8.4	9.8	11.6	11.6	10.4	4.1	4.7	5.6	2.7	5.1	2.7	0.4	0.7	12.7	0.5	0.2	11.6	6.1	4.2	4.5
CaO	21.8	27.2	21.4	11.7	12.3	12.3	11.7	9.5	10.1	5.4	6.6	11.0	9.7	6.4	30.6	45.55	51.86	13.8	16.3	14.4	16.7
Na_2O	0.7	0.8	1.08	3.3	3.5	4.0	8.7	7.7	7.4	9.9	7.4	7.6	10.4	10.6	0.13	0.3	0.2	2.8	5.1	5.8	5.9
K_2O	0.3	0.12	0.10	3.3	2.6	4.6	3.6	3.7	3.5	4.5	5.4	3.9	4.9	4.6	0.11	1.9	0.05	2.1	2.3	2.3	2.3
H_2O	0.8	0.7	0.8	1.5	0.9	2.1	0.6	0.7	0.7	0.9	1.2	0.7	0.9	0.9	0.5	1.3	0.5	1.6	1.4	1.2	1.6
CO_2	nil	0.02	0.04	0.3	0.1	1.9	1.0	0.2	0.5	0.8	0.2	0.1	0.3	0.7	43.6	36.90	43.46	0.9	1.3	1.2	1.4
P_2O_5	2.54	1.06	1.94	0.33	0.62	0.56	1.12	0.51	1.24	0.09	0.36	0.67	0.05	0.11	0.01	0.05	0.01	0.74	0.96	0.91	0.47
Total	99.7	99.0	100.6	98.0	100.9	100.7	99.5	100.0	100.9	100.4	99.9	99.4	100.2	99.5	99.9	100.8	99.6	99.8	100.2	100.6	99.7
Trace Element Content (ppm)																					
Ni	110	nd	nd	110	90	190	<10	<10	nd	110	130	nd	<10	<10	nd	<10	nd	150	220	100	360
Cr	nd	nd	nd	230	670	550	nd	nd	10	150	160	<10	nd	nd	11	nd	13	560	440	600	280
Co	66	26	35	13	56	46	17	35	12	21	24	18	nd	nd	nd	nd	nd	45	nd	28	56
Sr	300	300	320	71	1100	840	1300	1300	850	1600	2700	840	620	1400	3600	2600	2500	960	920	1000	800
Ba	300	16	140	320	810	1300	320	400	470	910	1300	330	830	2000	1100	890	360	490	280	160	120
Zr	190	470	660	220	300	210	220	210	260	340	470	300	30	260	nd	340	nd	180	120	nd	80
Nb	62	370	240	150	230	170	250	540	350	210	220	270	nd	170	71	10	620	110	nd	50	100
Y	22	68	45	27	17	25	22	44	41	26	32	36	<20	<20	53	81	<20	22	33	11	44
La	81	450	86	50	98	110	68	580	430	50	140	96	nd	60	650	700	260	59	40	19	85
Ce	nd	650	nd	nd	nd	nd	nd	930	1000	nd	nd	nd	nd	nd	1000	880	<500	nd	22	6	58
Nd	nd	1100	830	nd	nd	nd	nd	730	730	nd	nd	nd	nd	nd	820	1600	nd	nd	nd	nd	6
Yb	4	5.1	4.7	<4	<4	<4	<40	<40	<4	<4	<4	<4	<40	<40	<4	<4	<4	<40	<40	<40	<40
Sc	52	26	39	nd	nd	nd	-	-	-	-	-	-	nd	nd	-	-	-	34	27	46	62

[1] Includes Cl - 1.1%; [2] includes Cl - 1.2%; [3] includes Cl - 2.08%, SO_3 - 1.48% (from Campbell (1961).

From Currie (1976a).

TABLE 4
CHEMICAL COMPOSITIONS OF ICE RIVER COMPLEX ROCKS
(CONTINUED)

	Contact Syenite & Breccia				Melanocratic Syenite						Leucocratic Syenite			Sodalite Syenite			Zeolite & Syenite
Major Element Content (wt. %)																	
SiO_2	62.0	56.2	58.0	62.1	46.7	51.9	41.6	44.7	44.4	45.3	58.6	53.9	52.0	54.6	54.4	54.62	50.0
TiO_2	0.63	0.41	0.19	0.28	1.93	1.14	0.00	2.77	1.04	1.68	0.81	0.11	0.70	0.12	0.20	0.04	0.63
Al_2O_3	20.7	20.1	24.1	21.6	21.8	23.3	18.3	23.8	18.4	20.4	19.1	23.1	22.4	20.8	21.9	22.05	16.0
Fe_2O_3	3.3	1.0	2.0	1.1	1.0	1.2	2.1	1.2	2.6	2.1	1.3	0.8	0.6	3.1	2.0	0.46	6.6
FeO	0.1	4.1	0.1	1.4	5.8	4.8	7.8	5.5	5.9	7.1	2.1	0.8	3.0	0.4	0.9	0.32	1.4
MnO	0.12	0.12	0.12	0.15	0.18	0.19	0.18	0.13	0.42	0.32	0.12	0.05	0.16	0.07	0.11	0.01	0.14
MgO	0.2	2.0	1.6	2.0	2.8	1.0	5.1	1.4	0.6	1.0	0.5	0.1	0.4	0.1	0.8	0.05	2.4
CaO	0.3	4.1	0.5	0.2	6.1	3.6	11.8	6.5	12.1	7.8	1.9	1.6	3.4	0.7	1.2	0.74	3.1
Na_2O	7.8	5.7	6.0	9.9	7.6	7.1	4.7	9.0	6.8	8.3	5.7	7.8	7.99	11.5	10.7	10.12	8.4
K_2O	3.2	5.4	6.3	0.4	5.0	6.3	3.6	4.4	2.1	4.1	7.8	8.8	6.9	5.3	6.3	7.51	5.2
H_2O	1.3	0.9	1.9	0.9	0.6	0.7	0.8	0.9	5.4	0.9	0.9	1.0	0.7	0.8	0.8	0.76	3.4
CO_2	0.0	0.2	0.0	0.1	0.03	0.00	0.00	0.05	0.2	0.2	0.9	0.1	0.1	0.7	0.2	0.87	2.3
P_2O_5	0.05	0.28	0.02	0.03	0.47	0.09	0.77	0.19	0.31	0.22	0.09	0.00	0.08	0.02	0.01	0.03	0.06
Total	99.7	100.5	100.8	100.5	100.0	100.3	100.1	100.5	100.5	99.4	100.0	98.2	98.4	99.3[1]	99.8[2]	101.12[3]	99.6
Trace Element Content (ppm)																	
Ni	nd	nd	nd	<10	24	<10	36	nd	nd	<10	nd	21	nd	nd	nd	-	nd
Cr	nd	nd	nd	16	16	<10	17	<10	nd	nd	nd	nd	<10	<10	nd	-	nd
Co	nd	nd	nd	nd	40	nd	31	nd	nd	nd	nd	nd	nd	nd	nd	-	nd
Sr	88	2900	630	2900	1700	1200	990	2500	2000	1800	770	1100	2600	380	260	-	570
Ba	820	1800	570	2600	1600	1700	1000	3700	2600	3400	1400	350	2500	280	130	-	350
Zr	240	450	150	450	370	280	310	300	390	270	190	690	160	330	410	-	1000
Nb	130	200	110	200	310	270	180	510	1400	240	140	200	140	140	580	-	980
Y	nd	nd	nd	nd	42	51	35	47	94	28	<20	61	nd	nd	nd	-	300
La	190	150	50	150	170	55	73	94	1500	110	99	93	nd	nd	210	-	180
Ce	<50	nd	nd	nd	nd	nd	nd	nd	1700	nd	nd	nd	nd	nd	290	-	nd
Nd	<20	nd	nd	nd	nd	nd	nd	nd	740	nd	nd	nd	nd	nd	160	-	10
Yb	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	4	5.7	<4	-	-	-	<4
Sc	nd	nd	nd	nd	120	nd	17	nd	14	nd	nd	nd	nd	-	-	-	-

TABLE 5
ICE RIVER COMPLEX, GEOCHRONOLOGY

Date	Method	Reference	Comments
392±10	K/Ar, whole rock	Rapson (1963)	pyroxenite; age possibly slightly too old, excess argon possible in pyroxene
280±30	Rb/Sr, mica separate	Rapson (1963)	biotite pegmatite; Sr too low for satisfactory data, but
336±5	K/Ar, mica separate		K/Ar should be reliable
244±45	Rb/Sr, mica separate	Rapson (1963)	minette sill; Sr too low for satisfactory data, but
327±5	K/Ar, mica separate		K/Ar should be reliable
340±23	K/Ar, mica separate	Lowdon (1960)	syenite dyke; no chlorite
330±23	K/Ar, mica separate	Lowdon (1960)	pyroxenite; no chlorite
355±18	K/Ar, mica separate	Baadsgaard *et al.* (1961)	jacupirangite
360±18	K/Ar, mica separate	Baadsgaard *et al.* (1961)	minette
304±15	K/Ar, mica separate	Baadsgaard *et al.* (1961)	pegmatite
233±11	K/Ar, mica separate	Currie (1975)	meta-ijolite; no alteration
220±8	K/Ar, mica separate	Currie (1975)	nepheline syenite; no alteration
~380	U/Pb, zircon	R. Parrish (pers. comm., 1986)	preliminary data, additional analyses being performed

ROCK CANYON CREEK FLUORITE/RARE EARTH ELEMENT SHOWING (82J/3E)

The Rock Canyon Creek showing (Candy and Deep Purple claims) occurs near the headwaters of Rock Canyon Creek (Figure 6) in the eastern White River drainage, approximately 40 kilometres east of Canal Flats. It is accessible by conventional vehicles along the White River and Canyon Creek forestry roads, which join Highway 3A, 2 kilometres south of Canal Flats. The main mineralized zone lies between the 1525 and 2000-metre elevations in a valley that has been burnt-over and subsequently logged. Access is excellent, but exposure poor due to thick drift cover.

The Rock Canyon Creek prospect was discovered in 1977 during a regional exploration program carried out by Riocanex (then Rio Tinto Canadian Exploration Ltd.), in search of Mississippi Valley-type lead-zinc mineralization (Graf, 1985).

Between 1977 and 1979, mapping, soil and rock geochemistry and trenching were done to assess the fluorspar-lead-zinc potential of the property (Bending, 1978; Alonis, 1979). More recent work (Graf, 1981, 1985) attempted to establish the economic potential of the property in terms of other commodities. It was during this latter work that the anomalous rare earth element (REE) content of claims was recognized.

The Rock Canyon Creek area is underlain by a Cambro-Ordovician to Middle Devonian carbonate-dominated sequence (Leech, 1979; Mott *et al.*, 1986). The regional stratigraphy has been previously described by Mott *et al.* (1986) and only relevant points will be reiterated here. The southwestern boundary of the property is marked by a west-dipping thrust fault which places Cambrian and Ordovician strata over younger rocks (*see* Figure 6). The remainder of the area is underlain by an overturned to upright homoclinal sequence, younging to the east. This succession comprises coral-rich limestones of the Ordovician Beaverfoot Formation in the northwest, unconformably overlain by buff-weathering dolomites and gypsum solution breccias of the basal Devonian unit which are, in turn, conformably overlain by fossiliferous and nodular grey limestones of the Fairholm Group. The fluorspar and REE mineralization is stratabound, hosted mainly by the basal Devonian unit.

A carbonatite-related origin has been suggested for the showing (Graf, 1985; Hora and Kwong, 1986; Pell and Hora, 1987), but the actual mode of formation has yet to be established. Two possibilities exist for the genesis of the main mineralized zone: (1) carbonatite dykes or (2) metasomatically altered (fenitized) Devonian carbonate rocks, possibly associated with a deep-seated carbonatite intrusion. The latter interpretation is preferred due to the lack of unequivocal igneous material and the gradational contacts with fresh carbonates.

Mineralization

Four main types of fluorite mineralization are identified in the field. The first and most widespread consists of disseminations and fine veinlets of dark purple fluorite in a dark brown to dark orange-brown-weathering dolomitic matrix. Fluorite content generally varies from 2 to greater than 10 per cent of the rock. Bastnaesite ($CeCO_3F$) often occurs

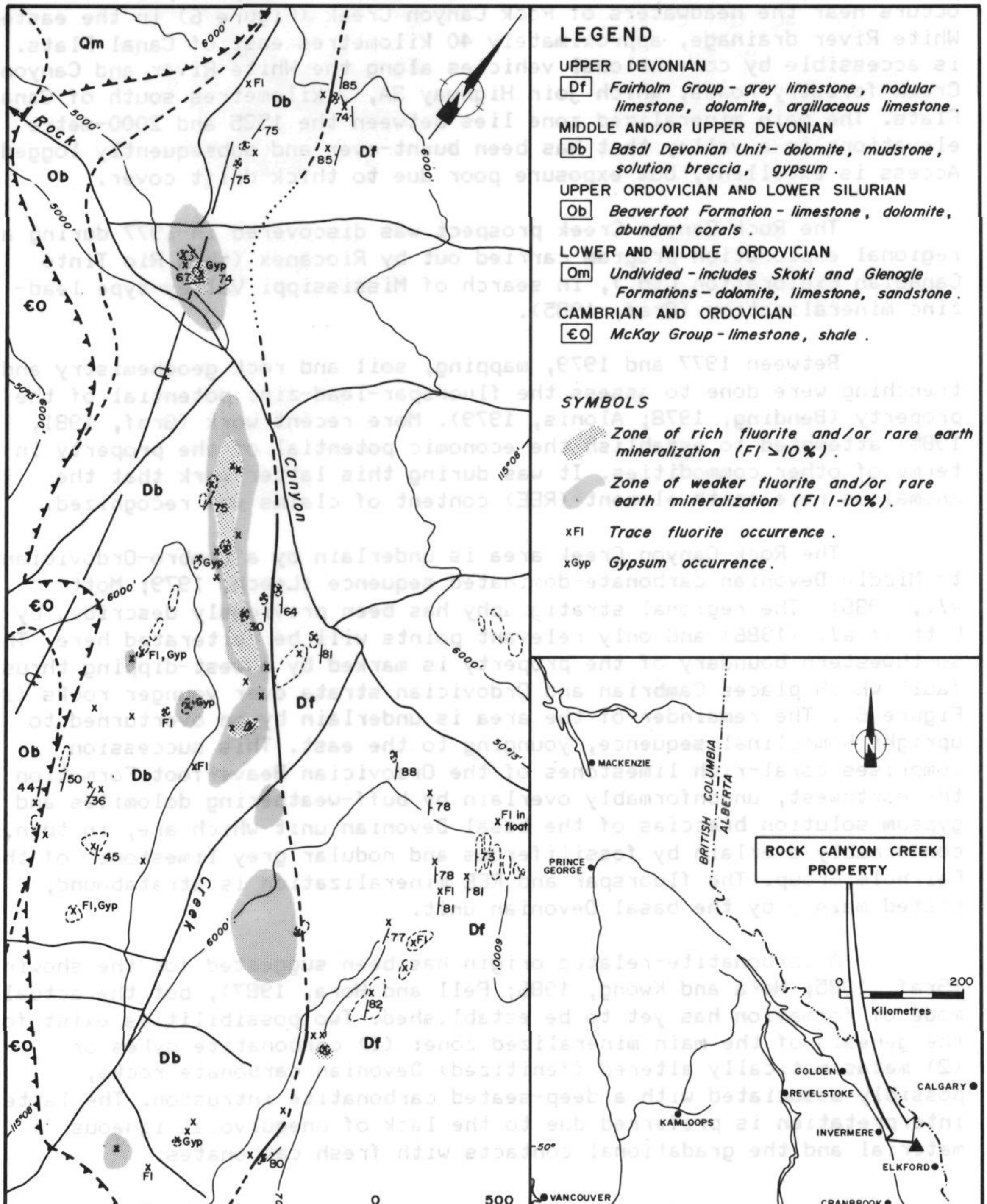


Figure 6. Geology of the Rock Canyon Creek fluorite/rare earth showing (from Pell and Hora, 1987).

TABLE 6
CHEMICAL ANALYSES, ROCK CANYON CREEK

Wt. %	1	2	3	4
SiO_2	0.39	3.16	3.18	14.90
TiO_2	0.02	0.02	0.04	0.11
Al_2O_3	2.32	1.07	0.81	2.27
$Fe_2O_3^T$	2.80	2.80	0.39	1.10
MnO	0.99	1.11	<0.01	0.01
MgO	10.30	14.40	2.40	8.96
CaO	34.70	29.40	46.60	32.10
Na_2O	0.08	0.05	0.06	<0.03
K_2O	0.23	0.25	0.58	2.47
LOI	29.97	35.49	40.80	32.80
P_2O_5	1.49	0.59	0.12	<0.09
Total	83.29	88.34	94.99	95.29
ppm				
Ni	-			
Cr	-			
Co	-			
Sr	9555	4160	1585	890
Ba	1.09%	2.57%	45	45
Zr	270	135	2160	715
Nb	-			
Y	-			
La	-			
Ce	-			
Nd	-			
Yb	-			
Sc	-			
Ta	-			
Th	-			
F	12%	4.8%	0.9%	2.9%

1 - RC85-A11 - massive fluorite in altered carbonate; 2 - RC85-B2 - brown altered carbonate with streaks of fluorite; 3 - RC85-C1 - light grey laminated carbonate with brown alteration patches; 4 - RC85-C2 - grey to buff carbonate with abundant fluorite.

All analyses done by ICAP, alkaline fusion.

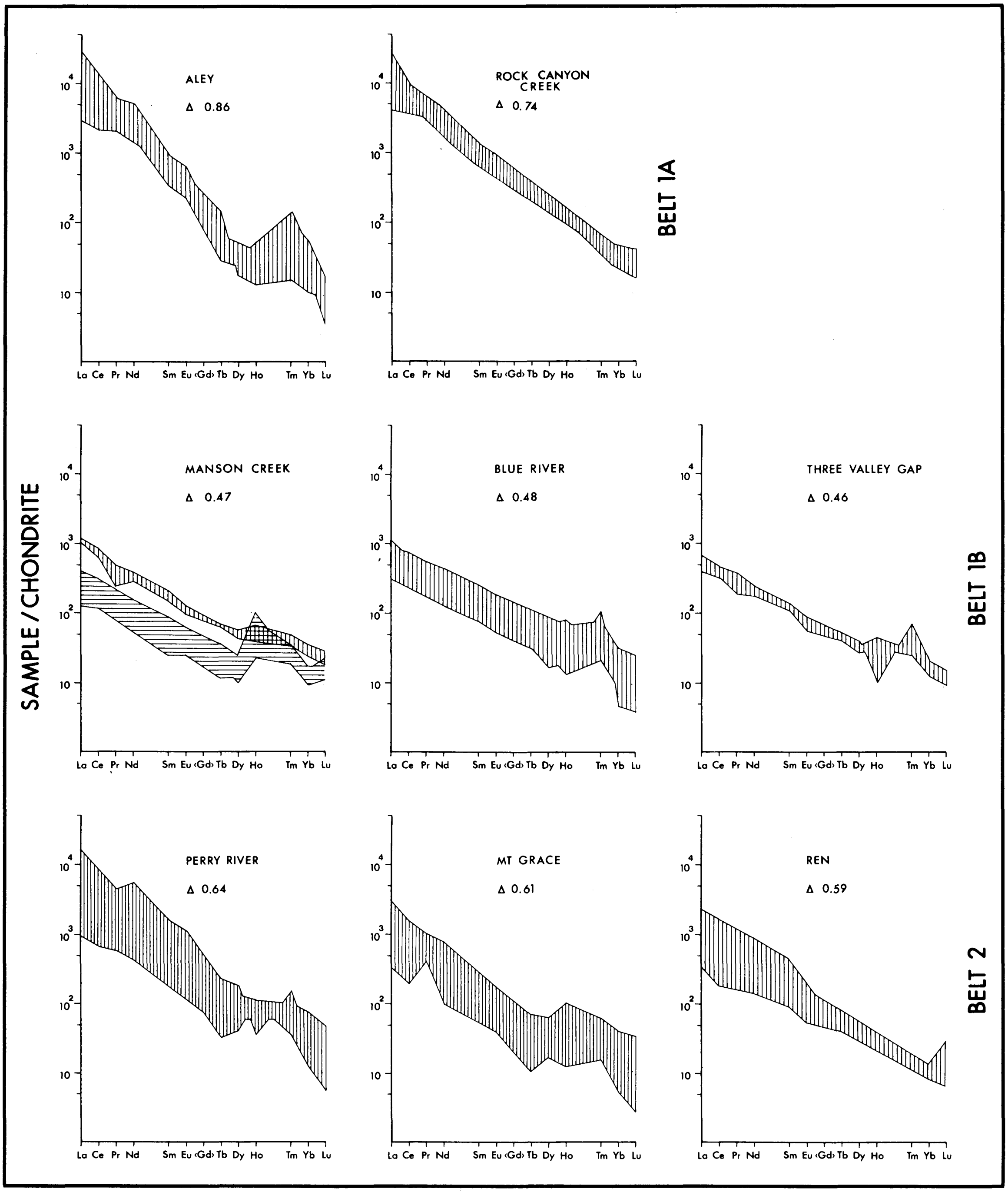


Figure 7. Chondrite-normalized rare earth element plots, British Columbia carbonatites. Chondrite rare earth values from Henderson (1984). Rock Canyon Creek rare earth element data from Graf (1985). Perry River and Mount Grace data from Höy and Pell (1986). Ren carbonatite data from Pilcher (1983).

along the margins of fluorite veins, as does coarse crystalline dolomite. Disseminated pyrite, gorceixite [$(Ba,Ca,Ce)Al_3(PO_4)_2(OH)_3$ H_2O], calcite, limonite, illite and barite are common accessory minerals (Hora and Kwong, 1986). Neutron activation analyses of up to 2.3 per cent rare earth elements and 2.7 per cent barium have been reported (Graf, 1985). Niobium, strontium and yttrium are also present in measurable amounts (Hora and Kwong, 1986). Contacts between mineralized and unmineralized dolomitic rocks are gradational; the amount of fluorite veining decreases and the colour of the rocks changes gradually from dark brown to buff, the characteristic colour of unaltered dolomites in the area. This type of mineralization defines a northwest-trending zone mappable for over a kilometre, subparallel to strike (Figure 6).

The second type of mineralization consists of massive, fine-grained purple and white fluorite, which commonly comprises greater than 40 per cent of the rock, together with accessory prosopite [$CaAl_2(F,OH)_3$], gorceixite, pyrite and minor barite, calcite, rutile and kaolinite (Hora and Kwong, 1986). The rare earth element and pyrite contents of these rocks are relatively low. Massive fluorite mineralization has not been found in place, but abundant float occurs at the southeast end of the zone of Type 1 mineralization, near the north-flowing branch of Rock Canyon Creek (Figure 6).

Fine-grained purple fluorite disseminated in white gypsum and locally interbedded with buff-weathering dolomite constitutes the third type of mineralization. Fluorspar is present in concentrations from trace amounts to a few per cent. Minor rare earth element enrichment is also reported (Graf, 1985). This type of mineralization is found randomly distributed throughout the basal Devonian unit.

The fourth type of fluorspar mineralization occurs in rocks tentatively assigned to the Devonian Fairholm Group and is found in one locality, at the 2135-metre elevation on the ridge east of the headwaters of Rock Canyon Creek (Figure 6). Massive purple fluorite forms the matrix of an intraformational conglomerate and constitutes greater than 20 per cent of the rock. Minor barite, pyrite and magnetite are also associated with this fluorite type.

Geochemistry

The interpretation that the Rock Canyon Creek showing is carbonatite related appears to be consistent with preliminary geochemical data (Tables 2 and 6). In addition to high fluorine, REE and barium, the rocks are enriched in strontium, yttrium, phosphorus (Graf, 1985) and niobium (Hora and Kwong, 1986) relative to ordinary carbonates. Chondrite-normalized rare earth element abundance patterns are typical of carbonatites (Figure 7) and fall within the field defined by other British Columbia carbonatites (Pell and Hora, 1987); however, the Rock Canyon Creek showing is more enriched in rare earths than most other examples, comparable only with the REE sweats and dykes associated with the Aley complex (Pell, 1986a; Mäder, 1987).

Dating

Timing of metasomatism (or carbonatite intrusion) is also poorly defined. Mineralization apparently occurred prior to the Jura-Cretaceous deformation, as no fluorite is observed west of the west boundary fault, and postdated at least part of the deposition of the basal Devonian unit. This broadly defines a time span of 280 Ma during which mineralization must have occurred. Some mineralization (Types 3 and 4, fluorite associated with solution breccias and intraformational conglomerate matrix) may have resulted from elemental remobilization, and therefore postdate the Type 1 and 2 fluorite/rare earth deposits. It has been suggested that mineralization may have been synchronous with deposition of the basal Devonian unit (Graf, 1985). A slightly younger age is favoured as most other carbonatites in the province are Devono-Mississippian to Early Mississippian (*circa* 350 Ma) in age (Pell, 1986d). Additional research is currently in progress to help resolve some of these ambiguities.

CARBONATITES AND SYENITE GNEISS COMPLEXES IN THE OMINECA BELT

MANSON CREEK AREA (93N/9)

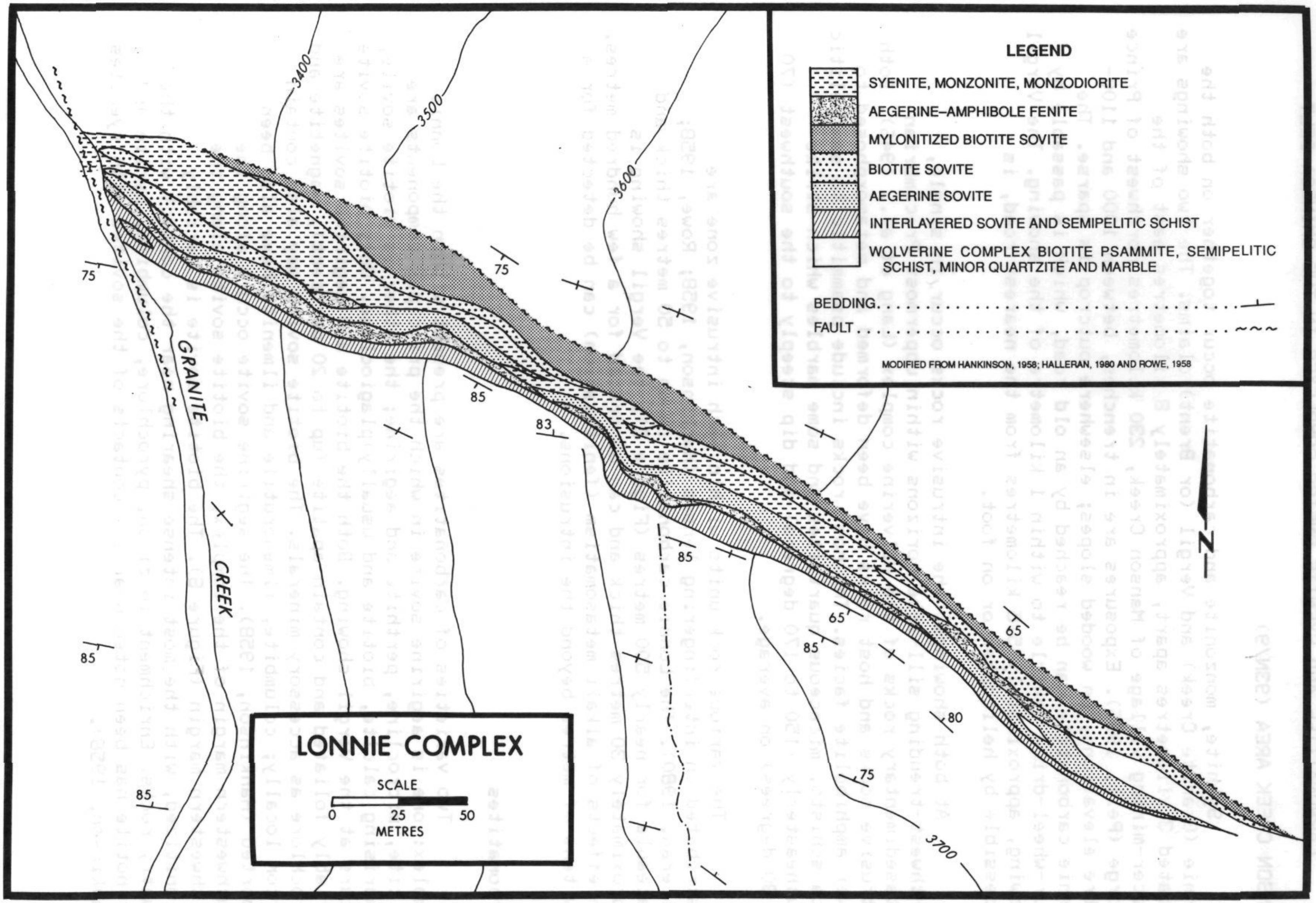
Syenite, monzonite and carbonatite occur together on both the Lonnie (Granite Creek) and Vergil (or Brent) claims. The two showings are located 3 kilometres apart, approximately 8 kilometres east of the placer-mining village of Manson Creek, 230 kilometres northwest of Prince George (Pell, 1985). Exposures are in trenches, between 1000 and 1100-metre elevations, on wooded slopes; elsewhere outcrop is sparse. The Lonnie carbonatite can be reached by an old road, which is passable by four-wheel-drive vehicle to within 1 kilometre of the showing. The Vergil showing, approximately 5.5 kilometres from the nearest road, is accessible by helicopter or on foot.

At both showings, the intrusive rocks occur in single, northwest-trending sill-like horizons within uppermost Precambrian metasedimentary rocks of the Wolverine complex (Lang *et al.*, 1946). Both intrusive rocks and host rocks have been deformed and metamorphosed to lower amphibolite facies. The host rocks include psammitic to semipelitic mica schists, micaceous quartzites and some marbles which strike southeasterly (150 to 170 degrees) and dip steeply to the southwest (70 to 80 degrees) on average.

The various rock units within each intrusive zone are distributed in interfingering lenses (Hankinson, 1958; Rowe, 1958; Halleran, 1980). The Lonnie carbonatite is up to 50 metres thick and traceable for nearly 500 metres (Figure 8); the Vergil showing is approximately 30 metres thick and can be traced for a few hundred metres. The effects of alkali metasomatism (fenitization) can be detected for a few tens of metres beyond the intrusions.

Carbonatites

Two varieties of carbonatites are present within the Lonnie complex: one is aegirine sovite in which the principal components are calcite, microcline, perthite and aegirine; the other is biotite sovite, comprising calcite, biotite and usually plagioclase. Only biotite sovite occurs at the Vergil showing. Both the biotite and aegirine sovites are variably foliated and contain apatite (up to 20 per cent), magnetite and pyrochlore as accessory minerals. The biotite sovite may also contain zircon locally; columbite, ilmenorutile and ilmenite have also been reported (Hankinson, 1958). The aegirine sovite occurs along the southwestern margin of the complex, the biotite sovite along the northwestern margin (Figure 8). The biotite sovite is variably mylonitized, with the most intense shearing near the contact with the country rocks. Enrichment in ziron, pyrochlore, columbite, pyrite and pyrrhotite has been noted near the contacts of the sovites with syenites (Hankinson, 1958).



MODIFIED FROM HANKINSON, 1958; HALLERAN, 1980 AND ROWE, 1958

Figure 8. Geological map of the Lonnie (Granite Creek) carbonatite complex.

Silicate Phases

Feldspathic intrusive rocks, monzodiorite, monzonites and syenites, outcrop as lenticular massess separating the carbonatite units (Figure 8). These intrusive rocks consist of potassium feldspar (orthoclase or microcline) and plagioclase in varying proportions; monzodiorites contain plagioclase >> K-feldspar; monzonites contain K-feldspar $\geq$ plagioclase and syenites have K-feldspar >> plagioclase. All phases contain accessory muscovite, biotite, calcite and apatite. Nepheline syenite is also locally present and contains significant amounts of zircon (3 to 15 per cent).

Fenites

Pods and layers of fenite occur within both the Lonnie and Vergil intrusive complexes. The fenite is medium to dark green in colour and rusty weathering. It consists of aegirine and sodic amphibole with microcline, plagioclase and calcite in varying amounts. The amphibole is strongly pleochroic, x - turquoise, y - colourless, z - prussian blue, with colour strongest at the rims. It is similar to the amphibole at the Aley complex, which has been identified (Mäder, 1986, 1987) as arfvedsonite. Trace constituents include pyrochlore, magnetite and zircon.

The hosting psammitic and semipelitic schists are recognizably fenitized for a few tens of metres beyond the intrusive contacts. Microcline, plagioclase and quartz are major constituents, with aegirine and arfvedsonite disseminated throughout, presumably replacing the original mafic silicate minerals. Biotite is present in trace amounts only. Calcite, apatite, magnetite and zircon may be present and coarse-grained arfvedsonite, magnetite and feldspar segregations may be developed locally.

Geochemistry

Major and trace element analyses of carbonatites, fenites and syenites from the Manson Creek area are summarized in Table 7. Fenites are notably enriched in iron and sodium, relative to other lithologies. Syenites may contain significant amounts of zirconium, up to 1.23 weight per cent. Rare earth element abundances are uniformly low, compared to those at Aley and Rock Canyon Creek (Table 2).

Niobium pentoxide values of between 0.1 and 0.3 weight per cent have been reported (Vaillancourt and Payne, 1979) from the Lonnie showing. A zone in the centre of the property averages 0.3 per cent Nb_2O_5 across a width of 7.6 metres and a length of 240 metres (Vaillancourt and Payne, 1979).

Dating

Preliminary uranium/lead systematics suggest that the Lonnie and Vergil carbonatites were emplaced in Late Devonian to Early Mississippian

TABLE 7
CHEMICAL ANALYSES OF ALKALINE ROCKS, MANSON CREEK AREA

Wt. %	Carbonatites			Fenite	Syenites	
	1	2	3	4	5	6
SiO_2	1.70	13.70	12.70	44.50	44.00	56.70
TiO_2	0.02	0.67	0.71	0.66	0.03	0.02
Al_2O_3	0.36	6.79	7.57	3.65	14.30	16.70
$Fe_2O_3^T$	1.40	6.21	5.70	19.60	0.80	0.59
MnO	0.59	0.37	0.24	0.24	0.23	0.11
MgO	0.31	2.20	1.85	2.48	0.17	0.12
CaO	52.90	36.60	36.10	10.90	16.30	6.09
Na_2O	0.44	1.21	3.48	10.30	4.97	6.94
K_2O	0.12	2.45	2.04	0.24	5.36	5.84
LOI	41.13	26.58	26.66	6.56	12.11	4.41
P_2O_5	0.13	2.64	2.20	0.76	1.47	0.61
Total	99.10	99.42	99.25	99.89	99.71	98.13
ppm						
Ni	<34	<89	<54	<78	<45	<47
Cr	6	21	13	179	32	45
Co	1.2	8.4	8.2	2.4	0.9	<0.5
Sr	7 310*	6 550	6 220	1 540	3 700	1 070
Ba	981	1 530	1 070	190	3 010	2 800
Zr	30*	30*	<20*	380*	<20*	12 290*
Nb	-	-	-	-	-	-
Y	-	-	-	-	-	-
La	347	401	371	88	135	43
Ce	600	741	673	172	286	107
Nd	179	245	206	56	102	35
Yb	7.7	6.2	5.2	2.1	3.8	3.5
Sc	0.5	0.6	0.2	12.6	0.3	0.4
Ta	0.2	6.0	2.5	11.0	14.9	39.3
Th	0.5	17.3	6.5	20.6	23.5	40.0

1 - L4179C - aegirine sovite, Lonnie claims; 2 - L4242B - biotite sovite, Vergil claims; 3 - L4184 - biotite sovite, Lonnie claims; 4 - L4174B - fenite, Lonnie claims; 5 - L197B - syenite, Lonnie claims; 6 - L4240B - syenite, Vergil claims.

*Trace element analysed by ICAP.
Major elements analysed by ICAP, alkaline fusion.
Trace elements analysed, using INAA by Bondar-Clegg, except where indicated.

times. Interpreted zircon ages of 350±10 and 370±20 Ma (R. Parrish, personal communication, 1985) were obtained.

BLUE RIVER AREA (83D/3, 6, 7)

A number of carbonatite layers occur within the semipelite-amphibolite division of the Hadrynian Horsethief Creek Group in the Monashee Mountains near Blue River, approximately 250 kilometres north of Kamloops (Figure 1). All are sill-like bodies which were intruded prior to the deformation and metamorphism associated with the Columbian orogeny (Pell, 1985). The carbonatites and hosting sedimentary rocks have been metamorphosed to upper amphibolite grade (kyanite to sillimanite zone). The Mud Lake (83D/3), Bone Creek (83D/6) and Verity (83D/6) showings (Figure 1) occur below treeline at elevations between 600 and 900 metres; consequently exposure is limited. The Paradise Lake (83D/6) and Howard Creek (83D/7) carbonatites are above treeline, well exposed, and were mapped in detail (Figures 9, 10a and 10b).

The Verity carbonatites can be reached by trails and logging roads which cross the North Thompson River and intersect Highway 5 at Lempriere Station, approximately 40 kilometres north of Blue River. The Bone Creek showings are accessed from a logging road which leaves Highway 5 approximately 23 kilometres north of Blue River. The Mud Lake carbonatite crops out along the Red Sands road, which intersects Highway 5, 3 kilometres north of Blue River. All roads are passable with four-wheel-drive vehicles. The Howard Creek and Paradise Lake localities are reached by helicopter, from Valemount.

Carbonatites in the Blue River area have been examined periodically, since the 1950s, for their vermiculite, uranium, niobium and tantalum potential. Previous descriptions are given by McCammon (1950, 1952, 1954), Rowe (1958), Currie (1976a), Meyers (1977), Ahroon (1979, 1980), Aaquist (1981, 1982a, 1982b, 1982c), White (1982, 1985) and Pell (1985).

Lithologies are very similar throughout this area and will be described by rock type rather than locality.

Carbonatites

Three types of carbonatite occur within this suite (Aaquist, 1982b, 1982c; Pell, 1985). One is a whitish weathering olivine sovite which contains predominantly calcite (60 to 85 per cent), olivine (3 to 20 per cent) and apatite (2 to 20 per cent). Accessory minerals which may be present are phlogopite, with either normal or reverse pleochroism (up to 8 per cent), diopside (10 per cent or less), magnetite, ilmenite, pyrite, pyrrhotite, pyrochlore, columbite, zircon, monazite, allanite and baddelyite. The sovite is usually medium grained and massive, but locally may contain pegmatitic phases with calcite and olivine crystals 2.5 to 3 centimetres in size and magnetite clusters over 20 centimetres in diameter. Zircon crystals up to 3 centimetres in size have also been found.

TABLE 8
CHEMICAL ANALYSES, ALKALINE ROCKS, BLUE RIVER AREA

Wt. %	Carbonatites								Fenite	Syenite		
	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	3.82	6.60	5.26	2.73	2.03	7.60	12.30	3.10	12.00	58.20	58.20	59.20
TiO_2	0.16	0.80	0.62	0.02	0.02	0.70	0.09	0.01	0.13	0.02	0.29	0.25
Al_2O_3	0.64	0.65	0.72	0.15	0.15	0.23	0.24	0.22	2.22	22.60	20.10	20.80
$Fe_2O_3^T$	4.28	10.70	10.30	4.35	6.48	7.35	8.41	7.61	2.62	0.30	2.69	2.20
MnO	0.21	0.23	0.24	0.31	0.38	0.21	0.41	0.37	0.24	0.01	0.04	0.03
MgO	2.60	6.88	5.59	14.50	19.00	14.80	15.20	16.30	2.65	0.04	0.17	0.31
CaO	45.40	39.80	40.90	28.10	28.70	32.90	30.60	29.10	42.90	0.83	0.56	0.69
Na_2O	0.10	0.15	0.15	0.10	0.27	0.11	0.05	<0.03	1.11	8.27	7.48	9.70
K_2O	<0.10	0.38	0.48	<0.10	0.25	0.29	0.12	0.12	0.59	8.07	5.49	5.08
LOI	33.37	25.64	28.17	39.79	40.38	35.46	27.12	37.26	30.92	1.36	0.90	1.18
P_2O_5	4.12	5.93	5.45	2.52	2.12	0.21	3.44	2.98	1.62	<0.09	<0.09	<0.09
Total	95.20	97.76	97.88	92.67	99.78	99.86	97.98	97.10	97.00	99.79	96.01	99.53
ppm												
Ni	-	<91	<64	<120	<120	<58	<91	<79	-	-	-	<32
Cr	-	22	21	23	24	34	35	40	-	-	-	88
Co	-	20.9	18.9	16.3	27.2	34.5	20.5	22.0	-	-	-	1.5
Sr	3600*	2710	3120	3810	4100	1320	2780	3110	4560*	900*	790*	910
Ba	220*	280	420	380	400	427	410	180	440*	5750*	1860*	3490
Zr	75*	820	870	30*	40*	350*	20*	20*	<15*	1260*	1260*	1330*
Nb	-	-	-	-	-	-	-	-	-	-	-	-
Y	-	-	-	-	-	-	-	-	-	-	-	-
La	-	254	241	171	134	103	200	174	-	-	-	0.9
Ce	-	548	530	371	279	208	415	339	-	-	-	3.9
Nd	-	234	223	147	119	81	165	133	-	-	-	1.9
Yb	-	4.2	4.1	1.4	1.0	1.8	2.0	1.4	-	-	-	0.6
Sc	-	3.3	6.8	20.3	13.7	19.3	38.4	34.7	-	-	-	0.1
Ta	-	7.9	12.8	150	206	16.9	96.8	51.4	-	-	-	10.6
Th	-	14.6	14.7	2.1	1.4	0.4	5.6	5.6	-	-	-	2.3

1 - P4330A - sovite, Paradise Lake; 2 - H4260 - sovite, Howard Creek; 3 - H4297A - sovite, Howard Creek; 4 - V4120 - beforsite, Verity; 5 - V4BEF - beforsite, Verity; 6 - V474D - beforsite, Verity; 7 - V431A - beforsite, Mud Lake; 8 - V462B - beforsite, Mud Lake; 9 - P4328B - fenite, Paradise Lake; 10 - P4323F - white sodalite syenite, Paradise Lake; 11 - P4319 - syenite, Paradise Lake; 12 - P4323H - nepheline and sodalite syenite, Paradise Lake;

*Trace elements by ICAP.
Major element by ICAP, alkaline fusion.
Trace elements by INAA, Bondar-Clegg, except where indicated.

TABLE 8 (continued)
CHEMICAL ANALYSES, ALKALINE ROCKS, BLUE RIVER AREA

Wt. %	Calc-syenite	Other Alkaline Rocks			Non-alkaline Rocks				
	13	14	15	16	17	18	19	20	21
SiO_2	41.80	45.30	41.80	47.10	31.80	46.60	55.80	50.80	60.50
TiO_2	2.18	5.65	2.18	1.84	0.40	0.23	0.40	0.60	0.62
Al_2O_3	20.10	8.53	20.10	1.03	9.72	4.88	5.93	13.30	18.00
$Fe_2O_3^T$	5.36	8.56	5.36	12.90	3.67	1.10	7.19	11.10	3.31
Mn	0.12	0.23	0.12	0.34	0.06	0.15	0.19	0.20	0.03
Mg	1.40	4.59	1.40	11.70	1.44	1.04	12.90	7.98	4.74
Ca	8.20	16.80	8.20	23.10	28.70	23.50	14.90	11.50	5.35
Na_2O	9.52	4.46	9.52	0.12	1.01	1.13	0.54	2.66	3.99
K_2O	3.50	1.20	3.50	<0.10	1.69	0.97	0.81	0.13	2.77
LOI	4.98	1.75	4.98	2.02	20.73	19.29	0.71	0.93	0.99
P_2O_5	0.44	1.11	0.44	0.23	<0.09	<0.09	<0.09	<0.09	<0.09
Total	97.60	48.18	97.60	100.48	99.31	98.98	99.46	99.29	100.39
ppm									
Ni	<40	<100	<39	<89	-	-	-	-	-
Cr	45	85	48	79	-	-	-	-	-
Co	10.5	19.0	12.0	38.2	-	-	-	-	-
Sr	3190	2770	3620	75*	1930*	155*	40*	70*	210*
Ba	5180	2050	1710	20*	<20*	180*	80*	20*	445*
Zr	190	880	340	20*	<20*	270*	55*	<20*	430*
Nb	-	-	-	-	-	-	-	-	-
Y	-	-	-	-	-	-	-	-	-
La	355	284	197	162	-	-	-	-	-
Ce	561	664	363	302	-	-	-	-	-
Nd	144	273	119	114	-	-	-	-	-
Yb	3.2	6.7	3.4	2.5	-	-	-	-	-
Sc	3.0	19.1	1.4	22.2	-	-	-	-	-
Ta	7.2	45.4	17.4	20.7	-	-	-	-	-
Th	14.1	15.8	8.8	0.9	-	-	-	-	-

13 - P4345FL - calcareous segregation in syenite, Paradise Lake; 14 - H4273A - hornblende sphene aegirine amphibolite, meta-ijolite (?), Howard Creek; 15 - H4273B - hornblende sphene nepheline meta-urtite, Howard Creek; 16 - V467A - fine-grained basic sill, Mud Lake; 17 - P4340A - Horsethief Creek marble, Paradise Lake; 18 - LP4355C - Horsethief Creek marble, west of North Thompson River; 19 - LP4355A - Horsethief Creek, biotite amphibolite, west of North Thompson River; 20 - P4328B - Horsethief Creek amphibolite.

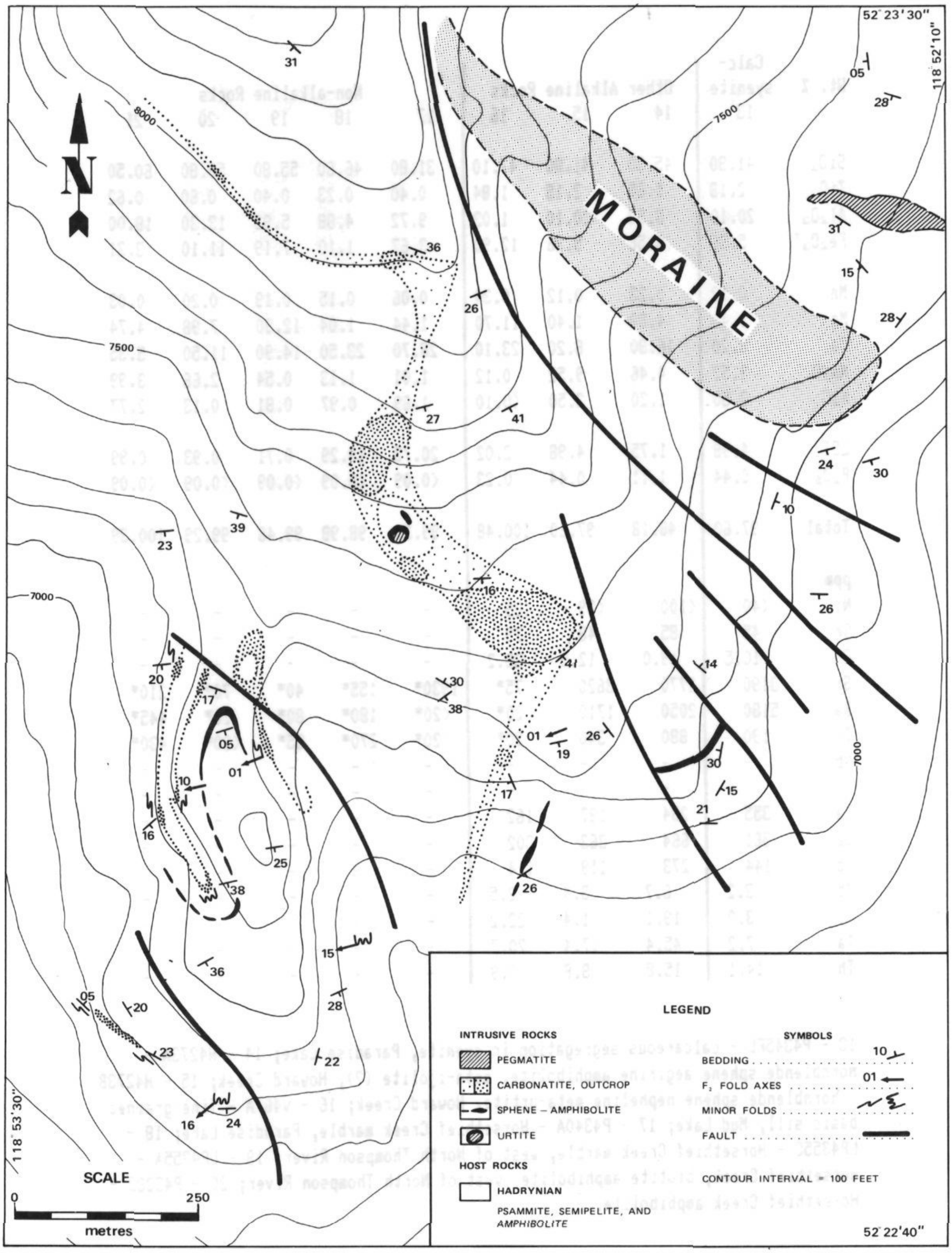


Figure 9. Geological map of the Howard Creek carbonatite occurrence (from Pell, 1985).

The second type is a buff-weathering dolomitic carbonatite (rauhaugite), with accessory amphibole (5 to 15 per cent), apatite (2 to 10 per cent), magnetite and minor phlogopite. Ilmenite, pyrochlore, columbite and zircon may be present in trace amounts. The amphibole may be richterite, soda-tremolite, tremolite or actinolite. Apatite and amphibole within the rauhaugite define a foliation parallel to both the edges of the carbonatite and the external schistosity. Locally, compositional banding with alternating apatite-amphibole-rich and carbonate-rich layers parallels foliation and contacts. Pegmatitic segregations are not found in the rauhaugite, but coarse pyrochlore and zircon crystals (1 to 1.5 centimetres in size) may be present.

Separate bands of sovite and rauhaugite occur at Verity and Howard Creek. Rauhaugite is present at both the Mud Lake and Bone Creek localities. At Paradise Lake, apparently continuous horizons (Figures 10a and 10b) grade from sovite to rauhaugite.

The third type of carbonatite, biotite sovite, is found at Paradise Lake only. It occurs as segregations or pods associated with nepheline syenite. Calcite, biotite, apatite and magnetite are the primary constituents and nepheline may also be present.

Nepheline Syenites

Nepheline and sodalite syenite gneisses crop out in the Paradise Lake area (Figures 10a and 10b). In general, the syenites comprise white to grey-weathering, medium-grained, layered and foliated gneisses, concordant with hosting Hadrynian Horsethief Creek Group rocks. Layering and foliation are parallel to the margins of the gneisses, to bedding in surrounding metasedimentary rocks and to regional foliation.

These syenites are typically composed of microcline (25 to 35 per cent), plagioclase (An_{30} to An_{40}, 25 to 35 per cent), nepheline (10 to 30 per cent) and biotite (7 to 15 per cent). Accessory minerals may include muscovite, sodalite, cancrinite, zircon and perthite. Trace minerals present are calcite, magnetite, pyrrhotite, pyrochlore and uranopyrochlore. The syenite gneisses are locally migmatitic, with massive, medium to coarse-grained, lensoidal leucosomes that are either predominantly composed of nepheline, microcline, plagioclase and sodalite or large perthite crystals.

Mafic Silicate Rocks

Mafic and ultramafic silicate rocks are present at Howard Creek (Figure 9). The most common variety is sphene-pyroxene-amphibole rock or melteigite, which may be layered and foliated or massive. It consists of aegirine-augite (approximately 50 per cent), strongly pleochroic hornblende (x - honey yellow, y - dark bluish green, z - dark forest green to opaque; 15 to 30 per cent) and sphene (10 to 20 per cent). Accessory minerals include nepheline, plagioclase, pyrite and calcite ± biotite, allanite and apatite. The rock is generally coarse grained with pyroxene crystals exceeding 3.5 centimetres in length and sphene crystals up to 2 centimetres in size. In the strongly foliated varieties,

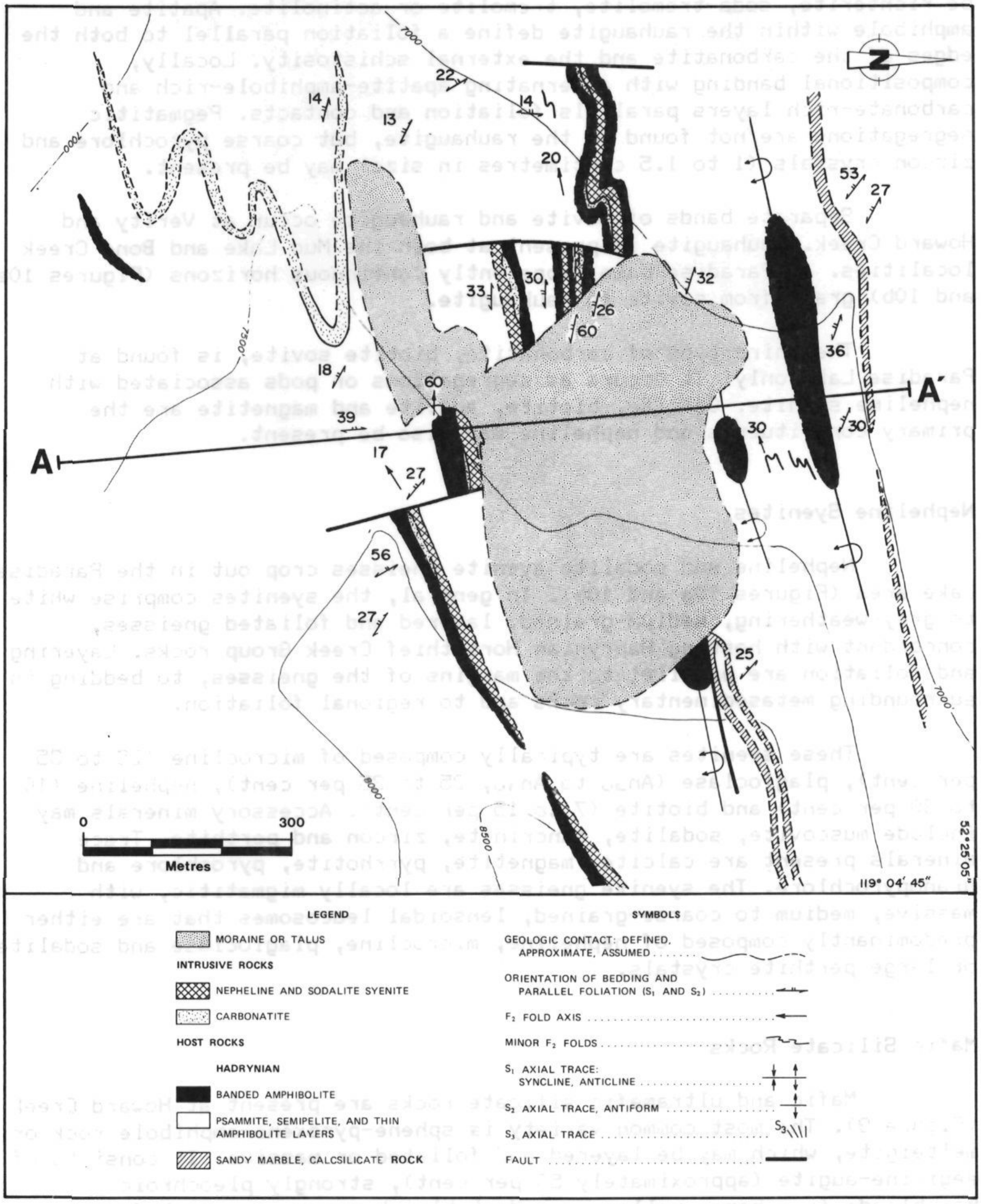


Figure 10a. Geology of the area south of Paradise Lake (from Pell, 1985).

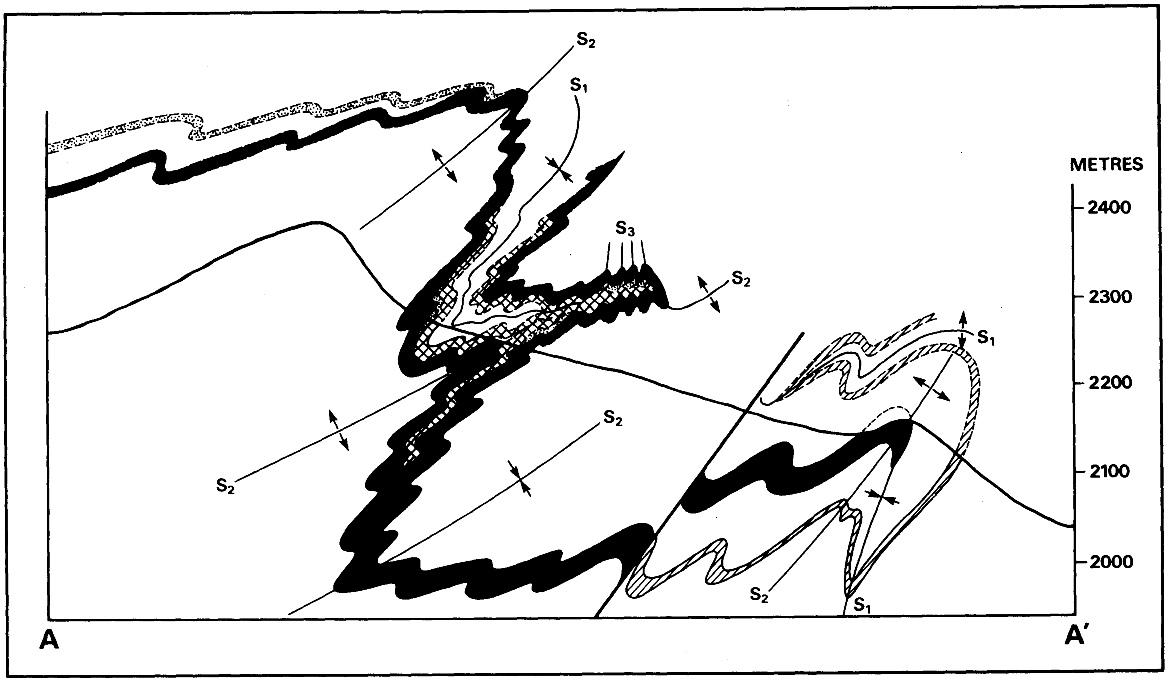


Figure 10b. Cross-section A-A', area south of Paradise Lake (from Pell, 1985).

hornblende predominates (50 to 55 per cent), with aegirine-augite, sphene and biotite abundant, and calcite, plagioclase, apatite, pyrite ± nepheline as trace constituents. At one locality, the melteigite is transitional to a coarse-grained, massive urtite composed of 25 to 40 per cent nepheline, 10 to 15 per cent potassium feldspar, 8 to 15 per cent plagioclase, 8 to 15 per cent aegirine, 15 to 20 per cent hornblende and sphene, biotite and calcite.

Fenites

Mafic fenites, 1 to 30 centimetres thick, separate carbonatites and host metasedimentary rocks. They vary from medium to coarse grained and massive to foliated. The fenites are generally composed of amphiboles (hornblende-actinolite, 45 to 80 per cent), clinopyroxene (generally diopside or augite, up to 35 per cent), apatite and opaques. Accessory minerals locally present are titanaugite, biotite, plagioclase, sphene, epidote, quartz (remnant) and calcite. In some localities a biotite/vermiculite layer is developed in place of the amphibole fenites. In all cases the metasedimentary rocks adjacent to the fenites appear unaltered.

Geochemistry

Major and trace element abundances for alkaline rocks in the Blue River area are summarized in Table 8. Carbonatites (both sovites and rauhaugites) are distinct from Horsethief Creek Group marbles; the carbonatites contain significantly less silica, aluminum and alkalis than the average marble and are enriched in iron, phosphorus and strontium (Table 8). Enrichment in niobium and tantalum has also been reported (Ahroon, 1979, 1980; Aaquist, 1981, 1982a, 1982b, 1982c), with Nb_2O_5 values of up to 0.46 per cent (Aaquist, 1982b) and tantalum values to 2400 ppm (Aaquist, 1982c).

Geochronology

Early attempts at dating did not provide definitive results on the age of alkaline intrusions. Potassium/argon dates of 205±8 Ma on phlogopite from Howard Creek, and 92.5±3.2 and 80.2±2.8 Ma on richterite from Verity were obtained (White, 1982). Subsequently, potassium/argon dates of 200±7 Ma on phlogopite and 94.4±3.3 Ma on hornblende from Howard Creek were obtained (G.P.E. White, personal communication, 1984). The young dates are most likely representative of the timing of metamorphism and not the emplacement of the igneous rocks.

More recent uranium/lead data have been obtained from zircon separates and indicate a mid-Paleozoic (Devono-Mississippian) age of emplacement. A sample from Verity yielded an age of approximately 325 Ma (G.P.E. White, personal communication, 1984). Zircons from Paradise Lake provided a 350±5 Ma date; a date of approximately 328±30 was obtained from Mud Lake samples (R. Parrish, personal communication, 1985).

TRIDENT MOUNTAIN (82M/16)

Nepheline syenites were first recognized in the Trident Mountain area by Wheeler (1965) and subsequently mapped by Perkins (1983). Trident Mountain is located in the Big Bend of the Columbia River, about 85 kilometres northeast of Revelstoke and 20 kilometres southeast of Mica Creek (Figure 1). The area is very rugged; the syenites are exposed on cliffs at elevations of 2200 to 3000 metres, adjacent to large icefields (Figure 11). Access is by helicopter from Revelstoke.

The syenite gneisses at Trident Mountain are white to grey weathering, medium grained and moderately to well foliated. They are composed of white to pinkish microcline (25 to 50 per cent), albitic plagioclase (10 to 30 per cent) and nepheline (10 to 40 per cent). Nepheline generally has an irregular poikiloblastic texture and is often partially altered to clay minerals. Green to olive pleochroic biotite is commonly the mafic silicate phase present and comprises from trace amounts to more than 30 per cent of the rock. Locally coarse-grained aggregates of randomly oriented biotite crystals are developed. Greenish acmitic pyroxene has also been reported (Currie, 1976a) from nepheline-rich phases. Accessory minerals may include sodalite, cancrinite, calcite, apatite, sphene, ilmenite, pyrochlore and zircon (crystals up to 1.5 centimetres in size). Local pegmatitic segregations are sporadically developed.

The syenites occur as a concordant lenticular mass high on the slopes of Trident Mountain. The host rocks are psammitic and kyanite-bearing pelitic schists (with rare calc-silicate bands) of the Hadrynian

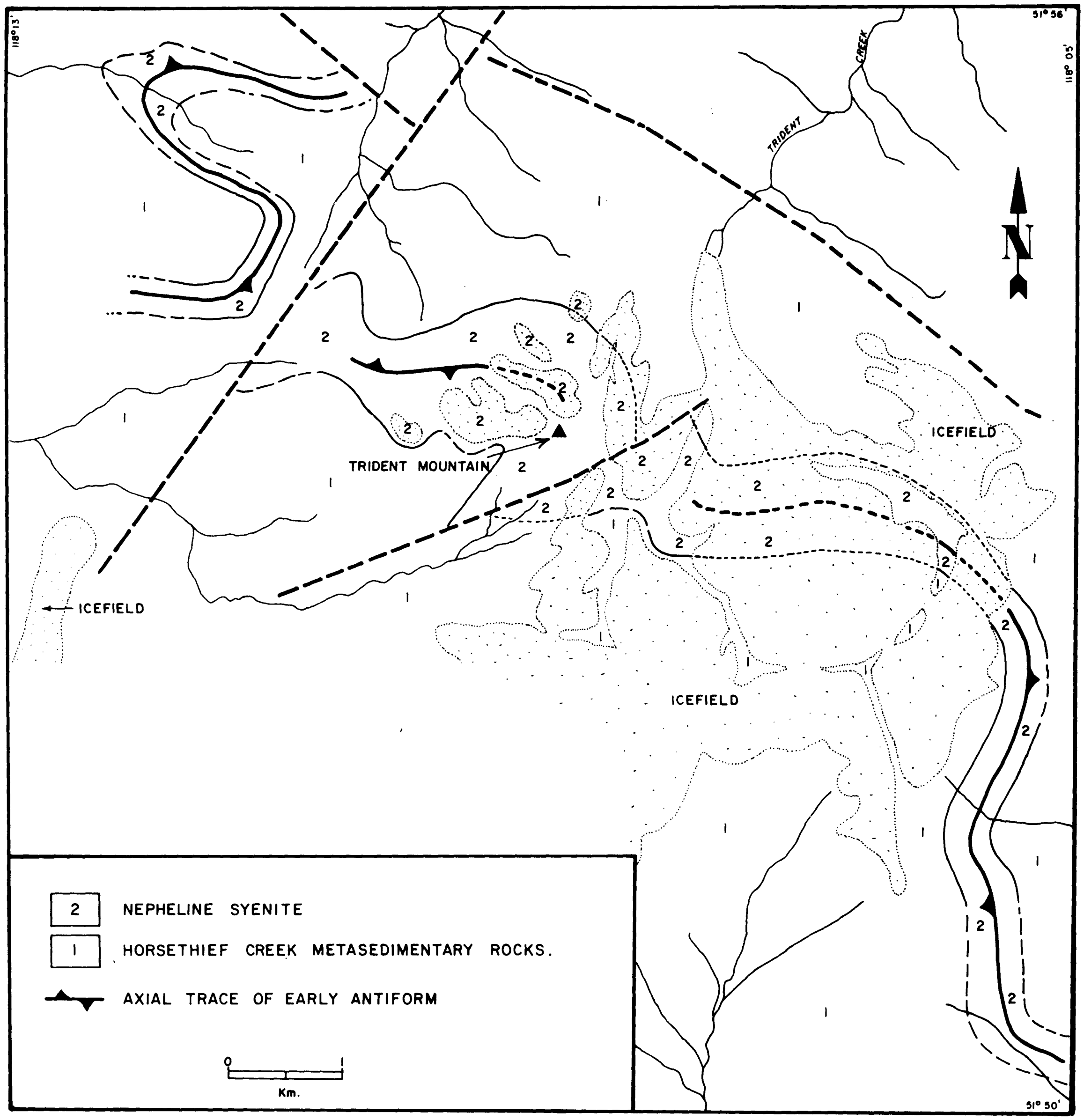


Figure 11. Geology of the Trident Mountain area, Selkirk Mountains (from Pell, 1986b; Perkins, 1983).

Horsethief Creek Group and are exposed in the core of an early isoclinal antiform which is refolded by later upright to overturned structures (Perkins, 1983). The syenites display compositional layering and a foliation parallel to the margins of the body, the axial plane of the antiform, and bedding in the metasedimentary rocks. The layering is defined by leucocratic (biotite less than 10 per cent) and melanocratic (biotite 30 to 40 per cent) phases with occasional calcareous layers (sovitic sweats?).

Mafic gneisses rich in amphibole, biotite and sphene are also present at Trident Mountain, but were not seen in outcrop (Pell, 1986b). They are cut by dykes of leucosyenite. Contacts between the mafic gneisses and syenite dykes are sharp. Xenoliths of country rock or mafic orthogneiss were observed in the melanocratic syenites (Pell, 1986b). The xenoliths have very diffuse contacts, suggesting reaction with, or partial digestion by, the syenitic magma. Mafic gneisses apparently represent an early phase of intrusion, cut by later leucocratic nepheline syenites.

Another mass of nepheline syenite is reported (Fyles, 1959, 1960; Currie, 1976a) at the mouth of the Sullivan River, approximately 15 kilometres northeast of Trident Mountain. The nepheline-bearing lithologies display a strong foliation, conformable to the surrounding metasedimentary rocks which are assigned to the Lower Cambrian Hamill Group. The only known outcrops of this syenite were in the Sullivan River delta, which is now flooded as a result of construction of the Mica Dam.

Dating

Preliminary uranium/lead isotopic analyses on zircons from the Trident Mountain syenite suggest an age of emplacement of *circa* 380 Ma (R. Parrish, personal communication, 1987). This is consistent with the Devono-Mississippian age obtained from Paradise Lake syenites which resemble the Trident Mountain gneisses. Uranium/lead data on pyrochlore yield a 60 Ma date (R. Parrish, personal communication, 1987) which indicates a metamorphic resetting.

CARBONATITES AND SYENITE GNEISS COMPLEXES ASSOCIATED WITH THE FRENCHMAN CAP GNEISS DOME

Intrusive and extrusive carbonatites, and syenite gneiss bodies occur within a mixed paragneiss succession along the margin of Frenchman Cap gneiss dome (Figure 12), one of several late domal structures near the eastern margin of the Shuswap Complex in southeastern British Columbia (Wheeler, 1965). The dome is exposed as a window between the Columbia River fault to the east and the Monashee décollement to the west (Read and Brown, 1981).

The core of Frenchman Cap Dome comprises a mixed paragneiss and orthogneiss succession of probable Aphebian age. It is basement to an unconformably overlying "mantling gneiss" or autochthonous cover succession, comprising a basal quartzite and overlying pelitic and calcareous rocks. The autochthonous cover succession hosts the carbonatites and syenite gneisses. The depositional environment of the cover succession has been interpreted as shallow marine or platformal by McMillan (1973), Höy and McMillan (1979) and Brown (1980).

The ages of the mantling paragneiss succession and carbonatites have not yet been unequivocally established. Based on regional correlations with platformal rocks to the east, a number of authors (Wheeler, 1965; Fyles, 1970; Höy and McMillan, 1979) tentatively assigned Eocambrian to Early Paleozoic ages to these rocks. Zircons from carbonatites and syenites from this area are being analysed and should provide a more reliable age for these alkalic rocks and the host succession.

Two phases of folding are prominent in the mantling gneiss succession and various generations of minor folds are also developed (Fyles, 1970; McMillan, 1970). All phases of folding deform both the extrusive and intrusive carbonatites and the syenite gneisses (Höy and Kwong, 1986).

Amphibolite facies regional metamorphism along the margin of Frenchman Cap Dome has produced sillimanite-kyanite, sillimanite and sillimanite-potassic feldspar assemblages in pelitic rocks. Calcsilicate assemblages contain diopside, garnet and actinolite. Carbonates and carbonatites are recrystallized to medium to locally coarse-grained granoblastic marbles (Höy and Kwong, 1986).

CARBONATITES AND ASSOCIATED ROCKS, WEST FLANK, FRENCHMAN CAP DOME (82M/2, 7, 10)

Carbonatites along the western margin of the Frenchman Cap Dome in the Perry River area (Figure 12) were originally described by McMillan (1970) and McMillan and Moore (1974). Two types were recognized. Type 1 carbonatites are conformable with bedding in hosting metasedimentary rocks and have metasomatic envelopes which may extend from 1 to more than 30 metres beyond the intrusive contacts (McMillan and Moore, 1974). They are interpreted to have formed as sills or dykes (McMillan and Moore, 1974; Currie, 1976a). Type 2 carbonatites are concordant bodies, associated with white marbles, which have no contact alteration zones

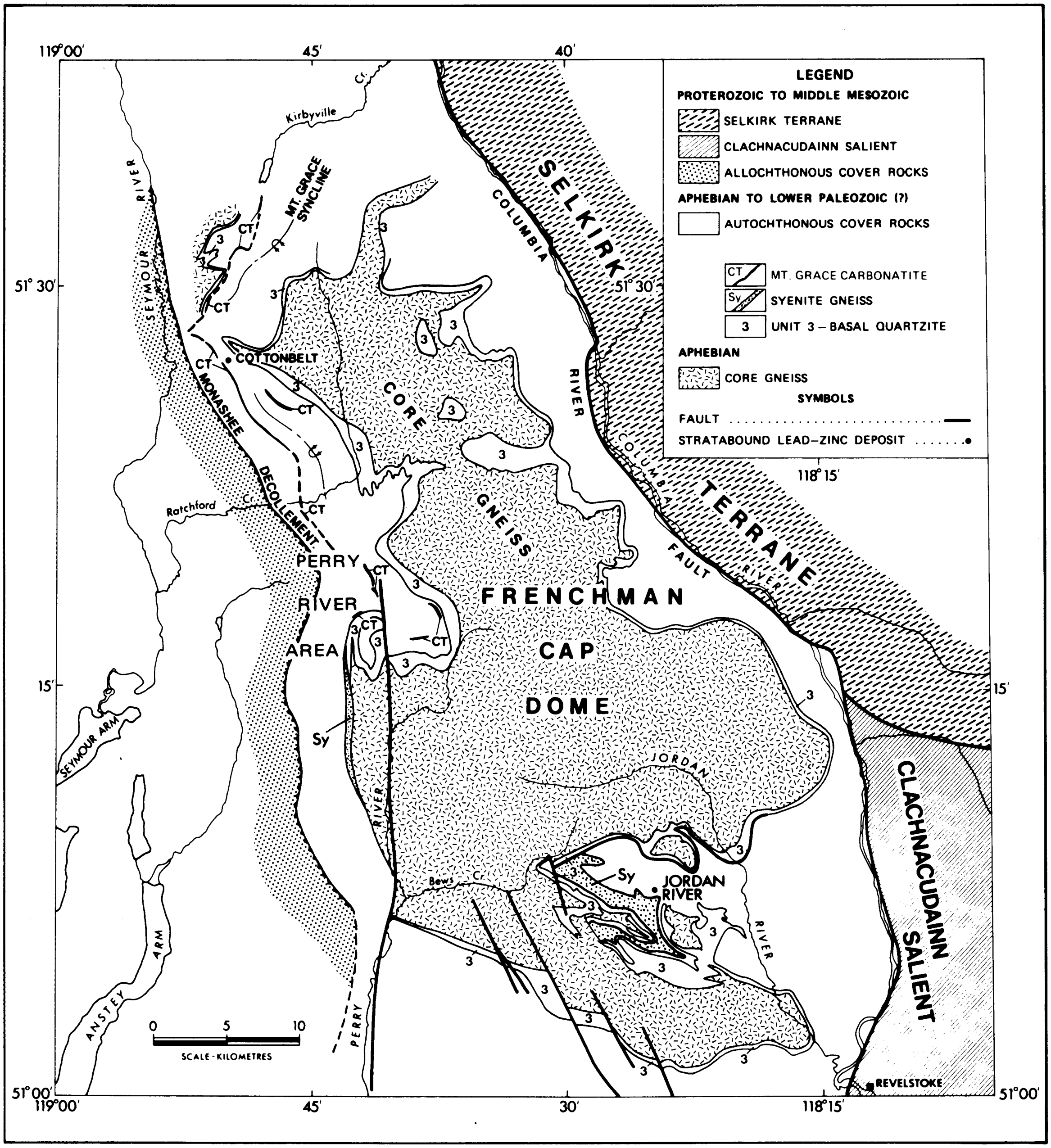


Figure 12. Geology of the Frenchman Cap area (from Höy and Kwong, 1986).

(McMillan and Moore, 1974). They crop out in strata which overlie those hosting Type 1 carbonatites (McMillan and Moore, 1974).

Detailed mapping in the Mount Grace area north of the Perry River (Höy, 1979) led to the discovery of new occurrences of the Type 2 carbonatite layer, referred to as the Mount Grace carbonatite (Höy and Kwong, 1986) and confirmed the suggestion (McMillan and Moore, 1974) that it is an extrusive layer. Recent work (Pilcher, 1983; Höy and Pell, 1986; Höy, in preparation) has shown that intrusive carbonatites occur at two stratigraphic levels. A new occurrence (Pilcher, 1983) is located stratigraphically above the Mount Grace extrusive layer and is referred to as the Ren, or Ratchford Creek carbonatite.

Perry River Intrusive Carbonatites (82M/7)

Several lenses of intrusive carbonatite are recognized in the Perry River area (McMillan and Moore, 1974). They occur low in the mantling gneiss stratigraphy, locally within a few metres of the core gneisses. These occurrences appear to be part of a single continuous zone at least 4 kilometres in length (*see* Figure 3 of McMillan and Moore, 1974) that is concordant with layering, but on a regional scale may cut up-section to the south (Höy and Pell, 1986).

The carbonatites consist of discontinuous lenses associated with mafic and syenitic fenites. Within the volumetrically more abundant fenites, carbonatites may occur as relatively thick, buff-weathering, foliated and laminated layers; as swirled, discontinuous lenses; or as small, irregular coarse-grained pods (Höy and Pell, 1986).

The carbonatites are sovites and consist of 70 to 90 per cent calcite and variable amounts of sodic amphibole (riebeckite), apatite and phlogopite. Phlogopites may display reversed pleochroism. Sphene, aegirine, plagioclase, magnetite, pyrrhotite, pyrochlore, chalcopyrite, pyrite and ilmenite may be present as accessory minerals (Höy and Pell, 1986).

Fenites

Fenites are well layered, probably reflecting original compositional variations in sedimentary strata. Three types are recognized; mafic pyroxene-amphibole fenite, syenitic fenite and albite fenite (Höy, in preparation). The mafic fenite is by far the most abundant; it has gradational contacts with interlayered albite fenite and sharp contacts with syenitic fenites. Remnant metasedimentary calcsilicate gneiss, quartzofeldspathic paragneiss and minor marble layers may occur within the fenites. In general, the contacts between mafic fenites and quartzofeldspathic paragneisses are sharp whereas those with more calcareous strata are gradational. Towards the centre of fenitized zones, paragneiss layers may be present but not calcsilicate gneisses. These relationships suggest that fenitization is selective, preferentially affecting more calcareous layers and only with increasing intensity affecting quartzofeldspathic strata to produce syenitic fenites (Höy, in preparation).

Pyroxene amphibole fenites are dark green to black and may be massive or foliated. They consist primarily of aegirine-augite, or rarely, aegirine, sodic amphibole, sphene and biotite. Biotite content ranges from trace amounts to over 50 per cent. Calcite, apatite, plagioclase (albite), epidote, zircon, chalcopyrite, magnetite and ilmenite may be present as accessory minerals. Potassium feldspar and nepheline have also been noted (Höy, in preparation). Pegmatitic lenses consisting of calcite, amphibole, pyroxene, euhedral sphene, magnetite and ilmenite are common throughout the fenite. Individual crystals may be in excess of 7 centimetres in size.

The mafic fenites are locally interlayered and gradational with leucocratic fenites (or albitites) consisting of approximately 90 per cent albite with aegirine-augite and minor amounts of biotite, sphene, apatite, epidote, microcline, magnetite, and locally, coarse molybdenite.

Syenitic fenites are foliated, compositionally banded and contain rare thin metasedimentary layers and occasional small discontinuous carbonatite lenses. They are composed of 70 to 80 per cent plagioclase (andesine) and microcline in varying proportions. True syenites are less common that monzonites (microcline is generally less abundant than plagioclase). Principal mafic minerals are aegirine or aegirine-augite ± biotite. Calcite, muscovite, sphene, magnetite, apatite, chalcopyrite and allanite are common accessory minerals. Variable amounts of nepheline may also be present.

Ratchford Creek (Ren) Intrusive Carbonatite (82M/7)

The Ren carbonatite, named after the claims on which it outcrops, is a concordant unit at least 3 kilometres in length and 20 to 200 metres in width. It is associated with pyroxene-amphibole fenites similar to those occurring with Type 1 carbonatites. It crops out south of Ratchford Creek in the core of the Mount Grace syncline (Figure 12) and is intrusive into strata which overlie those hosting the other known carbonatites (intrusive and extrusive) and syenites.

The Ren carbonatite weathers to a mottled orange-brown colour and has a well-banded to salt-and-pepper texture. It comprises, on average, 60 to 80 per cent carbonate minerals (calcite and dolomite) and 10 to 30 per cent apatite, with accessory biotite, amphibole, pyroxene and sphene, and minor pyrrhotite, pyrite, sphalerite, chalcopyrite, pyrochlore (?) and monazite (?) (Pilcher, 1983).

Intrusive Syenite (82M/2, 7)

A large intrusive syenite body crops out in the Perry River area (*see* Figure 12). It is a concordant unit up to 300 metres thick and 12 kilometres long (McMillan, 1973). It is internally foliated and layered with alternating bands of syenitic and feldspathoidal rock. Country rocks along its margins are metasomatically altered with development of a rusty zone enriched in feldspar, pyroxene, muscovite and/or pyrrhotite. The syenite gneiss intruded strata which underlie those hosting the extrusive carbonatite.

The predominant minerals in the syenite are microcline, perthite, plagioclase (albite to labradorite) and nepheline. Approximately 60 per cent of the rocks contain nepheline, with or withouth feldspars (McMillan and Moore, 1974). Biotite is the predominant mafic mineral; aegirine or aegirine-augite may also be present. Accessory minerals include muscovite, phlogopite, calcite, cancrinite, apatite, sphene, zircon, allanite, pyrochlore, grossular garnet, fluorite, molybdenite, magnetite and pyrrhotite (McMillan and Moore, 1974).

Mount Grace Extrusive Carbonatite (82M/7, 10)

The Mount Grace carbonatite layer averages 3 to 5 metres in thickness. Locally it narrows to less than a metre, but near its mapped northern limit (Figure 12), it is estimated to be greater than 60 metres thick. An associated increase in clast sizes here indicates close proximity to a source or vent area (Höy and Pell, 1986). Although in most places it is a single layer, it locally comprises a main layer plus a number of thinner layers separated by paragneiss and marble. It has been traced or projected beneath overburden for a strike length of at least 100 kilometres (Höy, in preparation). The contacts of the Mount Grace carbonatite with overlying and underlying calcareous gneisses are sharp, but in places they grade through approximately 1 metre into grey-weathering, massive to thin-bedded calcite marble. In contrast with intrusive carbonatites in the Perry River area, it has no fenitized margins. Detailed descriptions of the Mount Grace carbonatite have been published (Höy and Kwong, 1986; Höy and Pell, 1986; Höy, in preparation) and only a brief review will be presented here.

In the field, the carbonatite is recognized and characterized by an unusual pale to medium brown-weathering colour. Grains of dark brown phlogopite, colourless apatite and needles of amphibole weather in relief. Pyrrhotite, pyrochlore and zircon are locally developed accessory minerals. Monazite, barite, strontianite and possibly rare earth carbonate minerals are present in trace amounts (Höy, in preparation).

The Mount Grace carbonatite is commonly internally banded, with a layer or several layers of "blocky" tephra interbedded with finer grained, massive or laminated carbonatite. The blocky tephra layers contain three types of matrix-supported clasts: small granular albitite clasts up to 3 centimetres in diameter, consisting of pure albite or albite with variable amounts of phlogopite; syenite clasts, 1 to 10 centimetres in diameter, consisting of potassium feldspar with variable amounts of plagioclase, calcite, apatite and rare feldspathoids; and larger rounded to subrounded biotite-plagioclase gneiss, schist and quartzite clasts that are commonly up to 20 centimetres in diameter. The lithic clasts may be internally folded and have a pronounced layering or foliation that is randomly oriented with respect to the regional mineral foliation. The lithic and albitite clasts are generally randomly distributed throughout a tephra layer, but in some layers they are concentrated in the centre or occasionally graded with clast size increasing up-section (Höy and Pell, 1986).

TABLE 9
CHEMICAL ANALYSES OF ALKALINE ROCKS, WEST FLANK, FRENCHMAN CAP DOME

Wt. %	Nepheline Syenite Gneiss										Mount Grace	
SiO_2	51.44	57.34	46.18	55.67	51.33	41.77	53.02	53.57	51.88	2.20	15.15	9.46
TiO_2	0.27	0.30	0.94	0.28	0.38	0.52	0.21	0.60	0.88	<0.02	0.07	0.14
Al_2O_3	24.42	22.98	28.11	23.59	23.57	31.71	27.12	19.76	22.07	0.55	4.20	2.69
Fe_2O_3	1.40	0.59	4.08	0.63	0.44	0.29	1.14	4.10	1.27	2.64[1]	4.87[1]	4.47[1]
FeO	1.32	1.33	2.57	1.45	2.37	1.49	0.46	1.30	3.29			
MnO	0.10	0.07	0.29	0.09	0.09	0.10	0.09	0.15	0.14	0.27	0.61	0.47
MgO	0.15	0.24	1.12	0.15	0.79	0.46	0.31	0.37	0.26	3.47	4.54	4.36
CaO	4.23	0.59	4.63	2.06	2.97	3.47	6.33	2.79	2.26	48.05	34.85	41.24
Na_2O	9.44	5.06	3.00	4.12	7.51	12.23	4.24	6.04	5.07	0.36	2.30	1.16
K_2O	3.55	10.18	5.80	8.99	6.69	4.70	6.41	10.9	10.3	<0.03	0.38	0.69
H_2O	1.08	0.97	0.63	1.41	1.74	1.23	1.53	0.50	1.42	0.36	0.50	0.34
CO_2	2.49	0.35	2.17	0.12	1.22	0.41	0.53	0.62	0.70	<0.70	31.10	32.40
P_2O_5	0.16	-	0.60	0.10	0.36	0.16	0.31	<0.08	<0.08	0.06	0.06	0.53
Total	100.05[2]	100.00[2]	100.12[2]	99.02[2]	99.46[2]	98.54[2]	101.70[2]	100.70[3]	99.54[3]	98.68[4]	98.63[4]	97.95[4]
ppm												
Ni	-	-	-	-	-	-	-	-	-	-	-	-
Cr	-	-	-	-	-	-	-	-	-	-	-	-
Co	-	-	-	-	-	-	-	-	-	-	-	-
Sr	-	-	-	-	-	-	-	-	-	3300	5700	4600
Ba	-	-	-	-	-	-	-	-	-	3100	2800	3500
Zr	1400	1915	3700	2300	1150	2540	2185	-	-	-	-	-
Nb	1200	nd	2380	nd	1200	1200	nd	-	-	<10	100	300
Y	-	-	-	-	-	-	-	-	-	-	-	-
La	-	-	-	-	-	-	-	-	-	710	345	390
Ce	-	-	-	-	-	-	-	-	-	1050	560	660
Nd	-	-	-	-	-	-	-	-	-	350	230	290
Yb	-	-	-	-	-	-	-	-	-	-	-	-
Sc	-	-	-	-	-	-	-	-	-	-	-	-

[1] Total Iron expressed as Fe_2O_3.
[2] From McMillan (1973).
[3] From Höy and Pell (1986).
[4] From Höy and Kwong (1986).
[5] From Höy (in preparation).

TABLE 9
CHEMICAL ANALYSES OF ALKALINE ROCKS, WEST FLANK, FRENCHMAN CAP DOME
(CONTINUED)

Extrusive Carbonatite			Perry River Intrusive Carbonatites					Ren Intrusive Carbonatite			
7.96	12.72	4.84	6.77	0.39	6.38	0.79	4.10	1.51	4.57	0.85	4.15
0.08	0.21	0.07	1.32	<0.01	0.86	0.03	0.05	0.06	0.04	0.04	0.06
1.79	4.07	0.99	0.36	0.16	1.57	0.30	0.91	0.22	0.55	0.07	0.72
3.39^1	5.01^1	4.19^1	4.14^1	0.38^1	4.66^1	0.68^1	1.20	3.45^1	2.87^1	2.71^1	3.29^1
0.34	0.40	0.39	0.38	0.44	0.44	0.17	0.22	0.31	0.43	0.41	0.43
5.42	5.72	5.10	2.38	0.46	1.85	0.62	0.99	6.30	17.30	16.69	15.40
41.33	35.21	43.79	45.34	51.04	42.72	52.44	45.29	43.82	31.05	33.83	32.86
0.85	1.05	0.33	0.37	0.13	0.64	0.14	0.37	0.08	0.24	0.04	0.16
0.68	1.73	0.75	0.21	<0.01	0.85	0.09	0.04	0.02	0.12	0.01	0.17
0.43	0.76	0.10	0.06	<0.05	0.08	0.03	-				
34.80	29.20	34.70	29.92	39.05	33.92	35.06	35.95	36.61	38.27	43.46	38.36
0.07	0.07	1.60	0.21	<0.01	0.85	0.09	0.34	4.20	3.60	2.16	3.60
97.14^4	96.15^4	96.85^4	99.7^5	100.00^5	98.6^5	99.8^5	89.46^5	96.58^5	99.04^5	100.27^5	99.20^5
-	-	-	28	6	14	16	-	-	-	-	-
-	-	-	37	<25	25	25	-	<10	36	<10	38
-	-	-	-	-	-	-	-	-	-	-	-
5400	6600	5800	1600	3100	2100	1000	-	5188	4628	4271	4828
3200	3500	3600	1155	1217	2539	1205	-	213	1133	676	162
-	-	-	-	-	-	-	208	297	96	92	108
100	200	200	50	8	50	30	<100	60	27	25	1516
-	-	-	160	80	120	34	107	60	27	25	31
540	940	500	1470	704	>2000	317	-	-	-	-	-
810	1430	1020	2010	927	7630	614	-	-	-	-	-
230	405	430	654	271	3540	279	-	-	-	-	-
-	-	-	17.4	10.0	7.4	2.9	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-

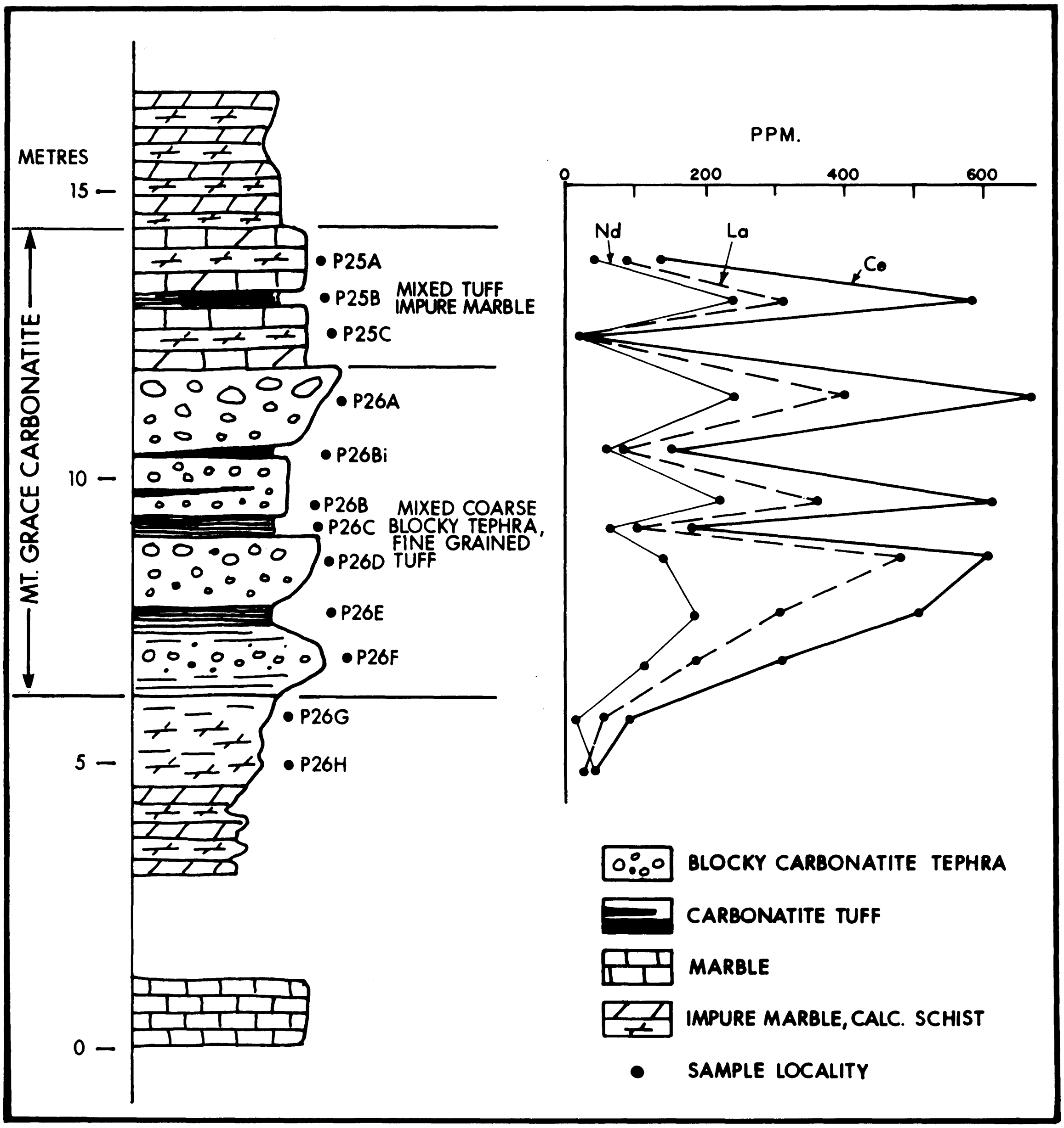


Figure 13. Detailed section of the Mount Grace carbonatite, Blais Creek showing. La, Ce and Nd values of selected samples from Höy and Pell (1986).

Geochemistry

Carbonatites from the Perry River, Mount Grace and Ratchford Creek (Ren) areas display a large compositional range with respect to major and trace elements (Tables 2 and 9). The majority of the Mount Grace extrusive and Perry River intrusive carbonatites are sovites (Ca dominated). At the Ren showing both sovites and rauhaugites (dolomitic carbonatites, with higher MgO) are present (Table 9). The carbonatites are all highly enriched, relative to carbonates of sedimentary origin, in strontium, barium, niobium and rare earth elements. These high values are characteristic of carbonatites elsewhere (*see*, for example, Le Bas, 1981). All the carbonatites show typical light rare earth element enrichment patterns on chondrite-normalized plots (Figure 7). Light rare earth enrichment is not as marked as that displayed by samples from the Aley or Rock Canyon Creek showings; however, total rare earth values and slope (measure of enrichment) are greater than those for samples from the Omineca Belt.

The Mount Grace carbonatite has total rare earth element concentrations ranging from approximately 600 ppm to greater than 8000 ppm (Table 2), significantly higher than sedimentary marbles. Selected rare earth element analyses of layered Mount Grace carbonatite and host rocks are plotted in Figure 13. The data confirm the existence of thin tuff layers within metasedimentary marble at the top of the carbonatite unit (sample H85P25B) and indicate that some of the fine-grained marble layers within the basal part of the carbonatite unit (those that have low REE concentrations, for example, H85P26B, H85P26I) may be largely of sedimentary origin with only a minor tuff component (Höy and Pell, 1986). This intimate interlayering of carbonatite and sedimentary marble supports argument for an extrusive origin for the Mount Grace carbonatite.

Dating

Uranium/lead systematics on pyrochlore from the Mount Grace carbonatite yield a 60 Ma date, which is indicative of metamorphism. Dating of zircons is currently in progress.

MOUNT COPELAND NEPHELINE SYENITE GNEISSES (82M/2)

The Mount Copeland syenite gneisses crop out along Hiren Creek and on the slopes south of Mount Copeland, in the Jordan River area (Figure 12) on the southeastern flank of the Frenchman Cap Dome approximately 25 kilometres northwest of Revelstoke. The alkaline rocks are readily accessible by an old mine road which leaves the Trans-Canada Highway just west of Revelstoke. During the summer of 1985 this road was passable with a four-wheel-drive vehicle, to within 2 kilometres of outcroppings of syenite gneiss.

Alkaline rocks in the Mount Copeland region were first identified by Wheeler (1965) in the course of regional mapping. The area was studied in detail by Fyles (1970) and Currie (1976b). The reader is referred to previous authors, in particular the work by Currie (1976b), for detailed descriptions.

The Mount Copeland syenites are exposed in a large antiformal structure and have been subjected to more than one phase of folding. They are apparently concordant with hosting metasedimentary rocks. All contacts appear gradational. Three main alkaline rock units have been defined (Currie, 1976b); a basal nepheline syenite gneiss, overlain by alkaline amphibolite, which is in turn overlain by calcareous and saturated syenites. The alkaline rocks intrude micaceous quartzites and calcsilicate gneisses of the Frenchman Cap autochthonous cover sequence. The metasedimentary succession has been correlated (Höy and McMillan, 1979; Brown, 1980) with a similar succession in the Perry River and Mount Grace areas. Based on these correlations, it appears that the gneisses at Mount Copeland lie stratigraphically beneath the Mount Grace extrusive carbonatite (Höy and Kwong, 1986).

Post-orogenic lamprophyre dykes are also present in the Mount Copeland area.

Nepheline Syenite Gneisses (Unit A1 of Currie, 1976b)

The nepheline syenite gneisses contain nepheline in excess of 10 per cent. They may be weakly (A1b) to strongly foliated (A1c), and locally have a spectacularly developed augen texture (Unit A1a) with large porphyroblasts of nepheline and alkali feldspar in a fine-grained groundmass. The augen gneisses (A1c) are predominantly composed of nepheline alkali feldspar, perthite, calcite, biotite and fluorite. Cancrinite is often present marginal to nepheline grains. Accessory minerals include tourmaline, apatite, sphene, riebeckite and rarely, poikilitic aegirine (Currie, 1976b).

The core parts of the nepheline syenite (Unit A1b) are weakly foliated and contain nepheline, potash feldspar and albite with lesser aegirine and sphene. Accessory minerals include calcite, present as small grains along narrow seams, fluorite, garnet and zircon. Traces of biotite, muscovite and cancrinite may also be present (Currie, 1976b).

The third type of nepheline gneiss may be transitional to the nepheline-free syenites. Microcline, perthite and fine-grained nepheline, commonly replaced by cancrinite and thompsonite, are the dominant constituents. Phlogopitic mica is the main mafic mineral, although it is rarely present in amounts greater than 5 per cent. Small amounts of aegirine and hastingsite may also be present. Accessory minerals include sphene, apatite, calcite and specularite (Currie, 1976b).

Alkaline Amphibolite (Unit A2 of Currie, 1976b)

A thin lens, or numerous parallel lenses, of alkaline "amphibolite" can be traced for more than 10 kilometres. It consists of gneissic and fissile medium to coarse-grained mesocratic to melanocratic rocks. Aegirine, biotite and sphene are the major constituents; calcite, apatite and potash feldspar may be present in minor amounts. Plagioclase is rare and, where present, often partially replaced by scapolite (Currie, 1976b).

Grey Syenitic Gneiss (Unit A3 of Currie, 1976b)

The strongly alkaline rocks previously described are surrounded by a thick shell of less alkaline rocks. Three principal types can be discerned: a fine-grained greenish grey syenite with slight gneissic banding (A3a); a white, aplitic leucosyenite (A3b); and a buff to pale pink, medium to coarse-grained syenite (A3c).

The fine-grained greenish grey syenite (Unit A3a) is dominated by plagioclase (An_{35}) and potash feldspar. The most prominent mafic mineral is biotite, although a diopsidic pyroxene may also be present. Calcite, sphene and epidote are common. Accessory minerals include apatite, muscovite and a zeolite, either analcite or thompsonite. Quartz is very rarely found (Currie, 1976b).

The aplitic leucosyenites (Unit A3b) contain albitic plagioclase, potash feldspar, muscovite and either calcite or diopside. Biotite, zircon, apatite, pyrite and molybdenite may be present in trace amounts. This rock is the host of the Mount Copeland molybdenite deposit. In the vicinity of the deposit, molybdenite is more abundant than elsewhere and epidote is present (Currie, 1976b).

The third group of syenites (Unit 3Ac) are, in general, buff to pink in colour and gneissic. This is an extremely heterogeneous unit, exhibiting a great variation in mineralogy. Potash feldspar and albitic plagioclase are generally present. In some specimens calcite or fine-grained aggregates of analcite and cancrinite may be found. Biotite, aegirine and a hastingsitic amphibole are the mafic species seen, and they may be present in combination or separately. Zircon, magnetite and apatite are common accessory minerals; tourmaline and fluorite have also been noted (Currie, 1976b).

Geochemistry

The nepheline syenite gneisses show a marked increase in silica content as compared to Units A1a to A1c (Table 10) that is proportional to a decrease in modal nepheline. Also, Unit A1a is richer in alkalis than the other nepheline gneisses. Unit A2 has an extremely high soda and potash content (Table 10) for normal igneous rocks of comparable silica and alumina contents. Currie (1976b) feels this could be attributed to fenitization. Major element data (Table 10) for syenites in Unit 3A indicate that they are only mildly alkaline.

Dating

The isotopic ratios resulting from lead and uranium analyses on zircons separated from Mount Copeland syenite gneisses yielded an age of emplacement of *circa* 770 Ma (Okulitch *et al.*, 1981). Subsequent analyses (R. Parrish, personal communication, 1986) are in agreement.

TABLE 10
CHEMICAL COMPOSITION OF SELECTED ROCKS FROM THE MOUNT COPELAND SYENITE COMPLEX

Wt. %	A1a		A1b			A1c		A2		A3a	A3b		A3c	D	
SiO_2	48.78	47.23	54.92	52.00	56.9	55.05	54.11	44.18	48.9	49.09	57.97	53.6	54.79	39.7	39.72
TiO_2	0.73	0.28	0.55	0.32	0.55	0.50	0.49	5.49	3.07	2.53	0.47	1.63	0.62	1.28	1.26
Al_2O_3	25.22	26.06	23.01	25.91	21.0	21.63	21.69	7.51	11.3	18.48	18.08	15.4	21.82	13.5	13.96
Fe_2O_3	3.46	3.64	2.57	0.89	2.6	1.07	2.48	8.06	1.3	0.22	0.04	2.6	3.81	2.6	2.64
FeO	0.23	1.59	2.62	0.21	2.6	5.16	0.62	7.20	10.2	7.17	0.51	6.1	0.49	5.4	5.17
MnO	0.12	0.28	0.22	0.05	0.24	0.28	0.11	0.37	0.15	0.05	0.23	0.16	0.12	0.14	0.14
MgO	0.32	0.31	0.67	0.23	0.7	1.07	0.19	7.76	8.4	2.81	0.11	6.0	0.29	7.6	7.45
CaO	3.08	1.52	1.53	1.32	1.6	0.29	3.01	9.68	10.1	11.57	6.53	4.8	2.51	11.0	10.22
Na_2O	9.89	12.61	6.06	5.40	6.1	2.31	5.85	3.69	2.3	2.63	9.32	2.5	4.33	1.9	1.62
K_2O	7.21	4.62	7.47	7.53	7.5	11.39	9.37	3.77	1.6	3.20	0.91	5.1	7.62	4.3	5.24
H_2O	0.30	0.88	0.49	4.72	0.5	1.11	1.26	1.21	2.2	0.82	0.18	1.7	2.29	1.9	1.96
CO_2	0.12	0.80	0.23	1.11	0.2	0.10	0.24	0.26	0.6	0.88	5.22	0.1	0.28	8.2	6.54
P_2O_5	0.01	0.03	0.02	0.02	0.02	0.03	0.01	0.59	0.28	0.49	0.14	0.37	0.01	1.68	1.73
Total	99.47	99.85	100.36	99.71	100.5*	99.99	99.43	99.77	100.4*	99.94	99.71	100.1*	98.98	99.3*	97.65
ppm															
Ni	20	<10	nd	33	-	80	64	220	-	98	nd	-	100	-	-
Cr	nd	nd	<10	nd	-	nd	nd	240	-	4.3	nd	-	nd	-	-
Co	nd	nd	nd	nd	-	nd	-	57	-	24	nd	-	nd	-	-
Sr	1900	1400	220	1800	-	1900	1800	940	-	1200	3100	-	3400	-	-
Ba	130	59	360	120	-	1200	320	280	-	1000	33	-	130	-	-
Zr	1900	580	270	92	-	2200	1600	600	-	2400	290	-	2700	-	-
Nb	510	140	nd	470	-	260	340	200	-	300	nd	-	470	-	-
Y	230	41	39	100	-	nd	5.8	6.8	-	9.5	nd	-	15	-	-
La	590	710	110	360	-	nd	44	270	-	34	83	-	500	-	-
Ce	99	1300	nd	<500	-	nd	780	510	-	540	nd	-	820	-	-
Nd	420	310	nd	<200	-	nd	330	550	-	630	nd	-	270	-	-
Yb	2.7	7.1	<4	8.9	-	<2	7.1	72	-	11	6.5	-	150	-	-
Sc	7.2	7.3	7.6	5.6	-	nd	7.8	31	-	12	<4	-	6.8	-	-

From Currie (1976a); *from Currie (1976b).

A1a - leucocratic nepheline augen syenites; A1b - nepheline syenite gneisses, pink and white; A1c - pink and grey nepheline-biotite syenites; A2 - black alkaline amphibolite; A3a - grey granular syenite;; A3b - grey syenite; A3c - greenish granular syenite; D - ocellar biotite lamprophyre dyke.

THREE VALLEY GAP (82L/16)

Carbonatites and leucosyenites are found along the Victor Lake Main logging road which joins the Trans-Canada Highway from the south, approximately 3 kilometres east of Three Valley Gap. Outcrop is limited to roadcuts, at elevations between 900 and 1500 metres. The road is in good shape, passable by conventional vehicles.

The carbonatites and syenites occur as thin, discontinuous bedding-parallel lenses in pelitic metasedimentary rocks. Both the intrusions and host rocks have been metamorphosed to upper amphibolite facies (sillimanite zone) and the pelites have been extensively migmatized. The host rocks are of uncertain affiliation. They crop out near the mapped boundary (Journeay and Brown, 1986) between Hadrynian Horsethief Creek Group strata and the autochthonous "mantling gneiss" succession of Frenchman Cap Dome. Tentatively these rocks are assigned to the mantling gneisses. Carbonatite lenses are generally 20 to 60 centimetres in width and have 10 to 30-centimetre-thick mafic fenites developed between them and adjacent rocks. Everywhere observed, the fenites are in direct contact with, and gradational to, syenites. Commonly the carbonatite occurs as lenses within the fenite.

Carbonatites, Fenites, Syenites

The carbonatites are primarily composed of calcite (45 to 50 per cent), biotite (5 to 20 per cent), apatite (5 to 15 per cent), perthite (up to 10 per cent), hornblende (5 to 30 per cent), augite (1 to 10 per cent) and traces of sphene. In places they contain feldspathic lenses or augen, similar in appearance to migmatitic leucosomes. Hornblende and augite are more abundant at the margins of the carbonatite lenses; biotite is the dominant mafic silicate mineral in the centre. All carbonatites display a well-defined biotite-amphibole foliation.

Fenites generally contain abundant augite, hornblende, calcite (25 per cent or less), scapolite and plagioclase. Accessory minerals include biotite, apatite, sphene and nepheline. Potassium feldspar, perthite, allanite, zircon and garnet (coarse-grained, brown body-colour) may also be present.

The leucosyenites generally contain potassium feldspar >> plagioclase > augite > sphene. They are massive, white, medium to coarse-grained rocks.

Geochemistry

The carbonatites at Three Valley Gap are calcitic (high CaO:MgO ratio), but tend to have more silicate phases developed within them than is typical and hence have high SiO_2 (Table 11). Rare earth element contents are low, relative to Perry River, Ren and Mount Grace carbonatites (Table 2) and slopes on chondrite-normalized rare earth plots (Figure 7) are flatter than for carbonatites on the west flank of the Frenchman Cap Dome (less light rare earth enrichment).

TABLE 11
CHEMICAL ANALYSES, THREE VALLEY GAP CARBONATITES

Wt. %	1	2	3
SiO_2	18.70	21.60	46.50
TiO_2	0.72	0.81	0.68
Al_2O_3	6.29	8.29	13.80
$Fe_2O_3^T$	8.70	8.16	8.33
MnO	0.26	0.23	0.21
MgO	2.70	2.42	2.15
CaO	33.20	29.80	18.90
Na_2O	0.92	1.60	2.18
K_2O	2.85	3.26	2.40
LOI	22.25	20.75	2.26
P_2O_5	3.21	3.20	2.40
Total	99.80	100.12	99.81
ppm			
Ni	<91	<64	<62
Cr	34	24	82
Co	11.1	13.0	10.0
Sr	2990	3050	1350
Ba	1660	1840	906
Zr	40*	350	60*
Nb	-	-	-
Y	-	-	-
La	212	206	131
Ce	401	396	275
Nd	151	140	111
Yb	4.4	4.2	2.8
Sc	15.7	10.0	1.7
Ta	109	6.8	9.7
Th	10.1	5.2	10.9

1 - 3VG136A - biotite sovite; 2 - 3VG135A - sovite; 3 - 3VG137 - border zone between carbonatites and host pegmatites.

*Trace element analysed by ICAP.
Major elements analysed by ICAP, alkaline fusion.
Trace elements analysed by INAA at Bondar-Clegg, except where indicated.

Dating

Zircon separates have been obtained, and age dating is in progress.

ALKALINE ULTRAMAFIC DIATREMES IN THE WILLISTON LAKE AREA

OSPIKA PIPE (94B/5)

Only one breccia pipe has so far been recognized in British Columbia north of Prince George (Figure 2). It is a small diatreme located on Cominco's Aley claims, approximately 140 kilometres north-northwest of Mackenzie, on the east side of Williston Lake between the Peace Reach and Ospika River. Access to the area is by helicopter from Mackenzie.

The diatreme crops out on forested slopes at approximately 1550 metres elevation (Figure 3). It is only a few hundred metres from the large Aley carbonatite complex (*see* Carbonatite and Syenite Complexes in the Rocky Mountains), but the relationships between the carbonatite and the diatreme are unclear (Pell, 1986c).

The Ospika pipe is a composite diatreme (roughly 20 by 50 metres in size) containing at least five distinct breccia and massive phases and intruding Ordovician carbonates of the Skoki Formation. It is massive to foliated and red-brown-weathering in outcrop, with fluorite present near the margins. The phases are differentiated by size and percentage of sedimentary rock fragments, macrocrysts and pelletal lapilli. Contacts between phases may be sharp or gradational.

The breccias contain 2 to 25 per cent subangular to subrounded sedimentary rock fragments. These fragments range from a few millimetres to 50 centimetres in size, with most in the 2 to 10-centimetre range. Larger fragments are dolomitic with prominent reaction rims. Rare cognate xenoliths are present, but no exotic xenoliths were found.

Phlogopite dominates the macrocryst assemblages, comprising 5 to 20 per cent of the rock, with titaniferous augite and rare altered olivine and bright green diopside also locally present. Phlogopites range from a few millimetres to 3 centimetres in size, augites from a few millimetres to 2 centimetres. The phlogopites are orange in colour and have normal pleochroism. In some samples, they have thin, bleached rims; in others thin rims are darker than the core of the grains.

The matrix to most phases is fine grained and light green-grey in colour. It is a good igneous or magmatic matrix consisting of fine-grained calcite + dolomite and felted phlogopite, chlorite, amphibole ± talc. It contains abundant fine-grained opaque oxides and, in some places, pyrite.

One distinct phase is composed of abundant small pelletal lapilli (50 to 60 per cent), macrocryptic phlogopite (5 to 10 per cent) and small sedimentary rock fragments (less than 10 per cent) in a fine to medium-grained carbonate matrix.

Clast and macrocryst-rich breccia dykes, 50 centimetres wide, crop out on ridges 0.5 to 1 kilometre away from the main breccia pipe. These dykes do not appear to be continuous with the diatreme at surface, but have very similar clast and macrocryst populations. Locally the matrix of the dykes is considerably more calcareous than that of the diatreme. Both the dykes and main breccia pipe have suffered some degree of alteration. Blue pleochroic sodium amphibole is ubiquitous, often rimming other phases.

The Ospika pipe and related dykes may be classified generally as ultramafic lamprophyres based on the criteria given by Rock (1986) and, more specifically, as aillikites. These are relatively common ultramafic lamprophyres that are often associated with carbonatites. They are similar to alnoites, but lack good evidence of melilite (Rock, 1986).

Rubidium/strontium isotopic studies on mica separates from the Ospika pipe give an age of 334±7 Ma. Potassium/argon studies on the same sample yielded 323±10 Ma.

ALKALINE ULTRAMAFIC DIATREMES IN THE GOLDEN - COLUMBIA ICEFIELDS AREA (82N, 83C)

Numerous diatremes are located along the Alberta - British Columbia border between 50 and 90 kilometres north of Golden (Figures 2 and 14). The terrain in the area is rugged and the diatremes outcrop at elevations of 2200 to 3000 metres. In all cases access is by helicopter.

Most of the diatremes are hosted by Upper Cambrian carbonate rocks and in most cases, consanguineous dykes are also present.

Microdiamonds have reportedly been recovered from heavy mineral separates taken from two of the pipes in this swarm (Northcote, 1983a, 1983b; Dummett *et al.*, 1985). Preliminary investigation suggests that these rocks are neither kimberlites nor lamproites, the two lithologies currently known to contain economic concentrations of diamonds. Further research currently in progress (M.Sc. thesis by O. Ijewliw at Queen's University) will detail the petrology and diamond potential of the Golden diatremes.

BUSH RIVER AREA (LARRY CLAIMS) (83C/3)

Near the headwaters of the Bush River (Figure 14) a suite of dykes and small diatremes intrudes Upper Cambrian strata. Three diatremes were examined (Figure 15), revealing two breccia types. The breccias appear quite different in the field, but the division is somewhat arbitrary.

One diatreme type comprises rusty weathering clast-dominated megabreccia. The clast:matrix ratio is approximately 3:2. Over 99 per cent of the clasts are subrounded to subangular fragments of the hosting sedimentary carbonate lithologies, with an average size of 10 to 40 centimetres. Altered granitoids and, less commonly, gabbroic rocks make up the balance of the xenolith population. The matrix is predominantly carbonate and quartz-sand grains.

The second diatreme type also consists of a clast-dominated breccia, is also massive, but is rusty to dark green weathering. The clast:matrix ratio is greater than in the first breccia type and the clast population more varied. Approximately 50 per cent of the clasts are subangular sedimentary rock fragments, carbonates, shales and some orthoquartzites. Two to 5 per cent of the xenoliths consist of granitic material; these fragments may be either rounded or angular and are in the 5 to 15-centimetre-size range. Rounded, 8 to 25-centimetre-sized fragments of altered igneous-looking material comprise 10 to 20 per cent of the xenoliths. These clasts consist of coarse, randomly oriented carbonate grains, chrome mica and opaque oxides. Spectrographic analyses indicate high silica content; these clasts are possibly altered syenites. Many of the rounded xenoliths are armoured, or mantled by a rim of fine-grained ultramafic igneous material. An additional 5 to 10 per cent of the breccia fragments are cognate xenoliths. The remainder of the clast population is made up of pelletal lapilli (also referred to as accretionary lapilli) ranging from a few millimetres to 3 centimetres in size and frequently cored by small fine-grained limestone fragments.

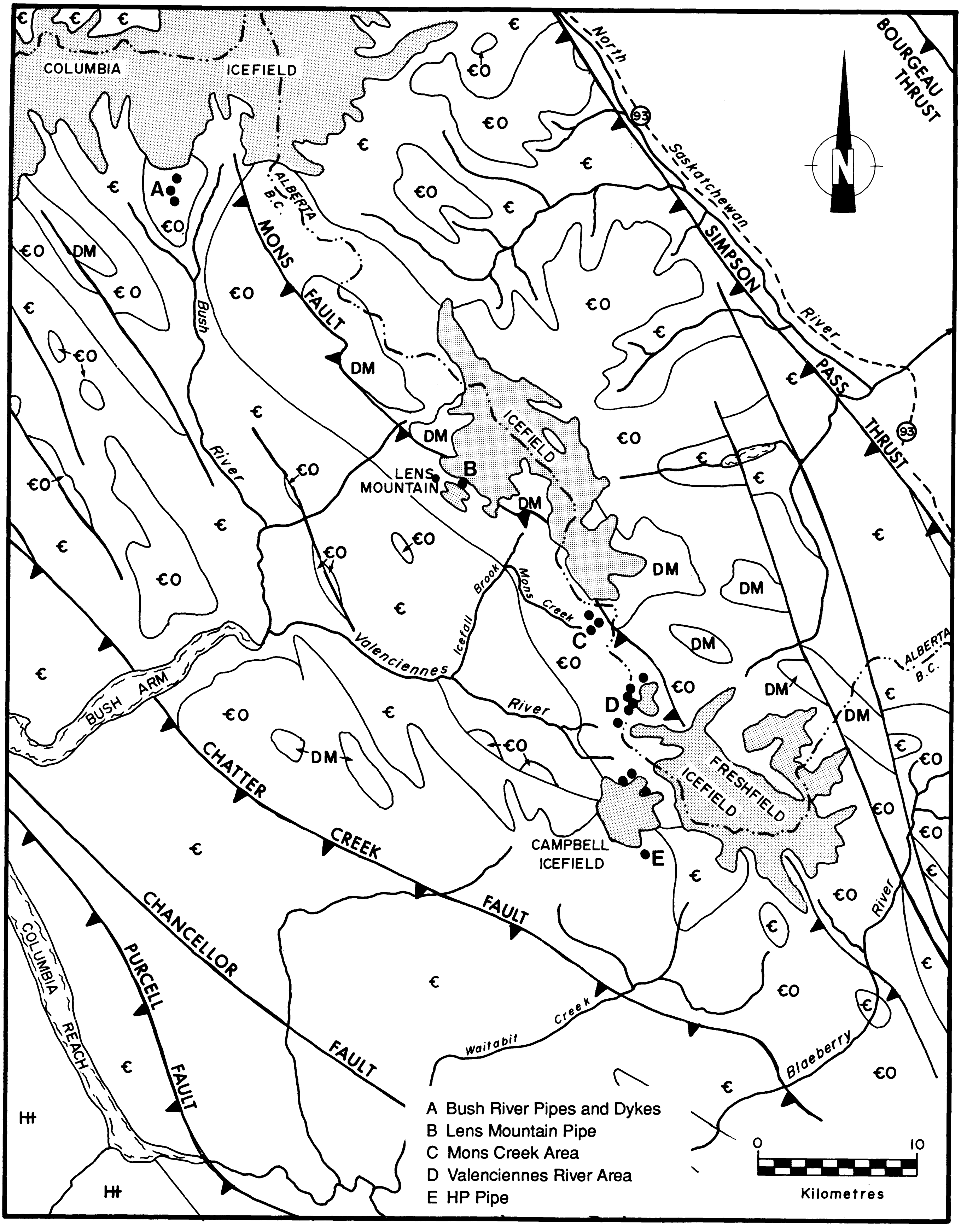


Figure 14. General geology and diatreme locations in the Golden - Columbia Icefields area. ● indicates diatremes or dyke swarms. Geology modified from Wheeler (1962) and Price (1967a, 1967b). For legend *see* Figure 18.

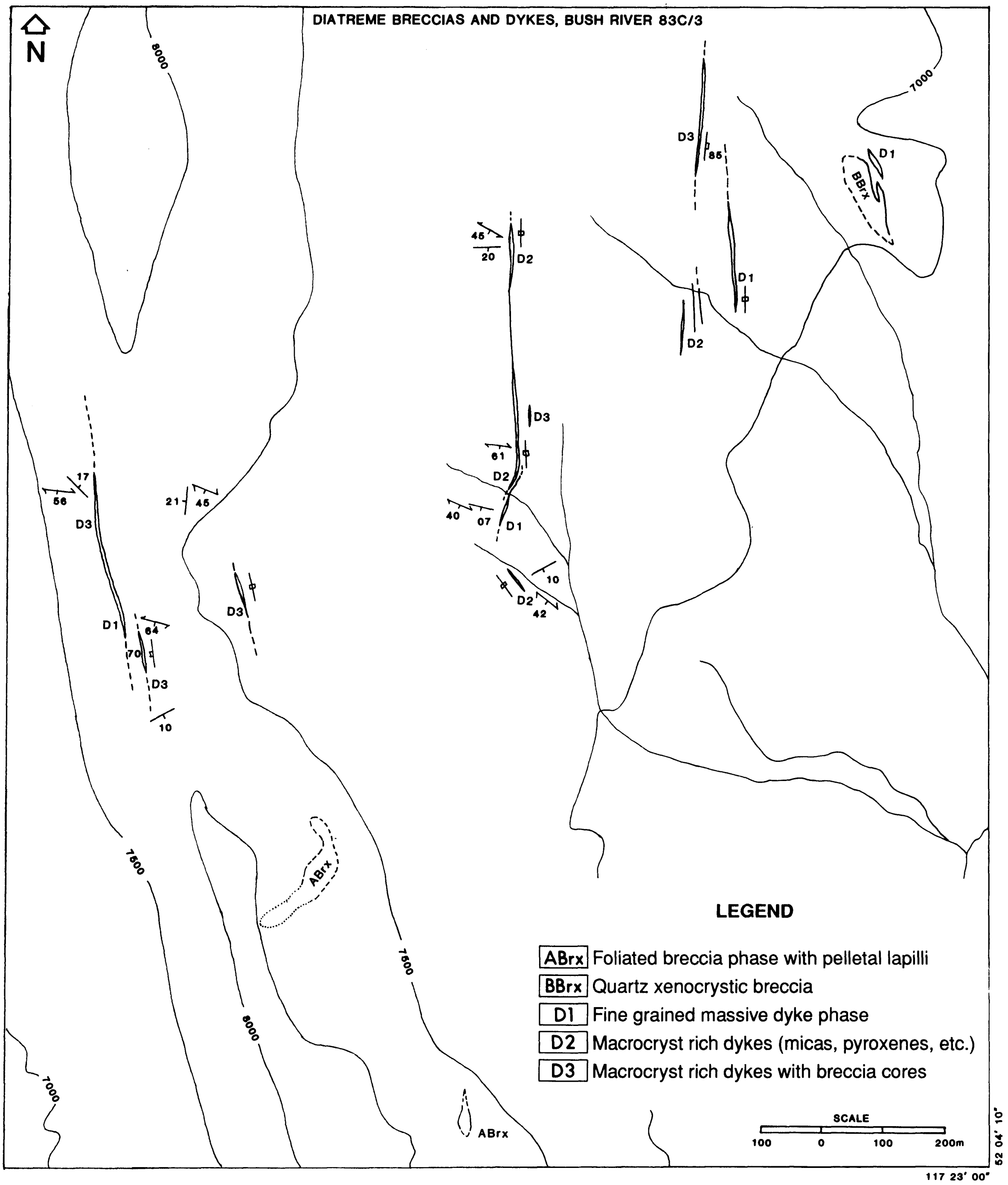


Figure 15. Diatreme breccias and dykes, Bush River area.

Armoured xenoliths and accretionary lapilli are features common to pyroclastic rocks (Fisher and Schmincke, 1984). The matrix of the breccia consists of chlorite ≥ calcite > quartz >> trace apatite. Silvery mica macrocrysts, up to 3 centimetres in size, are abundant. In thin section, the macrocrysts are highly altered.

Both homogeneous and zoned dykes are abundant throughout the area (Figure 15). The homogeneous dykes are fine grained and medium to dark green in colour. They may contain up to 10 per cent small, silvery, mica phenocrysts and minor amounts of spinel or other opaque oxides. Altered phenocrysts of pyroxene and subordinate olivine were noted in thin section. The zoned dykes have coarse xenolith and/or macrocryst-rich cores and finer grained margins. Contacts within the dykes may be gradational or distinct and often the margins have a strongly banded texture. A dyke with unaltered phlogopite megacrysts was observed in one locality.

Based on preliminary petrographic examination, the dykes and diatremes in the Bush River area may be assigned to the ultramafic lamprophyre family.

LENS MOUNTAIN AND MONS CREEK AREAS (JACK AND MIKE CLAIMS) (82N/14, 15)

At both Lens Mountain and Mons Creek (Figure 14) the dominant intrusive lithology consists of a buff-weathering, weakly foliated breccia with a low clast:matrix ratio (approximately 1:3). The "Jack Diamond" (Northcote, 1983b) was recovered from this lithology. Clasts are small subangular sedimentary rock fragments, predominantly carbonates, in the 2-millimetre to 2-centimetre-size range. The "matrix" is pale green in colour and consists of abundant rounded quartz grains (xenocrysts), carbonate, chlorite and iron oxides. At Mons Creek, this breccia grades into a clast-poor (5 to 10 per cent clasts) green breccia with a foliated matrix containing carbonate, chlorite and talc (?) or serpentine. In both areas, the enclosing sedimentary strata are steeply dipping; the breccias, however, display a weakly developed subhorizontal to shallow-dipping planar fabric. At Lens Mountain, a shallow-dipping layer of boulder breccia is enclosed in the sandy breccias.

It has been proposed (C. Fipke, personal communication, 1987) that these breccias are crater-infill material. Alternatively, they may be intrusive, formed through fluidizing of sediments by introduction of volatiles explosively exsolved from rising and vesiculating magmas (Pell, 1987).

At Lens Mountain, two separate small breccia pipes are also present. They are very similar to the first diatreme type described from the Bush River area (previous section). At Mons Creek, a small, light green, strongly foliated, fine-grained breccia also crops out. It contains sedimentary rock fragments, less than 1 centimetre in size and opaque oxides in a matrix consisting of dolomite >> quartz ≥ pyrophyllite > minor chlorite, calcite, muscovite and trace apatite. At Mons Creek, one small, altered crosscutting dyke and abundant unaltered float of porphyrytic dyke rock were observed. The dyke material comprises primary phenocrystic titanaugite, phlogopite and altered olivine ± chrome spinel, in a matrix containing microphenocrysts of titanaugite, phlogopite and melilite with carbonate and opaque oxides.

Most of the intrusive rocks in the Lens Mountain and Mons Creek areas have only minor igneous components due to intense sedimentary rock contamination, and are difficult to classify. The dykes at Mons Creek, however, have a preserved mineralogy which allows classification as ultramafic lamprophyres. The presence of melilite, which is easily recognized by its tabular habit with fractures normal to the length of the section, allows classification as alnöites.

VALENCIENNES RIVER PIPES (MARK CLAIMS) (82N/15)

Four or more diatremes and numerous dykes are hosted by Upper Cambrian rocks near the headwater of Valenciennes River (Figures 14 and 16). Two distinctly different diatreme types are present. The first are rusty brown-weathering, weakly to well-foliated composite pipes with both massive and breccia phases. Serpentinized olivine macrocrysts, coarse non-magnetic oxides and altered peridotite xenoliths are present in some phases. Typical breccias contain 40 per cent clasts, most of which are small (1 to 5 centimetres), with rare xenoliths up to 15 centimetres in size. Limestones, dolostones, shales and minor quartzites comprise the majority of the breccia fragments. Rare oxide macrocrysts may be present. The matrix is typically light green to grey in colour and contains calcite and/or dolomite, quartz, chlorite, muscovite, and traces of pyrite, apatite, talc and clay minerals. Bright green mica is commonly observed in hand sample (chrome-rich muscovite?). Chromite and ilmenite have been identified in heavy mineral separates (Northcote, 1983a). A microdiamond is reported to have been recovered from the largest diatreme (Figure 16) (Northcote, 1983a).

Associated dyke rocks are fine to medium grained, rusty to dark green weathering, with a light greenish grey to medium green fresh surface. Some of the dykes are porphyritic and all are altered. The phenocryst assemblage, so far as can be recognized, consists of olivine, pyroxene and mica. In some phases, olivine appears to be more abundant than pyroxene (ol > px ≥ mica) and in others pyroxene is far more abundant (px > ol ≥ mica). Some dykes are predominantly micaceous. It is difficult to accurately estimate proportions of phenocrysts as they are altered and only morphology can be used. Oxides are a common groundmass constituent. The dykes are generally peripheral to the diatremes, but locally crosscut them.

The second type of diatreme is brown weathering and moderately well foliated with angular to subangular sedimentary rock fragments set in a matrix of quartz grains, chlorite and carbonate. Clasts average 1 to 5 centimetres in size with some up to 20 centimetres. The clast:matrix ratio is 2:3. These diatremes are similar to the first type described in the Bush River area.

Although intense alteration makes classification difficult, the rocks in the Valenciennes River area, as evidenced phenocryst assemblages in dykes, also bear affinity to the ultramafic lamprophyre clan.

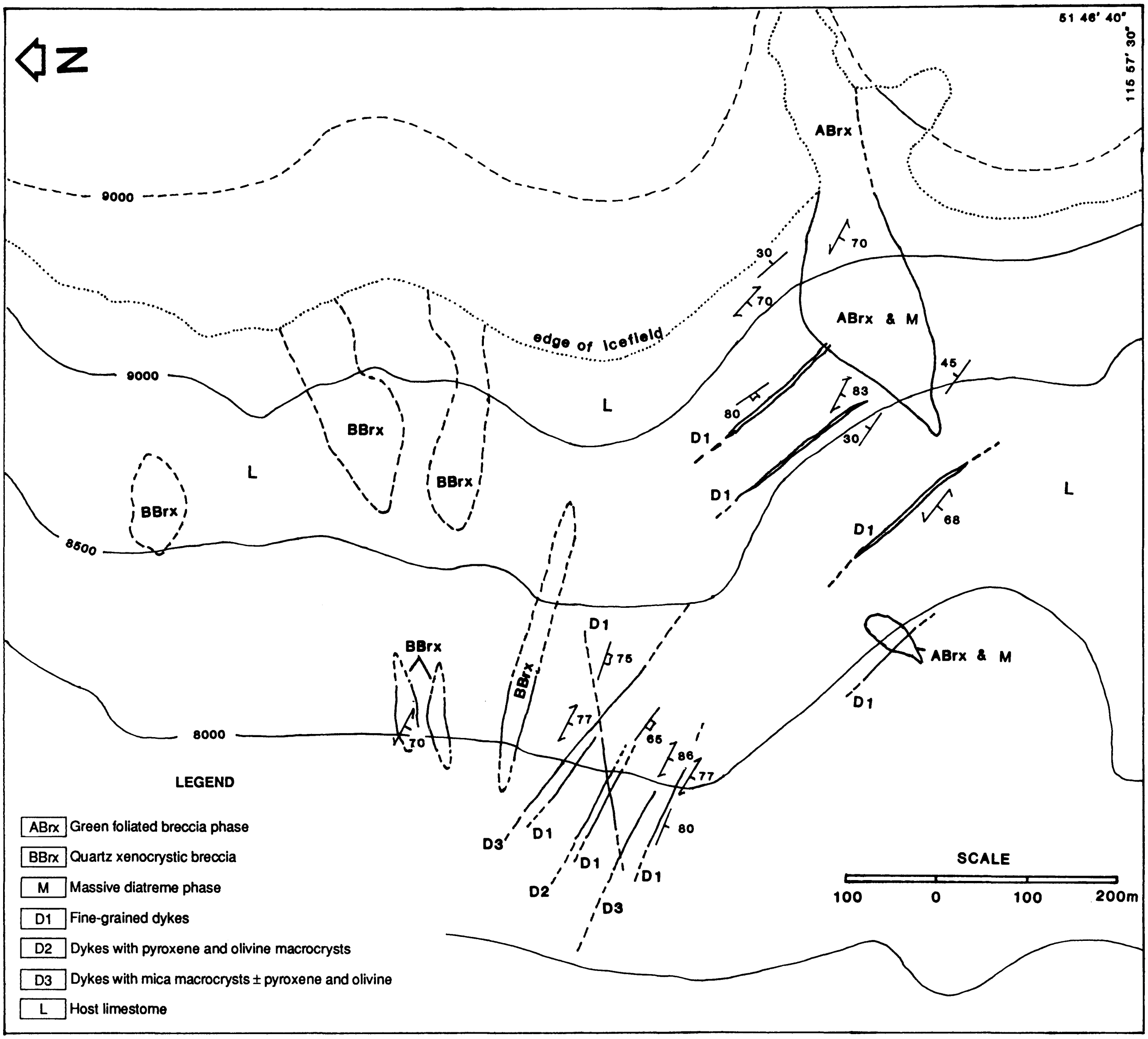


Figure 16. Diatreme breccias and dykes, Valenciennes River.

THE HP PIPE (82N/10)

The HP pipe is the most southerly diatreme so far recognized in the Golden - Columbia Icefields area (Figure 14). It is located approximately 50 kilometres due north of Golden and is exposed at an elevation of 2400 metres, near the toe of the Campbell Icefield. The HP pipe is small, covering an area of only 40 by 70 metres; however, it is exposed in a flat, recently deglaciated basin which offers nearly 100 per cent exposure and is therefore ideal for study.

The pipe has sharp, steeply dipping contacts with the horizontal to shallow-dipping grey Cambrian limestone beds which it intrudes (Figure 17). It is a composite diatreme, comprising five distinctly different breccia phases and numerous dykes. The breccias differ in clast-to-matrix ratios, megacryst abundances (black salitic pyroxene/green diopside/ biotite) and the presence or absence of additional phases such as oxides and pelletal lapilli (Table 12). Contacts between breccia phases may be gradational or sharp. A well-developed foliation, at high angles to the pipe's eastern and western margins, is present in phases 1 and 2. The other phases are moderately to weakly foliated.

The matrix of breccia phases 1, 2 and 3 is composed of calcite > biotite ≥ colourless clinoamphibole (tremolite?) ≥ chlorite > trace feldspar. In some localities melilite has been tentatively identified. Fine-grained spinel and garnet are disseminated throughout. The garnets are subhedral to euhedral in outline, light green to golden or brown in colour and often optically zoned. X-ray spectra indicate that the brown garnet is melanite, a titanium-bearing andradite, and the green garnet is titanium-free andradite (Ijewliw, 1986, 1987). Groundmass spinels are titanium-bearing magnetites. The groundmass has a magmatic texture, but apparently has been altered, either by metamorphism or metasomatism. The matrix of the pelletal lapilli-rich breccias is predominantly calcite ± amphibole (colourless to slightly bluish). Euhedral garnets commonly form rims on the lapilli. The lapilli breccias are clast and lapilli supported; the matrix fills void space. The lapilli are composed of material similar to the matrix of the other breccia phases.

Black clinopyroxene (sulite; C. Fipke, personal communication, 1987) bright green (chrome?) diopside and biotite are the dominant megacrysts. Biotite X-ray spectra show high iron:magnesium ratios and occasional zoning to iron-rich rims (Ijewliw, 1987). Red-brown chrome spinels with minor amounts of aluminum, magnesium and titanium (Ijewliw, 1987) have also been identified.

The breccia pipe and surrounding sediments are cut by numerous dykes (Figure 17). The dykes are generally fine grained and massive, but are variable with respect to xenolith, macrocryst, pelletal lapilli and obvious garnet content. D1 dykes (Figure 17) are massive and free of inclusions. They contain biotite and spinel phenocrysts; the biotites are often aligned (flow foliation?). D2 dykes have some (less than 5 per cent total) small limestone xenoliths and macrocrysts; they may also contain minor amounts of pelletal lapilli. D3a dykes are megacryst rich (15 to 20 per cent); D3b dykes are also megacryst rich and contain pelletal lapilli and visible garnet. In thin section, all phases contain some, generally fine-grained, garnet.

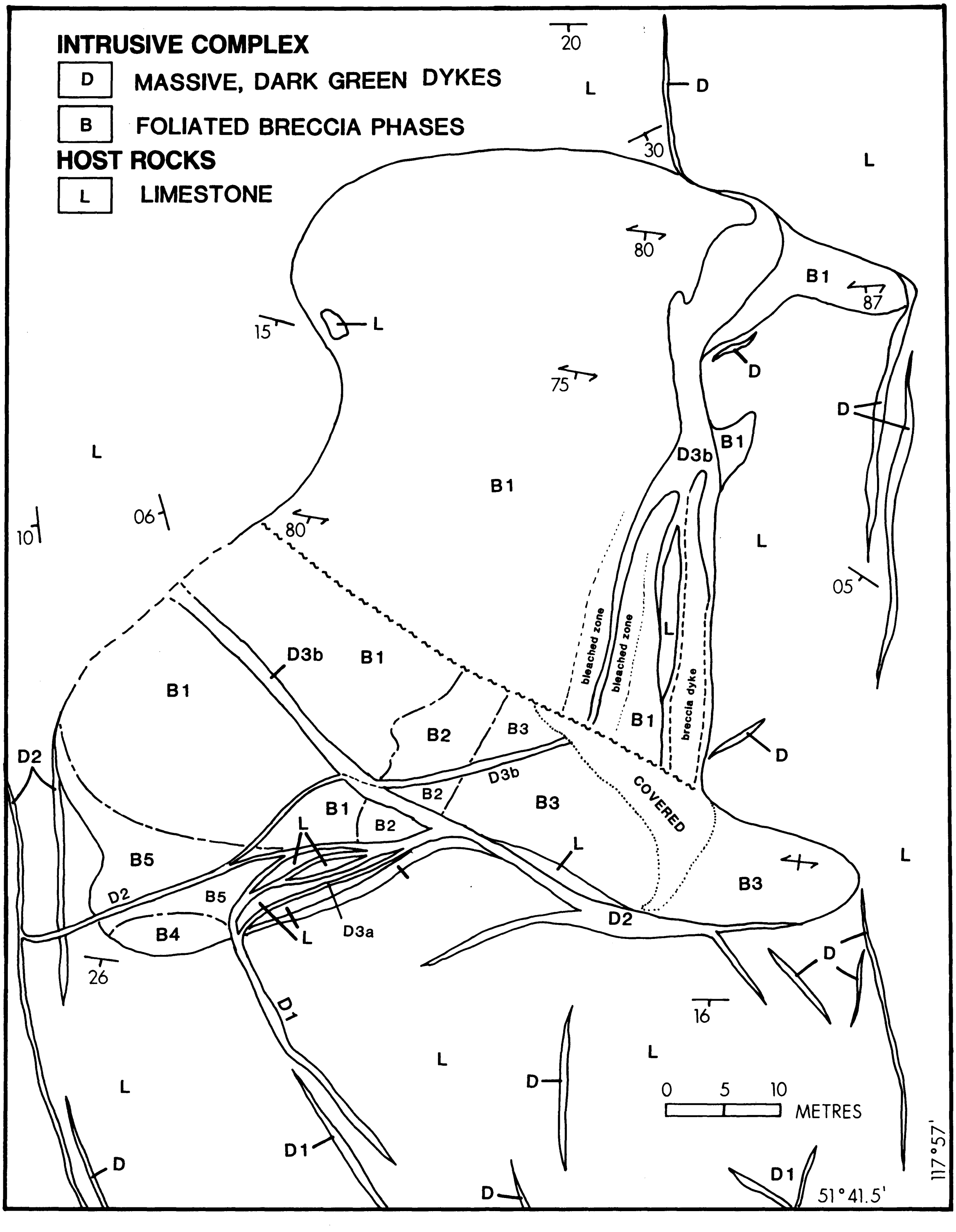


Figure 17. Geology of the HP pipe, south of the Campbell Icefield. Modified from Pell (1986a). Details on breccia and dyke phases supplied in text.

TABLE 12
FIELD CHARACTERISTICS OF HP PIPE BRECCIA PHASES

Breccia Phase	%	Xenolith Characteristics Type and Relative Abundance	Size	%	Megacryst Characteristics Type and Relative Abundance	Size	Other Comments
B1	50%	subangular to subrounded marmorized limestone - 80% rounded cognate xenolith 5-10% chert, granites, shale, gabbro	range 0.5-50 cm modally 3-5 cm	5-6%	salite 70% biotite 20-25% diopside 5-10%	0.2-8.0 cm 0.4-3.0 cm 0.5-2.5 cm	megacrysts and cognate xenoliths often core pelletal lapilli abundant pyrite minor oxides
B2	80%	subangular marmorized limestone - 70% rounded to angular cognate xenoliths - 20-25% quartzite, glimmerite, granite or syenite, shale	range 0.5-35 cm modally 3-5 cm	4-5%	salite >95% diopside 1% biotite trace	0.2-5.0 cm 0.7-2.5 cm 0.2-1.0 cm	salite megacrysts core pelletal lapilli trace amounts of pyrite present
B3	15%	chert, shale, marmorized limestone, gabbro angular to subangular	range 0.3-13 cm modally 3-5 cm	12%	salite 93% diopside 4-5% biotite 2-3%	0.2-2.0 cm 1.0-1.5 cm 0.2-1.5 cm	no obvious lapilli veined with calcite and epidote
B4	12-18%	subrounded to subangular marmorized limestone - 100%	range 0.5-15 cm modally 3-4 cm	2-3%	salite 97% diopside 2% biotite 1% or less	0.2-2.0 cm 0.3-1.5 cm 0.2-1.5 cm	abundant (>50%) pelletal lapilli, no obvious fragments in cores abundant euhedral oxides, 1-2 mm size
B5	25%	subangular marmorized limestone - 95% cognate xenoliths, shale, chert, sandstone	range 0.5-5 cm modally 1-3 cm	4-5%	salite 93% diopside 5% biotite 2%	0.1-4.0 cm 0.3-2.0 cm 0.5-2.0 cm	abundant (>50%) pelletal lapilli in 2-5 mm-size range; some pelletal lapilli cored by megacrysts

The HP pipe is difficult to classify. It exhibits many similarities to the other ultramafic lamprophyres and, if the melilite has been correctly identified, could be classified as an alnöite; however, there appears to be a significant metasomatic or metamorphic overprint introducing phases such as melanite/andradite and clinoamphibole. Biotite separates from this pipe have been analysed and yield a rubidium/strontium date of 348±7 Ma and potassium/argon dates of 391±12 and 396±10 Ma. These dates most reasonably represent age of emplacement; any metasomatic/metamorphic overprint does not appear to have greatly affected isotopic systematics.

ALKALINE ULTRABASIC DIATREMES IN THE BULL RIVER - ELK RIVER AREA

Forty or more breccia pipes and related dyke rocks occur within the Bull, White and Palliser River drainages (Figures 2 and 18) east of Cranbrook and Invermere (Grieve, 1981). The majority are hosted by the Ordovician/Silurian Beaverfoot Formation and underlying Mount Wilson and/or Skoki Formations, and exhibit similarities in petrography, degree of alteration and morphology.

SHATCH MOUNTAIN AREA (JOFF CLAIMS) (82J/11)

A number of small diatremes have been reported (D. Pighin, personal communication, 1984) south of the Palliser River on the ridges around Shatch Mountain, west of Joffrey Creek, approximately 55 kilometres east of Invermere (Figure 18). Two were examined, both exposed at the 2750-metre elevation and accessible by helicopter. Both are hosted by moderately to steeply east-dipping Ordovician-Silurian Beaverfoot-Brisco strata which are characteristically massive, thick-bedded grey limestones which contain rugosan corals.

The main breccia pipe (Figure 19) consists of small (up to 10-centimetre) subrounded to subangular fragments in a strongly foliated light green matrix. Clasts are predominantly limestone, dolostone and shale; some cognate zenoliths and rare pyroxenite nodules are present. In thin section, honey-coloured altered vesicular glass lapilli are the predominant constituents. Juvenile lapilli are also present and in some samples quite abundant. The matrix of the breccia consists of calcite with some quartz and chlorite and minor talc, anatase and apatite.

East (stratigraphically up-section) of the main breccia intensely hematized discontinuous layers consisting of juvenile lapilli, subangular lithic fragments, quartz and carbonate are apparently interbedded with grey limestone. These layers display moderate to well-developed graded bedding in one location (Figure 19). Graded breccia layers are immediately overlain by pink and buff dolostones, sandy crossbedded dolostones and sandstones, well-bedded siltstones and dolomitic siltstones of the basal Devonian unit.

The main breccia is tuffisitic, crater-infill material. The graded hematitic layers are epiclastics. This succession is overlain by basal Devonian strata and is therefore, pre-Middle Devonian in age. The apparently interbedded epiclastics and Beaverfoot Formation strata suggest that emplacement may have occurred in Ordovician-Silurian times.

South of the main tuffisitic breccia, a medium to fine-grained, massive igneous intrusive crops out (Figure 19). It is medium to dark green in colour with intensely brecciated and hematized margins. It contains 10 to 15 per cent altered clinopyroxene and olivine phenocrysts in a matrix containing fine-grained altered clinopyroxene and melilite (?) microphenocrysts. Opaque oxides are abundant.

Due to intensity of alteration, classification is difficult. The presence of glass lapilli and absence of biotite/phlogopite preclude these rocks from the ultramafic lamprophyre clan. Interpreted mineralogy

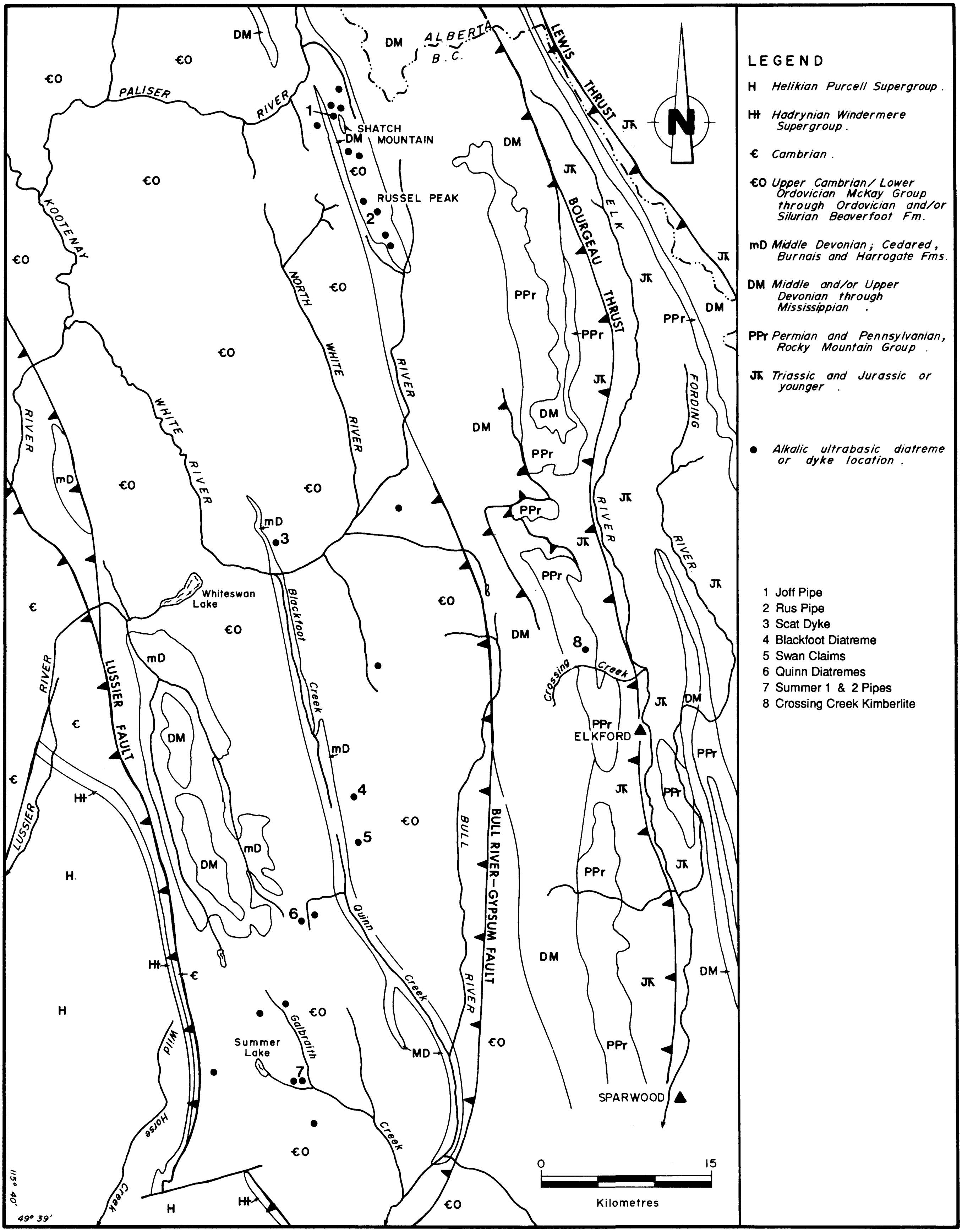


Figure 18. General geology and diatreme locations in the Bull River - White River area. Geology modified from Leech (1960, 1979) and Price (1981).

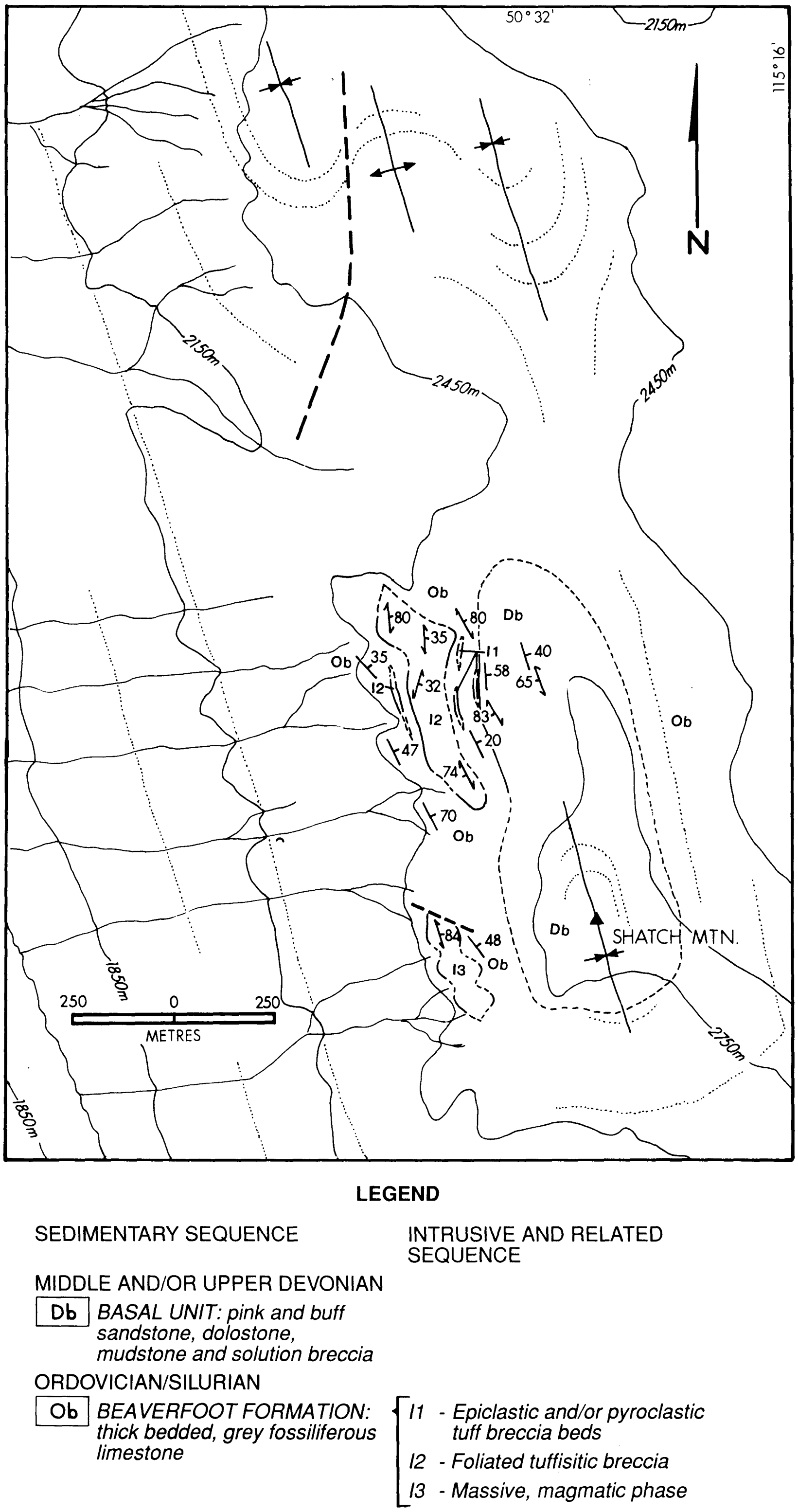


Figure 19. Geology of the Joff pipe, Shatch Mountain area (modified from Pell, 1986a).

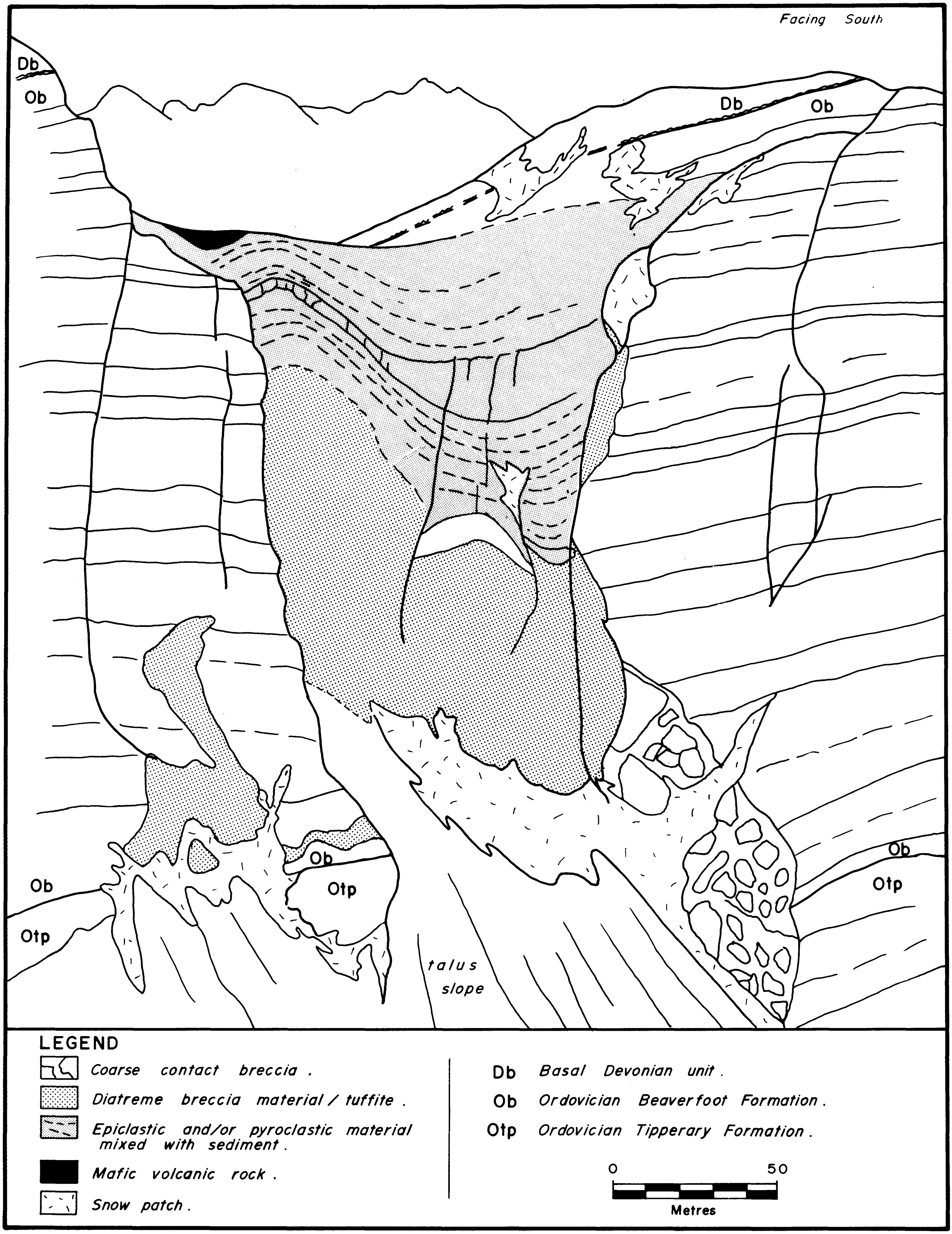


Figure 20. Geology of the Russell Peak diatreme (modified from Pell, 1987).

suggests an affiliation with the alkaline lamprophyre family and a tentative classification as olivine melilitite is proposed.

THE RUSSELL PEAK DIATREMES (82J/6)

Diatremes in southern British Columbia are typified by those in the Russell Peak vicinity (Figure 18). These pipes may be reached by helicopter from Fairmont Hot Springs. One pipe, south of Russell Peak (grid reference 5587000N, 625950E) is particularly well exposed on a cliff face and displays many features of pipe morphology (Figure 20). The lower portion of the exposed pipe comprises well-foliated, tuffisitic breccia containing abundant subangular sedimentary rock fragments and subrounded cognate xenoliths (autoliths) in a matrix of vesicular altered glass lapilli, monocrystalline quartz xenocrysts, calcite, dolomite, chlorite, minor talc, serpentine and opaque oxides. Exotic material is rare, if present. Rock fragments up to 25 centimetres in size are present, but the population mode is 2 centimetres and the clast:matrix ratio is approximately 1:1. The tuffisitic breccia is medium green in colour except along the pipe walls where it is red, due to the presence of abundant hematite. At the western margin of the pipe, near the base of the exposure, a coarse contact breccia crops out (Figure 20). It contains large (up to 4 or 5 metres), chaotic, angular wallrock fragments and subordinate matrix.

Between 50 and 100 metres of well-bedded pyroclastic and/or epiclastic material is exposed overlying the tuffisitic breccia (Figure 20). At the base of this zone, the material is similar in composition to the tuffisitic breccia, with increasing amounts of sedimentary material up-section. Thin layers of igneous material are apparently interbedded with the Ordovician-Silurian Beaverfoot Formation carbonate rocks, near the top and margins of the exposed pipe, implying an Ordovician-Silurian age (*circa* 435 to 440 Ma) for emplacement. The succession is unconformably overlain by Middle and/or Upper Devonian strata.

A small mafic body (flow?) outcrops near the exposed top of the crater zone (Figure 20) and represents the only unaltered material present in the diatreme complex. It is extremely porphyritic and comprises 5 to 20 per cent titanaugite and approximately 10 per cent altered olivine phenocrysts set in a matrix of 35 to 40 per cent titanaugite, 0 to 5 per cent olivine, approximately 10 per cent melilite and 5 to 10 per cent opaque oxide microphenocrysts with 15 to 25 per cent fine-grained groundmass. Trace amounts of chrome spinel are also present. (Note: all percentages are based on visual estimates only, and therefore very approximate). In a nearby diatreme, similar material occurs as small dykes crosscutting diatreme-zone tuffisitic breccia, suggesting that the phase was emplaced late in the intrusive sequence.

The modal mineralogy of the magmatic phase allows classification as an alkaline lamprophyre, possibly an olivine melilitite.

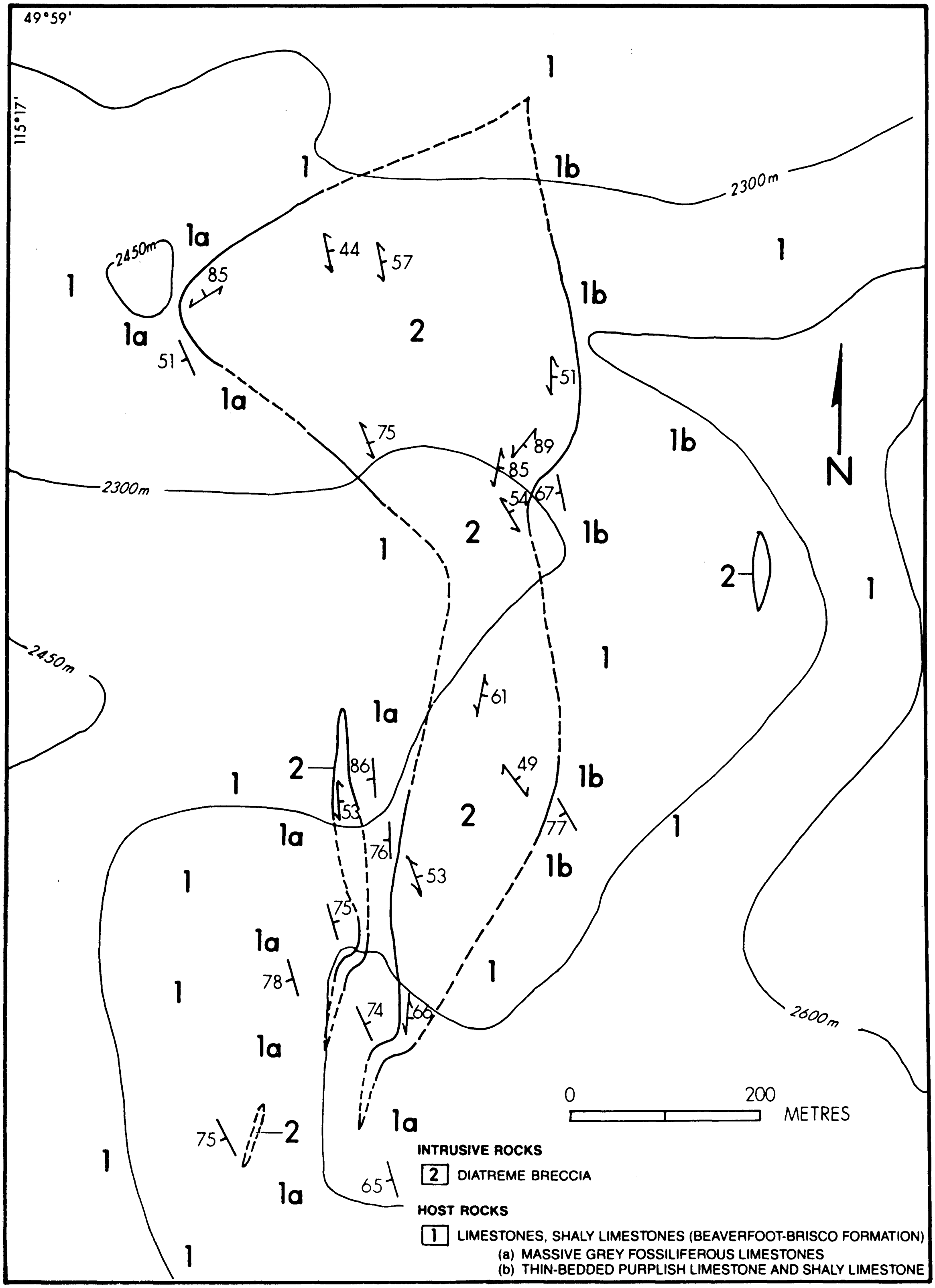


Figure 21. Geology of the Blackfoot diatreme (from Pell, 1986a).

BLACKFOOT DIATREME (82G/14)

The Blackfoot diatreme crops out at 2650 metres elevation on ridges east of the headwaters of Blackfoot Creek, approximately 65 kilometres northeast of Cranbrook (Figure 18). Access is by helicopter or on foot from a logging road in the Blackfoot - Quinn Creek valley. It is a recessive, green-weathering body discordant with rocks mapped by Leech (1960) as Ordovician to Silurian Beaverfoot-Brisco Formation. Folds are evident in the host rocks in the vicinity of the diatreme, where there is a deviation from the regional steep westerly dips (Figure 21). The Beaverfoot-Brisco Formation in the hangingwall is characterized by thick-bedded, massive, medium grey limestones containing rugosan corals and light grey limestones in which chain corals (favosites and halosites type) are present. Thin-bedded to laminated, non-fossiliferous, purplish weathering limestones and shaly limestones are present in the footwall. The contacts between the diatreme and the limestones are well exposed (Figure 21), and no thermal metamorphic effects are evident.

The Blackfoot breccia pipe is intensely foliated near its margins and fragments have been flattened in the plane of the foliation. The centre of the diatreme is moderately to strongly foliated. Foliation is generally parallel or subparallel to the margins of the diatreme (Figure 21). This was apparently a site of localized shearing during deformation.

The Blackfoot diatreme is a composite or branching pipe-like body. It contains approximately 30 per cent inclusions, most of which are sedimentary in origin (largely limestone, some shale and dolostone). These inclusions are subrounded to subangular and generally small (up to 10 centimetres in diameter). The largest xenoliths are purple-grey to buff-weathering carbonates likely derived from the Beaverfoot-Brisco Formation. Exotic xenoliths, predominantly clinopyroxenites, hornblendites and dunites, are relatively common and remarkably fresh. Eclogite nodules have also been reported at Blackfoot (C. Godwin, personal communication, 1984).

Clinopyroxenite nodules consist of 30 to 57 per cent green diopside, 0 to 15 per cent enstatite, 0 to 40 per cent olivine plus serpentine, 0 to 22 per cent hornblende with calcite, talc and minor ilmenite, spinel and pyrite (Ijewliw, 1986). Hornblendites contain approximately 75 per cent hornblende, 10 per cent clinopyroxene and 10 per cent ilmenite, with calcite, serpentine and traces of pyrite (Ijewliw, 1986). Dunites contain 63 per cent olivine, 14 per cent clinopyroxene and 17 per cent talc with accessory orthopyroxene and hornblende (Ijewliw, 1986).

Altered vesicular glass lapilli, yellow in colour, are present in the breccia, as are juvenile lapilli. Lapilli constitute about 25 to 30 per cent of the rock volume. Diopside, altered olivine, minor orthopyroxene and chrome spinel macrocrysts are also present. The matrix, which makes up a significant proportion of the sample volume, is a mixture of calcite >> talc > chlorite > plagioclase, minor potassium feldspar, sphene and apatite with a fibrous, matted texture. Bryozoan and brachiopod fragments have been noted (Pell, 1987) from similar breccias in nearby pipes.

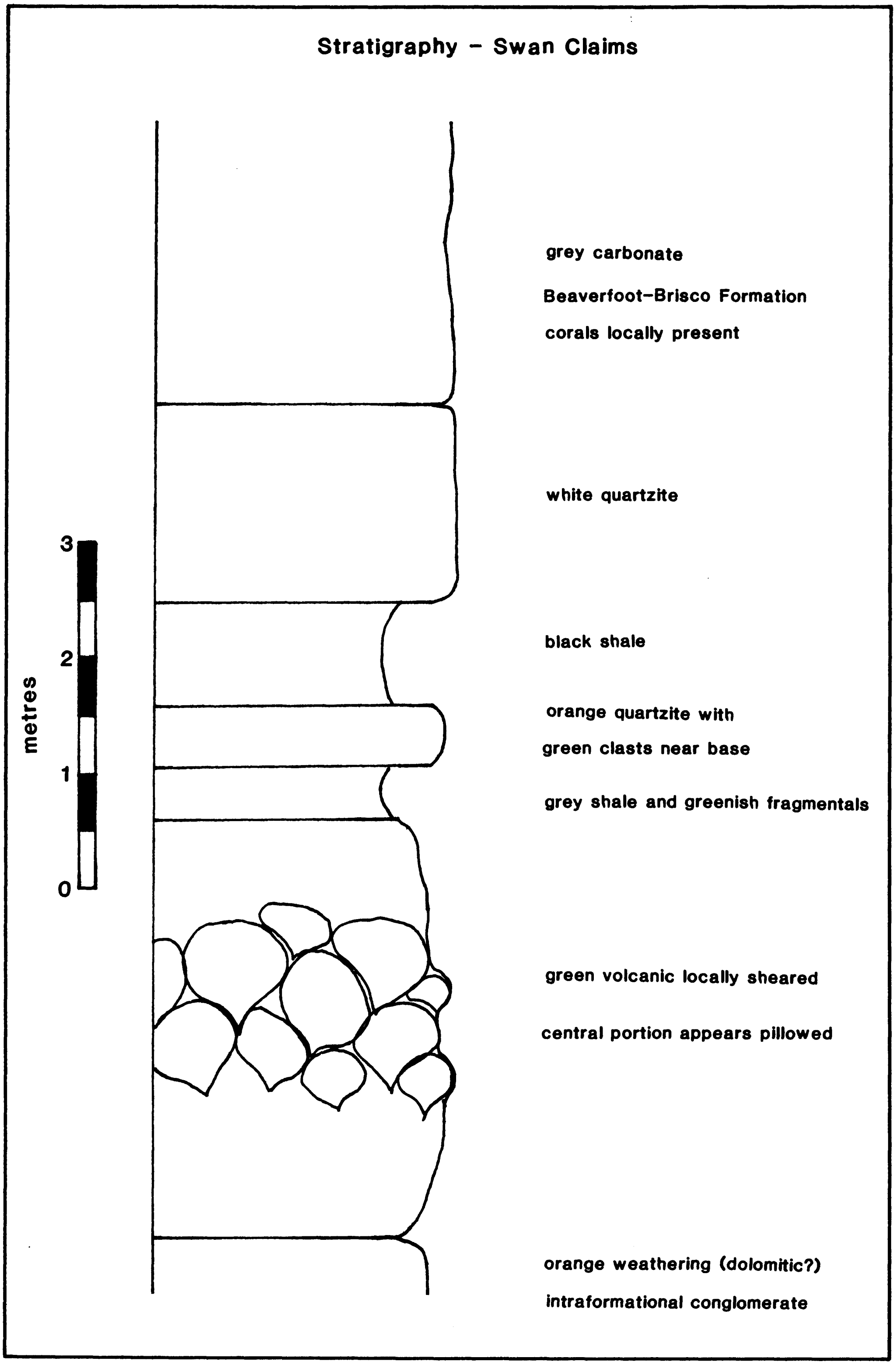


Figure 22. Stratigraphy, Swan claims.

Massive, fine-grained, dark green dykes cut the main pipe. These dykes are extremely altered. The Blackfoot diatreme is similar to both the Shatch Mountain and Russell Peak pipes and is therefore also an alkaline lamprophyre.

MOUNT HAYNES/SWANSON PEAK AREA (SWAN CLAIMS) (82G/14)

The Swan claims are located approximately 5 kilometres south of the Blackfoot pipe (Figure 18) in the Mount Haynes/Swanson Peak area. Igneous rocks outcrop at approximately 2400 metres elevation (grid reference 5533300N, 623650E).

The rocks exposed at this locality are extrusive flows. The main flow (Figure 22) is approximately 3 metres thick. It overlies an orange-weathering coarse limestone conglomerate and is overlain by a few tens of centimetres of mixed shaly tuff which is in turn overlain by a thin orange-weathering quartzite. The quartzite displays graded bedding and contains small (centimetre-size) greenish clasts of the underlying volcanics at its base. The quartzite is overlain by a thin black shale unit which is in turn overlain by 1.5 to 2 metres of white to pinkish weathering orthoquartzite (Figure 22). Thin to thick-bedded grey carbonates of the Beaverfoot Formation, containing relatively abundant fossil corals, overlie the quartzite. The stratigraphic position of this flow, which underlies a quartzite (Tipperary Formation?) beneath the Beaverfoot Formation, indicates that it is of probable Upper Ordovician age.

The igneous unit is fine grained and dark green in hand sample. In the central portion of the unit spherical pillow-like structures are preserved. In thin section, the rock displays a fine porphyritic texture consisting of approximately 10 per cent altered olivine (± pyroxene?) phenocrysts and 2 to 5 per cent melilite phenocrysts in a fine-grained altered groundmass that contains approximately 40 per cent melilite microphenocrysts and a few per cent opaque oxides. The melilite is present as euhedral crystals, rectangular in form. It has weak to anomalous birefringence, parallel extinction and displays well-developed peg structure. Crystals are length fast, and therefore near the akermanite end-member $[Ca_2Al(SiAl)O_7]$ (Phillips and Griffen, 1981).

These flows are extremely melilite rich and tentatively classified as olivine melilitites.

THE SUMMER PIPES (82G/11)

Two small intrusive bodies are exposed at the confluence of Galbraith and Summer Creeks (Figures 18 and 23), approximately 40 kilometres northeast of Cranbrook. Outcrops occur between 1250 and 1350 metres in elevation and can be reached from a logging road leading to a forest recreation site at Summer Lake and to the Top of the World Park. These pipes have been previously reported on by Grieve (1981) and Pell (1986c, 1987).

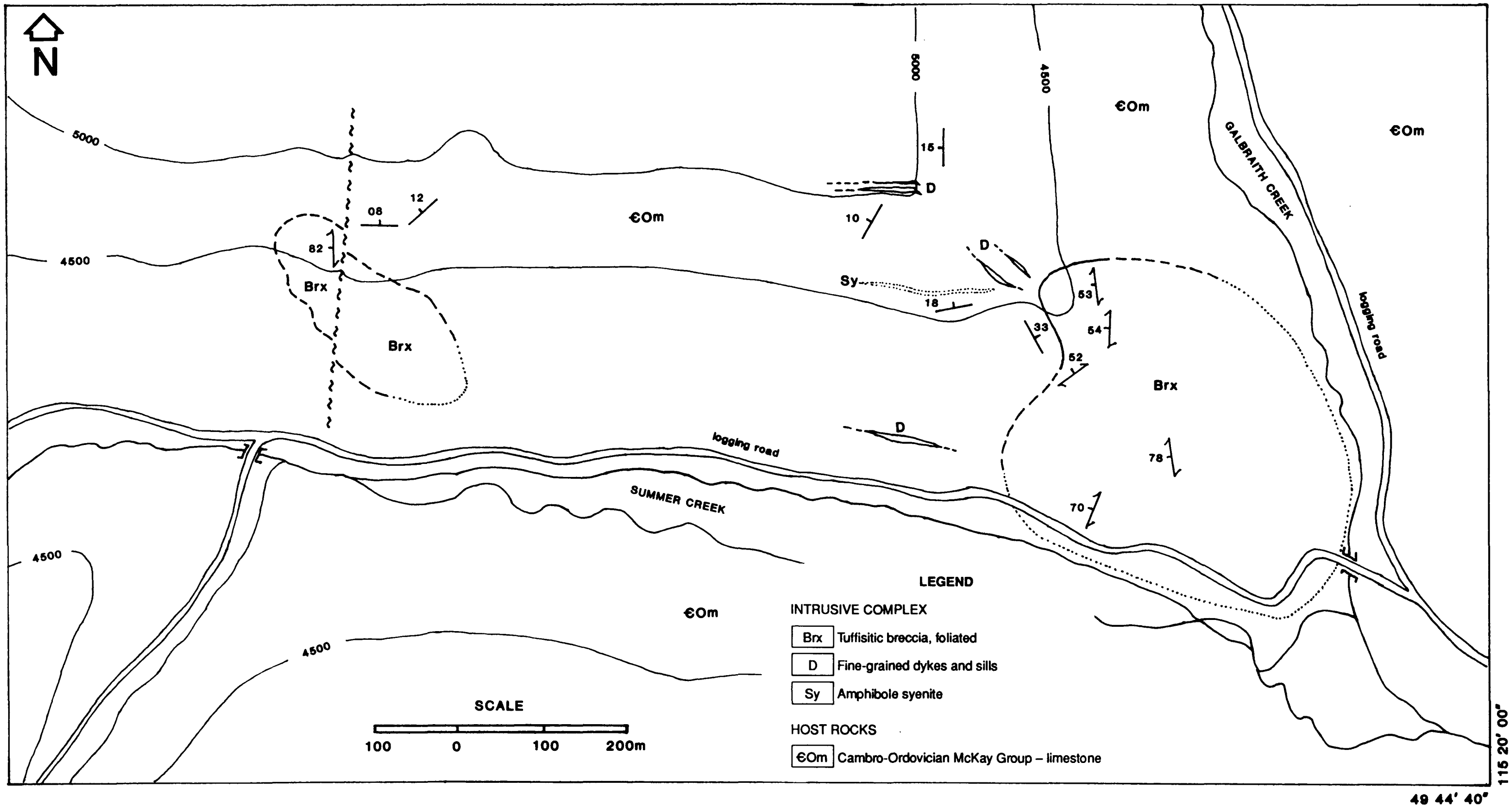


Figure 23. Diatreme breccias, Summer and Galbraith Creeks area.

The Summer diatremes form rusty weathering resistant knolls and are hosted in rocks mapped by Leech (1960) as Late Cambrian to Ordovician McKay Group. In the vicinity of the diatremes, the McKay Group consists of thin-bedded, grey micritic limestone, argillaceous limestone and intraformational limestone conglomerate. In only one place on one of the pipes is the contact between limestone and breccia exposed (Figure 23) and there, is subparallel to bedding in the limestones. This is most likely a local phenomenon, as the overall outcrop pattern indicates discordance. The limestones within 0.5 metre of the exposed contact are highly brecciated and material similar to the diatreme matrix forms veinlets in the limestone breccia. No other contact effects are evident.

The breccia pipes consist of angular to subrounded clasts in a medium green to grey matrix which is locally calcareous. The clast:matrix ratio is on the order of 1:1, with clasts ranging from granule to cobble size. The largest and most numerous fragments are angular limestone, limestone conglomerate and shale fragments up to 70 centimetres across, which comprise 90 per cent of all the clasts. The remaining 10 per cent are buff dolostones, crinoidal limestones, red-weathering, thinly laminated dolostones, granites, granitic gneisses, phlogopite-chrome mica-marbles (altered syenites?), fine-grained cognate xenoliths and autobreccia fragments. Resistant reaction rims were noted around many clasts.

The matrix is predominantly chlorite, serpentine (Grieve, 1981) and carbonate. In thin section, abundant juvenile lapilli (20 to 40 per cent) and altered olivine and clinopyroxene macrocrysts are evident. Minor chrome spinel may also be present. No vesicular glass lapilli were observed.

Adjacent to the diatremes are related dykes and sills. The dykes are fine grained, porphyritic and highly altered. They are texturally similar to dykes and flows in the Russell Peak and Mount Haynes/Swanson Peak areas. They contain what appear to be altered olivine, clinopyroxene and melilite. These dykes are locally vesicular; the vesicles are rimmed by coarse crystalline carbonate and infilled with serpentine.

Though still probably part of the same petrologic family, the Summer diatremes differ from those previously described in a number of ways: (1) they are hosted by Late Cambrian McKay Formation strata (Pell, 1986b), not by Ordovician-Silurian formations; (2) they are massive, brown-weathering, weakly foliated breccias as opposed to dominantly green-weathering, well-foliated tuffisitic breccias; and (3) they are devoid of volcanic glass lapilli.

THE CROSS DIATREME (82J/2)

The Cross diatreme is exposed at an elevation of 2200 metres on the north side of Crossing Creek, 8 kilometres northwest of Elkford. It is 60 kilometres east of the Rocky Mountain Trench, or approximately 20 kilometres east of the axis of the zone containing the other intrusions in the Elk River - Bull River areas (Figure 18). Access is by helicopter or by four-wheel-drive vehicle and a hike along an impassable road. It has previously been reported on (Meeks, 1979; Roberts *et al.*, 1980; Grieve, 1981, 1982; Hall *et al.*, 1986; Ijewliw, 1986, 1987; Pell, 1986c) and therefore will only be briefly described here. The Cross kimberlite is currently the topic of a Ph.D. dissertation by D. Hall at Queen's University.

The Cross diatreme intrudes Pennsylvanian Rocky Mountain Group strata (Hovdebo, 1957). It outcrops on a steep face and an area of approximately 55 by 15 metres is exposed. Its western contact is well exposed and clearly crosscuts shallow-dipping crinoidal dolostones and dolomitic sandstones. A minor shear zone forms the eastern contact. No thermal effects on the wallrocks were observed.

The diatreme is lithologically heterogeneous and very friable. The west end of the outcrop is a light green, strongly foliated rock containing some red hematized clasts, abundant pelletal lapilli and cobble-sized pellets, as well as autobreccia fragments (western breccia phase). Foliation is at a high angle to bedding in adjacent sediments. This grades eastwards to a massive, light green unit (western massive phase) which in turn grades into a rock with 40 per cent inclusions, 5 to 10 per cent of which are ultramafic xenoliths (central breccia phase). Further east the rock is a dark green, massive, unfoliated unit with fewer clasts but containing abundant, randomly distributed phlogopite books and ultramafic xenoliths (eastern massive phase). Bright red hematization is progressively more evident toward the top and centre of the outcrop where entire mineral or xenolithic fragments may be hematized. Pyrite is present as discrete grains in the groundmass and as rims surrounding clasts where it may, in turn, be enveloped by ragged, bright red hematite (red spotted phase). A thin dyke, 10 to 30 centimetres in width, cuts the central breccia phase.

Ultramafic xenoliths are almost entirely serpentinized pseudomorphs of olivine and pyroxene. The original presence of olivine is indicated by the typical olivine outline and fracture pattern. Olivines are completely serpentinized. Some relict pyroxene with characteristic cleavage and birefringence is preserved. Talc replaces pyroxene to a limited extent and also rims and veins serpentinized grains. Interstitial spinels are also present in minor amounts. The interstitial spinels analysed on the energy dispersive system of the scanning electron microscope are in the chromite-hercynite solid solution series and can best be represented by the formula $(Fe,Mg)(Cr,Al)_2O_4$ (Ijewliw, 1987). The xenoliths may be broadly classified as spinel lherzolites. Also preserved, although not as abundant, are garnet lherzolites and glimmerite xenoliths (Hall *et al.*, 1986).

Macrocrysts (0.5 to 5.0 millimetres) consist of completely serpentinized olivines, partially altered garnets, garnets with kelyphitic rims and phlogopites. They may be round, oval or lath-shaped in random orientation and make up 10 to 20 per cent of the rock volume. Garnets show a moderate to high degree of alteration or dissolution in reaction with the matrix. None are euhedral. They are rounded and irregular in shape and surrounded by kelyphitic rims or reaction coronas of opaque iron oxides (Ijewliw, 1987). The garnets are pyrope-rich. Phlogopites are occasionally zoned, with rims darker and more strongly pleochroic than cores and often displaying reverse pleochroism (Hall *et al.*, 1986).

The phenocryst population is comprised of completely serpentinized olivine, together with phlogopite and spinel. Phlogopite grains vary in size and are randomly oriented, square to rectangular in shape and relatively unaltered. Reddish brown translucent spinels are disseminated in the groundmass and show magnetite reaction rims (Ijewliw, 1987). The groundmass is composed of calcite and serpentine with minor apatite and anatase.

The Cross diatreme is the only true kimberlite so far recognized in the province. Rubidium/strontium dating of mica separates has yielded ages of 240 and 244 Ma for the Cross kimberlite (Grieve, 1982; Hall *et al.*, 1986).

ECONOMIC CONSIDERATIONS AND EXPLORATION POTENTIAL

Many metals and industrial minerals are either produced from alkaline rocks or are known to occur in economically significant amounts. Alkaline rocks are a major source of niobium and rare earth elements among the metals and of nepheline, barite, vermiculite, corundum and diamond among the non-metals (Currie, 1976a). Molybdenum, zirconium, copper, fluorite and apatite are also recovered from alkaline rocks. The important features of economically significant materials in alkaline rocks in British Columbia are outlined in the following summary.

NIOBIUM AND TANTALUM

Carbonatites contain the bulk of the world's reserves of niobium (Currie, 1976b), a metal which is used in the production of high-temperature specialty steels and superalloys for nuclear and aerospace applications. Tantalum is a relatively rare, heavy, inert metal that is used in electronics, chemical processing equipment and steel alloys. It is recovered principally as a coproduct of other metal mining and is often associated with tin. Tantalum may be present in significant amounts in carbonatites, where the Nb/Ta ratios commonly exceed 100 (Currie, 1976b).

Carbonatites in British Columbia are all anomalous in niobium. The Aley carbonatite complex appears to have the greatest niobium potential of any of the carbonatite complexes so far discovered. Work by Cominco Ltd. since 1982 has defined extensive zones containing between two-thirds and three-quarters of a per cent niobium pentoxide (K. Pride, personal communication, 1986), grades which easily rival the St. Honore complex in Quebec, which is currently being mined. The other complexes which have been examined all have average Nb_2O_5 values of 0.30 per cent or less. The potential is excellent, however, for additional carbonatites to be discovered in the province with potential ore grade niobium concentrations.

Tantalum is, in general, not abundant in British Columbia carbonatites. Most of the complexes have Nb:Ta ratios typical of carbonatites, approaching 100:1 or more. Carbonatites in the Blue River area, however, have anomalous Nb:Ta ratios, in the order of 4:1 and tantalum values of up to 2400 ppm are reported (Aaquist, 1982b). All carbonatites in the province are currently sub-economic with respect to tantalum.

RARE EARTH ELEMENTS AND YTTRIUM

Rare earth elements are concentrated in all alkaline rocks. In carbonatites, they are present mainly in the form of the cerium subgroup, or light rare earths. Yttrium, although not a rare earth element, is commonly grouped with them as its chemical properties are similar to the heavy rare earths. These elements are used principally in petroleum cracking catalysts, steel and metal alloying agents, glass polishing compounds and glass additives, permanent magnets and phosphors for television and lighting. The rare earths also have important potential in the fabrication of superconductors and applications in advanced ceramics and lasers, particularly yttria.

Significant rare earth element enrichment is reported from two localities in British Columbia, the Aley complex and Rock Canyon Creek, both in the Rocky Mountains. At Aley, narrow dykes enriched in rare earth elements, and locally fluorite, cut the altered sediments peripheral to the main complex. At Rock Canyon Creek a metasomatically altered (fenitized) zone rich in rare earths and fluorite, measuring approximately 1 kilometre by 100 metres, is present. In both areas samples containing in excess of 2 per cent total rare earth oxides have been obtained. At Aley, the dykes are narrow and discontinuous and not of major economic interest. At Rock Canyon Creek, local high rare earth values at surface, and the size of the zone, suggest that further work is warranted. The presence of these two highly anomalous occurrences indicates that British Columbia is highly prospective for economic accumulations of carbonatite-related rare earth elements.

ZIRCONIUM

Zirconium is strongly concentrated in some alkaline rocks and may comprise up to 2 weight per cent (Currie, 1976a). Its major application is in foundries where it is used in mineral form as facing for molds for metal casting. It is also used in refractories, nuclear power applications and chemical processing equipment. Of increasing importance is the application of zirconium in advanced ceramics which have such diverse uses as shuttle tiles, sensors and automobile exhausts. The principal sources of zirconium is zircon recovered as a byproduct from titanium placer deposits and baddeleyite produced as a coproduct from the Palabora, South Africa and Araxa and Pocos de Caldas, Brazil carbonatites.

Zircon is a ubiquitous phase in carbonatite and nepheline syenite gneiss complexes in British Columbia and crystals often exceed 1 centimetre in size. The Aley complex, Paradise Lake syenite, Verity carbonatite, Trident Mountain syenite and Lonnie and Vergil complexes all contain coarse zircon in excess of 1 per cent. In the Lonnie and Vergil complexes, the syenitic rocks may contain 3 to 15 per cent zircon locally. Although it is unlikely that any of these rocks could compete with placer deposits, it is possible that zirconium could be produced as a byproduct and should be explored for.

PHOSPHATES

Carbonatites commonly contain high concentrations of phosphate, largely in the form of the mineral apatite. These concentrations are mined at Palabora (Currie, 1976a). The primary use for phosphorous is as fertilizer. In British Columbia, all carbonatites contain some apatite. The Aley complex and carbonatites in the Blue River area are more enriched in apatite than many other carbonatites, containing on average 5 to 10 per cent apatite, with P_2O_5 contents up to 6 per cent (Tables 1 and 8) and averaging 3.5 to 4 per cent. The Ren carbonatite also has an average P_2O_5 content of approximately 3.5 per cent, with maximum values of 4.2 per cent (Table 9). Production of phosphates from these carbonatites as a primary commodity is unlikely in light of competition from sedimentary deposits, but byproduct recovery of apatite might prove feasible.

NEPHELINE AND NEPHELINE SYENITE

Nepheline and nepheline syenite are of major importance in the glass and ceramics industries due to their high alumina content in the presence of abundant sodium, which acts as a flux (Currie, 1976a). Small amounts are also used in paints and as fillers in plastics. Canada is currently the largest free world producer of nepheline syenite which is all quarried in the Blue Mountain region of Ontario (Currie, 1976a).

Nepheline syenite occurs in large volumes in a number of areas of British Columbia; the Ice River complex, Bearpaw Ridge, Paradise Lake, Trident Mountain, the Perry River area and at Mount Copeland. With the exception of the latter, most are relatively inaccessible. The Mount Copeland syenite gneisses, which are located 25 kilometres northwest of Revelstoke, may be reached by old mining roads. On average they contain more iron, manganese, calcium and potassium, and less sodium, silica and aluminum than those at Blue Mountain (*see* Table 10 and Currie, 1976a). In general, the Mount Copeland syenites are medium to coarse grained and many of the impurities (ferro-magnesian minerals - in particular biotite) could potentially be removed by crushing and magnetic separation techniques. Some of the other syenites, in particular the large body on Trident Mountain, are quite similar to those at Blue Mountain, however their remote location severely limits economic potential.

VERMICULITE

Vermiculite is a mineral which expands when heated. It is formed from alteration of biotite or phlogopite and is a characteristic accompaniment of ultrabasic rocks associated with carbonatites. Vermiculite is present in minor amounts associated with carbonatites in the Blue River area, but is not reported from other areas. The potential for vermiculite production in British Columbia is extremely limited.

MOLYBDENUM

Molybdenum is generally associated with granitic as opposed to syenitic rocks, but, in some cases, it may be present in alkaline complexes (Currie, 1976a). In British Columbia, the nepheline syenite gneisses associated with the Frenchman Cap Dome commonly contain molybdenite and molybdenum was mined at Mount Copeland for a number of years. Current economics, however, do not favour exploitation of molybdenum from such deposits.

DIAMOND

Diamonds were traditionally considered to be present in economic concentrations in kimberlites only. Recent studies have shown that diamonds may also be recovered from lamproites, and they have also been reported from such diverse rock types as peridotites and even carbonatites. In British Columbia, only one true kimberlite has been discovered, the Cross diatreme, but no results of laboratory research on mineral composition and/or diamond recovery were reported by the industry. Microdiamonds have, however, reportedly been recovered from two of the ultramafic lamprophyre diatremes in the Golden - Columbia Icefields area. A significant amount of additional research is necessary to establish if economic concentrations may be present, or if these finds were fortuitous.

DISCUSSION AND CONCLUSIONS

CARBONATITES AND SYENITE GNEISSES

Carbonatites and syenite gneisses crop out in three belts parallel to the Rocky Mountain Trench. The intrusions in Belt 1A, in the Rocky Mountain Fold and Thrust Belt, are Devono-Mississippian in age, hosted in Lower to Middle Paleozoic strata and therefore are relatively high-level intrusions. They tend to be large and elliptical in shape (for example, Aley carbonatite) and have significant alteration halos, or simply consist of metasomatic alteration zones (for example, Rock Canyon Creek showing). The carbonatites in Belt 1A tend to be significantly enriched in niobium, fluorine and rare earth elements.

Belt 1B lies within the Omineca Belt, immediately west of the Rocky Mountain Trench. The intrusions in this belt are also Devono-Mississippian in age, but are hosted in Precambrian strata; they were not emplaced as high in the stratigraphic succession as those in Belt 1A. The carbonatites in the Omineca Mountains are thin, discontinuous, sill-like intrusions with minimal amounts of associated fenite. They do not tend to be as enriched in niobium, fluorine or rare earth elements as their eastern counterparts.

Belt 2 comprises intrusive and extrusive carbonatites and nepheline syenite gneisses hosted in the autochthonous cover sequence of the Frenchman Cap gneiss dome. The enclosing metasedimentary rocks are of uncertain age. A single radiometric date has been obtained on one of the alkaline intrusive bodies (Mount Copeland syenite) suggesting an age of emplacement *circa* 770 Ma. If this date is correct, and if the intrusive syenite is correlative with the intrusive and extrusive carbonatites, the age of those bodies and the hosting succession must also be Precambrian. There is some evidence, however, that this may not be the case (T. Hoy, personal communication, 1987). This question may be resolved when additional dating has been completed.

The carbonatites in Belt 2 comprise high-level intrusions and extrusives. The intrusions are sill-like bodies with extensive fenitic aureoles. Work done to date indicates moderate enrichment in rare earth elements with or without niobium.

There appears to be a relationship between depth of emplacement, degree of associated metasomatism and enrichment in economically interesting elements. All of these factors are probably related to the original volatile content of the magma. The most favourable areas for additional exploration would appear to be those underlain by Lower to Middle Paleozoic strata of North American affinity.

KIMBERLITES AND LAMPROPHYRES

Three petrologically, geographically and temporally distinct suites of ultrabasic diatremes can be recognized in British Columbia. The first suite, examples of which are found north of Golden and in the Ospika River area (Figure 14), is characterized by macrocryst-rich breccias and dykes. The macrocryst population consists of titaniferous augite, phlogopite, green diopside, spinel and olivine, with either augite or phlogopite most abundant. In some cases, microphenocrystic melilite is present in small amounts. These rocks are tentatively classified as ultramafic lamprophyres; those with melilite are alnoites, those without are aillikites.

The breccia pipes commonly contain multiple phases of intrusion characterized by variable proportions of xenoliths, macrocrysts and accretionary or pelletal lapilli. The breccia matrix in some cases is magmatic. These pipes are characteristic of the diatreme facies material, as described from kimberlite pipes (Clement and Reid, 1986).

Rubidium/strontium dates of 334±7 and 348±7 Ma have been obtained from phlogopite separates from two of these pipes. They indicate that their emplacement occurred in Devono-Mississippian time, as is the case for the majority of carbonatites. Aillikites and alnoites are noted for their affiliation with carbonatites (Rock, 1986).

The second suite of intrusions is found in the Bull River area (Figure 18). These pipes are characterized by chaotic breccias containing abundant vesiculated glass lapilli, juvenile lapilli and rare altered olivine, altered pyroxene and chromian spinel macrocrysts. The matrix of these breccias is not magmatic; they are crater-facies tuffisitic breccias. The upper parts of the crater zone contains bedded epiclastic and/or pyroclastic rocks. Toward the periphery, thin layers of igneous material are apparently interbedded with Ordovician/Silurian Beaverfoot carbonate rocks, suggesting an age of emplacement of approximately 435 to 440 Ma.

The craters containing these rocks are envisaged to have a "champagne glass" structure, similar to that of lamproite or basaltic craters, with no extensively developed root zone or diatreme facies.

The breccias are commonly associated with porphyritic dykes and flows, characterized by the presence of phenocrystic olivine and titanaugite, with abundant melilite, titanaugite and opaque oxide microphenocrysts in a fine-grained groundmass. These rocks are tentatively classified as alkaline lamprophyres, possibly of the variety olivine melilitite.

In one locality (Swan claims) olivine melilitite flows, which appear to be pillowed, stratigraphically underlie Beaverfoot Formation strata indicating that emplacement of these alkaline lamprophyres spanned at least a short period of time.

The third petrologically distinct rock type is represented by one example, the Cross kimberlite, located at Crossing Creek, north of Elkford (Figure 18). As the name implies, it is the only true kimberlite so far recognized in the province. It is apparently a deeply eroded pipe remnant and contains two generations of olivine plus phlogopite, pyroxene, garnet and spinel megacrysts as well as garnet and spinel lherzolite nodules (Hall *et al.*, 1986).

Rubidium/strontium isotopic ratios indicate that the Cross pipe was emplaced in Permo-Triassic time, *circa* 245 Ma (Grieve, 1982; Hall *et al.*, 1986).

At this point it is difficult to completely assess the depth of origin and diamond potential of these rocks. When compared to current models (Haggerty, 1986), it appears that the probability of British Columbia diatremes containing diamonds is low. From craton to margin, a sequence of kimberlite plus diamond, kimberlite without diamond (for example, Cross) and diamond-free ultrabasic diatremes (non-kimberlitic) is commonly proposed (Haggerty, 1986). In an attempt to establish the original positions of the diatremes relative to the North American continent, their positions have been projected onto cross-sections (Figure 24). If these sections were restored to predeformational configurations, the pipes contained in the most westerly thrust sheet would have been the furthest outboard. The Cross kimberlite is in the Bourgeau thrust sheet and is the easternmost of the diatremes. The alkaline lamprophyres in the Bull River area are carried by the Bull River - Gypsum fault (Figure 24), which is west of the Bourgeau thrust. As the faults are traced to the north, the Bull River - Gypsum thrust apparently dies out and the displacement is accommodated by the Simpsons Pass thrust. The alnoitic rocks, north of Golden, are carried on a thrust (the Mons fault) which lies west of the Simpsons Pass thrust (Figure 24) and, therefore apparently originated the furthest outboard of the continent. If Haggerty's model is applicable to western North America, it is unlikely that diamonds could be found in non-kimberlitic rocks originating so far from the stable craton. However, much more work is necessary before this hypothesis can be accepted or rejected.

TECTONIC IMPLICATIONS

The emplacement of carbonatites, kimberlites and other alkaline rocks in the Canadian Cordillera appears to be related, in part, to the extension and/or rifting along the western continental margin that produced and deepened the basin into which the miogeoclinal succession was deposited. There is evidence for a number of periods of extension, when deep faults and fractures released pressure and triggered partial melting, which ultimately resulted in alkaline magmatism. The western continental margin does not appear to have behaved in a passive manner, and is therefore not strictly analogous with the present day Atlantic margin as earlier workers have proposed (Stewart, 1972; Stewart and Poole, 1974).

The earliest event recorded by alkaline activity is apparently Proterozoic in age (*circa* 770 Ma) and may be related to the initiation of the basin into which the Hadrynian Windermere Supergroup rocks were deposited. This is indicated by intrusive syenites hosted in the autochthonous cover succession on the Frenchman Cap Dome. Diabase dykes and sills of similar age (770 Ma) record extension preceding Windermere deposition in northern Canada (Armstrong *et al.*, 1982).

The second event occurred in Ordovician-Silurian time, as indicated by the presence of alkaline lamprophyres (olivine melilitites) of that age in the Bull River area of southern British Columbia. The

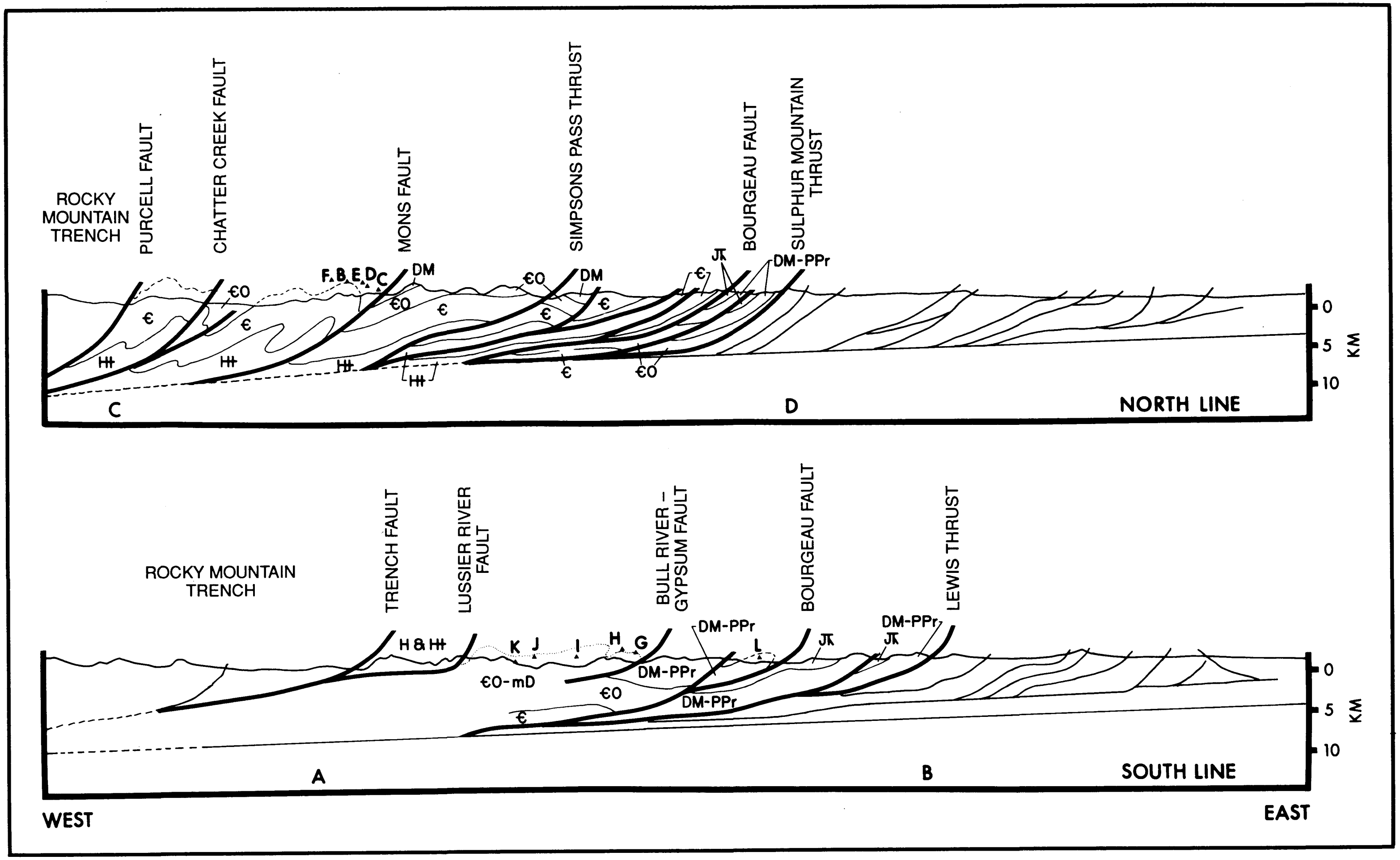
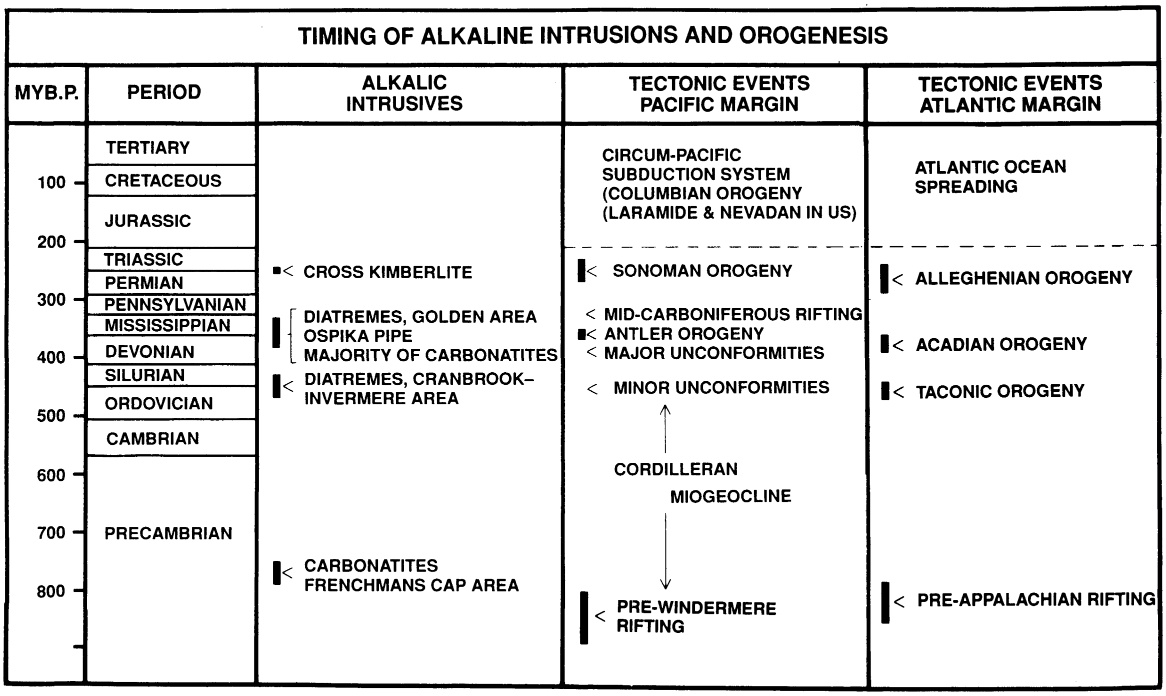


Figure 24. Structural position of diatremes. B - Bush River; C - Lens Mountain; D - Mons Creek; E - Valenciennes River; F - HP pipe; G - Shatch Mountain; H - Russell Peak; I -Blackfoot; J - Quinn Creek; K - Summer; L - Crossing Creek. Geology modified from Wheeler (1963), Wheeler *et al.* (1972), Leech (1979), Price (1981).

Bearpaw Ridge sodalite syenite may also prove to be of Ordovician-Silurian to Silurian age as originally proposed by Taylor and Stott (1979). They believed it to be a subvolcanic pluton related to flows in the Nonda Formation. Diatreme breccias in the Yukon Territory (for example, Mountain diatreme) are also the same age (Godwin and Price, in press). This extensional event on the Pacific margin appears to have occurred shortly after the Taconic orogeny occurred (Dickinson, 1977) in the Appalachians (Figure 25).



modified from Dickson, 1977

Three periods of alkaline magmatism are evident; they show a general temporal relationship with Appalachian orogenic events. The most extensive intrusive event occurred in Devono-Mississippian times, during which major extensional tectonics must have been active along parts of the western North American margin.

Figure 25. Timing of alkaline intrusions and orogenesis.

A third period of extension resulted in the intrusion of carbonatites in Belts 1A and 1B, and the diatremes in the Rocky Mountains north of Golden and in the Ospika River area, at the end of the Devonian (*circa* 350 Ma). The tectonic instability resulting from this major Devono-Mississippian extensional event is also evident in the stratigraphic record; volcanic rocks (some peralkaline in composition), synsedimentary block faults and chert-pebble conglomerates are reported from the Mid-Devonian to Early Mississippian sequence in the northern Canadian Cordillera (Gordey, 1981; Mortensen, 1982). As with the earlier Pacific margin extension, this event followed shortly after compression on the Atlantic margin, in this case, the Late Devonian Acadian orogeny (Figure 25). Also, the Mid-Carboniferous extension occurred synchronous with, or slightly postdated compression associated with the Antler orogeny in the southern Cordillera.

The last Paleozoic extensional event is inferred from the presence of Permo-Triassic kimberlite in the Rocky Mountains. Although only one example is known to occur, it is possible that other alkaline intrusions of similar age or other evidence for extension may be discovered. Permo-Triassic extension, as with the previous two events, immediately postdated compression on the Atlantic margin (the Alleghanian orogeny) and occurred approximately synchronously with compression in the southern Cordillera (Sonoman orogeny).

In Late Jurassic to Early Tertiary time, a compressional regime was established on the Pacific margin and orogenesis occurred, while rifting and the opening of the Atlantic took place on the opposite margin of the continent. During orogenesis, the continental margin prism was telescoped and the alkaline igneous rocks deformed, metamorphosed and transported eastwards in thrust sheets. The present distribution of the intrusions near the Rocky Mountain Trench is due to original location along a rifted continental margin and subsequent telescoping, rather than Trench tectonics. No known syn or post-orogenic carbonatites or alkaline ultramafic diatremes have been discovered in the Canadian Cordillera.

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