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CARBONATITES, NEPHELINE SYENITES, KIMBERLITES AND RELATED ROCKS IN BRITISH COLUMBIA

This is a Contribution to the Canada/British Columbia Mineral Development Agreement 1985-1990

By Jennifer Pell

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INTRODUCTION

A previously poorly documented alkaline igneous province is present in the Canadian Cordillera. It comprises carbonatites, 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.

Carbonatites are ultrabasic igneous rocks composed of more than 50% carbonate minerals. They may contain significant amounts of olivine, magnetite, pyroxene, sodic amphibole, biotite, vermiculite, apatite, columbite, zircon, rare-earth 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 byproduct 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 western world producer of nepheline syenite (Currie, 1976a). Since the 1950s a number of carbonatite complexes in British Columbia have been prospected for various commodities at different times; their vermiculite, niobium, zirconium and rare-earth potential has been explored. None have any history of production.

Kimberlites are volatile-rich, potassic, ultrabasic igneous rocks which occur as small volcanic pipes, dikes 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 a 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 hostrocks 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.

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, titanium-rich phlogopite, clinopyroxene, amphibole (titanium and potassium-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. Diatreme breccia pipes in British Columbia have been targets for diamond exploration since the mid-1970s (Grieve, 1981; Dummett *et al.*, 1985) even though most are not true kimberlites; microdiamonds have been discovered in heavy mineral separates from two of these pipes (Dummett *et al.*, 1985). Diamonds are also known to occur in kimberlites from the Colorado-Wyoming State-Line district (McCallum and Marbarak, 1976), from the Mountain diatreme in Yukon (Godwin and Price, 1987) and from placer deposits in Alaska (Forbes *et al.*, 1987) where stones over 1 carat in size have been recovered.

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. Consequently, this suite has important implications because it documents the characteristics of carbonatites and related rocks emplaced in a continental margin environment, and details the subsequent effects of orogenesis.

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 on either side of the Rocky Mountain Trench. Carbonatites and related rocks are also reported from a number of areas in the western United States, for example, the McClure Mountain, Iron Hill, Gem Park and Wet Mountain areas of Colorado (Larsen, 1942; Olson and Wallace, 1956; Parker and Sharp, 1970; Nash, 1972; Hildebrand and Conklin, 1974; Armbrustmacher, 1979, 1984; Armbrustmacher *et al.*, 1979), the Lemitar Mountains, central New Mexico (McLemore, 1987) and the Mountain Pass area, California-Nevada State-Line (Olson *et al.*, 1954; Jaffe, 1955; Warhol, 1980; Woyski, 1980).

Three discrete areas hosting carbonatites can be defined within British Columbia: the Foreland Belt, east of the Rocky Mountain Trench; the eastern edge of the Omineca Belt; and in the vicinity of Frenchman Cap dome, a core gneiss complex, also within the Omineca Belt. The eastern or Foreland Belt (Figure 1) hosts carbonatites and related rocks within Paleozoic strata, predominantly in the Main and Western ranges of the Rocky Mountains. This belt contains the Aley carbonatite complex (Mäder, 1986, 1987), Wicheeda Lake showing (Prince and George claims, Betmanis, 1987; Mäder and Greenwood, 1988), Bearpaw Ridge sodalite syenite, the Ice River syenite and carbonatite complex (Currie, 1975, 1976a) and the Rock Canyon Creek fluorite and rare-earth showing, a carbonatite-related deposit (Hora and Kwong, 1986). The Aley, Ice River and Bearpaw Ridge intrusions are subcircular to elliptical in plan, generally have extensive metasomatic alteration or contact metamorphic halos and are hosted by Middle Cambrian to Middle Devonian miogeoclinal rocks. Alkalic rocks in the Wicheeda Lake area define a linear zone, and consist of small plugs, dikes and sills. The Rock Canyon Creek showing is an elongate zone of fluorite and rare-earth metasomatic alteration in Devonian carbonate rocks, possibly

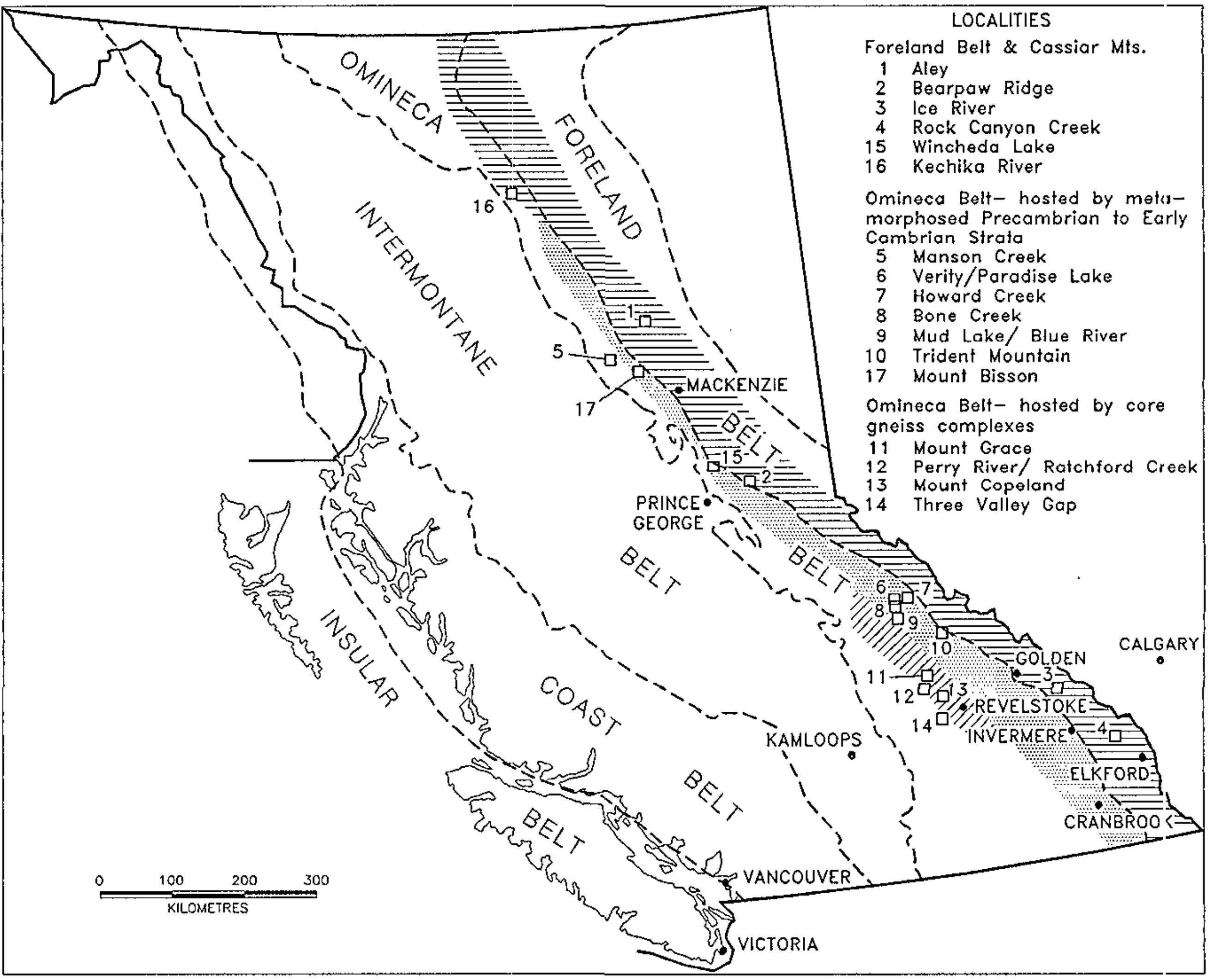

Figure 1. Index map, carbonatite and nepheline syenite gneiss complexes.

related to a buried carbonatite. Carbonatites in this belt exhibit varied mineralogy and are enriched in niobium, fluorine and rare-earth elements relative to other British Columbia occurrences. During the Columbian orogeny the intrusions were subjected to sub-greenschist to 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. Locally, small faults cut the alkalic rocks.

The Kechika River complex is located a few kilometres west of the Rocky Mountain Trench, in the Cassiar Mountains (Fox, 1987; Pell *et al.*, 1989). It is morphologically similar to the Wicheeda Lake showing, consisting of dikes and plugs and probable pyroclastic layers distributed in a linear belt. Although not in the Rocky Mountains, it exhibits many similarities to alkalic rocks in the Foreland Belt and for the purposes of this discussion, will be considered with them.

Carbonatites and syenites are found along the eastern margin of the Omineca Belt, extending westward from the Rocky Mountain Trench for 50 kilometres or more. All the intrusions within this belt are hosted by late Precambrian (Upper Proterozoic) to Early Cambrian metasedimentary rocks. They generally form foliated, sill-like bodies that have been multiply deformed and metamorphosed to amphibolite facies during the middle Mesozoic orogeny; some small plugs and discordant dikes are also present. 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 at the Lonnie and Vergil showings (Rowe, 1958; Currie, 1976a), syenites and monzonites in the Mount Bisson – Munroe Creek area (Halleran, 1988; Halleran and Russell, 1990), carbonatites with nepheline and sodalite syenites and some urtites in the Blue River area, including the Verity, Paradise and Howard Creek localities (Rowe, 1958; Currie, 1976a; Pell, 1987) and nepheline and sodalite syenites at Trident Mountain and Kinbasket Lake (Currie, 1976a; Perkins, 1983). No carbonatites in this zone are known to contain potentially economic concentrations of niobium or rare-earth elements; however, pegmatites dramatically enriched in light rare-earth element have been reported from the Mount Bisson area (Halleran and Russell, 1990).

The most westerly area contains intrusive and extrusive carbonatites and syenite gneiss bodies in a mixed paragneiss succession along the margins of the Frenchman Cap gneiss dome north of Revelstoke (Wheeler, 1965; McMillan, 1970; McMillan and Moore, 1974; Höy and Kwong, 1986; Höy and Pell, 1986) in the core of the Omineca Belt (Figure 1). The Frenchman Cap gneiss dome is one of several late domal structures located near the eastern margin of the Shuswap Complex (Wheeler, 1965; Read and Brown, 1981). The core of the dome comprises mixed gneisses of probable Aphebian age that are unconformably overlain by 'mantling gneiss', an autochthonous cover sequence which hosts the carbonatites and syenites. The intrusive and extrusive alkaline rocks in this area are conformable bodies that were deformed and metamorphosed to upper amphibolite facies during the Columbian orogeny. 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. Both of the intrusive and extrusive carbonatites are moderately enriched in rare-earth elements, but no significant niobium mineralization has been reported.

Several tens of kilometres to the south of the Frenchman Cap Dome, near Three Valley Gap, another carbonatite is hosted by migmatitic gneisses of uncertain affinity. It exhibits many similarities in field relationships and geochemical signatures to the intrusions of the Blue River and Manson Creek areas along the eastern margin of the Omineca Belt.

DISTRIBUTION AND GENERAL CHARACTERISTICS OF KIMBERLITES AND ALKALINE ULTRABASIC DIATREME BRECCIAS

Alkaline ultrabasic diatremes and dikes have been discovered in the Western and Main ranges of the Rocky Mountains and in the Cassiar Mountains of British Columbia (Figure 2). With the exception of the Cross diatreme, all are hosted by Cambrian to Silurian miogeoclinal rocks (Roberts *et al.*, 1980; Grieve, 1981; Pell, 1986c, 1987b). The Cross diatreme, which is located in a more easterly structural position, is hosted by carbonate rocks of the Pennsylvanian to Permian Rocky Mountain Group (Hovdebo, 1957; Grieve, 1985). All the diatremes intruded the miogeoclinal sequence of platformal carbonate and clastic rocks prior to the Columbian orogeny. The effects of deformation and metamorphism are manifest 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. Diatreme breccias are also found in the Mackenzie Mountains, Yukon (Mountain diatreme, Godwin and Price 1987; Coates Lake diatreme, C. Jefferson, personal communication, 1987); kimberlites and related alkalic ultramafic diatremes have been found in north-central Montana (Hearn, 1968; Hearn and McGee, 1983); kimberlites also occur in the Colorado-Wyoming State-Line District (*e.g.* Sloan pipe, Hausel *et al.*, 1979, 1981; McCallum *et al.*, 1975; McCallum and Marbarak, 1976).

Ultrabasic diatremes are present in five geographic regions of British Columbia. Within each area the diatremes are, for the most part, petrologically similar. The first suite is found in the Cranbrook – Bull River area (Figure 2) where examples of crater facies and extrusive rocks have been recognized. The upper parts of the diatremes are characterized by bedded epiclastic and/or pyroclastic material overlying a chaotic fragmental breccia containing abundant vesiculated glass lapilli. In one pipe, small mafic flows and dikes are exposed near the top of the crater zone. These rocks are porphyritic and consist of abundant clinopyroxene and less abundant olivine phenocrysts, clinopyroxene, oxide and potassium feldspar microphenocrysts in a fine-grained groundmass. Deeper levels within the craters are characterized by juvenile lapilli-rich breccias with rare macrocrysts of chrome spinel, altered pyroxenes and altered olivines sporadically distributed throughout. Micas are not present in these rocks. Sedimentary rock fragments, granitic clasts and a variety of pyroxenite and periodotite xenoliths have been recovered from these pipes. Tentatively, these rocks are interpreted to have an alkaline lamprophyre affinity.

The second suite, found north of Golden (Figure 2), is characterized by macrocryst-rich breccias and dikes. The macrocryst population consists of titaniferous augite or salite, phlogopite, green chrome diopside, spinel and rare olivine, with either clinopyroxene or phlogopite most abundant (Ijewliw, 1987; Pell 1987a). Sedimentary fragments are predominant in the breccias; gabbroic and granitic xenoliths, as well as cognate material, spherical structures and nucleated autoliths are also present locally. These pipes are multiphase intrusions, with massive and multiple breccia phases cut by related dikes. Petrologically, the diatremes appear to bear some affinity to alkaline and ultrabasic mica lamprophyres (alnoites and aillikites) as defined by Rock (1986). These diatremes and dikes are associated with quartz xenocryst rich breccias, containing sedimentary rock fragments and little recognizable igneous material. Microdiamonds have reportedly been recovered from heavy mineral separates taken from two pipes of this type (Dummett *et al.*, 1985).

In a third area, near Williston Lake and the Ospika River, northern Rocky Mountains, a single pipe has been discovered near the Aley carbonatite complex. It exhibits many similarities to the pipes in the Golden area; it is a multiphase diatreme characterized by macrocrystic green chrome pyroxene, augite, pholgopite and spinel. Based on mineralogy it can be classified as an aillikite, a type of ultrabasic lamprophyre.

A diatreme breccia and related dikes are also known in the Kechika area of the Cassiar Mountains in northern British Columbia. These breccias are rich in juvenile lapilli, contain abundant sedimentary rock fragments, rare chrome spinels and are devoid of xenocrystic micas (Pell *et al.*, 1989), similar to breccias in the Cranbrook – Bull River area.

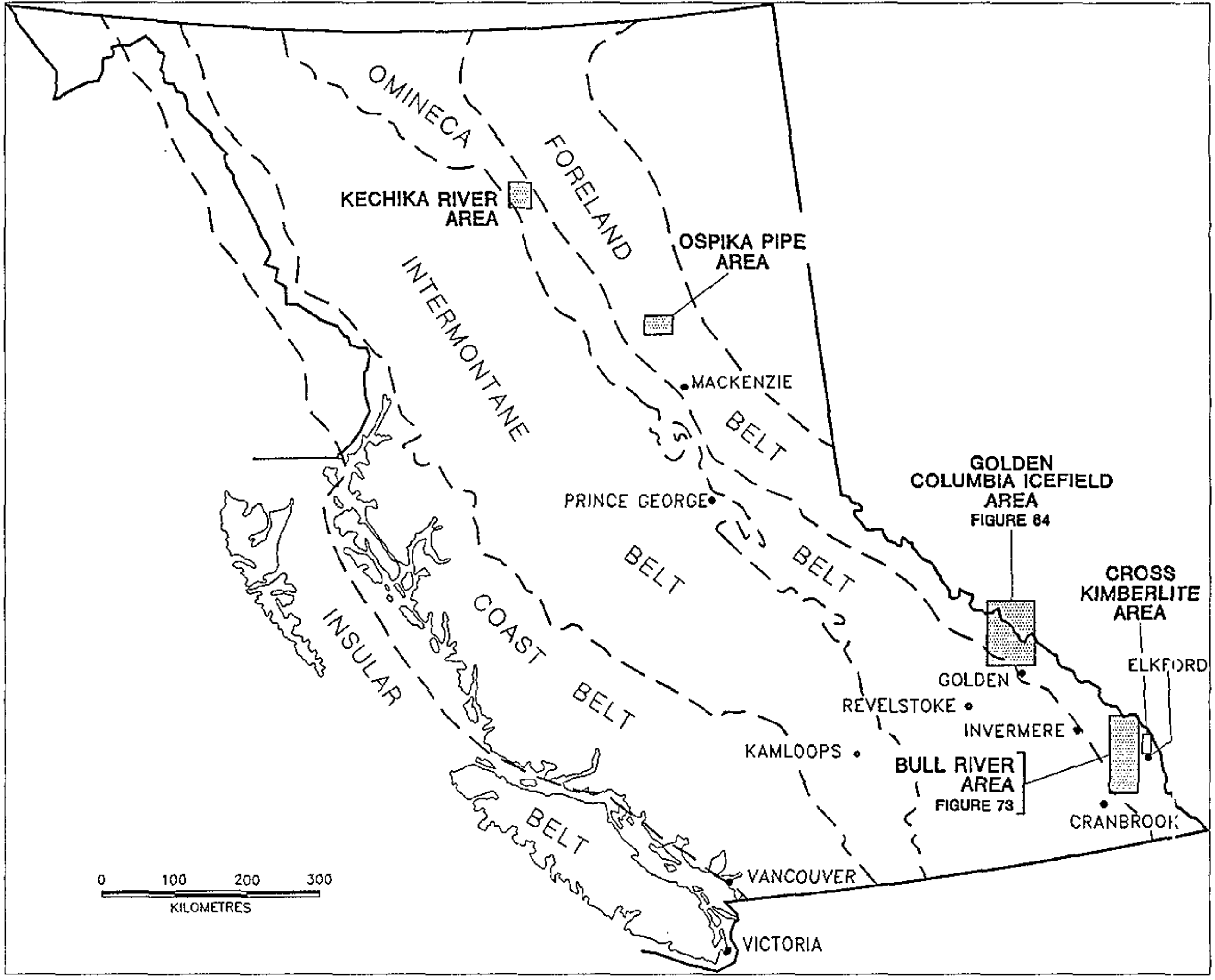

Figure 2. Index map, alkaline ultrabasic diatreme swarms (from Pell, 1987). For details on the Ospika Pipe *see* Figure 3 or Mäder (1987).

The last geographically and petrologically distinct rock type is represented by one example, the Cross diatreme, located at Crossing Creek, north of the town of Elkford. To date, this breccia pipe is the only true kimberlite recognized in the southern Canadian Cordillera (Grieve, 1981, 1982; Hall *et al.*, 1986; Ijewliw, 1986, 1987). It is a multiple intrusion with massive and breccia phases containing 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. Massive phases have a magmatic matrix of serpentine, carbonate, microphenocrystic olivine and spinels. No diamonds have been reported from this pipe. The ratio of ultramafic to sedimentary xenoliths is greater in the Cross diatreme than in any of the other breccia pipes and it is characteristic of the diatreme facies of kimberlites (Hawthorne, 1978; Clement and Reid, 1986).

GEOLOGICAL WORK

Prior to this study, documentation of carbonatites, syenite gneisses and alkaline ultramafic diatreme breccias was limited to studies of a few complexes and brief descriptions of some of the others. In the Foreland Belt, the Ice River complex had been the subject of a number of studies, dating back to the turn of the century (Dawson, 1885; Barlow, 1902; Allan, 1914; Jones, 1955; Rapson, 1963, 1964). The most comprehensive study of the complex was completed by Currie (1975). Other carbonatite complexes, syenites, kimberlites and diatremes in the Rocky Mountains had only received brief mention in the literature. Carbonatites hosted by metamorphosed strata along the eastern margin of the Omineca Belt had also received only brief mention in overview publications (Rowe, 1958; Currie, 1976a). Carbonatites and syenite gneisses associated with core complexes in the Omineca Belt were discovered and studied in the course of regional mapping (Fyles, 1970; McMillan, 1970, 1973; McMillan and Moore, 1974). Subsequent studies (Currie, 1976b; Höy and Kwong, 1986; Höy, 1988) provide detail on these suites.

Work by the author was begun in 1984 and included field mapping during the summers of 1984, 1985 and 1986. All the carbonatite-syenite localities (with the exception of the Wicheeda Lake and Mount Bisson showings, discovered late in the project) and a large number of the diatreme breccias were mapped and sampled. The purpose of this study is to document alkaline rock occurrences in British Columbia; to describe their petrography, geochemistry, economic geology and field relationships; and to determine the timing and tectonic controls of emplacement, providing a basis for future, detailed studies. Most new work concentrated on previously undocumented occurrences; previously studied suites were examined for comparison purposes.

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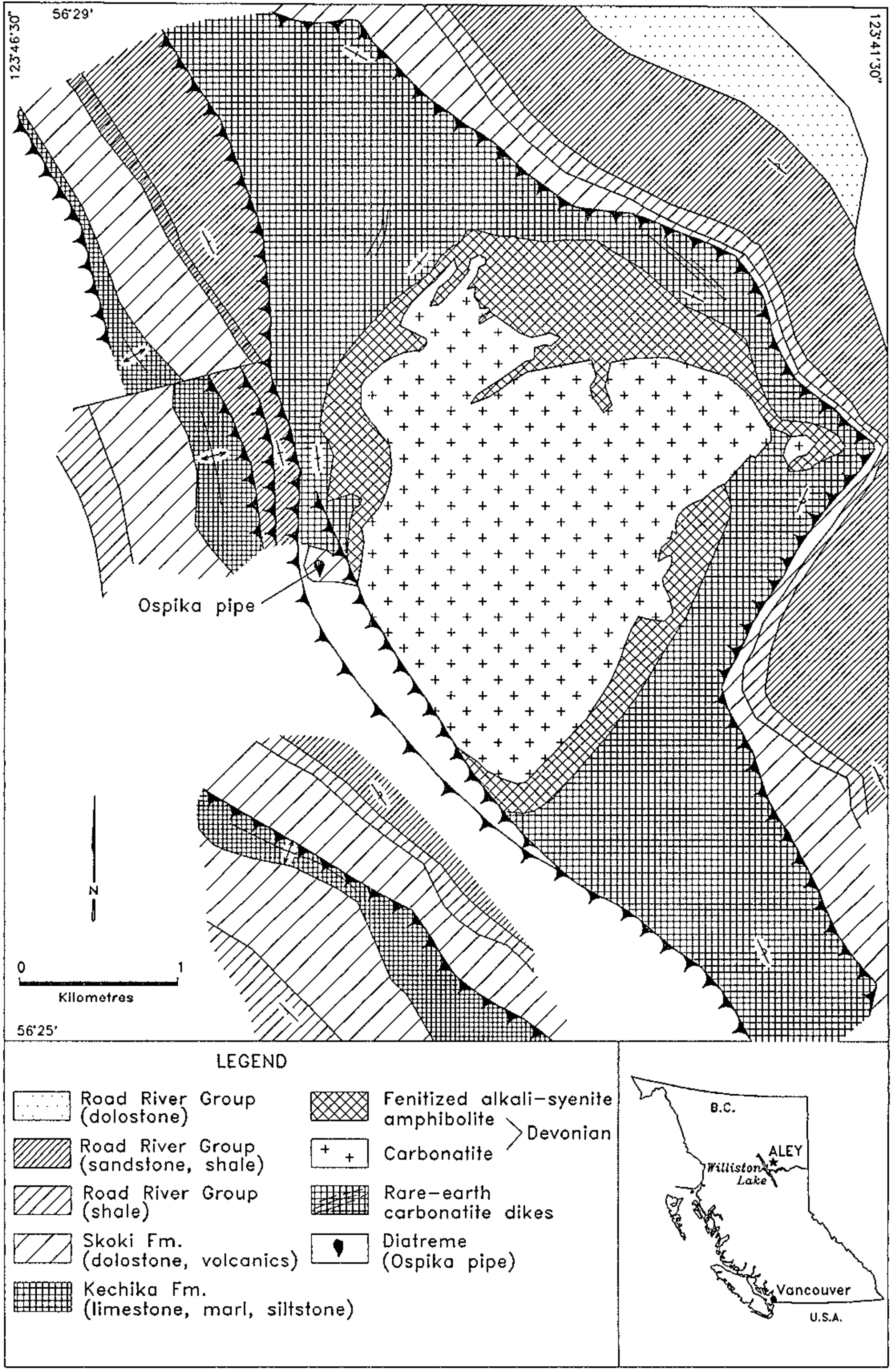


Figure 3. Geological map of the Aley carbonatite complex (from Mäder), 1987.

CARBONATITE AND SYENITE COMPLEXES IN PALEOZOIC STRATA, ROCKY AND CASSIAR MOUNTAINS, FORELAND BELT

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 - 2200 m elevation) 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 outer edge of the continental shelf, was intruded by the Aley carbonatite complex prior to the main Late Jurassic to Early Cretaceous orogenic event. The youngest unit affected by the intrusion is the mid-Ordovician(?) Skoki volcanic sequence. Much of the following description of the carbonatite complex is summarized from the work of Mäder (1986, 1987).

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 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-enriched carbonatite dikes intrude the contact aureole (Figure 3). Ultrabasic lamprophyre dikes and a diatreme breccia pipe (Ospika pipe) intrude altered and fresh carbonates outside the complex. These will be discussed later in this report.

RAUHAUGITE CORE ZONE

The core of the Aley complex is approximately 2 kilometres in diameter. It comprises more than 50% of the exposed complex and consists of dolomite (80-99%) and apatite (1-10%) with minor amounts of phlogopite, pyrite, magnetite, monazite, strontianite and zircon. It is generally a massive and homogeneous unit, weathering a buff to brownish colour. 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; primary fersmite is rare. Columbite $[(Fe,Mn)(Nb,Ta)_2O_6]$ is present as a replacement of fersmite.

Mineral banding or layering is common, particularly near the margins of the complex, and is characterized by aligned flattened grains and aggregates of apatite. In mineralized zones, magnetite, pyrochlore, fersmite and biotite also exhibit some alignment and compositional zoning. Field studies indicate that the mineral layering is steeply dipping and strikes approximately parallel to the margins of the complex. It has been interpreted as vertical flow banding, a primary igneous texture (Mäder, 1986) as is observed in many other carbonatite complexes (*e.g.*, Oka).

SOVITE ZONES

Sovite zones (dikes and 'sweats') occur locally near the margin of the rauhaugite core zone and in the surrounding amphibolite zone. The sovites exhibit a more variable mineralogy than the rauhaugites. Calcite with or without dolomite dominates (40-95%) and there are accessory to major amounts of apatite (2-10%), biotite (0-5%), magnetite (0 to 40%), richterite, a sodic amphibole (0-5%), pyrochlore (0-2%), fersmite and pyrite (Pride *et al.*, 1986). Zircon and rare baddeleyite associated with zirkelite have also been reported; mineral banding is well developed.

'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 dikes cut both members, indicating the 'amphibolite' margin predated emplacement of the carbonatite core zone.

The massive phase is a medium to coarse-grained, dark green rock consisting primarily of sodic amphibole (magnesio-arfvedsonite), 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. Mäder (1986, 1987) has recognized microsyenite textures in the massive amphibolite, and suggests that it is a primary igneous phase with a metasomatic (fenitic) overprint, as opposed to fenitized country rock. This appears to be the most reasonable interpretation

Plate 1. Rounded xenoliths of quartzite and syenite in the breccia phase of the "amphibolitic" margin, Aley complex.

for the origin of this rock; however, the true nature of the primary igneous phase is so obscured that classification is difficult.

The breccia phase contains subrounded clasts of dominantly orthoquartzite, with some siltstone, albitite and microsyenite fragments in a matrix that is similar to the massive phase and locally grades into it. The clast-to-matrix ratio is highly variable and clast-supported breccias are developed locally; on average, clasts comprise 1 to 30% of the rock volume. Their subrounded nature gives this unit the appearance of a conglomerate (Plates 1 and 2). The quartzite and siltstone xenoliths range from a few millimetres to approximately 30 centimetres in diameter. Reaction rims consisting predominantly of fine-grained aegirine commonly envelop the xenoliths. The quartzite xenoliths are probably derived from Lower Cambrian quartzite formations which the complex must have sampled during its ascent. Microsyenite and albitite clasts may represent deeper level intrusives or fenites associated with the original magma chamber. The extreme roundness of clasts is similar to many of the diatreme breccias and may be a result of gas-streaming abrasion.

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 greyish to a distinct buff hue. The altered rocks may superficially resemble material

Plate 2. Rounded quartzite xenoliths weathering out of the "amphibolite" margin, Aley complex.

Plate 3. Chocolate brown-weathering, REE-enriched dikes in carbonate host rocks, Aley complex, *(colour photo, page 135).*

TABLE 1
CHEMICAL ANALYSES, ALEY CARBONATITE COMPLEX

	Rauhaugite core								Sovite					Rare earth dikes						Amphibolite margin							Clast in amphibolite
wt %	*1*	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
SiO2	0.50	0.28	0.52	1.08	0.69	5.80	2.42	7.22	2.17	3.84	3.53	1.67	1.02	0.65	7.30	0.56	2.31	0.80	0.40	66.36	75.15	53.00	60.17	44.00	20.41	7.93	60.02
TiO2	<0.01	<0.01	0.01	0.72	0.18	0.20	0.20	0.14	0.04	0.10	0.08	0.02	0.03	0.01	0.04	0.02	0.01	0.00	0.01	0.68	0.41	0.35	1.31	0.15	0.15	0.41	0.85
Al2O3	0.26	0.14	0.16	0.12	0.49	0.34	0.15	0.30	0.02	0.03	0.51	0.24	0.18	0.21	0.67	0.49	0.08	0.04	0.12	4.28	8.30	1.33	6.39	8.69	1.73	0.08	16.50
Fe2O3(T)	-	-	-	-	5.48	4.91	2.50	2.65	2.29	4.34	13.68	3.59	1.80	-	-	5.82	3.94	5.33	5.61	11.10	-	12.91	10.98	4.36	2.54	19.92	1.35
FeOT	2.95	1.08	1.92	0.76	-	-	-	-	-	-	-	-	-	8.41	10.49	-	-	-	-	-	3.88	-	-	-	-	-	-
MnO	0.26	0.87	0.77	0.25	0.22	0.90	0.22	0.22	ND	ND	ND	0.23	0.40	4.11	3.30	1.58	1.37	1.66	2.68	0.27	0.14	0.35	0.45	0.49	1.37	0.44	0.17
MgO	17.34	16.68	14.79	18.02	16.50	16.60	14.90	12.77	5.85	7.71	2.92	2.60	1.80	11.29	7.91	13.48	14.77	13.74	13.07	2.55	0.87	16.00	3.61	5.22	3.72	9.18	1.66
CaO	32.89	34.82	34.29	33.71	31.20	28.20	31.00	32.74	45.69	41.47	41.34	45.50	46.00	28.14	24.59	27.73	30.44	29.39	28.18	4.05	2.28	3.50	3.98	14.80	35.88	25.32	4.59
Na2O	0.63	0.08	ND	ND	0.06	0.05	0.08	0.00	0.48	0.46	0.18	0.08	0.12	1.13	0.79	0.10	ND	ND	ND	7.79	3.85	7.71	8.72	3.83	2.83	0.04	8.86
K2O	0.02	0.01	0.02	0.01	<0.10	0.26	0.13	0.02	0.05	0.13	0.03	0.11	0.13	0.04	0.06	0.02	ND	ND	ND	0.24	3.68	1.15	0.20	3.10	0.52	0.03	0.37
LOI	43.52	42.00	40.16	41.96	36.46	39.96	37.08	27.86	38.72	36.06	30.20	35.36	39.69	42.55	33.11	-	40.38	41.08	41.42	0.84	1.16	-	-	15.45	26.39	20.02	5.16
P2O5	1.74	1.36	8.69	3.15	6.07	1.81	5.29	11.42	4.60	5.03	7.73	4.64	1.44	0.14	0.09	0.34	0.60	0.90	0.52	0.70	0.20	0.68	0.60	0.45	3.23	9.13	0.09
TOTAL	100.11	97.32	101.33	99.78	97.35	99.03	93.97	95.34	99.91	99.17	100.20	94.04	92.61	96.68	88.35	50.14	93.90	92.94	92.01	98.86	99.92	96.98	96.41	100.54	98.77	92.50	99.62
ppm																											
Ni	-	-	-	-	< 2	< 2	5	10	-	-	-	< 2	3.00	-	-	-	4	2	1	-	-	-	-	14	7	< 2	14.00
Cr	-	-	-	-	< 20	< 20	< 20	< 20	-	-	-	< 20	< 20	-	-	-	27	29	15	-	-	-	-	36	< 20	< 20	45.00
Co	-	-	-	-	10	4	10	11	-	-	-	12	8	-	-	-	6	2	< 5	-	-	-	-	-	15	< 5	19
Sr	359	4377	4449	457	831	3391	1426	2023	5281	4630	686	3506	5446	5500	70	-	3015	1864	8612	300	141	670	-	642	3663	2023	266
Ba	39	1225	85	33	45	59	24	38	314	248	308	323	500	6200	69300	12300	238	584	15027	1340	184	540	461	1663	-	450	-
Zr	66	465	499	497	146	35	70	290	604	559	308	563	98	580	96		34	20	52	270	887	390	-	40	79	290	22
Nb	490	168	1796	1384	5699	683	6759	13525	3290	4610	5030	891	3360	< 5	29	10	534	115	< 5	71	72	280	10	119	803	5697	322
Y	41	14	69	122	140	18	249	138	97	93	122	129	95	13	96	-	65	26	8	6	18	21	-	48	227	138	10
La	310	142	322	355	388	205	598	558	314	248	308	307	400	2670	2290	-	7046	8725	2789	63	60	235	-	813	1020	379	54
Ce	750	224	909	856	816	390	1115	1215	708	823	1318	590	762	4760	7210	-	12100	12500	4000	170	143	110	-	1260	2070	905	90
Nd	240	59	310	297	-	-	-	-	ND	ND	ND	-	-	1020	3580	-	2940	3260	1080	56	46		-	-	941	-	33
Yb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11.6	10.0	3.5	-	-	-	-	-	21	-	0.6
Sc	-	-	-	-	33	28	41	36	-	-	-	46	43	-	-	-	2.6	2.6	1.7	-	-	-	-	32	5.6	31	2.7
Ta	18	ND	17	166	1	< 2	< 2	171	< 20	< 20	59	230	201	-	-	-	< 2	< 2	< 2	-	-	-	-	<2	53	579	< 2
Th	130	ND	21	184	375	5	23	712	65	106	464	253	243	28	840	293	151	105	61	< 7	< 7	< 20	12	67	108	592	3.5
F%					0.56	0.34	0.63					0.35	0.24	-	-	-	1.32	0.32	0.07	-	-	0.90	0.30	ND	-	-	-

Analysis 1, 14, 15, 20 - by XRF from Mäder (1987); Analysis 2, 3, 4, 21 by XRF from Mäder (1986);
Analysis 9, 10, 11, 16, 22, 23 by XRF, Cominco Ltd., reported in Mäder, 1986, also reported in Mäder, 1987
Analysis 5, 6, 7, 12, 13 major elements by ICAP; trace elements by XRF B.C. Geological Survey Branch Analytical Lab.
Analysis 17, 18, 19, 24, 25, 27 major and trace elements by XRF, B.C. Geological Survey Branch Analytical Lab, except for REE, Sc & Th by INAA, Bondar-Clegg (17,18,19 La by XRF).
Analysis 8, 26 major and trace elements by XRF British Columbia Geological Survey Branch Analytical Lab.

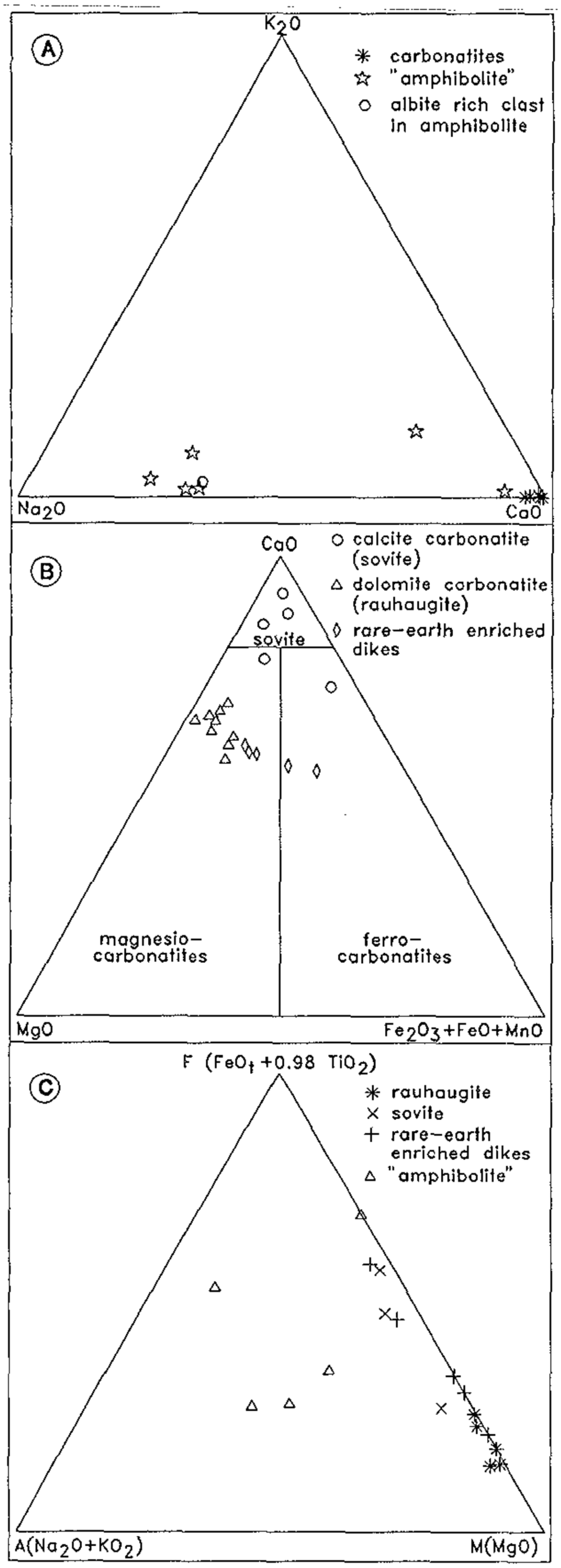


Figure 4. Major element ternary plots of carbonatites and "amphibolitic" margin. Aley; Plot 4b after Wooley, 1982.

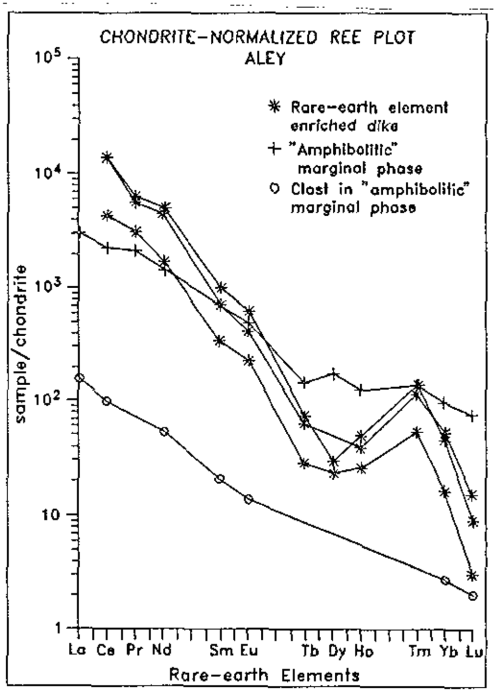


Figure 5. Chonodrite-normalized rare-earth element plots - Aley.

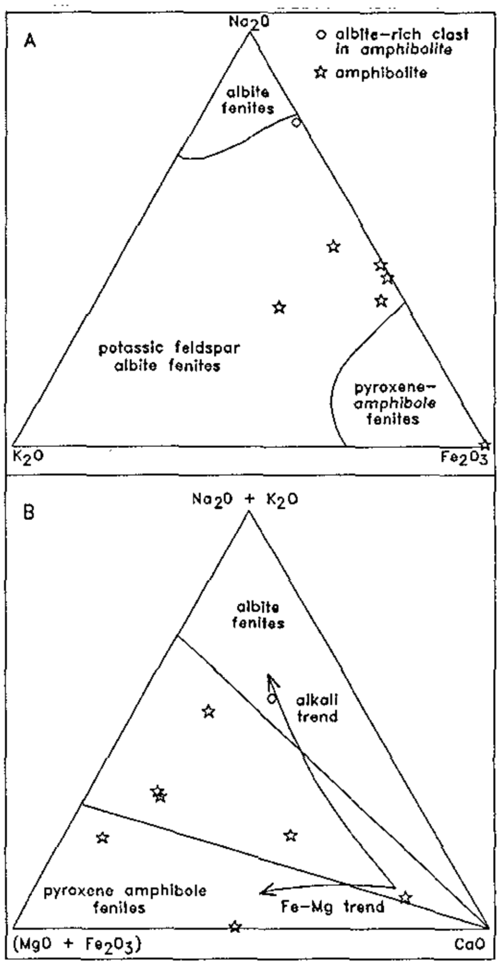


Figure 6. Ternary plots for fenites, Aley; Figure 6a after Höy, 88; Figure 6b after Le Bas, 1981.

from the rauhaugite core zone. Apatite, pyrite and magnetite are locally developed in the alteration zone. Silicification and development of green amphibole occurs immediately adjacent to the contact (10-40 cm). White mica and potassium feldspar are the only common metamorphic minerals observed in impure marles, marls and siltstones and the degree of alteration decreases outward from the complex. Trace element abundances (Nb, REE, Th, F) can be correlated with the degree of alteration, also decreasing outward.

RARE-EARTH-BEARING DIKES

Dikes or 'sweats' enriched in rare-earth elements (REE) occur throughout the complex but are most common in the outer alteration halo. The dikes weather a distinct, dark reddish brown (Plate 3), are generally intruded parallel to bedding and average 0.5 to 1.5 metres in thickness. Their primary component is ankerite. Accessory minerals include purple fluorite, quartz, pyrite, barite, bastnaesite $[(Ce,La)CO_3F]$ and other rare-earth carbonate minerals (K.R. Pride and U.K. Mäder, personal communications, 1986). Rare-earth carbonate minerals are fine grained, commonly intergrown and comprise 3 to 6% of the rock.

GEOCHEMISTRY

Carbonatites, both rauhaugites and sovites, are very low in silica, aluminum and alkalis, and high in phosphorus, up to 11.42% P_2O_5 (Table 1). Calcite carbonatites predominantly plot within the sovite field on a CaO-MgO-Fe_2O_3+FeO+MnO carbonatite diagram, dolomitic carbonatites within the magnesio-carbonatite field and rare-earth-enriched dikes span the magnesio- to ferrocarbonatite boundary (Figure 4b). All are enriched in the incompatible elements thorium, niobium, zirconium and light rare earths. Extensive zones within the rauhaugite core containing between two-thirds and three-quarters of a percent niobium have been defined, and local concentrations of over 2% Nb_2O_5 are present (K.R. Pride, personal communication, 1987). Barium, strontium and total rare-earth elements may reach major element concentrations of 7.74, 0.5 and approximately 2%, respectively (Table 1 and Appendix 1) in the rare-earth- bearing dikes. Cerium is the dominant rare-earth element present; lanthanum and neodymium are also abundant. Fluorine, manganese, barium and, to a lesser extent, iron are also enriched in the dikes relative to rauhaugites and sovites, while niobium and tantalum are depleted.

The 'amphibolitic' margin has variable major element concentrations (Table 1 and Figures 4 and 5) and trace element patterns similar to typical carbonatites, but with much lower concentrations. It is compositionally different from 'typical' pyroxene-amphibole fenites in that it contains significantly more sodium and potassium (Figure 6), which may be a result of its original alkaline igneous or syenitic composition.

GEOCHRONOLOGY

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.

WICHEEDA LAKE COMPLEX (PRINCE AND GEORGE CLAIMS, 93I/5; 93J/8, 9)

A series of carbonatite plugs, sills and dikes, associated with alkaline silicate rocks, are located on the Prince and George claims near Wicheeda Lake, approximately 80 kilometres northeast of Prince George (latitude 54°31'N, longitude 122°04'W; Figure 1). Access to the area is by helicopter. Elevations range from 820 to 1490 metres, and the area is largely forested. Outcrops are limited to ridge tops and some rock bluffs. The claims were staked in 1986 by Teck Explorations Limited when anomalous niobium values were detected in samples previously collected from a minor base metal showing.

The alkaline rocks intrude northwest-striking, steeply to subvertically dipping dolostones, limestones and argillaceous rocks of uncertain age. The Wicheeda Lake area straddles the boundary of two map sheets, mapped by different workers (Armstrong *et al.*, 1969; Taylor and Stott, 1979) and lithologic formations do not correlate across the map-sheet boundaries. On one map sheet (Armstrong *et al.*, 1969), strata which host the alkaline rocks are assigned to the Upper Cambrian Kechika Group, which is in thrust contact, to the southwest of the property, with Lower Cambrian clastic rocks of the Misinchinka Group. Taylor and Stott (1979) correlate strata hosting the carbonatites with the

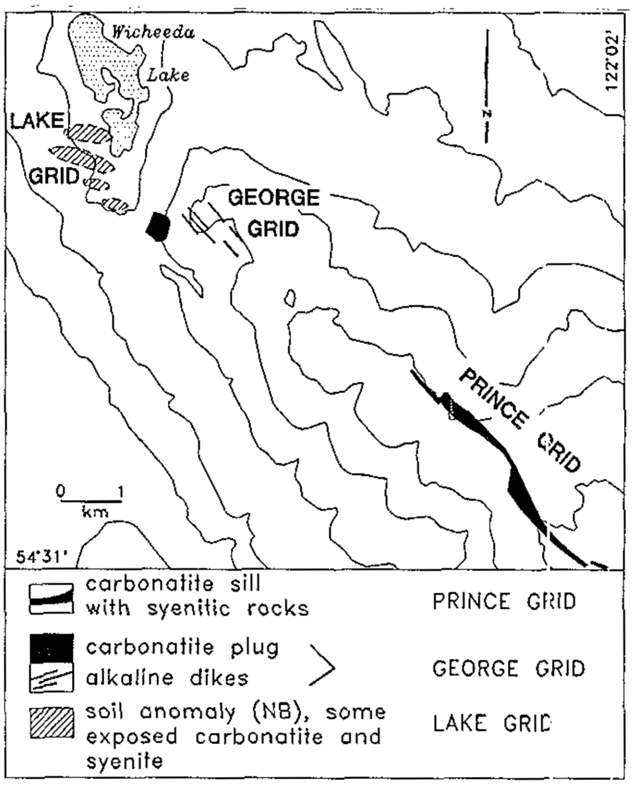


Figure 7. Location map of the intrusive bodies of the Prince and George groups of claims, Wicheeda Lake from Mäder and Greenwood, 1988.

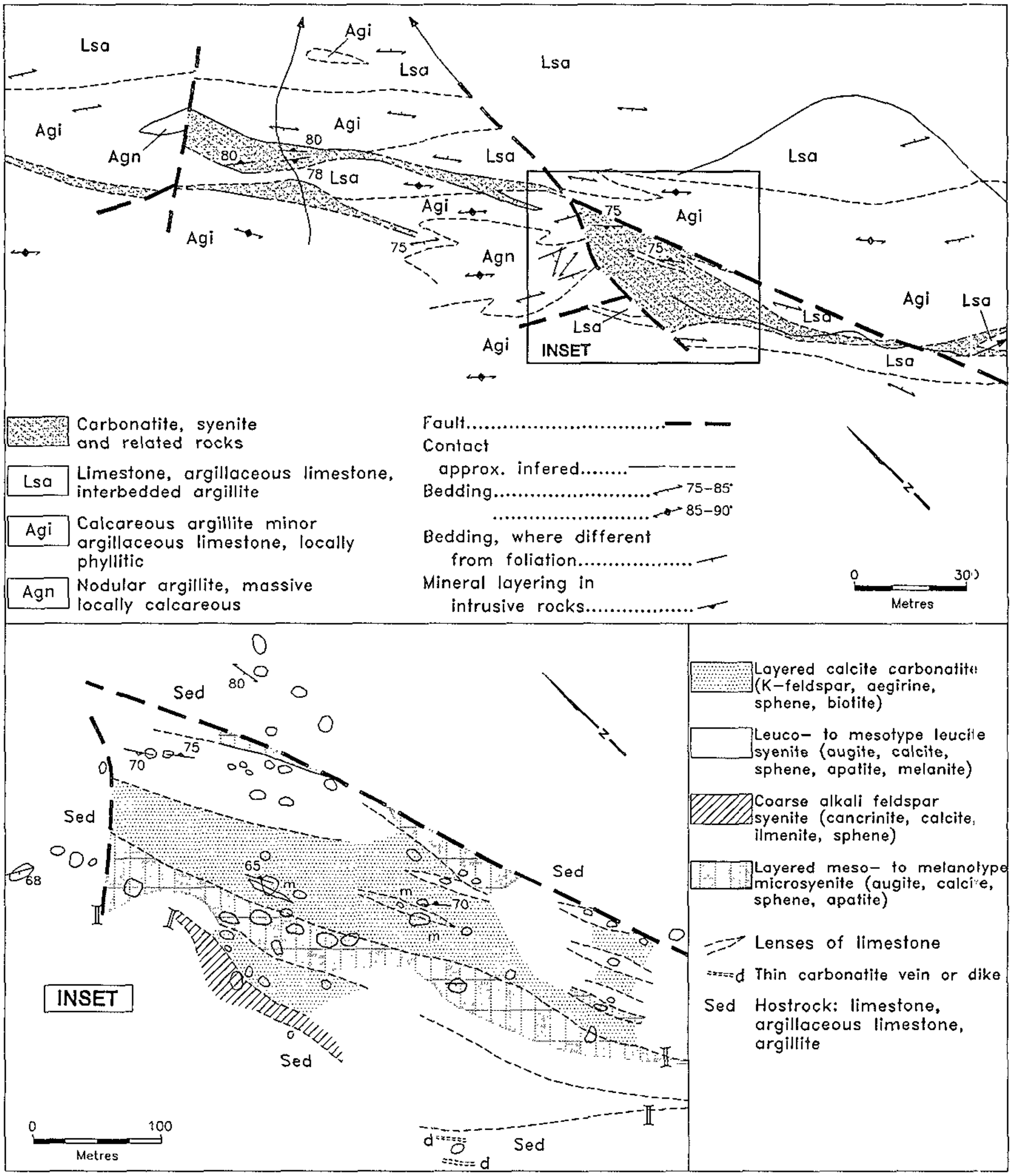


Figure 8. Geological map of the southwestern part of the Prince grid (enlargement) from Mäder and Greenwood, 1988.

Lower Ordovician Chushina and Middle Ordovician Skoki formations, overthrust by Precambrian Misinchinka Group metasedimentary rocks. The following descriptions of the complex are summarized from the work of Mäder and Greenwood (1988).

The carbonatite sills, plugs and dikes are distributed in a northwest-striking linear zone in excess of 8 kilometres long (Figure 7). All the intrusions show mineralogy typical of igneous alkaline rocks, but each stock has distinctive petrographic features. As a whole, the suite is characterized by the ubiquitous presence of ilmenite and sodic pyroxene. Carbonatites range from almost pure sovites to pyroxene-biotite-rich varieties to rare-earth-rich ferrocarbonatites. Silicate rocks include syenites and leucitites rich in albite and potassium feldspar. Most of the rocks are medium grained and often display mineral layering. In all cases, thermal and metasomatic effects on country rocks are apparently minimal.

CARBONATITES AND ASSOCIATED SYENITIC ROCKS

A carbonatite-syenite sill complex has been traced for nearly 3 kilometres along strike on the southeastern part of the property (Prince grid; Betmanis, 1987; Mäder and Greenwood, 1988). Approximately half way along its length the sill is cut by a northerly striking fault (Figure 8) and lithologies to the northwest of the fault differ from those to the southeast. Southeast of the fault, where the sill is the thickest, white, layered sovite intrudes coarse-grained leucosyenite, augite-leucite-syenite and layered, fine-grained augite-syenite. All rock types are rich in sphene. Northwest of the fault, medium to coarse-grained sovites which contain feldspars, aegirine, biotite, pyrite, apatite and pyrochlore are present. These rocks exhibit a pronounced mineral layering and are intercalated with syenites rich in albite and potassium feldspar and also contain aegirine and biotite. Contacts between carbonate and silicate rocks are locally either distinct or gradational. Locally, analyses of nearly 1% Nb_2O_5 were returned from samples taken from trenches in this area (Betmanis, 1987).

An oval carbonatite plug, approximately 250 metres in diameter, is exposed south-southeast of Wicheeda Lake (Figure 7) on the northwestern part of the property (George grid; Betmanis, 1987; Mäder and Greenwood, 1988). The intrusion is predominantly an ankeritic carbonatite, locally containing ankerite phenocrysts up to 5 centimetres long and pyrite cubes which reach 2 centimetres across. Potassium feldspar, ilmenite, monazite and rare-earth carbonate minerals are present as minor constituents. Along the southwestern margin of the plug, albite-rich rocks are intermixed with ilmenite-rich carbonatite. Some rare-earth mineralization is hosted by this carbonatite. Samples from one trench, 42 metres long, averaged 2.60% total rare-earth elements, including a shorter sample interval of over 4% total rare earths (Betmanis, 1988). Soils in the vicinity also contain high rare-earth concentrations, with one sample containing over 4% total rare earths (Betmanis, 1987). The majority of these values are concentrated in the light rare earths.

A third carbonatite body is poorly exposed west of the southern end of Wicheeda Lake (Lake grid; Betmanis, 1987; Mäder and Greenwood, 1988). It consists of sovite with accessory apatite, feldspar, aegirine and, locally, coarse (0.1 to 0.8 millimetre) euhedral pyrochlore crystals. Some samples collected from this area contained slightly in excess of 1% total rare earths (Betmanis, 1988).

ALKALINE DIKES

Three varieties of alkaline dikes are present peripheral to the ankeritic carbonatite plug south-southeast of Wicheeda Lake. They are quite thin (50-150 cm) and slightly discordant to bedding and schistosity. The first type is a potassium feldspar porphyry with a fine-grained groundmass containing albite, biotite and accessory calcite, ilmenite and zircon. The second type comprises abundant blue sodalite phenocrysts in a fine-grained groundmass of albite and sodalite with accessory calcite, ilmenite, sphalerite and zircon. Rare xenoliths of microsyenite are also present. A third type of dike, which cuts the sodalite-rich dikes, consists of an intermediate feldspar augite porphyry with an aphanitic groundmass.

GEOCHEMISTRY

Whole-rock geochemical data are not available for samples from the Wicheeda Lake area. Limited data indicate that the intrusive rocks are enriched in elements typical of alkaline rocks and carbonatite complexes (*e.g.* Nb, Ba, Sr,

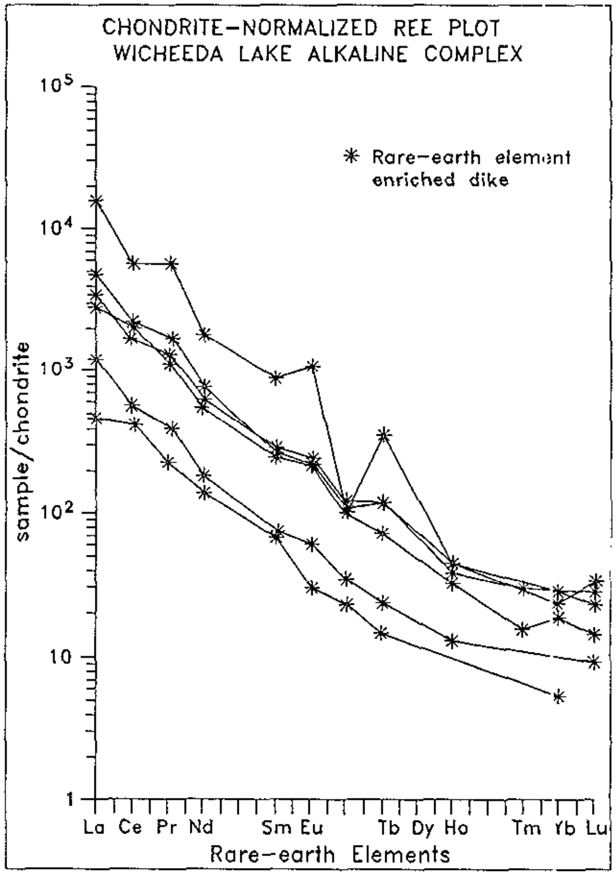


Figure 9. Chondrite normalized REE plot - Wicheeda Lake alkaline complex.

REE). Rare-earth element analyses (Betmanis, 1987; summarized in Appendix 1) indicate that these rocks are enriched in light rare earths; chondrite-normalized plots (Figure 9) display patterns typical of other alkaline intrusions in British Columbia.

GEOCHRONOLOGY

No radiometric date has been obtained on the Wicheeda Lake rocks. Due to lack of outcrop, unambiguous field relationships are not exposed. The intrusive rocks display well-developed fabrics in thin section and outcrop that are concordant with the regional schistosity. They are, therefore, interpreted as having been intruded prior to the Columbian orogeny and, together with their host strata, were subsequently deformed during orogenesis (Mäder and Greenwood, 1988).

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″N, longitude 121°35′30″E). 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; access to the ridge crest is on foot or by helicopter.

The syenite intrudes Silurian Nonda Formation volcaniclastic rocks (Figure 10), which are predominantly alkaline mafic tuffs, locally containing limestone clasts. Regionally, the hostrocks have attained lower greenschist facies metamorphism; however, biotite is present in the volcanics immediately adjacent to the sodalite syenite. The syenite is massive, medium grained and white weathering. Three apparently separate bodies crop out; an oval stock, 500 metres by 1000 metres in area, is flanked by two smaller sill-like bodies (Figure 10). The stock contains randomly oriented feldspar laths (1-5 centimetres long) with interstitial mafic silicate, feldspathoid and opaque minerals. The sills have feldspar phenocrysts up to 4 centimetres long, in a groundmass of felted feldspar laths. The main intrusions are roughly parallel to bedding in the hostrocks; however, crosscutting dikelets (Plate 4) were observed. Intrusion ap-

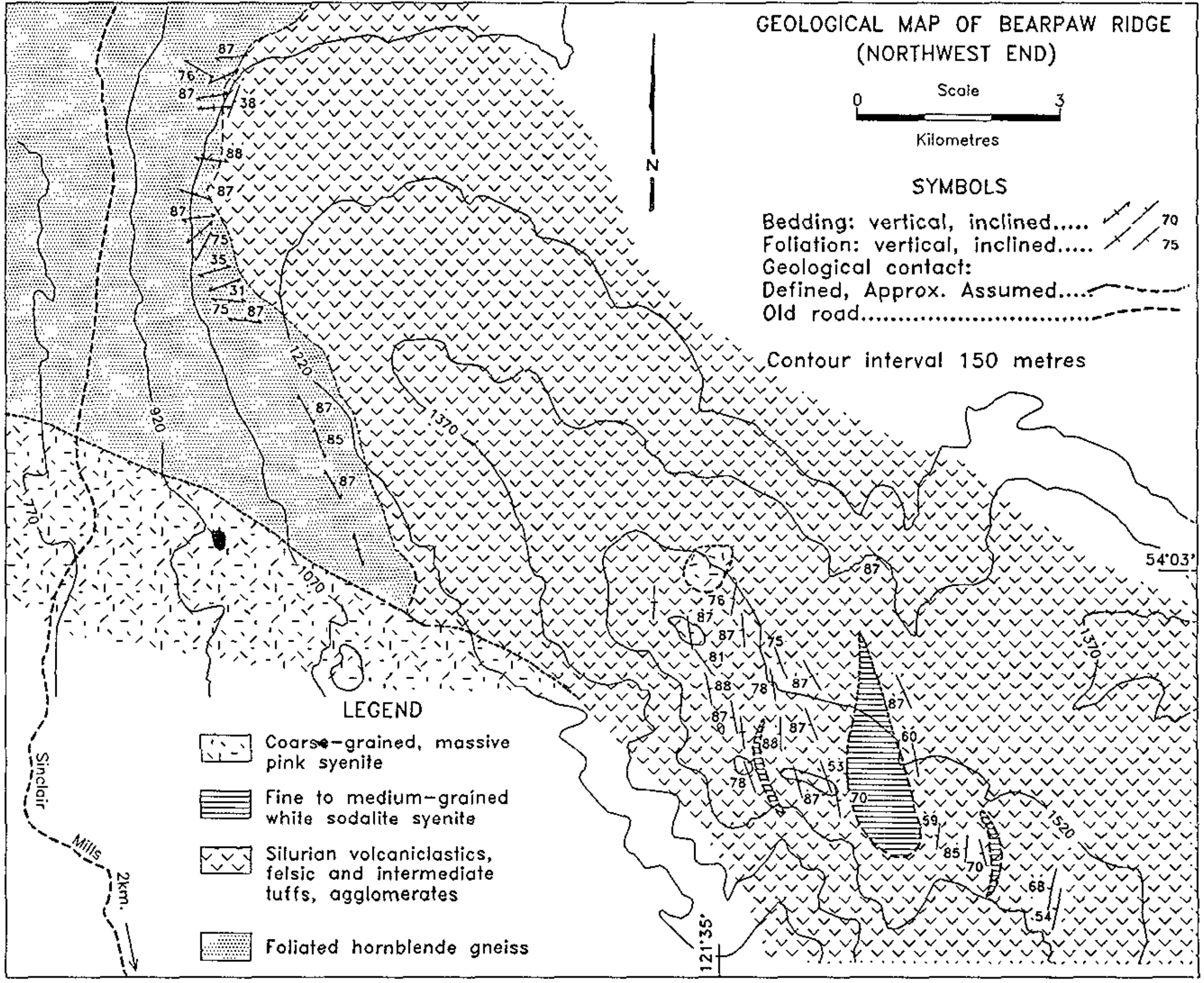


Figure 10. Geological map of Bearpaw Ridge (from Pell, 1985).

Plate 4. Boulder containing syenite dike (white) crosscutting banded volcaniclastic rocks. Banding parallel to pen, Bearpaw Ridge.

parently 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 folded and foliated orthogneiss of unknown age crops out on the western lower slopes of Bearpaw Ridge (Figure 10). 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.

A second body of syenite, also previously unmapped, crops out on the southwestern end of the ridge, intruding both the dioritic gneiss and the volcaniclastics (Figure 10). 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% of the rock. This syenite appears to be postorogenic and unrelated to the sodalite syenite on the ridge crest. It is, however, petrographically similar to Cretaceous syenites described elsewhere in the Cordillera.

SODALITE SYENITE

The white-weathering sodalite and related feldspathoid-poor syenites generally comprise 80 to 90% 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%), muscovite

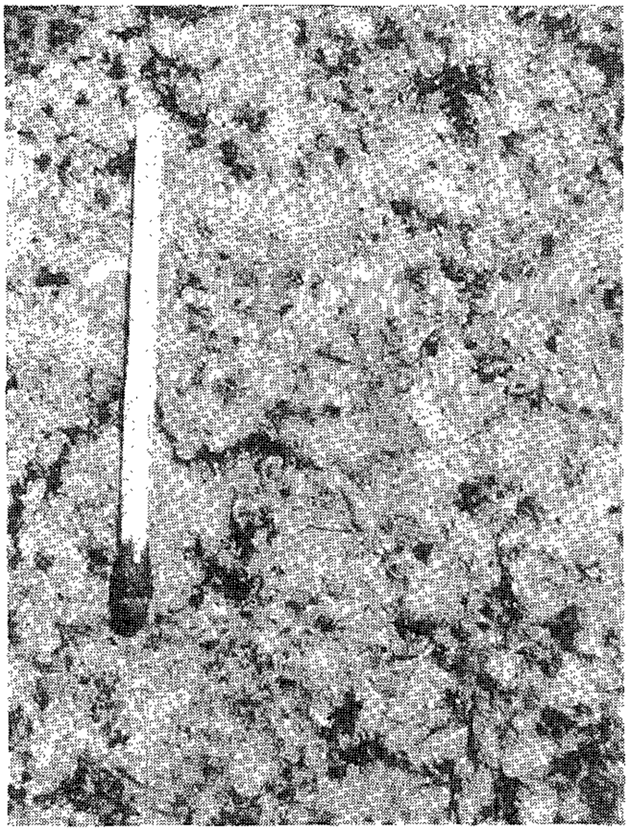


Plate 5. White weathering syenite with disseminated sodalite, Bearpaw Ridge.

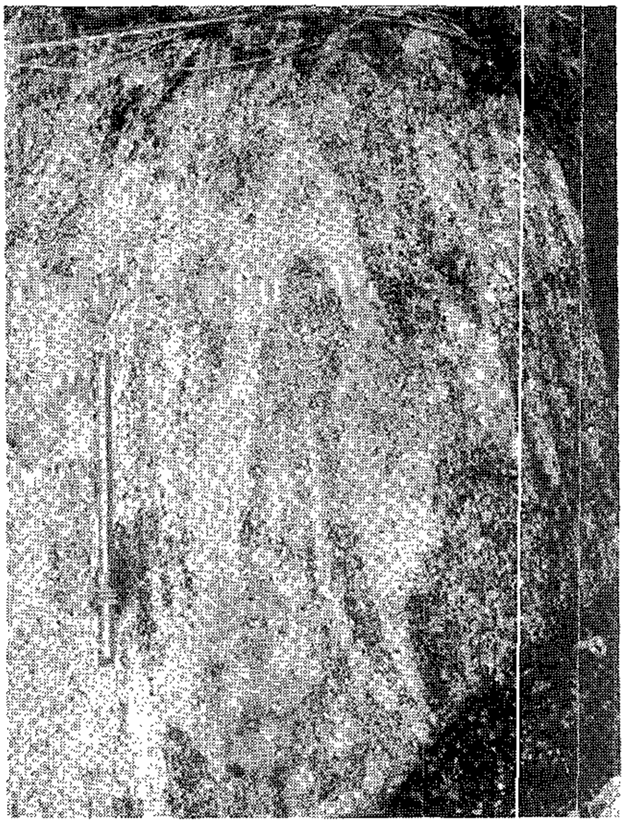


Plate 6. Folded and foliated dioritic orthogneiss, present on the lower slopes of Bearpaw Ridge.

(generally only a few percent) and traces of chlorite. In one sample, alteration patches, consisting of fine-grained muscovite and epidote, comprise 30% 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% feldspathoid minerals, generally sodalite and cancrinite or cancrinite alone (Plate 5). No nepheline was noted. Aegirine (strongly pleochroic from marsh to blue-green) and biotite are also locally present in minor amounts. Trace minerals, identified by scanning electron microscopy, include magnetite (titanium free), allanite, zircon, monazite, apatite, pyrochlore, thorite ($ThSiO_4$) and cheralite $[(Ca,Ce,Th)(P,Si)O_4]$.

NONDA FORMATION VOLCANICLASTIC ROCKS

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 groundmass of opaque oxides, plagioclase and clinopyroxene microphenocrysts and chlorite. Some vesicles are present.

ORTHOGNEISS

Folded and foliated dioritic orthogneiss (Plate 6) crops out on the lower slopes of the western end of Bearpaw Ridge. It varies from a banded gneiss containing approximately 70% calcic plagioclase (bytownite) with 5% olivine, 15% augite, 5 to 10% magnetite-ilmenite and a trace of apatite, to a mafic gneiss with 10% calcic plagioclase, 30% olivine, 35% augite, 15 to 20% magnetite-ilmenite and 2 to 3% 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% of the more mafic gneiss. In some localities, the gneiss is remarkably

TABLE 2
CHEMICAL ANALYSES, BEARPAW RIDGE

	Syenites (alkaline)						Nonda Formation volcanics		Other rocks		
wt %	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_3T	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	7	-	2	< 24	219	28	1	1	3
Cr	62	67	50	-	30	44	475	116	51	9	179
Co	1.4	1.9	4	-	5	1.6	56	17	2	29	5
Sr	50	205	1751	-	1023	290	288	342	55	1063	344
Ba	50	170	722	-	1079	486	445	545	-	785	678
Zr	613	756	1831	-	717	429	133	103	134	232	110
Nb	-	-	147	-	167	-	44	11	45	16	7
Y	-	-	58	-	35	21	25	14	20	24	10
La	95	108	155	-	122	78	11	34	-	26	61
Ce	135	156	222	-	174	111	38	71	-	72	96
Nd	28	32	-	-	-	22	-	-	-	-	-
Yb	2.7	2.9	-	-	-	1.9	-	-	-	-	-
Sc	0.3	0.2	3.8	-	2.7	0.3	33	23	-	1.4	21
Ta	8.5	10	17	-	8	7.5	4	< 2	1	< 2	1
Th	36.3	38.3	56	-	39	29.4	11	15	17	1	15

1 - 84211A - sodalite syenite(?); 2 - B4211 - grey to pink granular syenite;
3 - B4203A -white porphyritic syenite dike; 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 - postorogenic aegirine syenite; 10 - B4170C - diroite gneiss; 11 - B4163 - granite.
Major elements analyzed by ICAP, alkaline fusion. Trace elements analyzed by XRF;
1, 2 & 6, traces by INAA, Bondar-Clegg.

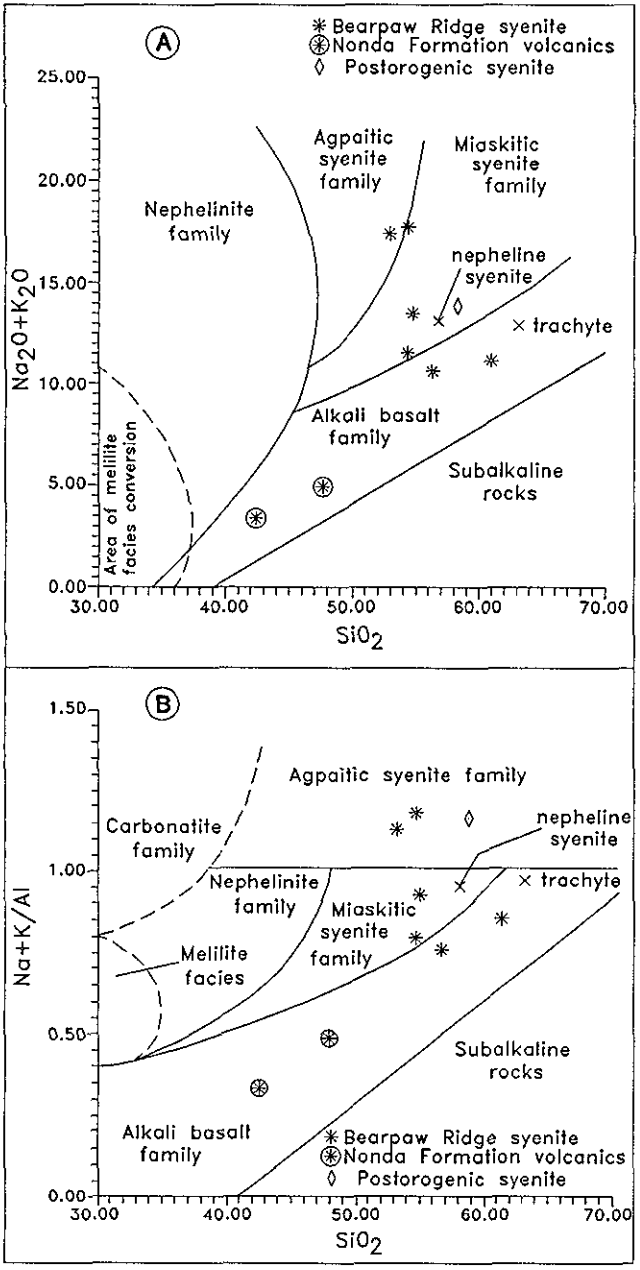


Figure 11. (A) Alkali vs. silica diagram Bearpaw Ridge; (B) Agpaitic index plot - Bearpaw Ridge syenites.

well preserved; in others it is strongly altered, consisting of chlorite, epidote, plagioclase, sericite and prehnite.

POSTOROGENIC SYENITE

A second type of syenite outcrops on the southwest end of Bearpaw Ridge. It is massive, coarse grained and pink weathering with randomly oriented feldspar laths up to 1.5 centimetres long. It comprises 30 to 35% potassic feldspar, 20 to 25% plagioclase and 10 to 20% microperthite with up to 10% clinopyroxene (aegirine-augite to aegirine), 5% hornblende, 5 to 7% 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 microscopy, include ilmenite, pyrite, barite, monazite, sphalerite and arsenopyrite.

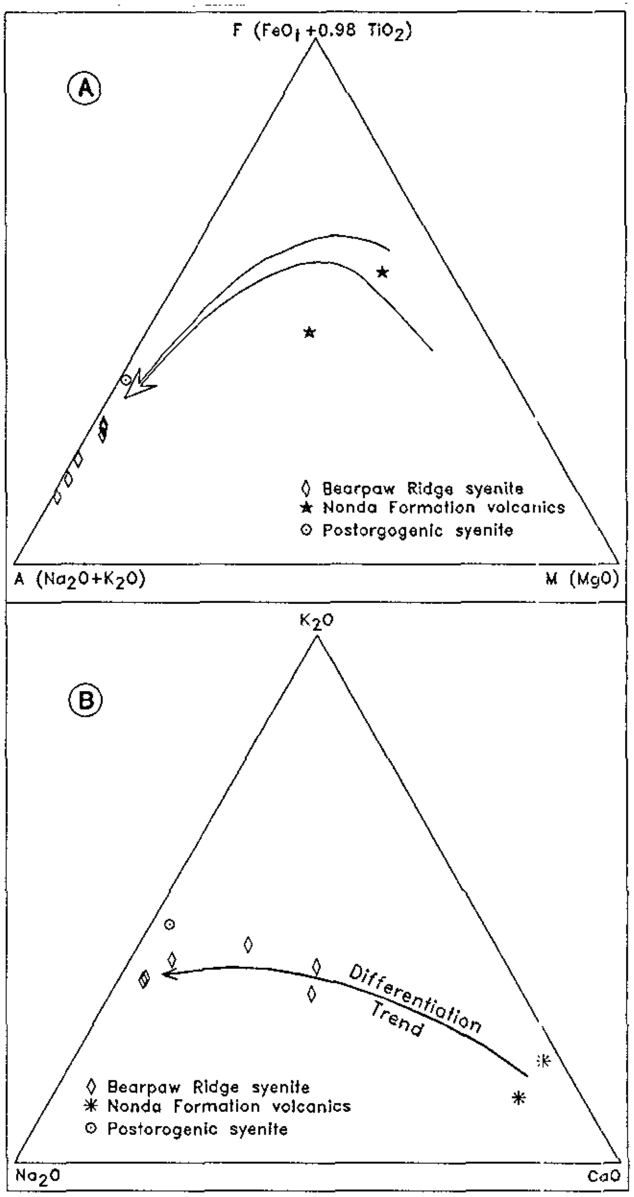


Figure 12. Major element ternary plots, Bearpaw Ridge

GEOCHEMISTRY

The preorogenic feldspathoidal syenites on the crest of Bearpaw Ridge are variable in major element content (Table 2), and alkali-silica and agpaitic index plots (Figure 11) indicate they span the range from saturated syenites, through miaskitic syenites to agpaitic syenites, with an average compositional range in the miaskitic syenite field. Compositional differences with the postorogenic syenite which crops out on the lower slopes of Bearpaw Ridge are slight; the feldspathoidal syenites are higher in Al_2O_3, CaO, Zr, Nb, Ta and Th and, on average, lower in SiO_2, Fe_2O_3, TiO_2 and P_2O_5 than the postorogenic syenite (Table 2; Figures 11 and 12). Other major elements show no systematic variation. On alkali-silica and agpaitic index plots (Figure 11) the postorogenic syenite falls within the agpaitic syenite field, however it would be erroneous to classify this rock type as such based on a single analysis.

The Nonda Formation volcanic and volcaniclastic rocks have alkali/silica ratios which allow them to be classified as alkali basalts (Figure 11). Chemical trends suggest that they may be genetically related to the syenites on the ridge crest (Figure 12).

GEOCHRONOLOGY

Taylor and Stott (1979) suggested that the sodalite syenite is a subvolcanic intrusion, related to the formation of the Nonda volcaniclastics. If so, it would be approximately Silurian in age. The chemistry of these rocks suggests that this may be a viable interpretation; however, this alone is not sufficient to establish this relationship and therefore the age of the intrusion. No radiometric dates are available and, until the intrusion has been dated, its age is uncertain.

ICE RIVER COMPLEX (82N/1)

The Ice River complex is an alkaline ultramafic intrusion located 23 kilometres south of Field, at latitude 51°10′N, longitude 116°25′W. It is an arcuate mass, some 18 kilometres long, with a total exposure of 29 square kilometres, most of which lies within Kootenay and Yoho National Parks (Figure 13). Access is difficult due to steep mountainous topography, lack of roads and regulations imposed by Parks Canada.

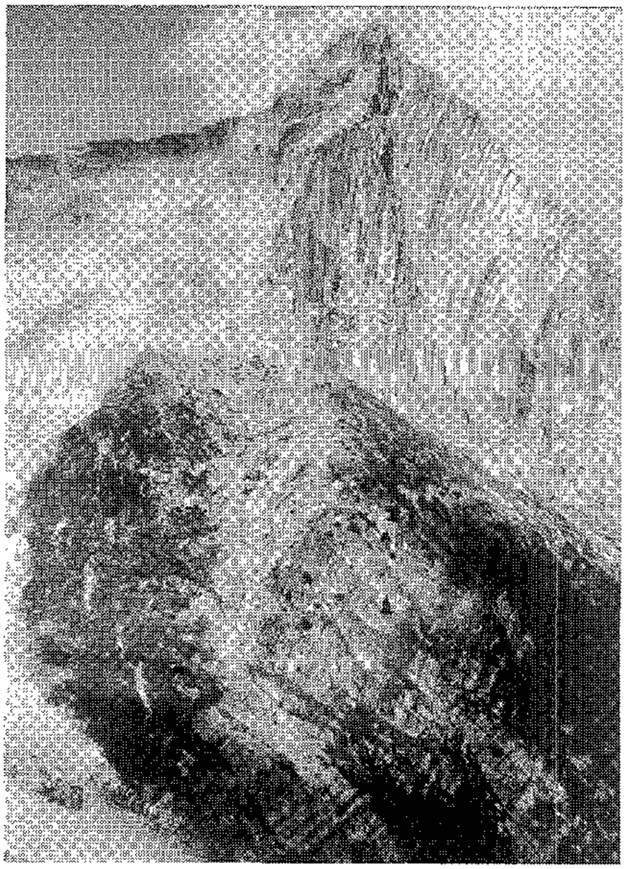


Plate 7. Contact between syenites (light grey massive) of the Ice River complex and steeply dipping Paleozoic carbonate rocks, Butress Peak. The contact here is clearly intrusive.

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); much of the following description is summarized from Currie's Memoir 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 and is also drawn upon extensively. In view of the many previous studies of the Ice River complex, only a brief description will be given here.

Two distinct suites are present within the complex: an early, rhythmically layered, feldspar-free intrusion of jacupirangite, ijolite and urtite, cored by a carbonatite plug and crosscut by carbonatite dikes rich in mafic silicates and oxides; and a later zoned and crosscutting syenitic series, associated with a zeolite and feldspar-bearing carbonatite. The alkaline rocks intruded Cambrian and Ordovician shales and carbonates of the Chancellor, Ottertail and McKay formations (Plate 7; Figure 13). Contact metamorphism of the enclosing sedimentary rocks resulted in the formation of hornfels and skarns. Some limited soda metasomatism also occurred. The complex and its hostrocks were deformed and subjected to low-grade regional metamorphism during the Columbian orogeny.

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, and characterized by a repetitive sequence of graded layers, 10 to 200 metres thick, with nepheline increasing in abundance toward the top of each layer. 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 products of nepheline. In many cases, the jacupirangite has been fractured and intruded by later, more felsic phases (Plate 8).

Ijolites are the most common component of the layered series. They vary from a slightly more mafic variety (melaijolite) 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 and

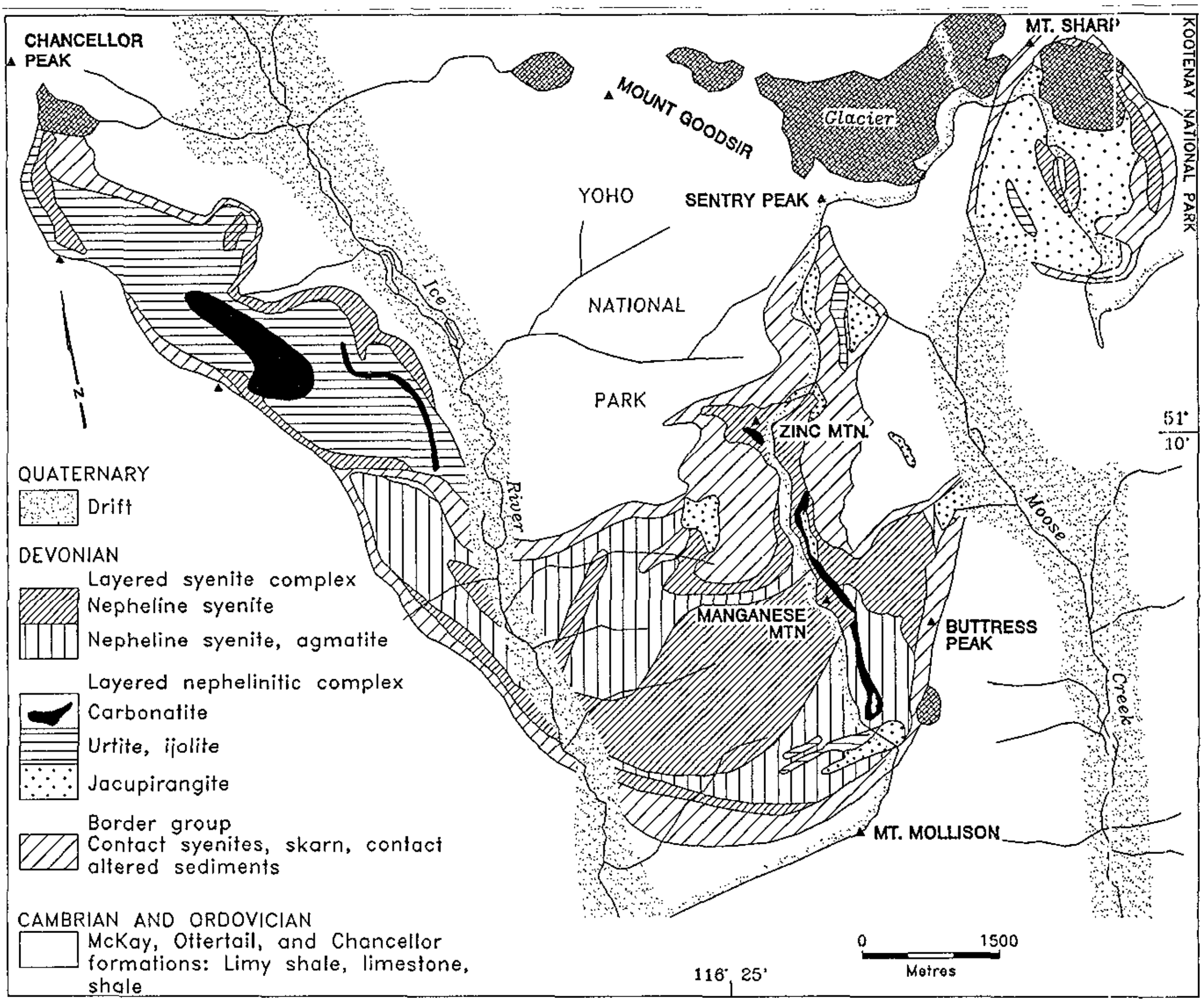


Figure 13. Geology of the Ice River complex (from Currie, 1976a).

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, there is a strong alignment and segregation of minerals. 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 minor amounts to comprising approximately 50% 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% of the rock. Sodalite is present in quantities from trace amounts to 20%, and is generally more abundant in the leucocratic syenites. It occurs both disseminated throughout the syenite and concentrated in veins cutting the syenites. Accessory minerals include sphene (no perovskite), apatite, cancrinite and minor opaques. Zeolite-rich syenites are present locally; fluorite and pyrochlore have also been reported (Peterson, 1983).

CARBONATITES

Carbonatites crop out in a number of localities in the Ice River complex and display considerable lithologic variation. Complex relationships with other alkaline rocks pre-

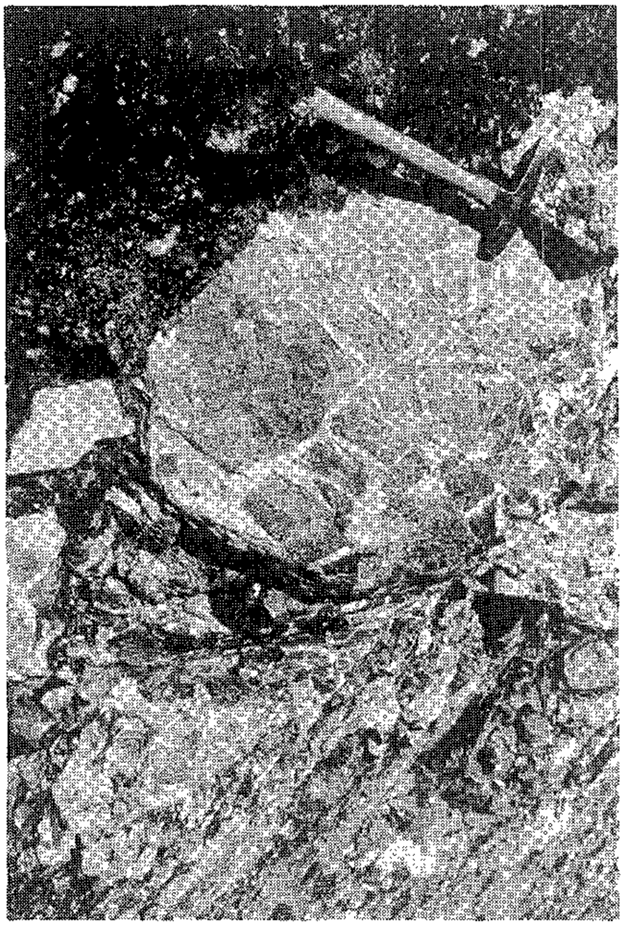


Plate 8. Jacupirangite (dark grey massive) of the Ice River complex and steely dipping carbonate rocks, Butress Peak. The contact here is clearly intrusive.

Plate 9. White-weathering, coarse-grained carbonatite dike, Mount Sharp area, Ice River complex. Coarse-grained dark minerals are books of biotite. Sugary appearance of white matrix produced by coarse apatite grains mixed in with the calcite.

clude 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 13) as layered lenticular masses and as smaller dikes. 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. The black carbonatites commonly occur as dikes 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. The red-weathering carbonatite is similar to the black, but it contains fewer non-carbonate minerals (less than 10%); both siderite and zeolites are absent, serpentine is distinctly yellow-brown rather than grass-green, and pyrochlore and xenotime are present. The buff carbonatite is generally coarse grained and composed of calcite, aegirine, apatite, pyrite and trace pyrochlore.

White-weathering carbonatite dikes (Plate 9) intrude the ultramafics exposed on Sharp Mountain (Figure 13). They consist predominantly of calcite and fluorapatite with aegirine (occasionally containing hedenbergitic cores), phlogopite, pyrite and ilmenite/magnetite. Some samples contain feldspar-rich xenoliths (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, 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 dikes occur within the Ice River complex and contiguous country rocks. They contain phenocrysts of strongly pleochroic orange-

TABLE 3
CHEMICAL COMPOSITIONS OF ICE RIVER COMPLEX ROCKS

wt %	Jacurpirangite			Mela-ijolite			Melanite Ijolote		Ijolite				Urtite		Carbonatite								
																		A	A	A	B	B	B
Si02	34.2	37.9	33.6	41.6	42	40	35.9	39	40.2	43.7	43.9	40.3	43.5	44.2	1.2	7.7	1.6	9.92	12.38	9.65	20.24	22.93	16.24
Ti02	5.62	5.64	7.14	2.21	3.22	2.42	4.4	2.04	3.48	1.2	2.44	3.58	0.19	0.14	0.02	0.09	0.05	0.07	0.38	0.07	0.73	0.77	2.21
Al203	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	2.84	1.62	2.76	4.65	6.14	4.51
Fe203	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	0.2	1.62	5.9	0.53	5.37	8.7	6.89
Fe0	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	-	-	-	-	-	-
Mn0	0.12	0.06	0.18	0.2	0.2	0.18	0.17	0.28	0.2	0.15	0.2	0.12	0.5	0.51	1.75	0.31	0.4	0.13	0.14	0.07	0.98	1.1	1.15
Mg0	10.6	8.4	9.8	11.6	11.6	10.4	4.1	4.7	5.6	0.27	5.1	2.7	0.4	0.7	12.7	0.5	0.2	0.44	2.01	0.4	8.85	4.27	2.25
Ca0	21.8	27.2	21.4	11.7	12.3	12.3	11.7	9.5	10.1	5.4	6.6	11	9.7	6.4	30.6	45.55	51.86	44.62	39.73	47.12	27.58	19.13	27.8
Na20	0.7	0.8	1.08	3.3	3.5	4	8.7	7.7	7.4	9.9	7.4	7.6	10.4	10.6	0.13	0.3	0.2	1.79	1.44	1.12	nd	2.25	1.91
K20	0.3	0.12	0.1	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	0.03	0.36	0.32	2.74	1.45	0.4
H20	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	-	-	-	-	-	-
C02	nil	0.02	0.04	0.3	0.1	1.9	1	0.2	0.5	0.8	0.2	0.1	0.3	0.7	43.6	36.9	43.46	29.37	23.43	35.03	23.76	25.27	27.87
P205	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	0.1	7.81	8.23	2.06	0	0.2	0.92
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	98.64	95.62	99.13	94.9	92.21	92.15
ppm																							
Ni	110	nd	nd	110	90	190	<10	<10	nd	110	130	nd	<10	<10	nd	<10	nd	9	40	<2	49	61	40
Cr	nd	nd	nd	230	670	550	nd	nd	10	150	160	<10	nd	nd	11	nd	13	3	10	<20	65	125	135
Co	66	26	35	13	56	46	17	35	12	21	24	18	nd	nd	nd	nd	nd	10	34	8	43	28	16
Sr	300	300	320	71	1100	840	1300	1300	850	1600	2700	840	620	1400	3600	2600	2500	13763	13628	12768	3954	11610	7907
Ba	300	16	140	320	810	1300	320	400	470	910	1300	330	830	2000	1100	890	360	528	392	221	21396	21511	24874
Zr	190	470	660	220	300	210	220	210	260	340	470	300	30	260	nd	340	nd	248	415	587	35	60	93
Nb	62	370	240	150	230	170	250	540	350	210	220	270	nd	170	71	10	620	<5	<5	<5	224	150	514
Y	22	68	45	27	17	25	22	44	41	26	32	36	<20	<20	53	81	<20	145	143	43	159	125	199
La	81	450	86	50	98	110	68	580	430	50	140	96	nd	60	650	700	260	535	930	489	641	418	350
Ce	nd	650	nd	nd	nd	nd	nd	930	1000	nd	nd	nd	nd	nd	1000	880	<500	878	1562	704	1530	852	639
Nd	nd	1100	830	nd	nd	nd	nd	730	730	nd	nd	nd	nd	nd	820	1600	nd	-	-	-	-	-	-
Yb	4	5.1	4.7	<4	<4	<4	<40	<40	<4	<4	<4	<4	<40	<40	<4	<4	<4	-	-	-	-	-	-
Sc	52	26	39	nd	nd	nd	-	-	-	-	-	-	nd	nd	-	-	-	39	36	41	26	26	32
Ta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<2	<2	<2	6	14	13
Th	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	79	81	<6	511	703	510

wt %	Lamprophyre				Contact syenite and breccia					Melanocratic syenite					Leucocratic syenite			Sodalite syenite			Zeolite & syenite
																		(1)	(2)	(3)	
Si02	40.6	38.2	38.9	37.3	62	56.2	58	62.1	46.7	51.9	41.6	44.7	44.4	45.3	58.6	53.9	52	54.6	54.4	54.62	50
Ti02	2.29	4.1	4.5	4.3	0.63	0.41	0.19	0.28	1.93	1.14	0	2.77	1.04	1.68	0.81	0.11	0.7	0.12	0.2	0.04	0.63
Al203	13.4	15.6	16.3	16.4	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
Fe203	2.7	4.1	5.6	4.1	3.3	1	2	1.1	1	1.2	2.1	1.2	2.6	2.1	1.3	0.8	0.6	3.1	2	0.46	6.6
Fe0	7.1	4.6	5.1	4.3	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	0.4	0.9	0.32	1.4
Mn0	0.16	0.22	0.22	0.2	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
Mg0	11.6	6.1	4.2	4.5	0.2	2	1.6	2	2.8	1	5.1	1.4	0.6	1	0.5	0.1	0.4	0.1	0.8	0.05	2.4
Ca0	13.8	16.3	14.4	16.7	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
Na20	2.8	5.1	5.8	5.9	7.8	5.7	6	9.9	7.6	7.1	4.7	9	6.8	8.3	5.7	7.8	7.99	11.5	10.7	10.12	8.4
K20	2.1	2.3	2.3	2.3	3.2	5.4	6.3	0.4	5	6.3	3.6	4.4	2.1	4.1	7.8	8.6	6.9	5.3	6.3	7.51	5.2
H20	1.6	1.4	1.2	1.6	1.3	0.9	1.9	0.9	0.6	0.7	0.8	0.9	5.4	0.9	0.9	1	0.7	0.8	0.8	0.76	3.4
C02	0.9	1.3	1.2	1.4	0	0.2	0	0.1	0.03	0	0	0.05	0.2	0.2	0.9	0.1	0.1	0.7	0.2	0.87	2.3
P205	0.74	0.96	0.91	0.47	0.05	0.28	0.02	0.03	0.47	0.09	0.77	0.19	0.31	0.22	0.09	0	0.08	0.02	0.01	0.03	0.06
Total	99.8	100.2	100.6	99.7	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	99.8	101.12	99.6
ppm																					
Ni	150	220	100	360	nd	nd	nd	<10	24	<10	36	nd	nd	<10	nd	21	nd	nd	nd	-	nd
Cr	560	440	600	280	nd	nd	nd	16	16	<10	17	<10	nd	nd	nd	nd	<10	<10	nd	-	nd
Co	45	nd	28	56	nd	nd	nd	nd	40	nd	31	nd	nd	nd	nd	nd	nd	nd	nd	-	nd
Sr	960	920	1000	800	88	2900	630	2900	1700	1200	990	2500	2000	1800	770	1100	2600	380	260	-	570
Ba	490	280	160	120	820	1800	570	2600	1600	1700	1000	3700	2600	3400	1400	350	2500	280	130	-	350
Zr	180	120	nd	80	240	450	150	450	370	280	310	300	390	270	190	690	160	330	410	-	1000
Nb	110	nd	50	100	130	200	110	200	310	270	180	510	1400	240	140	200	140	140	580	-	980
Y	22	33	11	44	nd	nd	nd	nd	42	51	35	47	94	28	<20	61	nd	nd	nd	-	300
La	59	40	19	85	190	150	50	150	170	55	73	94	1500	110	99	93	nd	nd	210	-	180
Ce	nd	22	6	58	<50	nd	nd	nd	nd	nd	nd	nd	1700	nd	nd	nd	nd	nd	290	-	nd
Nd	nd	nd	nd	6	<20	nd	nd	nd	nd	nd	nd	nd	740	nd	nd	nd	nd	nd	160	-	10
Yb	<40	<40	<40	<40	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	4	5.7	<4	-	-	-	<4
Sc	34	27	46	62	nd	nd	nd	nd	120	nd	17	nd	14	nd	nd	nd	nd	-	-	-	-
Ta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Th	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

(1) includes Cl - 1.1%;(2) includes Cl - 1.2%; (3) includes Cl - 2.08%; SO3 - 1.48% (Campbell, 1961).
A, B XRF analysis, this study; A - carbonatite dikes from the ultramafic suite, Sharp Mountain;
B - carbonatites from the Buttress Peak, Mount Mollison area, extremely biotite rich.
All other analyses from Currie, 1976a.

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. Field relationships indicate that the dikes were emplaced late in history of the complex.

GEOCHEMISTRY

Rocks of the layered ultramafic complex belong to the nephelinite family and plot predominantly within the nephelinite fields on alkali-silica and agpaitic index diagrams (Figure 14). They form a cogenetic suite and exhibit systematic major element variation with SiO_2, Na_2O and K_2O increasing and CaO, TiO_2, Fe_2O_3 and FeO decreasing with decreasing colour index (that is, from jacupirangite to urtite, Table 3; Figure 15). Rocks of the ultramafic suite are generally lower in SiO_2 and higher in CaO and TiO_2 than those of the syenitic series (Table 3).

Syenites of the Ice River complex range from nephelinitic (melanocratic varieties) to agpaitic (leucocratic and feldspathoidal varieties) in composition (Figure 16). They exhibit systematic major element variation with decreasing CaO, MgO and total iron, and increasing alkalis with decreasing colour index (from melanocratic to leucocratic and feldspathoidal varieties, Figure 17).

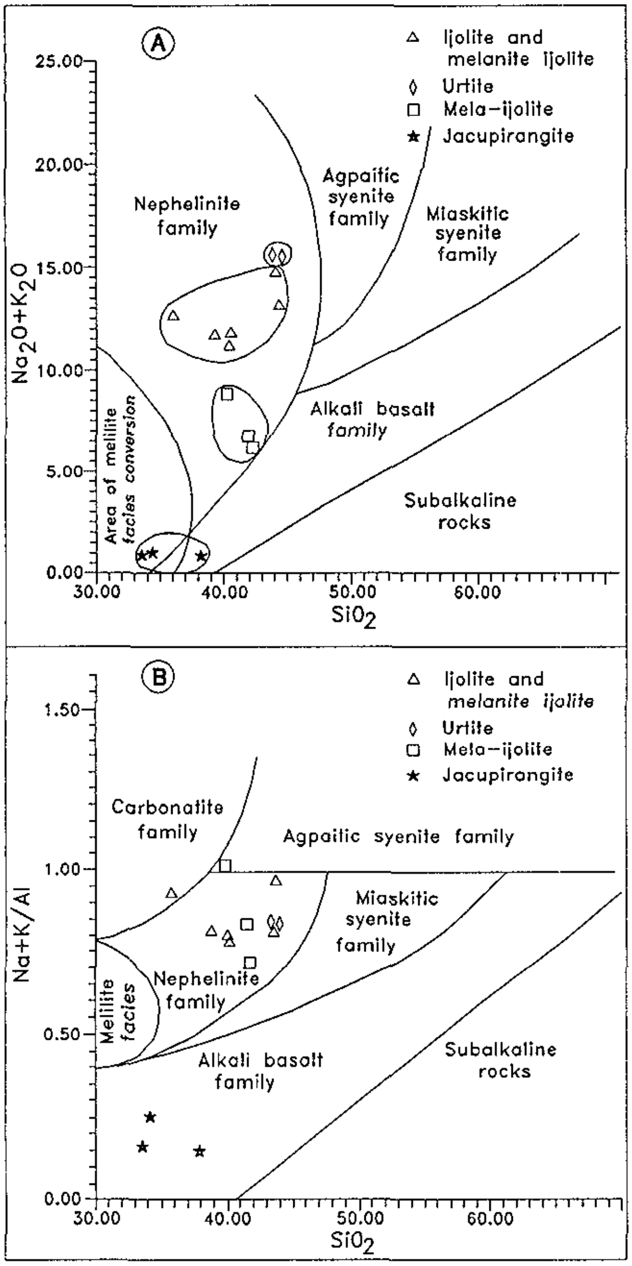


Figure 14. Alkali-silica and agpaitic index plots, Ice River ultramafic suite.

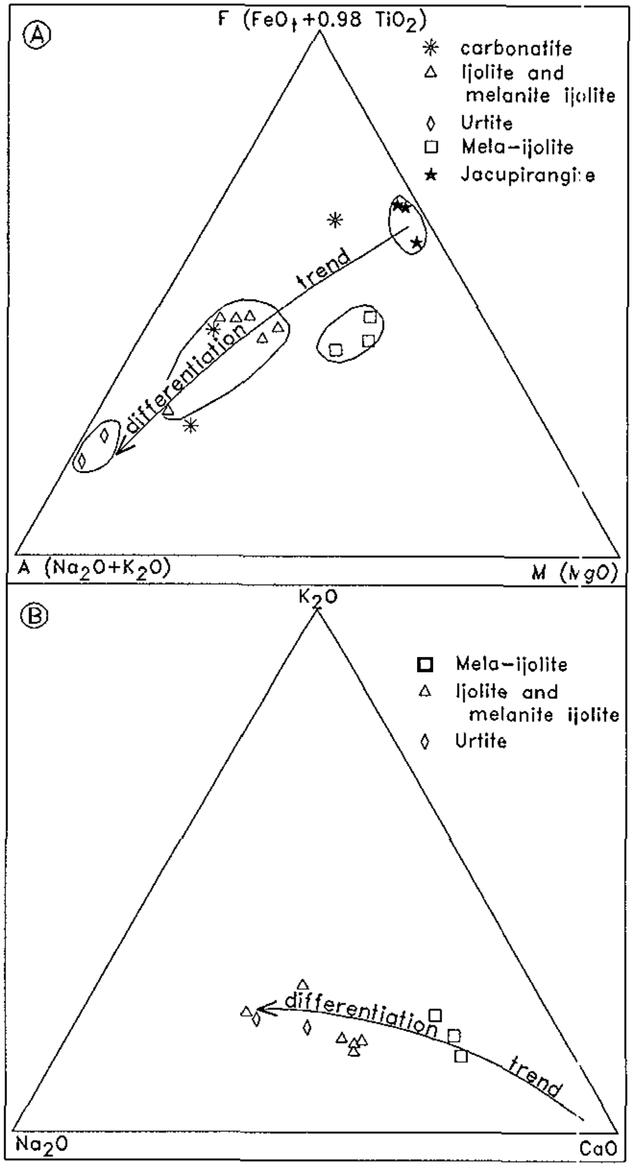


Figure 15. Ternary major element plots, Ice River ultramafic suite.

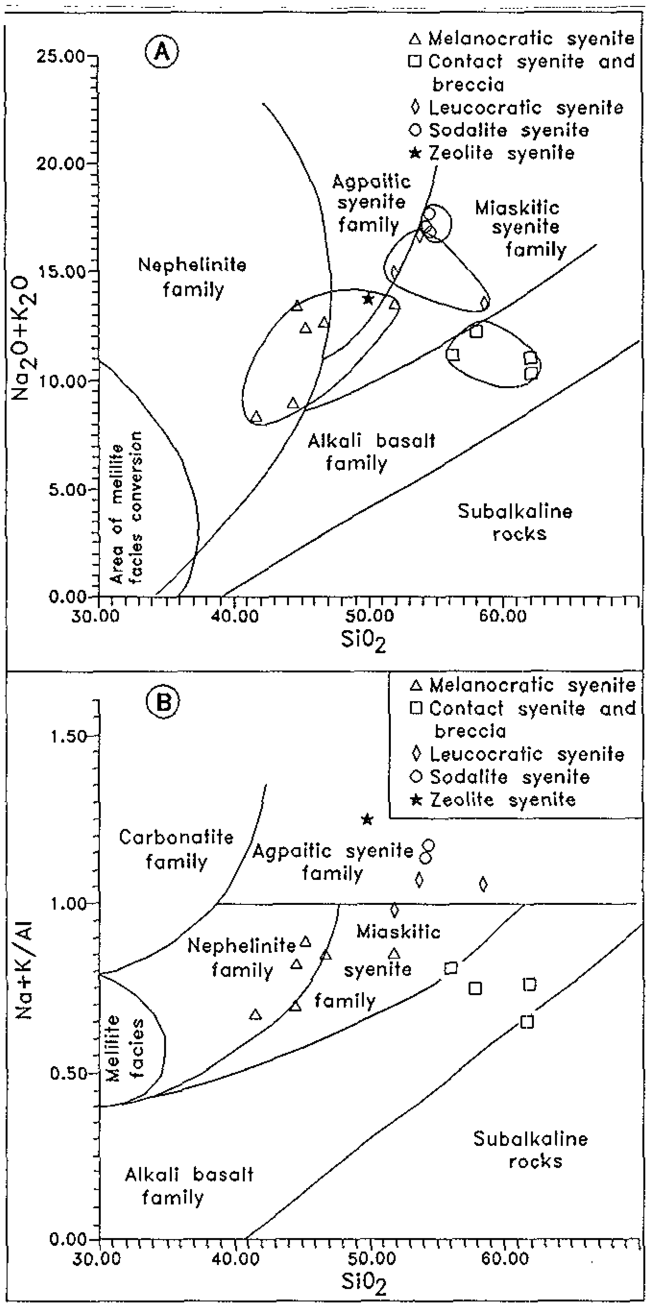


Figure 16. Alkali-silica and agpaitic index plots, Ice River syenite suite.

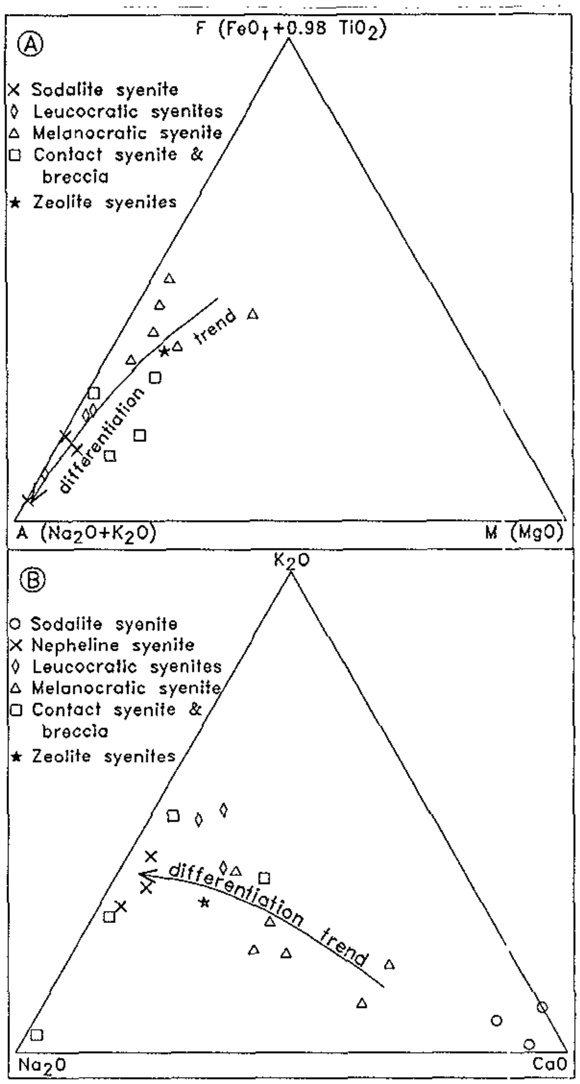


Figure 17. Ternary major element plots, Ice River syenitic suite.

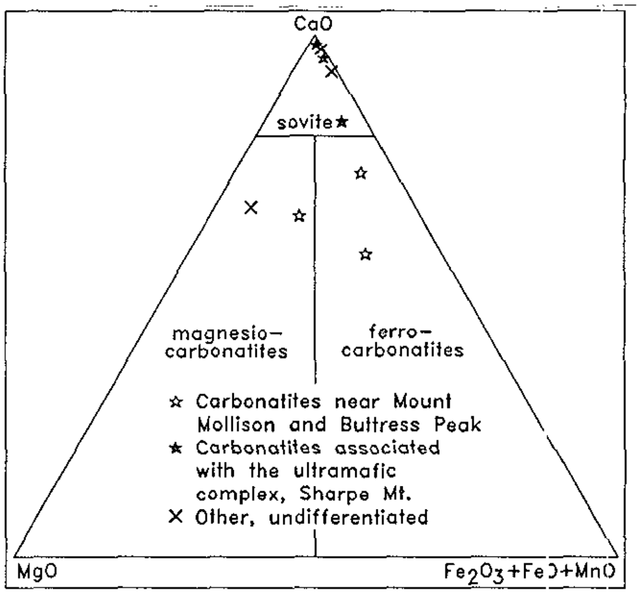


Figure 18. Major element ternary plot, Ice River Complex carbonatites.

Carbonatites are predominantly sovites and ferrocarbonatites (Figure 18) and, together with some of the melanocratic syenites, have relatively high concentrations of 'incompatible' trace elements (Nb, Y, REE), barium and strontium (Table 3).

GEOCHRONOLOGY

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)

TABLE 4
ICE RIVER COMPLEX - GEOCHRONOLOGY SUMMARY

Published Date	Recalculated*	Method	Reference	Comments
392±10	374±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 K-Ar should be reliable
336±5	321±5	K-Ar, mica separate	Rapson, 1963	Minette sill; Sr too low for satisfactory data but K-Ar should be reliable
(244±45)		Rb-Sr, mica separate		
327±5	312±5	K-Ar, mica separate		
340±23	348±27	K-Ar, mica separate	Lowdon, 1960	Syenite dike; no chlorite
330±23	334±26	K-Ar, mica separate	Lowdon, 1960	Pyroxenite; no chlorite
355±18	362±18	K-Ar, mica separate	Baadsgaard, 1961	Jacupirangite
360±18	367±18	K-Ar, mica separate	Baadsgaard, 1961	Minette
304±15	310±15	K-Ar, mica separate	Baadsgaard, 1961	Pegmatite
(233±11)	(231±10)	K-Ar, mica separate	Currie, 1975; Wanless, 1973	Meta-ijolite; no alteration (discordant, low)
(220±8)	(227±10)	K-Ar, mica separate	Currie, 1975; Wanless, 1973	Nepheline syenite; no alteration (discordant, low)
(408±15)	(415±15)	K-Ar, mica separate	Wanless, 1966	Altered lamprophyre
(421±11)		K-Ar, hornblende separate	Stevens, 1982	Hornblende from syenite; excess argon
368-370 Ma		U-Pb, zircon sphene	Parrish, 1987	207Pb/206Pb ages on zircon as follows: 359.9±2.2; 363.1±2.2; 364.9±2.2; sphene 368.8±7.0; 357.3±8.4; 361.2±9.0; 356.6±16.1.

** Data are recalculated using currently accepted decay constants, R.L. Armstrong, personnal communication, 1987.*

examined contact relationships and concluded that the complex was a sample of Precambrian basement and the contact with the sediments was an unconformity. Radiometric dates obtained in the early 1960s (Lowdon, 1960; Baadsgaard *et al.*, 1961; Rapson, 1963) suggested a mid-Paleozoic age, *circa* Devono-Mississippian (Table 4). Currie (1975), uncertain of the validity of the early radiometric work, had additional material analysed and obtained Early Triassic ages (*see* Table 4). In evaluating his, and earlier work, Currie suggested a preferred age of emplacement of *circa* 245 Ma. Recent work on uranium-lead zircon systematics (Parrish *et al.*, 1987; *also see* Table 4) indicates that the mid-Paleozoic dates most closely represent the true age of emplacement.

ROCK CANYON CREEK FLUORITE AND 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 19) in the eastern White River drainage, approximately 40 kilometres east of Canal Flats (latitude 50°12′N, longitude 115°08′W). It is accessible by conventional vehicles along the White River and Canyon Creek forestry roads, which join Highway 3A two 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 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. 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. During this latter work it was discovered that the property also contained anomalous concentrations of rare-earth elements (REE).

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.* and only relevant points will be reiterated here. The southwestern boundary of the property is marked by the easternmost in a series of west-dipping thrust faults which place Cambrian and Ordovician strata over younger rocks (Figure 19). 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 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, 1987), which consists of metasomatically altered (fenitized) Devonian carbonate rocks, possibly associated with a deep-seated carbonatite intrusion.

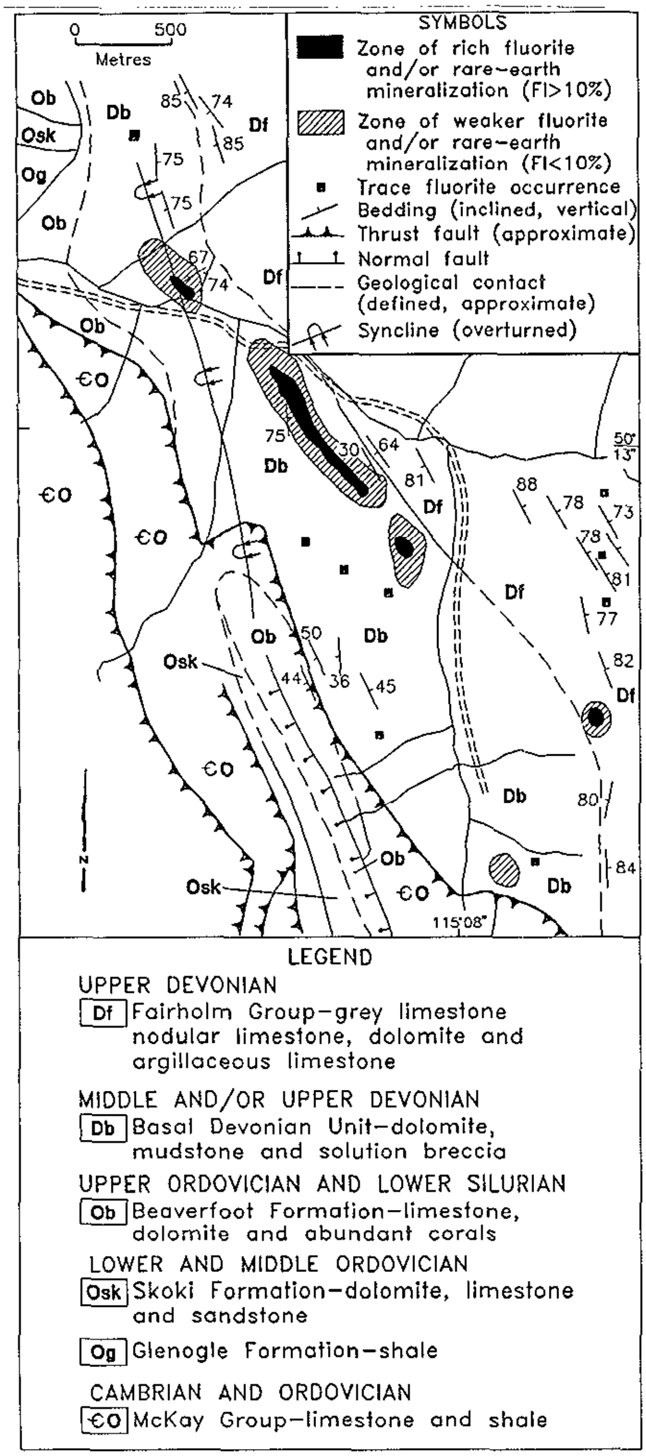


Figure 19. Geology of the Rock Canyon Creek fluorite rare-earth showing. Modified from Pell and Hora (1987) and Mott (1986).

MINERALIZATION

Four main types of fluorite mineralization are identifiable 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% of the rock. Bastnaesite ($CeCO_3F$) often occurs along the margins of fluorite veins, as does coarsely 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). Parisite [$CaCe_2(CO_3)_3F_2$] has also been identified from fy of the Rock luorite veins by scanning electron microscopy and may be associated with bastnaesite. Neutron activation analyses of up to 2.3% rare-earth elements and 2.7% barium have been reported (Graf, 1985; also Appendix 1). Niobium, strontium and yttrium are also present in measurable amounts (Table 5). 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 grey or 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 19).

The second type of mineralization consists of massive, fine-grained purple and white fluorite, which commonly comprises greater than 40% 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). Chemical analyses indicate that this type of mineralization can contain up to 71% CaF_2. 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 19).

Fine-grained purple fluorite disseminated in white calcite which is locally interbedded with buff-weathering dolomite and forms the matrix of solution breccias constitutes the third type of mineralization. Fluorspar is present in concentrations from trace amounts to a few percent. 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 19). Massive purple fluorite which constitutes greater than 20% of the rock, forms the matrix of an intraformational conglomerate (Plate 10) and locally replaces the fragments. Minor barite, pyrite and magnetite may also be present.

GEOCHEMISTRY

The interpretation that the Rock Canyon Creek showing is carbonatite related appears to be consistent with preliminary geochemical data (Table 5; Appendix 1). In addition to high fluorine, REE and barium, the rocks are enriched in Fe_2O_3, MnO, MgO, strontium, yttrium, phosphorus and niobium (Table 5) relative to the unaltered Devonian carbonates. Chondrite-normalized rare-earth element abundance patterns are typical of carbonatites (Figure 20) and fall within the field defined by other British Columbia carbonatites, however, the Rock Canyon Creek showing is more enriched in rare earths than most other examples, comparable only with the REE ‘sweats’ and dikes

TABLE 5
CHEMICAL ANALYSES, ROCK CANYON CREEK

	Type 1 mineralization								Weakly altered carbonates, adjacent to Type 1 mineralization				Type 2 mineralization			Type 4 mineralization
wt %	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SiO_2	0.39	3.16	0.85	2.89	0.94	2.82	1.04	4.08	14.90	31.36	3.18	15.84	9.34	7.84	6.39	22.79
TiO_2	0.02	0.02	0.01	0.03	0.03	0.06	0.03	0.01	0.11	0.26	0.04	0.11	0.04	0.41	0.02	0.10
Al_2O_3	2.32	1.07	0.20	1.10	0.37	1.24	0.43	0.66	2.27	5.32	0.81	2.92	17.05	15.31	17.16	2.25
Fe_2O_3	2.80	2.80	2.95	3.26	5.28	7.41	5.49	3.64	1.10	2.04	0.39	1.06	0.53	1.81	0.64	1.29
MnO	0.09	1.11	0.78	1.01	1.09	1.49	1.62	0.96	0.01	0.16	<.01	0.1	<.01	<.01	<.01	0.02
MgO	10.30	14.40	12.86	12.61	13.40	11.80	14.26	14.00	8.96	10.53	2.40	4.23	0.17	0.22	0.78	11.79
CaO	34.70	29.40	37.45	37.57	32.89	26.36	29.00	30.81	32.10	19.05	46.60	40.49	42.08	39.59	42.38	26.84
Na_2O	0.08	0.05	nd	nd	0.16	0.23	0.22	nd	<0.03	0.08	0.06	0.01	0.18	0.24	0.55	0.21
K_2O	0.23	0.25	nd	nd	0.01	0.02	0.06	nd	2.47	3.27	0.58	0.93	0.05	0.13	0.24	1.17
LOI	29.97	35.49	33.30	35.36	35.61	34.28	39.78	38.56	32.80	25.68	40.80	34.04	12.88	12.02	9.59	27.78
P_2O_5	1.49	0.59	0.36	0.31	0.34	1.52	0.92	0.30	<.09	0.26	0.12	0.14	0.17	1.67	0.14	0.04
Total	83.29	88.34	88.76	93.14	90.12	87.23	92.85	93.02	95.29	98.01	94.99	99.87	82.49	79.24	77.89	
ppm																
Ni	9	8	3	<2	6	-	-	4	7	11	2	24	3	-	-	<2
Cr	22	28	12	<20	39	-	-	17	27	26	<20	34	10	-	-	12
Co	10	6	7	7	7	-	-	9	8	10	6	11	2	-	-	4
Sr	7759	3428	1334	1676	1024	3723	1358	1483	608	735	1369	981	1129	>10000	1260	300
Ba	9820	24226	11538	4078	1306	14953	950	10942	54	5352	46	790	13840	12215	13582	136
Zr	49	41	28	42	37			34	45	75	21	52	23	-	-	41
Nb	54	158	149	303	181			20	40	162	5	53	48	-	-	63
Y	278	157	147	174	165	317	146	224	15	90	<5	157	15	163	17	21
La	5654	2833	4876	2318	5319	6072	3803	2683	24	45	5	18	125	530	111	44
Ce	8596	4365	6285	3957	7858	8986	6302	5009	19	95	42	48	178	948	142	45
Nb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Yb	-	-	-	-	4	-	-						1	-	-	<3
Sc	81	69	92	81	107	-	-	70	32	38	43	47	47	-	-	25
Ta	<2	7	<2	<2	<3	-	-	<2	<2	<2	<2	<2	5	-	-	<3
Th	1120	188	305	201	412	407	263	428	43	52	47	36	134	460	45	76
F	12.00%	4.80%	6.52%	4.50%	6.40%	2.96%	3.13%	1.75%	2.90%	1.43%	0.90%	0.51%	33.28%	32.00%	34.56%	6.08%

Sample descriptions: 1 - massive fluorite in altered carbonate:
2 - brown, altered carbonate with streaks of fluorite;
3 - brown, altered carbonate with abundant fluorite;
4 - brown, altered carbonate with fluorite;
5 - fluorite veins in altered carbonate;
6 - fluorite in altered carbonate;
7 - chocolate-weathering altered carbonate rock with fluorite;
8 - brown, altered carbonate;
9 - grey to buff carbonate with abundant fluorite;
10 - grey to buff, laminated carbonate with minor fluorite;
11 - light grey laminated carbonate with grey alteration patches;
12 - grey to buff, laminated carbonate with traces of fluorite;
13 - massive purple and white fluorite with some calcite;
14 - purple fluorite;
15 - massive white and purple fluorite;
16 - intraformational limestone conglomerate with fluorite matrix;
Samples 1,2,5,6,7,9,11and 13 to16 major elements by ICP; trace elements by XRF or INAA;
Samples 3,4,8,10,12 major and trace elements by XRF

Plate 10. Intraformational conglomerate with matrix entirely consisting of dark purple fluorite from the Devonian Fairholm Group along the ridge crest east of the Rock Canyon Creek (type 4 fluorspar mineralization).

associated with the Aley complex (Mäder, 1987), and possibly some lithologies in the Kechika River area.

GEOCHRONOLOGY

Timing of metasomatism is 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 and 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.

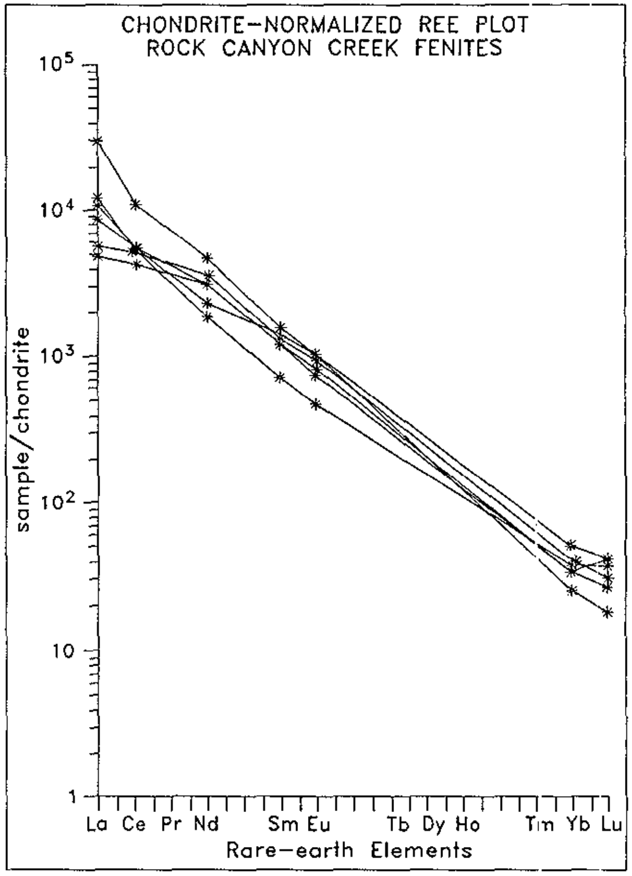


Figure 20. Chonodrite normalized REE plot - Rock Canyon Creek fenites.

KECHIKA RIVER AREA (94L/11, 12, 13)

A suite of alkaline igneous rocks consisting of trachytes, trachytic breccias, crystal and lapilli tuffs, syenites, melanocratic augite syenites, an alkaline diatreme and related dikes and numerous strongly sheared and altered rocks, crops out in the Kechika Ranges of the Cassiar Mountains (RAR and REE claims). These rocks have been explored for their yttrium and rare-earth element potential.

The alkaline rocks are intermittently exposed in a northwest-trending zone in excess of 20 kilometres long, the centre of which is approximately 58°42′ north and 127°30′ west (Figure 21). Elevations in the area range from 1180 to 2375 metres, and there is excellent exposure above treeline. Access is by helicopter from Dease Lake, approximately 160 kilometres to the west or from Watson Lake, Yukon, which is approximately 150 kilometres north of the property.

The area is underlain by unmetamorphosed to weakly metamorphosed Cambrian to middle Paleozoic strata (Gabrielse, 1962). To the northeast of the area (Figure 21), thick-bedded quartzites of probable Early Cambrian age are folded in a broad open antiform with a northwest-trending axis. Along the southwestern limb of the antiform, the quartzites are in contact with a thick, southwest-dipping section of phyllites, thin-bedded marbles and massive, blocky weathering dolostones of probable Middle and Upper Cambrian and Ordovician age (Gabrielse, 1962). Chlorite, sericite, sericite-graphite and calcareous phyllites are all present within this succession. To the southwest, the phyllites are bounded by a gently southwest-dipping fault, which juxtaposes green tuffs and cherty tuffs overlain by fossiliferous grey limestones and pink and black quartzites with the phyllites. The limestones, which contain beds rich in rugosan corals, favosites-type corals, bryozoans and brachiopod fragments are probably of middle Paleozoic age (Silurian). The cherts, tuffs and limestones in the fault panel outline an overturned antiform and, to the southwest, are in fault contact with graphite-sericite and chlorite-sericite phyllites similar to those to the northeast. The gently dipping, northeastern bounding fault apparently has had normal movement along it, as younger strata are present in the hangingwall package, however, geometry and the presence of the hangingwall anticline imply that at one time there probably was thrust motion along this fault. The southwestern fault is a moderate to steeply southwest-dipping thrust which places older rocks over younger rocks. The alkaline rocks are present in the tuff-chert-limestone thrust panel, between the two phyllitic units.

DISTRIBUTION AND FIELD RELATIONSHIPS OF ALKALINE ROCKS

Alkaline igneous rocks occur in four main areas of the property (Figure 21). Dark green, intrusive mafic syenites (malignites), displaying good igneous textures, predominate in the south. These syenites contain some irregular leucocratic zones and are brecciated along their margins. Numerous small sills, dikes and metasomatic alteration zones are present peripheral to the main intrusive body.

A diatreme breccia pipe is exposed near the centre of the property (Figures 21 and 22; *see* Chapter 5). The pipe contains xenoliths of numerous sedimentary and igneous rock types and rare chrome spinel xenocrysts, in a pale green, carbonate-rich tuffisitic matrix. The diatreme, which is close to the northeast bounding fault, is weakly to strongly deformed and locally cut by carbonatite dikes and carbonate-sulphide veins.

A large area underlain by igneous rocks, including the main mineralized zone, is present immediately northwest of diatreme (Figure 22). It consists of a complex, southwest-dipping homoclinal sequence of moderately to strongly deformed (sheared) igneous and pyroclastic rocks.

The base of the sequence is composed of pale green to pale orange weathering, variably calcareous rocks that locally contain rare chrome spinels. These rocks are interlayered with a minor amount of grey aplite and buff to brown-weathering, fine to coarse breccias interlayered with fine-grained, laminated beds. Well-developed graded layers are present locally. The coarse breccias and the bases of the graded beds consist of lithic fragments, 1 to 3 centimetres

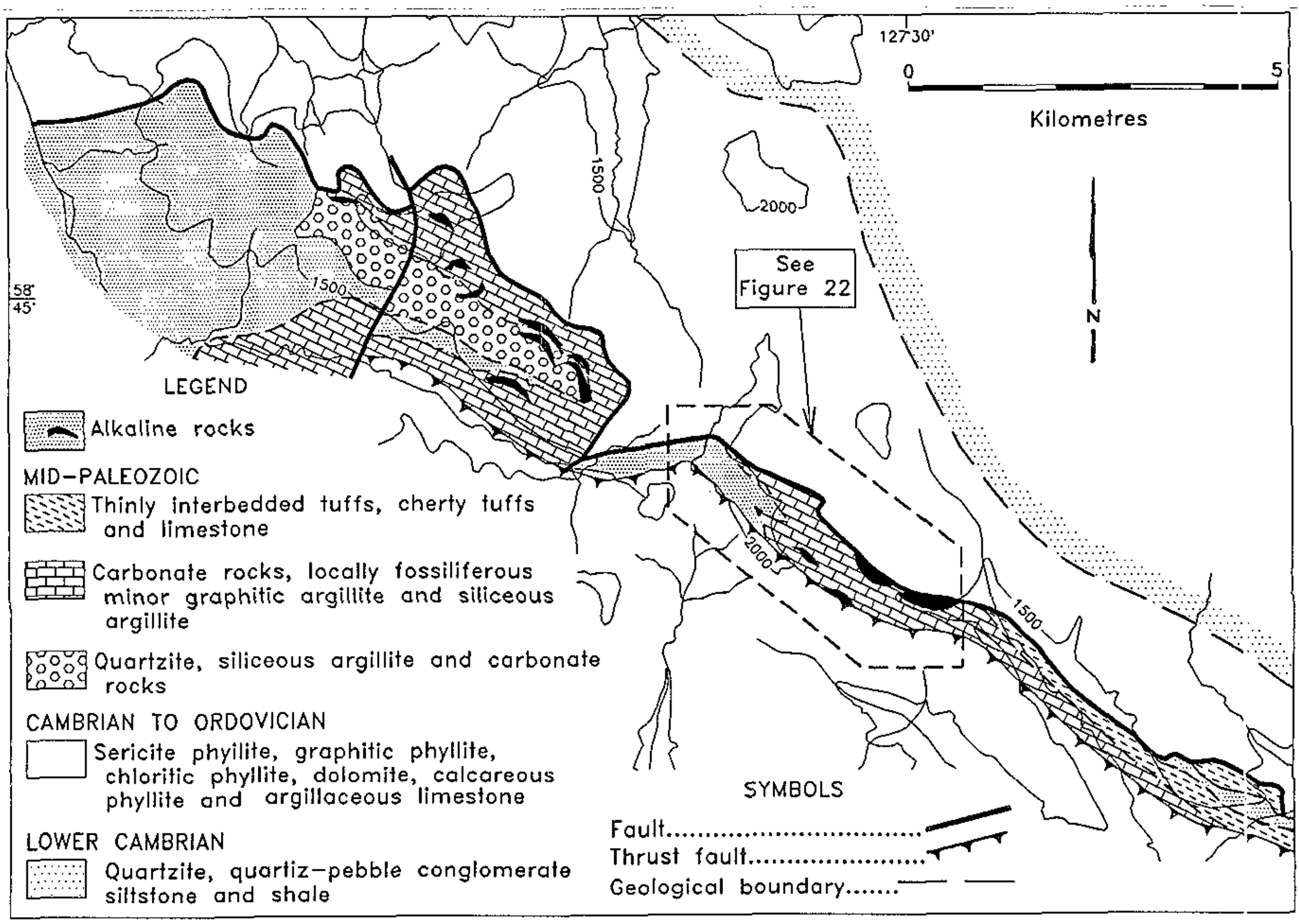


Figure 21. Generalized geology Kechika area.

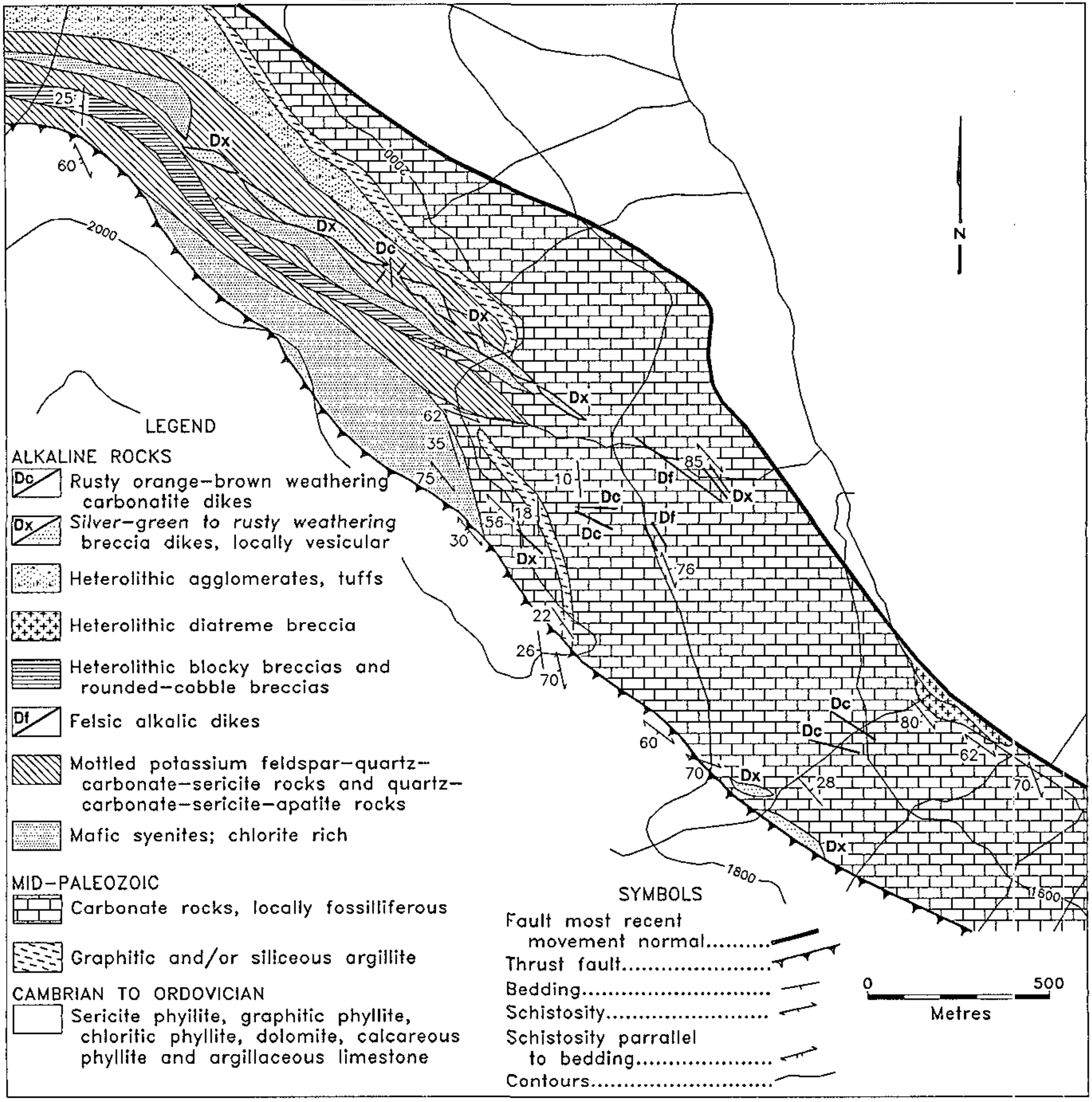


Figure 22. Geology of the central part of the belt of alkaline rocks, Kechika area.

across, in a welded tuff matrix containing abundant flattened pumice fragments and altered crystals. Fine-grained, carbonate-rich material is present at the top of the graded beds. This part of the section is interpreted as comprising a series of fine-grained, locally calcareous tuffs, crystal and lapilli welded tuffs with some interlayered sedimentary material and, locally, sills.

It is overlain by predominantly white to locally buff and pinkish weathering rocks containing varying amounts of quartz, feldspar, apatite, carbonate and sericite. Yttrium minerals occur within this white-weathering horizon, apparently related to phosphate-rich areas. Locally this rock type grades into grey-weathering (graphitic?) varieties or rusty weathering, extremely carbonate and sericite-rich varieties. This unit is generally weakly to moderately foliated, strongly lineated and, in thin section, displays a mylonitic fabric. These rocks are tentatively interpreted as trachytic or syenitic tuffs or flows with, possibly, a minor sedimentary component; the degree of deformation makes recognition of the protolith very difficult.

Dark green mafic syenites that grade from medium-grained, igneous-textured rocks to foliated chlorite schists near the margins, are present near the top of the sequence. The mafic syenites appear to have been intrusive into the white-weathering, quartz-feldspar-apatite-carbonate-sericite sequence and are now present as a megaboudin.

These rocks are structurally overlain by an unusual breccia unit. To the north, this breccia consists of predominantly subangular clasts in a very fine grained, buff to light grey matrix rich in pummice fragments. To the south, it is rusty weathering and contains predominantly subrounded fragments in a carbonate-rich matrix. In both areas the breccia is multilithic, containing a variety of sedimentary and igneous rock fragments; notably absent within the fragment suite are mafic syenites. Fluorite and pyrite are common accessory minerals in the breccias, both disseminated within the matrix and replacing fragments. Locally, a unique, buff-weathering feldspar-porphyrytic trachyte structurally underlies the breccias and contributes clasts to the breccias. The trachytes are interpreted as flows or sills, and the breccias as volcanic tuff-breccias with a matrix that varies laterally from lapilli tuff to fine-grained calcareous tuff.

The breccia sequence is overlain by a second buff to white-weathering feldspathic unit. It is quite similar to the mineralized, white-weathering quartz-feldspar-carbonate-sericite-apatite unit, however, it generally does not contain as much sericite or carbonate and is more massive than the lower unit. At the north end of the zone, this unit is in fault contact with lower Paleozoic phyllites; to the south it interfingers with black siltstones and is overlain by a pale to medium green weathering, medium-grained igneous flows or sills of uncertain affiliation. Rusty weathering carbonatite dikes and green to orange-weathering fragmental dikes or sills occur in numerous locations throughout the sequence.

At the north end of the property a thick section of alkaline igneous rocks is exposed. It consists mainly of a complex sequence of pale green to orange to buff-weathering agglomerate breccias and tuffs, buff and grey aplite layers, white-weathering quartz-feldspar-carbonate-sericite rocks and some sedimentary interlayers. Only reconnaissance traverses have been completed in this area and a detailed stratigraphy has not been established. Although lithologies are superficially similar to those in the central part of the area, no zones of high-grade mineralization have yet been discovered.

PETROGRAPHY: SYENITES

Syenites and melanocratic titaniferous augite syenites (malignites) are exposed at the south end of the property. The melanocratic syenites, which are present as large dikes

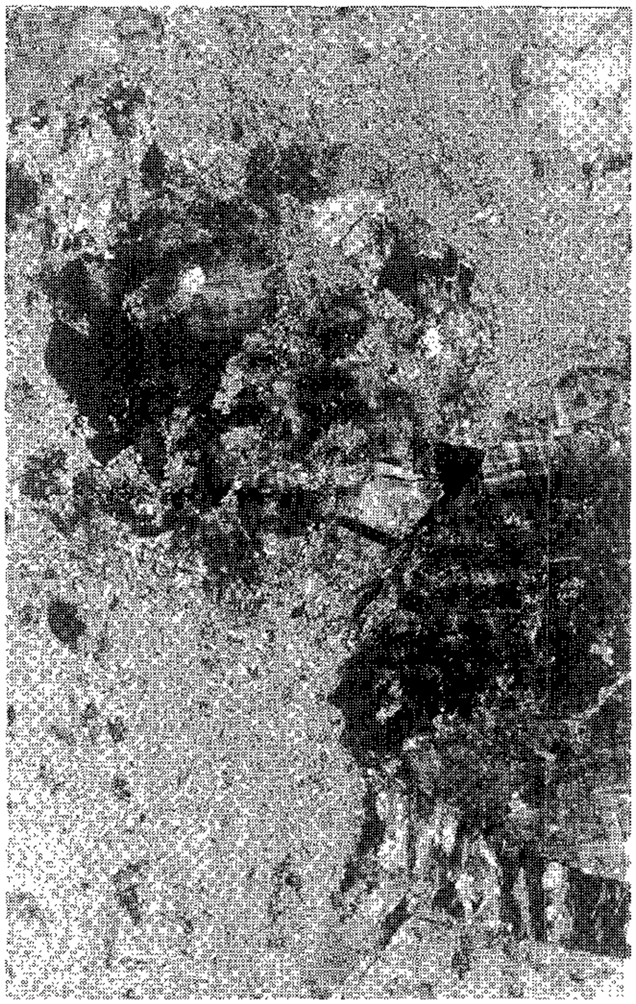


Plate 11. Potassium feldspar porphyroclasts in a fine-grained carbonate-sericite-feldspar-quartz matrix from a sheared leucosyenite, Kechika area. Long dimension is 7 mm.

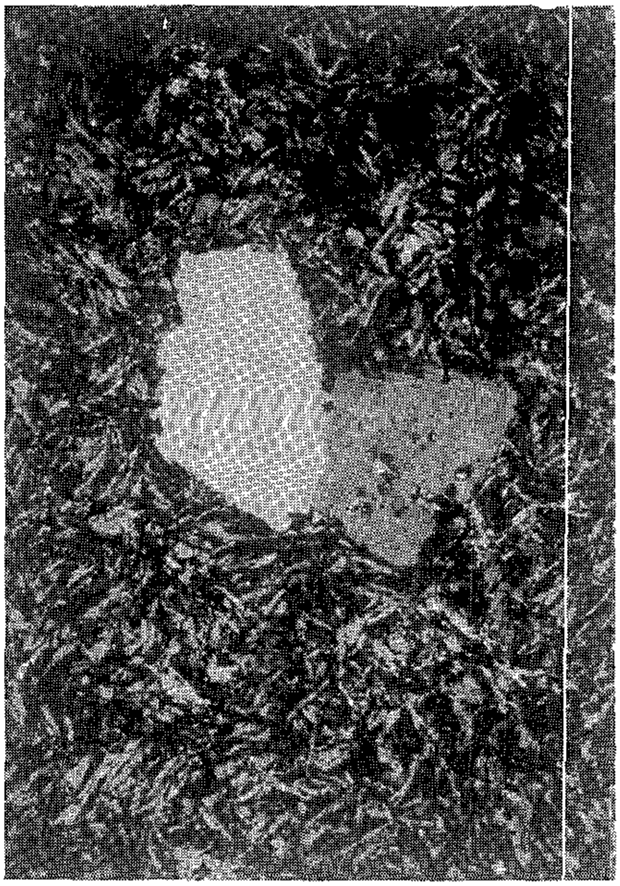


Plate 12. Typical trachyte, Kechika area, note feldspar phenocryst in a matrix predominantly consisting of felted feldspar laths with minor disseminated carbonate and opaque, *(colour photo, page 135).*

or elongate stocks, are fine to medium-grained, dark green to bluish grey rocks with small pyroxene and feldspar phenocrysts. They contain 40 to 60% microcline, 5 to 20% albite and 10 to 20% augite with titaniferous rims. Garnet (melanite), biotite, sodalite, cancrinite, allanite, magnetite/ilmenite, pyrite, fluorite and apatite/monazite are all present as accessory phases. Veins or segregations containing coarse calcite and dark purple fluorite±biotite±epidote are locally present within the malignites. In the central and northern parts of the property, melanocratic syenites are strongly sheared and chlorite rich.

Leucocratic syenites crop out in the southern part of the property, generally as irregular zones within the melanocratic syenites. They are light grey, medium-grained, massive rocks containing 35 to 40% microcline and 10 to 20% albite, with fluorite, sodalite, cancrinite, sphene, biotite, pyrite and pyrochlore present in variable amounts. Crosscutting calcite-pyrite-fluorite veinlets are common. The syenites vary from massive and relatively unaltered to sheared. Sheared syenites contain potassium feldspar porphyroclasts in a fine-grained recrystallized and altered matrix containing abundant clay minerals, quartz, plagioclase, dolomite and muscovite (Plate 11).

PETROGRAPHY: TRACHYTES

Buff, grey or pinkish weathering trachyte dikes and sills (or flows) are exposed in the central and northern parts of the area. For the most part, they appear aplitic in hand specimen, however, some varieties contain 2 to 5-millimetre feldspar phenocrysts in an aplitic matrix. In thin section, the porphyritic feldspars are generally polycrystalline and exhibit both simple and 'checkerboard' twinning; they appear to be perthitic in composition. The phenocrysts are present in a fine-grained groundmass of felted feldspar microlites with minor disseminated carbonate and opaques (Plate 12).

PETROGRAPHY: FELDSPAR-QUARTZ-CARBONATE-SERICITE ROCKS

Fine-grained, extremely fissile and micaceous phyllites to massive, white to buff-weathering rocks are commonly associated with other alkaline rocks in the central and northern areas of the property. They locally have mylonitic textures and contain varying amounts of quartz, carbonate (generally dolomite, although calcite and iron-rich magnesite have also been noted), muscovite, potassium feldspar, phosphates and pyrite. Massive varieties commonly have irregular dolomitic patches in a siliceous matrix.

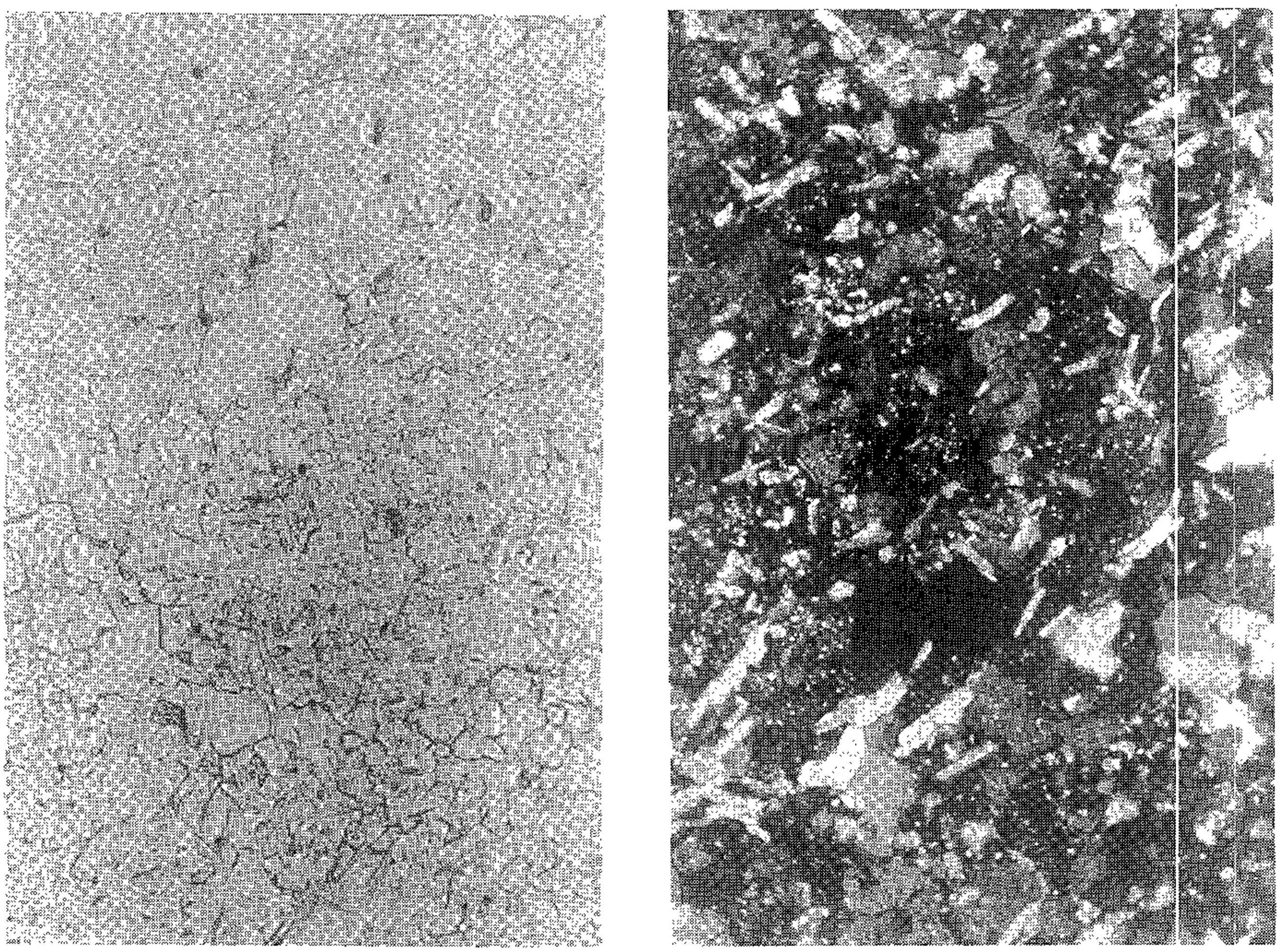


Plate 13. An apatite-rich zone in the quartz-feldspar-sericite-carbonate-(apatite) rocks. The high relief, low birefringent material (medium to dark grey) is all apatite with rare earth enriched phosphate minerals. Low relief material (white to black) is quartz and feldspar. The lath shaped grains are sericite. Plane polarized light and crossed nicols.

Locally phosphate minerals comprise in excess of 25% of the sample (Plate 13). In such rocks, a number of phosphate minerals may be intergrown, with apatite the most common species. Monazite (containing cerium, neodymium, lanthanum, calcium, thorium), xenotime (yttrium phosphate, with minor dysprosium, gadolinium and calcium) and a yttrium-thorium-calcium-dysprosium-gadolinium-bearing phosphate have been identified by scanning electron microscopy. Minor amounts of an iron-thorium-yttrium-calcium silicate mineral have also been noted.

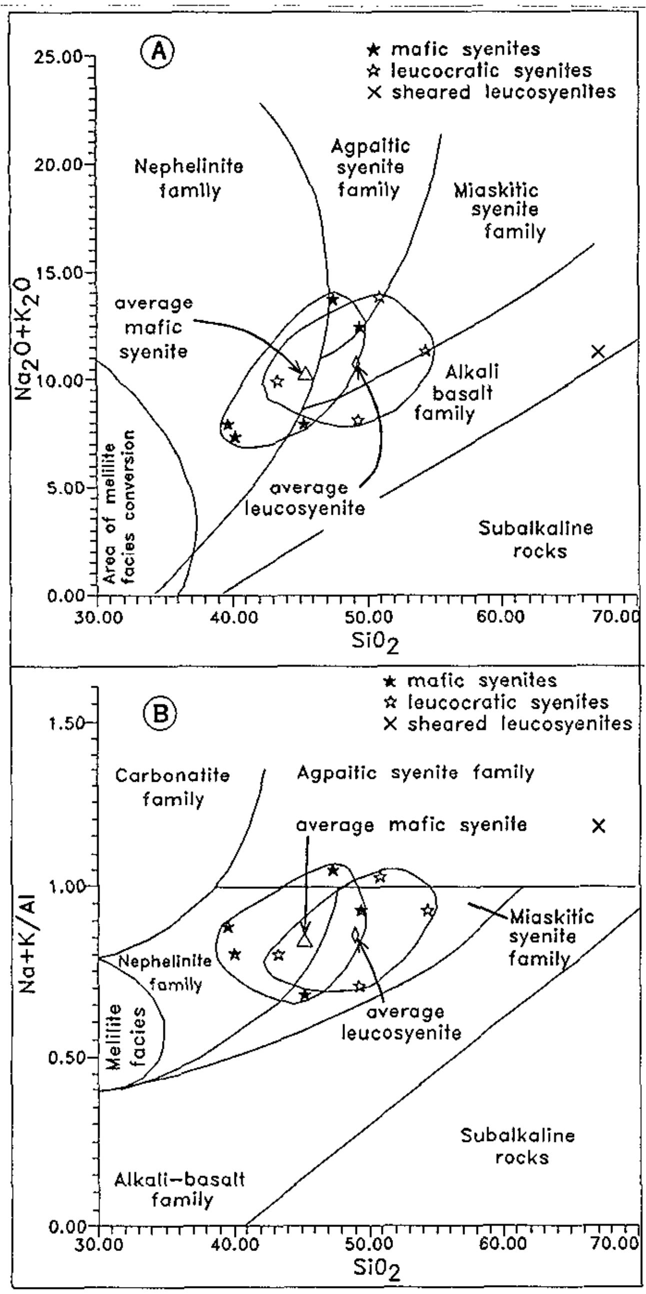


Figure 23. Alkali-silica and agpaitic index diagrams, Kechika syenites.

In some samples, potassium feldspar porphyroclasts are preserved in a fine-grained quartz-carbonate-sericite matrix, which suggests that the mylonite had a syenitic or trachytic protolith. In other cases, the rocks are very fine grained and completely recrystallized; no textural evidence of the protolith remains. Field evidence indicates that these rocks are conformable to bedding in the hosting limestones and were possibly flows or tuff layers. The high degree of

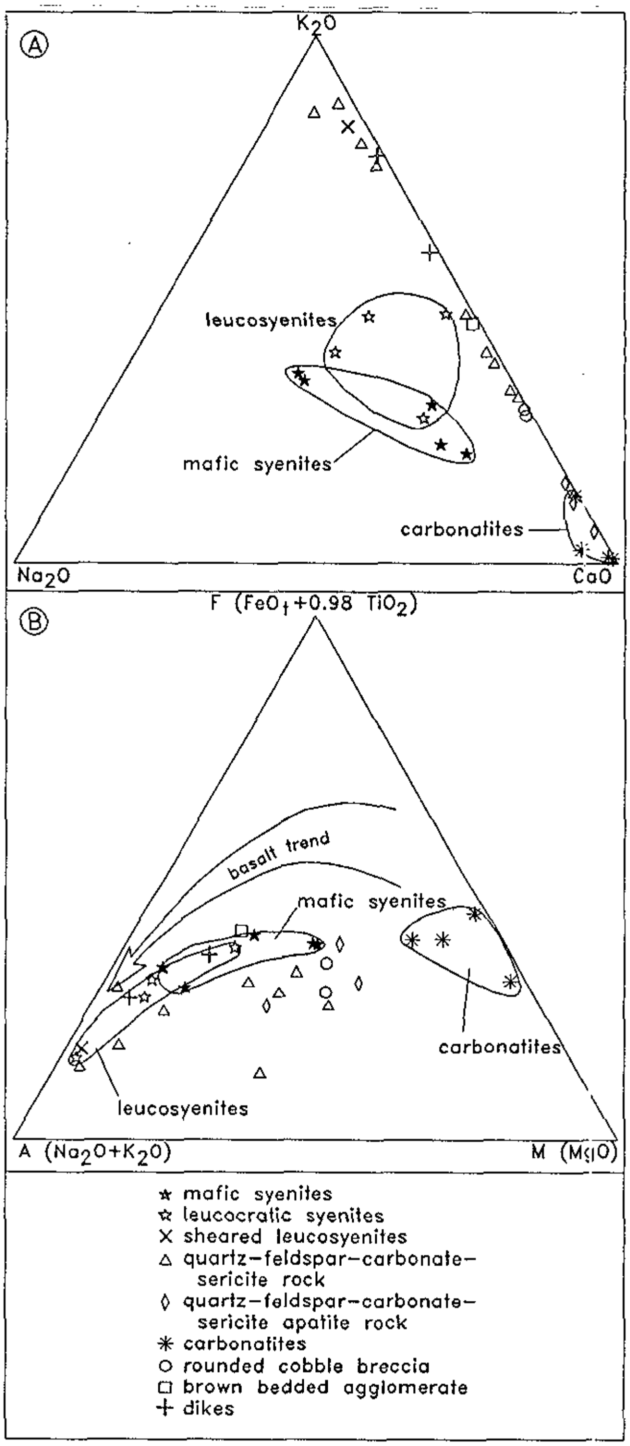


Figure 24. Major element ternary plots, Kechika igneous suite.

TABLE 6
GEOCHEMISTRY OF SELECTED KECHIKA SAMPLES

wt %	Mafic syenites					Leucosyenites				Sheared leuco-syenite	Quartz - K-feldspar - sericite - carbonate rocks								
SiO2	45.30	40.12	47.52	49.49	39.70	49.38	54.45	43.39	51.05	67.28	29.86	58.35	39.38	46.85	72.17	72.47	65.84	55.02	70.88
TiO2	1.19	1.39	1.05	0.88	1.65	0.82	0.52	0.76	0.46	0.45	0.02	0.04	1.80	0.08	0.68	0.15	0.49	0.08	0.11
Al2O3	17.58	13.78	19.45	19.87	13.72	17.25	18.58	19.42	19.86	14.96	7.92	7.44	10.83	7.52	14.67	11.05	17.52	9.63	13.38
Fe2O3	7.14	8.00	6.59	6.66	8.63	6.33	4.70	4.67	2.39	2.22	5.40	4.01	4.69	5.28	1.53	3.96	1.68	1.95	2.15
MnO	0.26	0.23	0.16	0.20	0.43	0.23	0.17	0.14	0.05	0.04	0.23	0.25	0.13	0.17	0.01	0.01	0.01	0.06	0.04
MgO	3.92	7.23	3.27	1.74	8.01	3.26	1.41	1.22	0.42	0.36	7.50	3.88	4.75	4.73	1.03	0.32	0.57	4.90	0.94
CaO	11.65	13.17	5.97	5.16	9.37	9.55	6.17	9.07	6.70	1.76	14.12	8.40	12.79	10.90	1.10	0.96	0.87	7.96	2.39
Na2O	3.48	2.98	6.78	6.14	2.68	3.24	3.09	0.90	5.48	0.41	0.15	0.21	0.37	0.20	0.17	0.24	0.95	0.24	0.24
K20	4.48	4.34	6.96	6.33	5.29	4.92	8.28	9.06	8.19	10.90	6.60	5.32	8.82	5.52	5.05	8.48	10.90	7.28	8.15
LOI	2.78	6.02	3.23	1.84	6.17	2.96	2.66	8.13	5.18	2.00	20.88	11.95	14.20	15.93	2.35	2.14	1.72	12.63	2.95
P2O5	0.36	0.33	0.29	0.26	0.44	0.25	0.14	0.16	0.18	0.15	0.04	0.03	2.42	0.02	0.34	0.07	0.01	0.06	0.02
Total	98.14	97.59	101.27	98.57	96.09	98.19	100.17	96.74	99.96	100.53	92.72	99.88	100.18	97.20	99.10	99.85	100.56	99.81	101.75
ppm																			
Ni	76	180	56	18	168	<20	<20	7	11	19	<20	<69	40	7	18	30	5	5	<20
Cr	150	350	100	19	354	<50	<50	10	12	13	110	340	92	22	75	11	10	28	<50
Co			35	24	39			17	18	18			42	16	7	36	7	11	
Rb	270	220	316	316	285	230	220	279	248	83	160	100	166	124	144	164	175	137	170
Sr	1600	1100	2153	2198	2438	2800	1500	1593	5534	58	400	150	376	154	50	42	42	108	65
Ba	1600	3100	1245	1949	1720	1900	2000	4059	1881	679	30700	<210	377	898	405	619	199	3058	230
Zr	120	140	270	380	143	120	415	257	169	357	89	93	158	85	528	122	896	169	325
Nb	130	81	194	241	272	140	405	303	141	136	43	74	104	40	65	63	273	55	270
Y	<5	20	41	31	62	<5	24	33	27	38	47	69	770	19	40	18	80	44	63
La	100	77	120	134	342	130	120	99	71	39	120	640	49	52	15	18	101	71	71
Ce	170	130	183	174	613	200	210	170	128	93	240	960	86	101	15	60	208	162	140
Nd			46	46	248					58				31	29	22	41	88	
Yb	<5	<5	8	5	5	<5	<5	8	8	11	<5	7	48	5	11	11	11	3	5
Sc	8.6	19.0	10.7	6.5	22.8	3.7	3.3	7.9	5.1	0.2	2.7	3.6	17	10.2	<.2	<.5	<.7	6.9	0.7
Ta	11	8.2	11	10	5	10	7.8	19	12	15	<1	<1	10	5	10	12	21	5	17
Th	22	14	46	37	293	31	54.2	35	35	19	269	583	208	56	58	22	45	138	57.3
U	3.5	2.4	48	41	40	5.4	17	34	52	25	1.4	2.3	51	33	51	26	34	35	10
V			122	112	239			81	27	14			155	121	72	49	6	94	
F	6200	7000	3100	4700	7500	3200	15000	5300	15000	320	460	700	2900	320	1800	820	760	460	2900

wt %	Quartz - K-feldspar - apatite sericite - carbonate rocks				Carbonatites				Rusty breccia with rounded cobbles		Brown bedded agglomerate	Dikes		Carbonate veins or "sweats"		Sulphide-rich alteration zones		
SiO2	41.95	37.02	36.08	28.68	15.25	19.46	26.65	9.57	30.23	28.49	39.30	68.15	45.86	26.20	37.59	6.57	9.51	3.09
TiO2	0.08	0.06	0.06	0.07	0.38	0.05	0.12	0.05	0.56	0.51	1.85	0.30	2.30	0.91	0.75	0.30	0.59	0.66
Al2O3	8.54	9.11	5.16	5.53	3.09	3.92	0.90	0.94	9.67	8.65	10.53	15.40	14.01	7.48	16.54	2.90	0.82	0.58
Fe2O3	2.14	2.04	2.83	4.83	7.81	8.99	5.58	9.81	5.39	7.17	7.58	3.06	5.79	6.25	8.37	29.29	4.11	5.83
MnO	0.05	0.07	0.08	0.26	0.42	0.3	0.38	0.64	0.21	0.19	0.18	0.06	0.16	0.37	0.29	0.14	0.68	1.20
MgO	0.43	2.15	2.47	6.20	10.11	10.00	11.36	11.28	7.19	7.24	3.90	0.64	3.09	8.29	3.05	6.92	3.74	1.72
CaO	20.71	22.02	24.60	20.57	24.34	20.86	19.82	25.44	16.01	15.25	10.42	2.03	6.86	18.23	17.95	13.25	48.64	50.30
Na2O	0.14	0.16	0.26	0.26	1.20	0.11	0.18	0.13	0.23	0.15	0.25	0.13	0.29	0.26	2.69	0.11	0.13	0.14
K20	3.46	3.19	1.66	3.85	0.76	3.11	0.28	0.29	6.40	6.43	9.07	7.49	10.35	5.96	2.85	1.06	0.63	0.20
LOI	1.82	6.38	7.15	18.66	32.53	30.97	30.83	38.71	20.83	18.58	14.93	3.56	9.31	21.53	7.73	25.86	14.11	22.71
P2O5	19.30	13.70	18.20	8.30	0.23	0.02	0.03	0.08	0.12	0.16	0.01	0.09	0.47	0.19	0.25	0.14	0.04	0.03
Total	98.62	95.90	98.55	97.21	96.12	97.79	96.13	96.94	96.86	92.82	98.02	100.91	98.49	95.67	98.06	86.54	83.00	86.96
ppm																		
Ni	<98	43	65	22	<88	<20	<58	9	29	<20	29	<20	25	54	68	<45	<89	<110
Cr	<440	340	20	17	260	<50	<50	45	80	<50	<50	<50	<50	450	<50	64	280	390
Co			84	37				11										
Rb	85	88	39	95	<49	69	<31	43	160	160	220	180	63	130	210	27	<53	<65
Sr	430	400	624	685	505	275	510	467	660	570	140	71	150	815	3500	185	1100	1300
Ba	1700	310	1898	522	1500	310	3900	713	2000	1500	130	270	5200	500	590	<100	<300	<310
Zr	<9	<9	190	100	75	68	59	26	83	76	130	470	180	95	<5	70	53	32
Nb	130	120	43	32	130	37	195	38	85	62	60	94	34	30	93	23	125	130
Y	4400	4300	6671	2645	103	20	120	61	<5	9	9	62	21	37	<5	35	450	340
La	360	250	222	51	875	60	360	478	41	53	23	130	20	450	120	480	1120	1870
Ce	590	440	543	105	1020	110	320	628	59	95	54	270	48	630	210	610	1050	1970
Nd			402	140				166										
Yb	<230	<120	227	157	<22	<5	<21	<4	<5	<5	<5	6	<5	8	<5	<5	<37	<30
Sc	8.9	5.7	28.7	22.9	8.8	1.7		27.1	6.4	4.3	11	2.2	17	6.7	7.9	3.8	5.8	4
Ta	2.4	1.7	60	22	2.2	1.1	<1	5	3.5	3.4	3.7	10	3.8	2.5	5.2	<1	<1	<2.2
Th	2920	2380	3312	1322	748	55.4	620	225	16	55.6	11	36	7.4	316	13	54.9	778	972
U	<33	37	99	101	2.2	<.5	4.6	46	0.9	1.8	0.7	6.5	1	3.7	7.1	<.5	1.4	<1.3
V			47	69				213										
F	12500	11500	12700	6200	720	140	1450	170	10000	7500	220	2400	900	16000	12500	9700	24.83%	18.24%

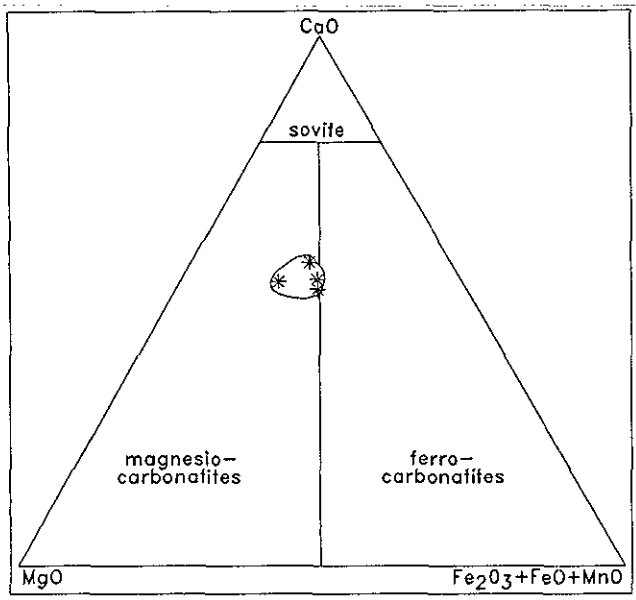


Figure 25. CaO-MgO-Fe2O3t+MnO carbonatite plot, Kechika.

deformation within these rocks, compared with the other rock types, may be a result of original incompetence, in which case a tuffaceous protolith is favoured. Phosphate-rich rocks are distributed in discontinuous lenses up to a few metres thick and several tens of metres parallel to overall layering.

PETROGRAPHY: CARBONATITES

Fine-grained igneous carbonate rocks, with a distinctive orange-brown-weathering colour are also present in the Kechika area. They occur as dikes which are generally less than a metre wide and crosscut both other alkaline rocks and the carbonate hostrocks. Volumetrically the carbonatites are an insignificant part of the alkaline suite.

The carbonatites are dolomite or ankerite rich (80%), and contain quartz. Accessory phases include microcline, muscovite, barite, iron oxides, pyrite, fluorapatite, gorceixite, xenotime and an unidentified thorium-calcium-yttrium-iron phosphate mineral. The carbonatites are locally fragmental, containing subangular to rounded lithic clasts of various rock types.

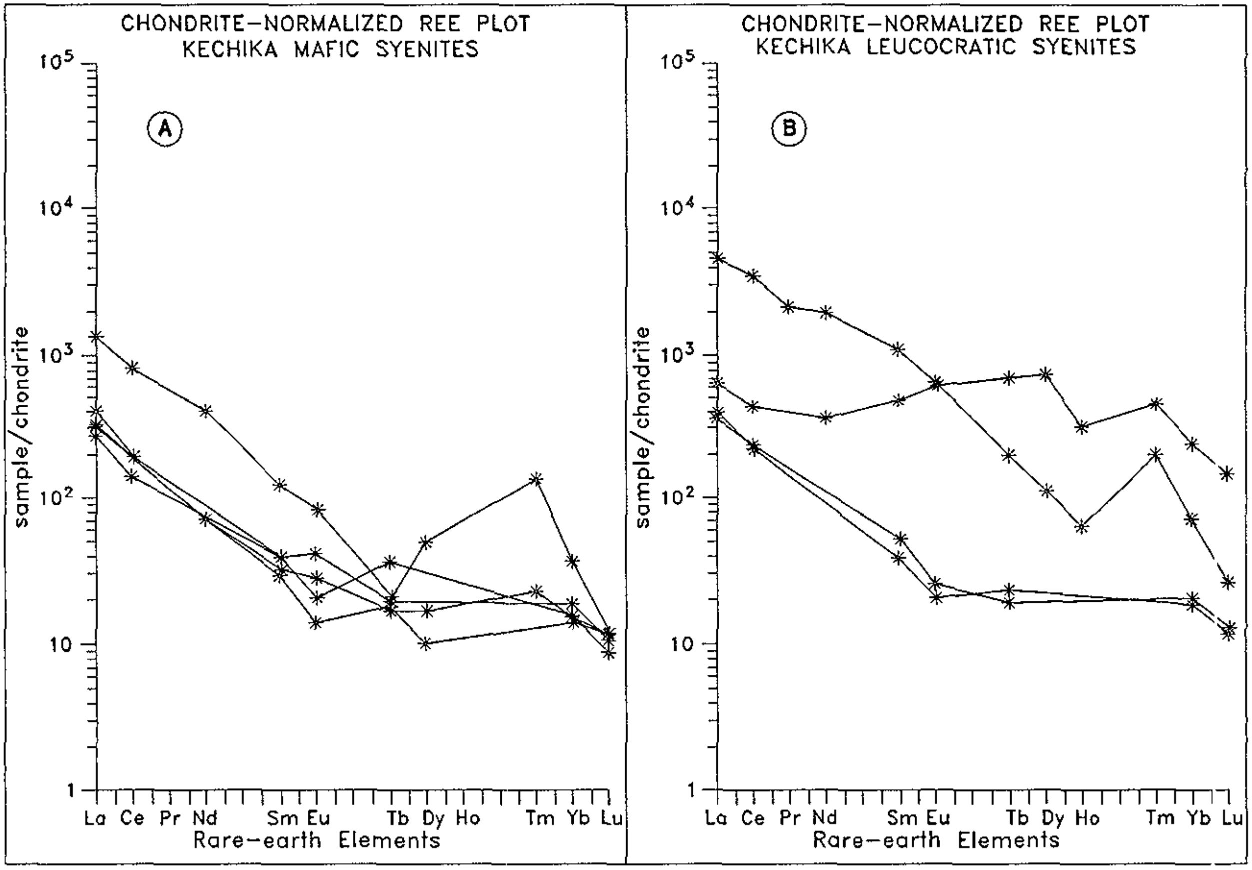


Figure 26. (A) Chondrite normalized REE plot - Kechika mafic syenites; (B) Chondrite-normalized REE plot - Kechika leucocratic syenites; (C) Chondrite-normalized REE plot - Kechika quartz-feldspar-carbonate-sericite rocks; (D) Chondrite-normalized REE plot - Kechika quartz-feldspar-carbonate-sericite-apatite rocks; (E) Chondrite-normalized REE plot - Kechika carbonatites; (F) Chondrite-normalized REE plot - Kechika veins, shears and alteration zones.

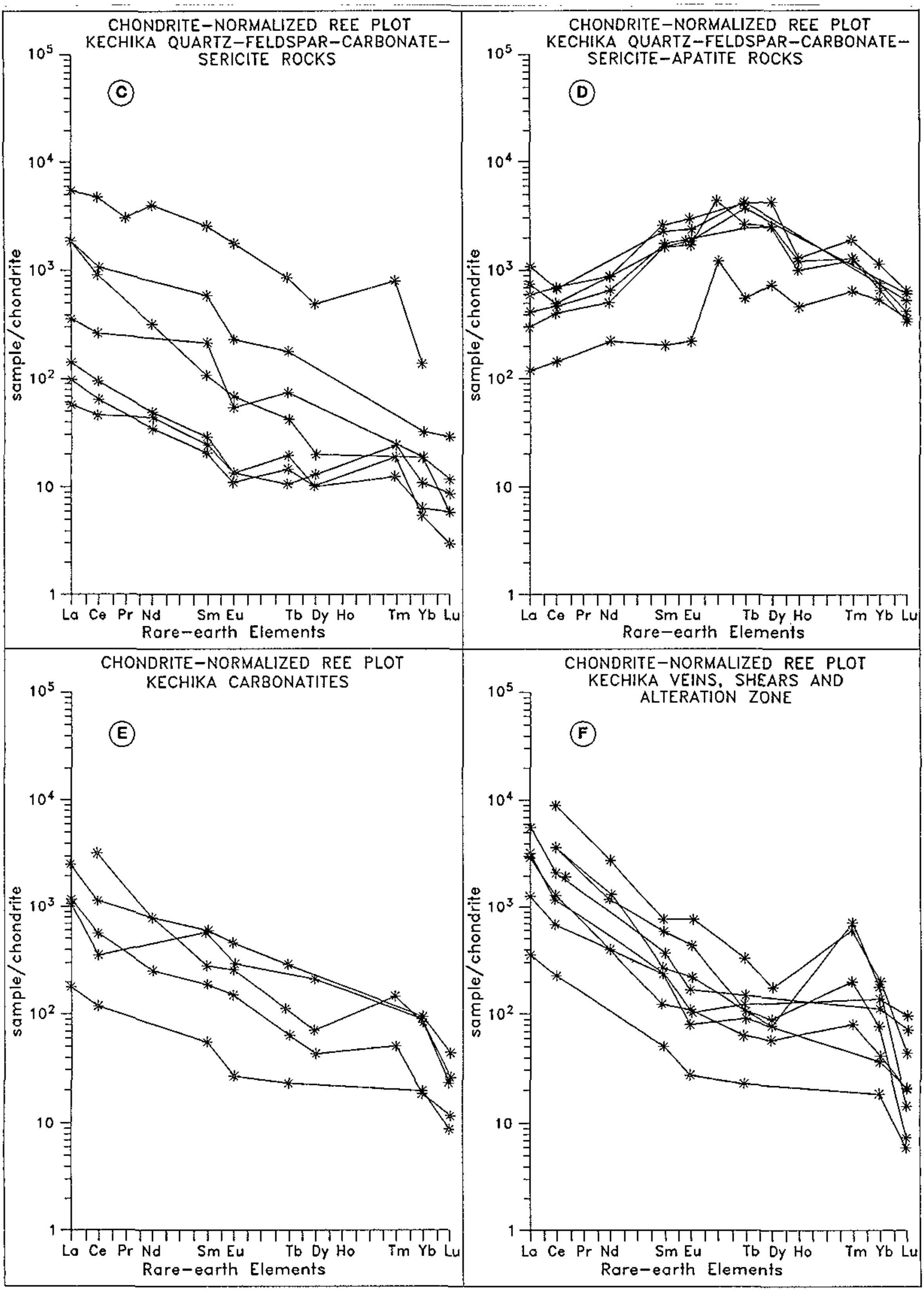


Figure 26 (continued)

GEOCHEMISTRY

Syenites from Kechika have variable alkali/silica ratios (Figures 23a and b; Table 6); however, the 'average' leucosyenite plots in the miaskitic syenite field and the 'average' mafic syenite plots in the nephelinite field, near the miaskitic syenite boundary. Syenites are enriched in sodium (Figure 24a) and moderately enriched in barium and strontium relative to other rock types in the Kechika area (Table 6). On an AFM diagram, the syenites define a trend subparallel to a typical basalt trend, but displaced away from the iron apex (Figure 24b). Carbonatites fall within the magnesiocarbonatite field, close to the boundary with the ferrocarbonatite field and well removed from calcite carbonatites (Figure 25). Quartz-feldspar-carbonate-sericite and quartz-feldspar-carbonate-sericite-apatite rocks are variable in composition (Figure 24, Table 6). They are generally sodium poor and calcium or potassium rich. Apatite-rich varieties can contain over 19% P_2O_5.

As with other alkaline suites, rocks in the Kechika River area are generally enriched in rare-earth elements (Appendix 1). Chondrite-normalized rare-earth element plots of most rock types from the Kechika area (Figure 26A to F) show light rare-earth enrichment typical of carbonatite and alkaline rock complexes. Some carbonatites locally containing up to 3.77% cerium and lanthanum oxides. Of particular interest are the quartz-feldspar-carbonate-sericite-apatite rocks which, as well as containing significant amounts of P_2O_5, have anomalous concentrations of middle and heavy rare-earth elements and yttrium. Values of up to 1.13% Y_2O_3, 0.30% Nd_2O_3, 0.11% Sm_2O_3, 0.03% EuO, 0.14% Dy_2O_3 and 0.05% Tb_2O_3 are reported by Pell *et al.* (1990). The samples enriched in middle and heavy rare earths give convex-upward, positively sloping chondrite-normalized rare-earth patterns (Figure 26d) which are not typical of carbonatite suites. Almost flat chondrite-normalized rare-earth patterns are occasionally produced by leucocratic syenites as well (Figure 26b).

GEOCHRONOLOGY

No radiometric dating has been completed on the Kechika River alkaline rocks. The presence of mylonites and their distribution suggest that they were emplaced prior to orogenesis. Field relationships, in particular the presence of bedded agglomerates and tuffs with sedimentary interlayers, suggest that the alkaline suite is coeval with the host carbonate sequence, that is, mid-Paleozoic.

Clear crosscutting relationships between many of the alkaline phases are largely obscured by deformation and, for the most part, the sequence of deformation cannot be established. Mafic syenites in the central part of the area must have been emplaced late in the sequence, as clasts of these rocks were never found in the agglomerates or breccias. Carbonatite dikes, which crosscut quartz-feldspar-carbonate-sericite rocks and some tuffs, appear to be some of the youngest igneous rocks in the sequence.

CARBONATITES AND SYENITE GNEISS COMPLEXES IN METAMORPHOSED PRECAMBRIAN TO EARLY CAMBRIAN STRATA, OMINECA BELT

MANSON CREEK AREA (93N/9)

Syenite, monzonite and carbonatite occur together on both the Lonnie (Granite Creek) and Vergil (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. Exposures are in trenches, between 1000 and 1100 metres elevation, 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 (latitude 55°40′45″N, longitude 124°23′15″W). The Vergil showing, approximately 5.5 kilometres from the nearest road, is accessible by helicopter or on foot (latitude 55°42′45″N, longitude 124°25′15″W).

At both showings, the intrusive rocks occur in single, northwest-trending, sill-like sheets within uppermost Precambrian metasedimentary rocks of the Wolverine Complex (Lang *et al.*, 1946). Both intrusive rocks and hostrocks have been deformed and metamorphosed to lower amphibolite facies. The hostrocks include psammitic to semipelitic mica schists, micaceous quartzites and some marbles which strike southeasterly (150°-170°) and dip steeply to the southwest (70°-80°) 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 27); 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 carbonatite 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

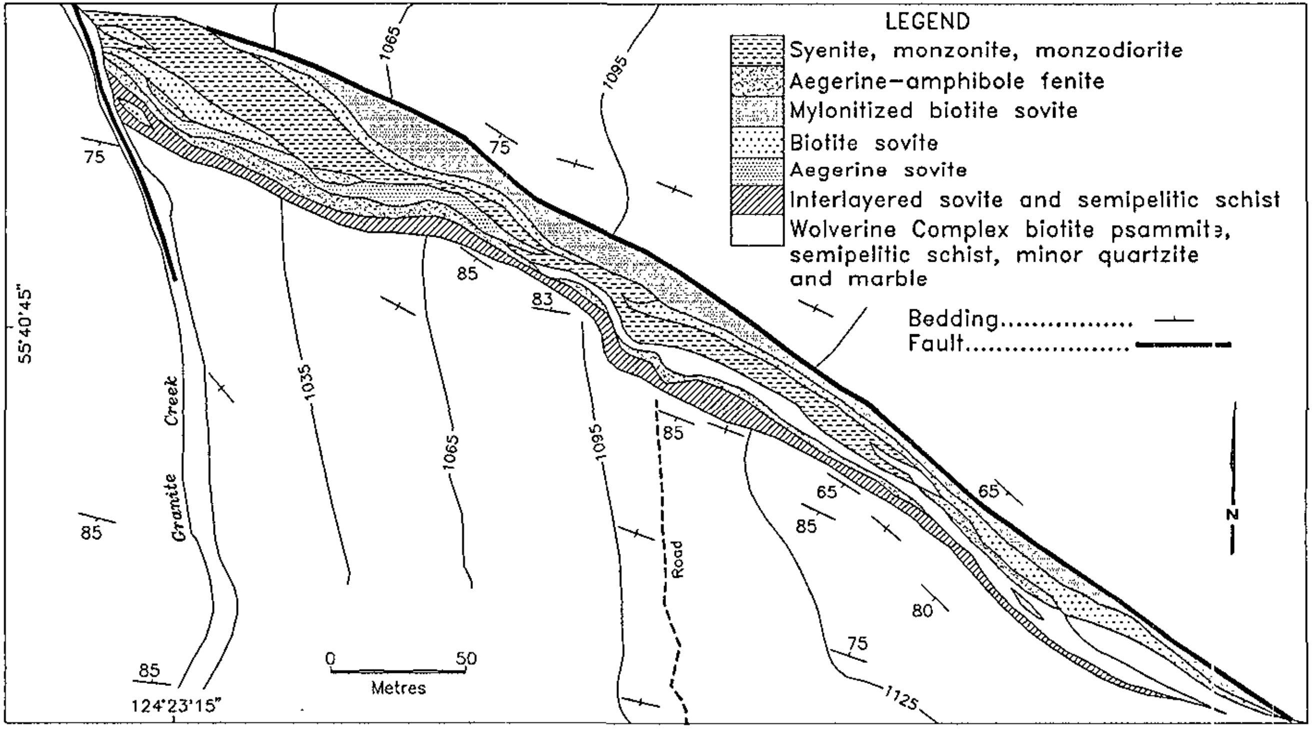


Figure 27. Geological map of the Lonnie (Granite Creek) carbonatite complex (contours metric), after Rowe, 1958.

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%), magnetite and pyrochlore as accessory minerals. The biotite sovite may also contain zircon; columbite, ilmenorutile and ilmenite have also been reported (Hankinson, 1958). At the Lonnie showing, aegirine sovite occurs along the southwestern margin of the complex and biotite sovite along the northwestern margin (Figure 27). The biotite sovite is variably mylonitized, with the most intense shearing near the contact with the country rocks. Enrichment in zircon, pyrochlore, columbite, pyrite and pyrrhotite has been noted near the contacts of the sovites with syenites (Hankinson, 1958).

SILICATE PHASES

Feldspathic intrusive rocks, monzodiorite, monzonite and syenite, outcrop as lenticular masses separating the carbonatite units (Figure 27). These intrusive rocks consist of potassium feldspar (orthoclase or microcline) and plagioclase in varying proportions; plagioclase greatly exceeds potassium feldspar in the monzodiorites, in the monzonites the proportions approach equality and potash feldspar greatly exceeds plagioclase in the syenites. All phases contain accessory muscovite, biotite, calcite and apatite. Nepheline syenite is also locally present and contains significant amounts of zircon (3-15%).

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 (Plate 14) 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 as magnesio-arfvedsonite (Mäder, 1986, 1987). Trace constituents in fenites 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

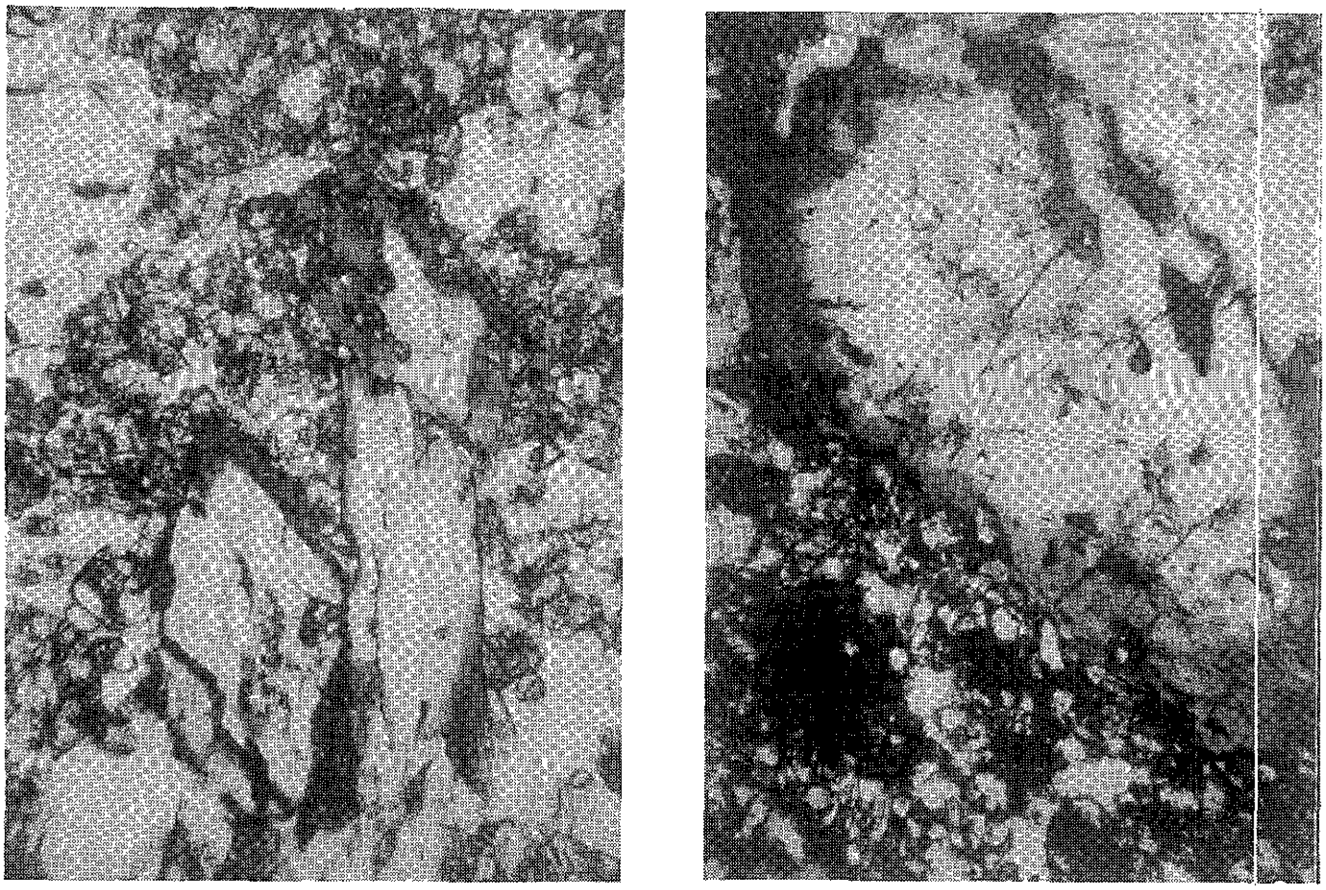


Plate 14. Blue pleochroic amphibole (magnesio-arfvedsonite) and finer grained aegirine (light green) in ultrafenite, Lonnie area. Long dimension of photomicrograph is 2.5 millimetres, *(colour photo, page 135).*

coarse-grained arfvedsonite, magnetite and feldspar segregations are developed locally.

GEOCHEMISTRY

Carbonatites in the Manson Creek area are all true sovites, no magnesio- or ferrocarbonatites were observed (Figure 28; Table 7). Aegirine sovites are depleted in silica and aluminum and enriched in strontium, relative to biotite sovites. Fenites are notably enriched in iron and sodium, relative to other lithologies (Figure 29; Table 7). With increasing degree of fenitization, that is from recognizable metasediments to ultrafenite, the rocks exhibit a systematic increase in iron and alkalis relative to calcium (Figure 30a) and fenitization appears to be a combination of 'typical' iron-magnesium and alkali fenitization trends. The fenites, even ultrafenites (aegirine and arfvedsonite rich) are enriched in sodium relative to typical pyroxene-amphibole fenites (Figure 30b).

Syenitic rocks are quite varied in composition (Figures 29 and 31; Table 7) but, on average, plot within the miaskitic

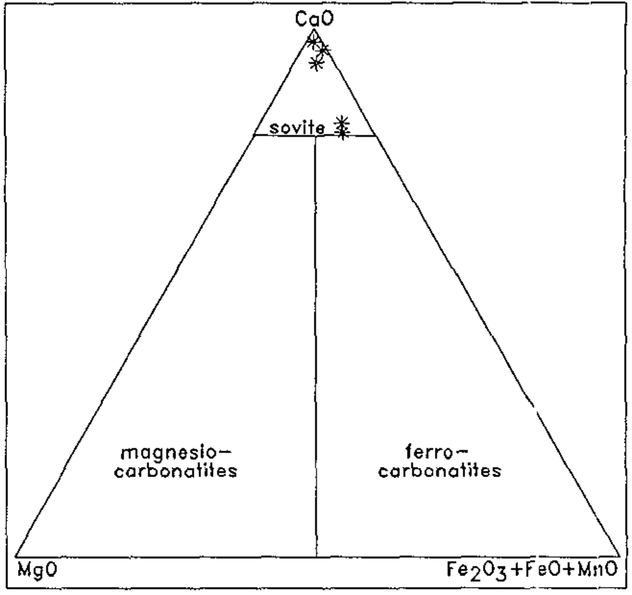


Figure 28. CaO-MgO-Fe_2O_{3t}+MnO carbonatite plot, Lonnie complex.

TABLE 7
CHEMICAL ANALYSES OF ALKALINE ROCKS, MANSON CREEK AREA

	Carbonatites					Syenites and contact syenites						Fenite				
wt %	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SiO2	1.70	13.70	12.70	7.81	12.00	44.00	56.70	51.09	53.77	32.88	36.44	44.50	35.96	38.82	73.15	57.82
TiO2	0.02	0.67	0.71	0.01	0.08	0.03	0.02	0.53	0.03	0.40	0.20	0.66	0.38	0.28	0.60	0.83
Al2O3	0.36	6.79	7.57	2.22	3.06	14.30	16.70	14.93	15.38	11.74	12.14	3.65	2.48	3.26	11.61	7.46
Fe2O3T	1.40	6.21	5.70	0.37	1.44	0.80	0.59	5.39	0.57	4.84	2.63	19.60	11.66	6.91	4.52	18.69
MnO	0.59	0.37	0.24	0.16	0.28	0.23	0.11	0.26	0.15	0.25	0.37	0.24	0.30	0.34	0.24	0.16
MgO	0.31	2.20	1.85	0.60	1.21	0.17	0.12	1.73	0.18	1.36	1.15	2.48	2.11	1.13	1.11	2.19
CaO	52.90	36.60	36.10	48.29	43.72	16.30	6.09	8.85	9.78	23.12	20.19	10.90	14.56	24.21	0.34	1.34
Na2O	0.44	1.21	3.48	0.36	0.99	4.97	6.94	5.57	5.37	3.53	2.46	10.30	5.79	3.99	5.55	10.33
K2O	0.12	2.45	2.04	0.49	0.19	5.36	5.84	1.89	4.82	1.50	4.43	0.24	0.50	1.14	1.61	0.27
LOI	41.13	26.58	26.66	38.89	34.38	12.11	4.41	7.98	7.48	17.47	17.89	6.56	11.48	18.06	0.77	0.46
P2O5	0.13	2.64	2.20	0.11	2.14	1.47	0.61	1.05	1.29	1.65	0.34	0.76	0.71	1.13	0.05	0.04
Total	99.10	99.42	99.25	99.31	99.49	99.71	98.13	99.27	98.82	98.74	98.24	99.89	85.93	99.27	99.55	99.59
ppm																
Ni	< 2	< 2	< 2	2	9	4	4	4	8	7	5	5	5	6	28	33
Cr	< 20	9	7	< 20	< 20	36	52	15	14	< 20	< 20	153	34	24	77	62
Co	7	10	10	8	7	5	3	12	11	9	9	< 5	2	8	38	31
Sr	12009	6907	6643	8780	7959	4125	1110	1940	3143	5360	6738	1506	2303	5095	233	32
Ba	986	1455	1097	1926	662	2634	2230	1321	2752	1191	2479	129	215	387	2084	43
Zr	76	127	77	154	385	2030	10363	1062	170	298	322	756	641	198	2324	311
Nb	< 5	306	78	2	43	1444	884	1589	2465	358	1274	883	19	387	253	17
Y	62	69	54	66	77	46	78	44	33	56	53	16	19	36	90	11
La	347	401	371	345	398	135	43	247	222	265	254	88	102	190	173	22
Ce	600	741	673	483	660	286	107	426	398	470	392	172	176	325	130	31
Nd	179	245	206			102	35					56				
Yb	7.7	6.2	5.2			3.8	3.5					2.1				
Sc	46	30	31	41	37	11.2	4.1	7.2	8.4	20.5	18.5	16.8	16.3	23	4.8	17
Ta	< 2	2	<2	< 2	< 2	17	37	11	25	9	3	< 2	< 2	< 2	8	< 2
Th	< 6	< 6	< 6	< 6	< 6	8	17	28	25	< 6	6	18	8	65	244	19

1-L4179C	*aegirine sovite, Lonnie claims*
2-L4242B	*biotite sovite, Vergil claims*
3-L41184	*biotite sovite, Lonnie claims*
4-L4242C	*white, massive sovite, Vergil claims*
5-L4252	*carbonatite breccia, Vergil claims*
6-L4197B	*syenite, Lonnie claims*
7-L4240B	*syenite, Vergil claims*
8-L4250	*syenitic breccia, Vergil claims*
9-L4174A	*massive syenite, Lonnie claims*
10-L4248	*mixed syenite/carbonatite, Vergil claims*
11-L4197D	*carbonatite/syenite contact, Lonnie claims*
12- L4174B	*ultrafenite, Lonnie claims*
13- L4197E	*ultrafenite, Lonnie claims*
14- L4179E	*banded, calcareous fenite, Lonnie claims*
15- L4178	*fenitized metasediment with carbonatite veinlet, Lonnie claims*
16- L4174D	*fenitized metasediment, Lonnie claims*

Samples 1,2,3,6,7,12,- major elements analyzed by ICAP; trace elements by XRF; REE by INAA at Bondar-Clegg.

Samples 4, 5,8,9,10,11,13,14,15,16,- Major and trace elements by XRF.

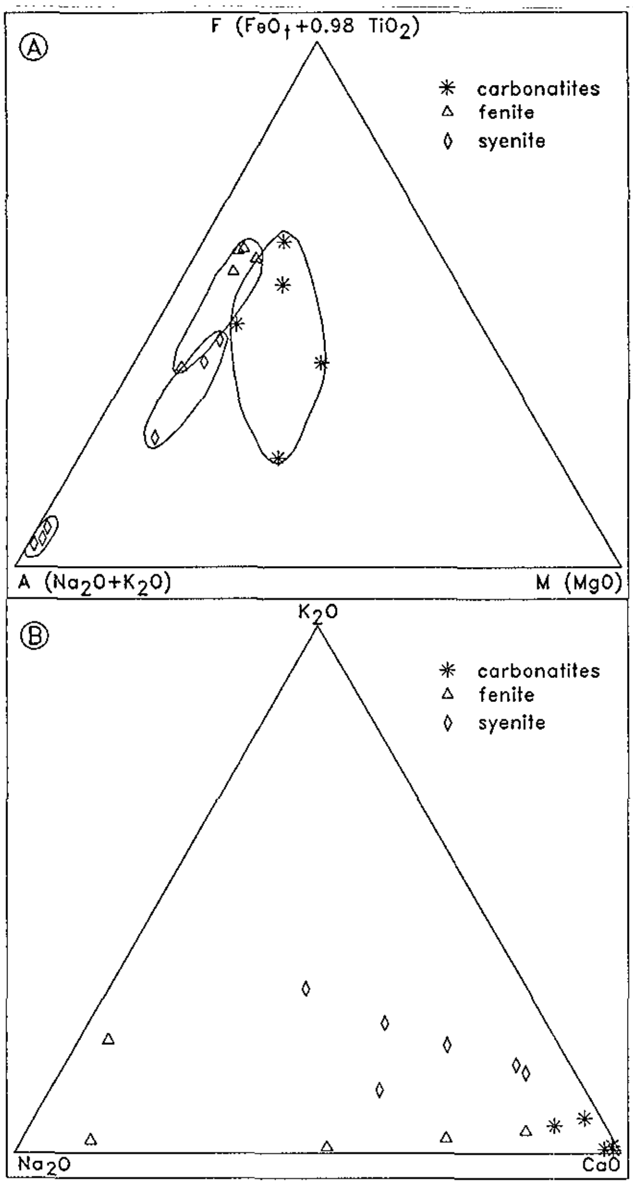


Figure 29. Major element ternary plots, Manson Creek area carbonatite complexes.

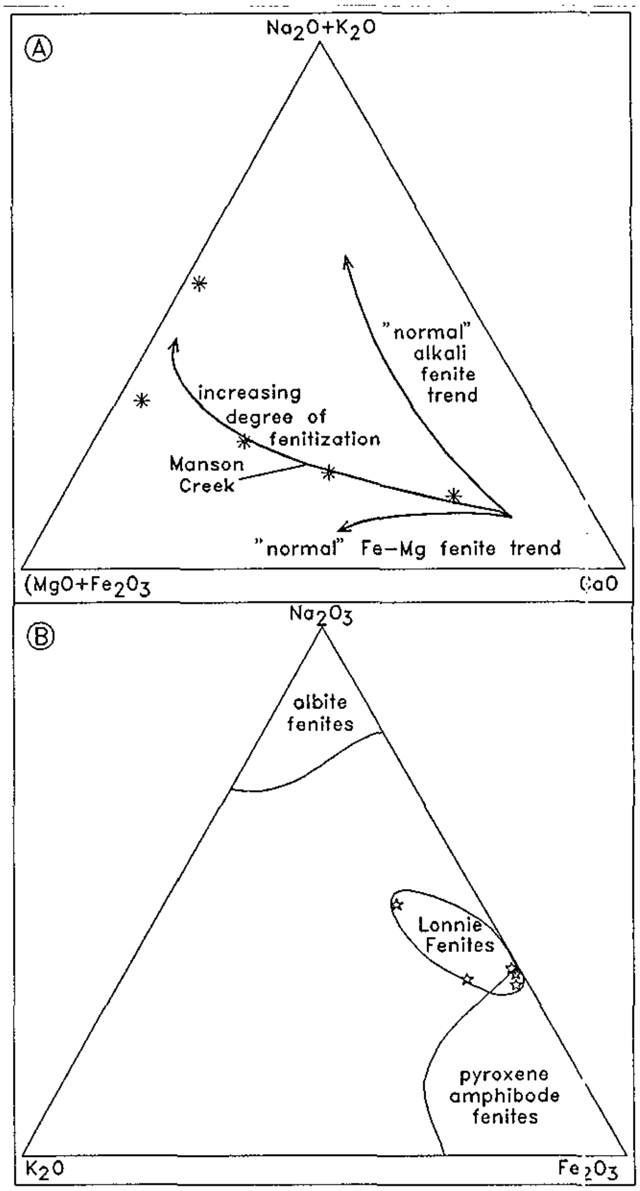


Figure 30. Ternary fenite plots, Manson Creek area carbonatite complexes.

syenite field (Figure 31). These rocks may contain significant amounts of zirconium, up to 1.23%, and are enriched in barium and niobium relative to other igneous and metasomatic rocks in the area. Niobium pentoxide values of between 0.1 and 0.3% have been reported from the Lonnie showing. A zone in the centre of the property averages 0.3% Nb_2O_5 across a width of 7.6 metres and a length of 240 metres (Vaillancourt and Payne, 1979).

Rare-earth element abundances of rocks in the Manson Creek area are uniformly low, compared to those at Aley, Kechika River and Rock Canyon Creek (Appendix 1) and, as indicated by the shallow slope on chondrite-normalized plots, the light rare-earth enrichment is not as marked (Figure 32).

GEOCHRONOLOGY

The Lonnie and Vergil carbonatites contain zircon, pyrochlore and other uranium-bearing minerals that are amenable to uranium-lead geochronology. Zircons from samples collected from the Lonnie and Vergil carbonatite-syenite complexes are generally large crystals that are equant and clear. Analyses from these samples are discordant, but indicate a uranium-lead age of 340 Ma and lead-lead ages of 351 to 365 Ma (Appendix 2), which is similar to the age of the zircons from the Ice River complex in the Rocky Mountains. Preliminary uranium-lead systematics do not yield precise ages for these zircons, but do suggest that the Lonnie and Vergil carbonatites were emplaced in Late Devonian to early Mississippian time.

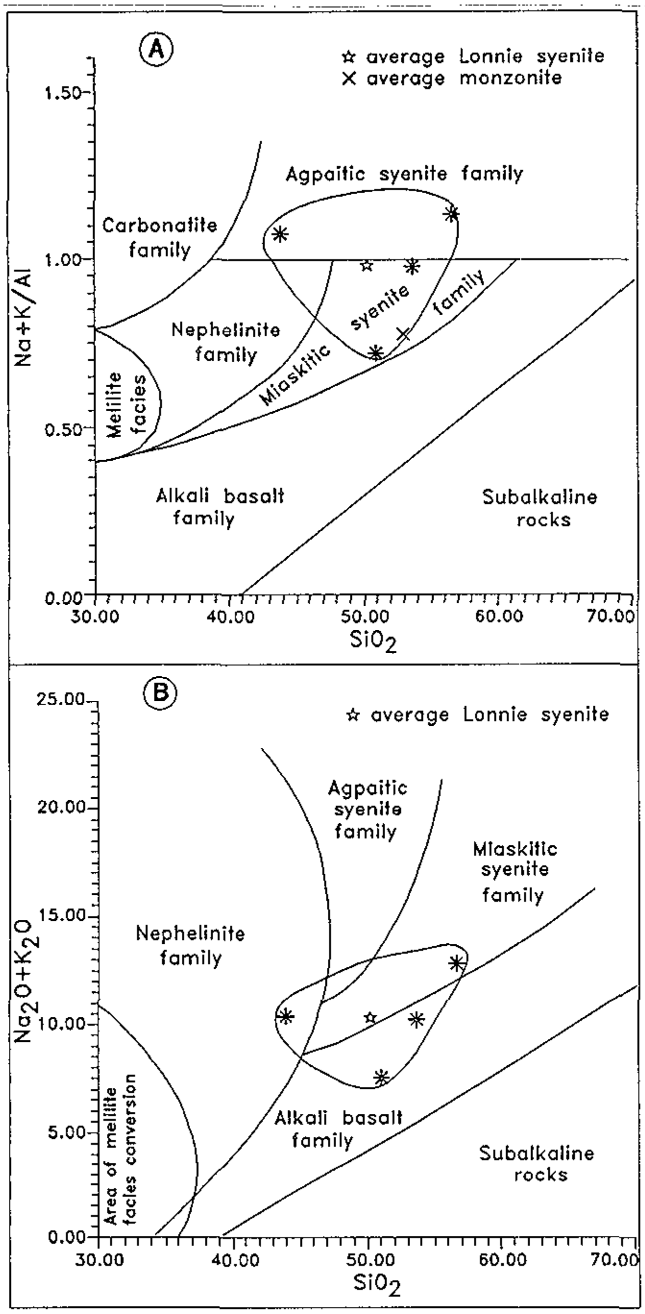


Figure 31. Alkali-silica and agpaitic index plots, Lonnie complex silicate rocks. (A) Agpiatic index plot - Lonnie complex silicate rocks; (B) Lonnie - alkali vs silica diagram.

MOUNT BISSON - MUNROE CREEK AREA (93N/9; 93O/5, 12)

Alkalic syenites are exposed in the Mount Bisson – Munroe Creek area of north-central British Columbia (latitude 55°31′00″N, longitude 124°00′00″W), 64 kilometres northwest of the town of Mackenzie (Figure 1). They were discovered in 1986 and 1987 by A.A.D. Halleran. The mineralogy and field relationships were described by Halleran (1988) and Halleran and Russell (1990) and are summarized from these works.

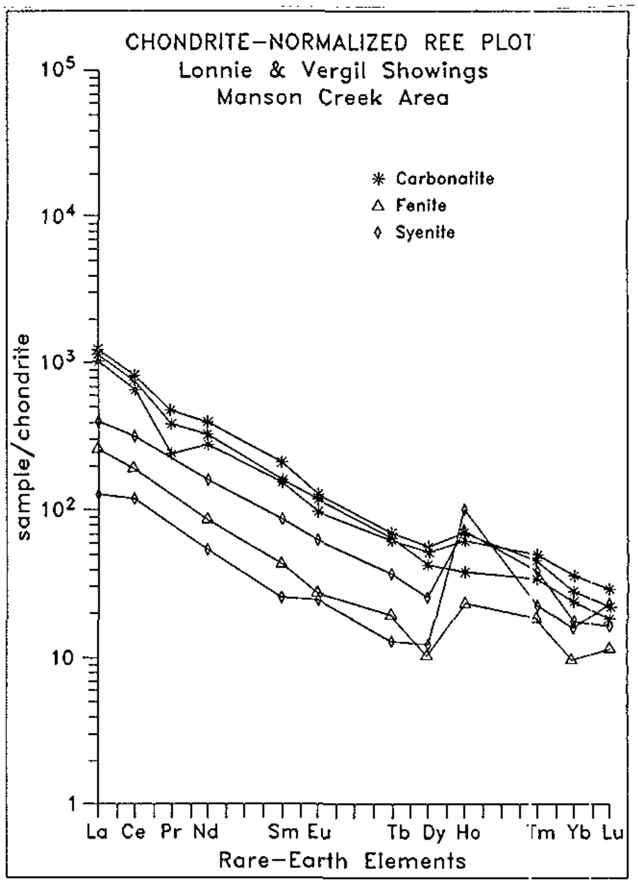


Figure 32. Chondrite-normalized REE plots, Lonnie and Vergil showings, Manson creek area.

The alkalic rocks are hosted by high-grade metamorphic rocks assigned to the Wolverine complex, of probable late Proterozoic age, and are exposed in a 5 by 10 kilometre area, south and east of the Manson River, in the Wolverine Ranges of the Omineca Mountains. Within this area, a number of discrete alkalic dikes and dike swarms are present, associated with alkalic pegmatite dikes or segregations, intrusive breccias and large metasomatic alteration halos (fenites); unfoliated, fine-grained quartz monzonite to quartz syenite intrusions are also present, but may or may not be related to the alkaline syenites. The relationship between the intrusion of alkaline rocks and metamorphism is unclear from the available literature.

The area is accessible from good logging roads that run along the west side of Williston Lake from Windy Point, at the south tip of the lake, to Manson Creek.

ALKALIC DIKE ROCKS

Three types of syenite dikes are present in the Mount Bisson – Munroe Creek area: the first rich in alkali feldspar; the second containing abundant aegirine-augite; and the third a suite of rare-earth element enriched dikes which contain allanite as the main rare-earth mineral. The alkali feldspar dikes contain 90% potassium feldspar rimmed with plagioclase, and 10% mafic minerals, predominantly aegirine-augite. The aegirine-augite dikes contain, on average, 40 to 60% aegirine-augite grains, up to 1.5 centimetres across, 35% perthite, 3% sphene with rare allanite inclusions, 1% apatite and traces of allanite, magnetite, chalcopyrite and malachite. These dikes are banded, with the mafic minerals concentrated in thin, discrete zones. The allanitic dikes are also rich in aegirine-augite; they consist of approximately 80% aegirine-augite, 8% potassium feldspar, 5% apatite, 3% allanite and 2% sphene, with accessory calcite and biotite.

PEGMATITES

Two types of alkalic pegmatites are described by Halleran and Russell (1990), aegirine-augite pegmatites and allanite pegmatites. They occur in zones 1 to 4 metres wide by in excess of 30 metres long; it is unclear, however, whether they are distinct dikes or, simply, coarse-grained segregations or pods within fenite zones. The aegirine-augite pegmatites contain zoned antiperthite (An_{23}), subhedral aegirine-augite grains [with inclusions of plagioclase (An_{34}), sphene, hornblende and biotite], minor perthitic potassium feldspar, occasional elongate quartz crystals and late, fracture-filling epidote. The allanite pegmatites consist of perthite, up to 35% allanite, 5% sphene, plagioclase (An_{25-27}), apatite and minor to trace amounts of aegirine-augite, quartz, zircon and opaques. Allanite crystals are 0.03 to 2.0 centimetres in size and commonly occur with sphene and apatite. Late quartz veins, up to 5 centimetres wide, locally cut the allanite pegmatites.

INTRUSIVE BRECCIAS

An intrusive breccia zone, over 40 metres long, is exposed in one area. It consists of intrusive clasts supported by a fine-grained, green matrix which contains 25% relic potassium feldspar, 10% plagioclase, altered blue-green amphibole and traces of sphene and apatite.

FENITES

Fenitized Wolverine Complex rocks are exposed over a broad area. The fenites are generally banded, with melanocratic layers consisting of aegirine-augite, sphene, allanite, apatite and minor hornblende, and leucocratic layers dominated by plagioclase or potassium feldspar and apatite. Banding in the fenites reflects original bedding or layering in the Wolverine rocks which the fenite zones grade into; melanocratic bands were probably amphibolite or biotite schist layers while the leococratic bands were probably original quartzofeldspathic layers. Fenites are differentiated from hostrocks by the presence of aegirine-augite and rare-earth element bearing minerals, an increase in alkali feldspar and a decrease in quartz.

QUARTZ MONZONITES AND QUARTZ SYENITES

Fine-grained, massive, leucocratic quartz monzonite and quartz syenite intrusions are also present in the Mount Bisson – Munroe Creek area. They are very fresh in appearance and may be unrelated to the more alkaline rocks. There are at least four large intrusions (1 by 3 km in size) and a number of smaller satellite bodies. They contain quartz, plagioclase (An_{22-24}), potassium feldspar, biotite, chlorite and traces of magnetite, allanite, apatite and zircon.

GEOCHEMISTRY

No detailed geochemical data are available from the alkaline rocks in the Mount Bisson – Munroe Creek area; however, data on elements of commercial interest have been published (Halleran and Russell, 1990). Niobium reportedly occurs in concentrations of up to 0.8% and rare-earth elements are present in some pegmatites and dike-rocks in concentrations of 0.3 to 14.0% and 0.8 to 4.26%, respectively.

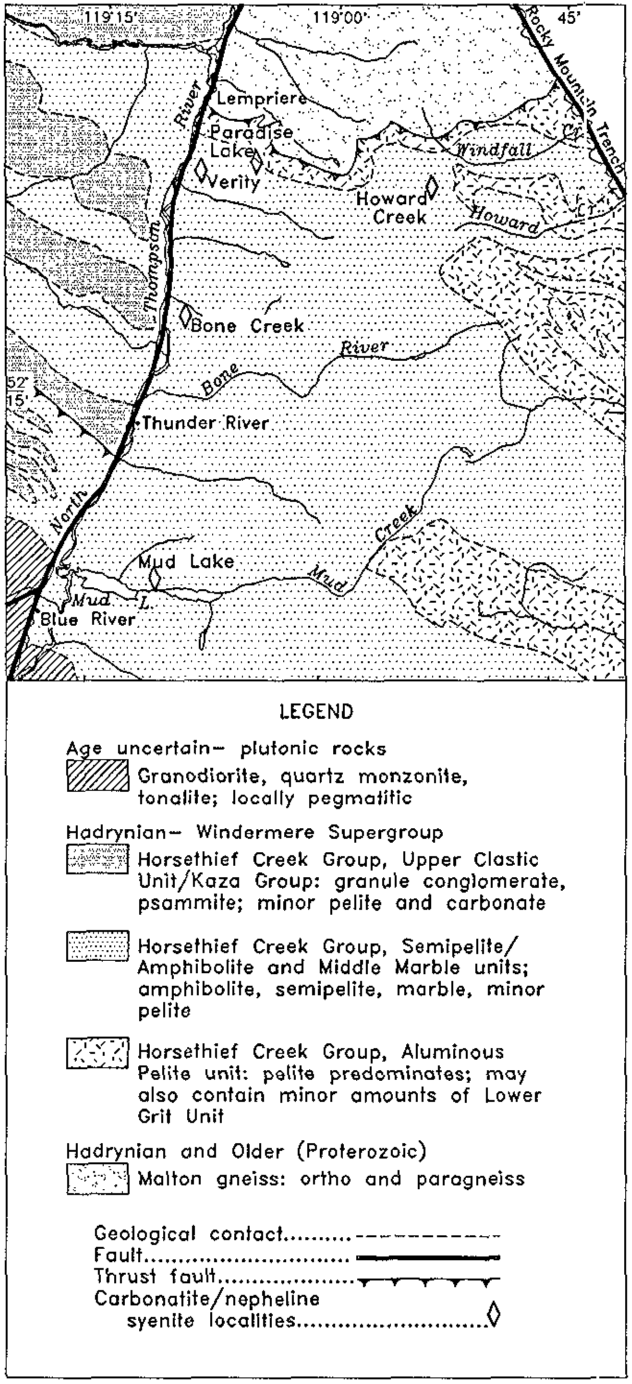


Figure 33. Geology and carbonatite/syenite localities in the Blue River area.

These values represent total rare-earth concentrations; however, the values are mainly in the light rare earths. Fenites contain 0.07 to 0.64% light rare earths over widths of 1 to 2 metres.

GEOCHRONOLOGY

No absolute dating has been done on the alkaline rocks. They obviously postdate the Late Proterozoic rocks of the Wolverine Complex; from published data, the timing of emplacement relative to metamorphism is unclear and an upper limit on the age difficult to establish. Within the sequence, the syenitic dikes appear to be the latest alkaline rocks emplaced as they crosscut both the alkaline pegmatites and the fenites.

Quartz monzonites and quartz syenites probably postdate the alkaline rocks and may be completely unrelated to them; angular fenite xenoliths are reported to occur within the quartz-bearing intrusions. From descriptions given, these intrusions sound as if they are postorogenic; however, until some radiometric dating is completed, their ages will remain unknown.

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

A number of carbonatite and nepheline syenite 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 (Figures 1 and 33). All are sill-like bodies which were intruded prior to the deformation and metamorphism associated with the Columbian orogeny. The carbonatites, syenites and hosting sedimentary rocks have been subjected to three phases of deformation (Plate 15) and metamorphosed to upper amphibolite grade (kyanite to sillimanite zone). The Mud Lake (83D/3, latitude 52°07′55″N, longitude 119°10′44″W), Bone Creek (83D/6, latitude 52°17′09″N, longitude 119°09′42″W) and Verity (83D/6, latitude 52°23′51″N, longitude 119°09′13″W) showings (Figure 33) occur below treeline at elevations between 600 and 900 metres; consequently exposure is limited. The Paradise Lake (83D/6, latitude 52°24′19″N, longitude 119°05′47″W) and Howard Creek (83D/7, latitude 52°23′00″N, longitude 118°53′26″W) carbonatites are above treeline, well exposed and were mapped in detail (Figures 34, 35a and 35b).

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, three kilometres north of Blue River. All roads are passable with four-wheel-drive vehicles. The

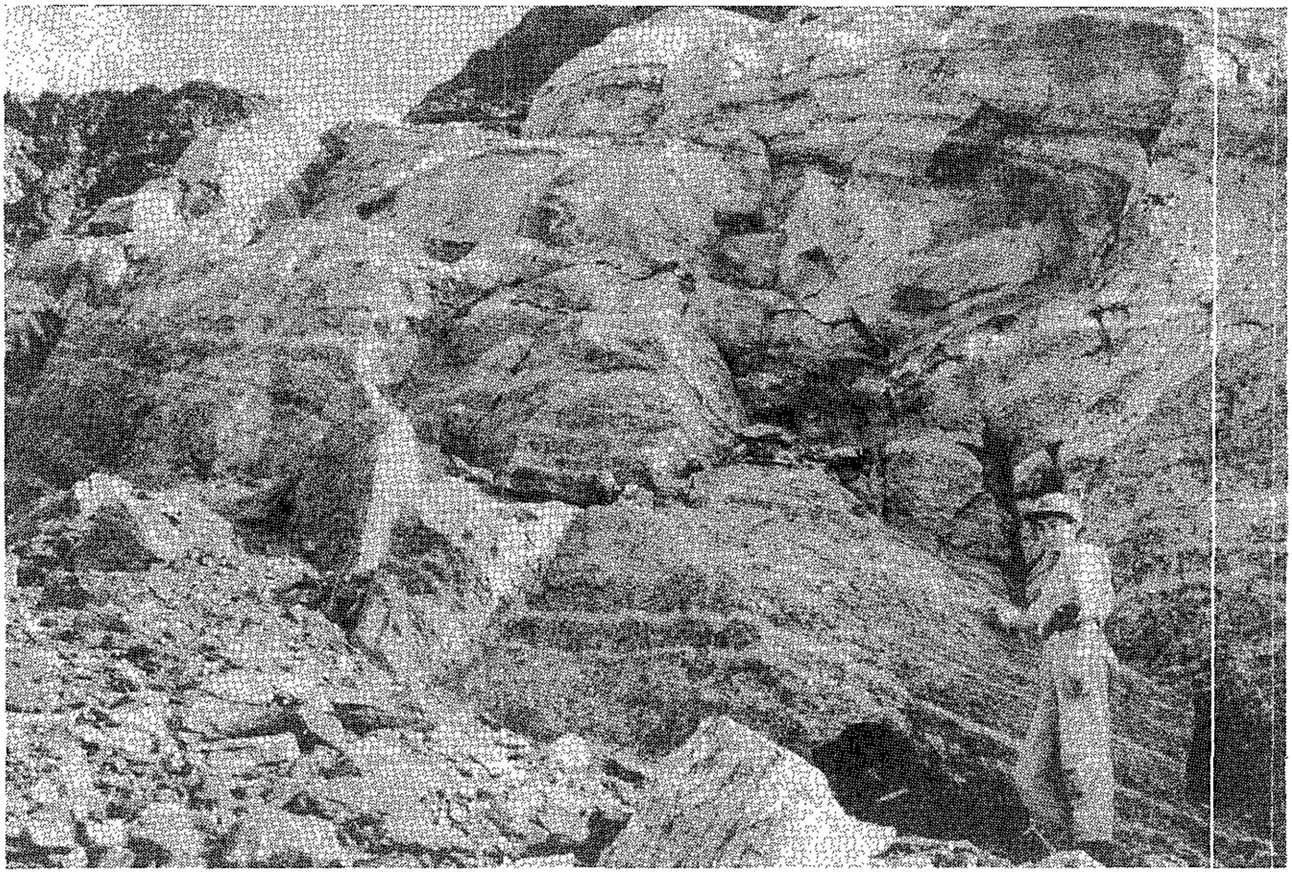


Plate 15. F_2 folds in banded nepheline syenite, Paradise Lake.

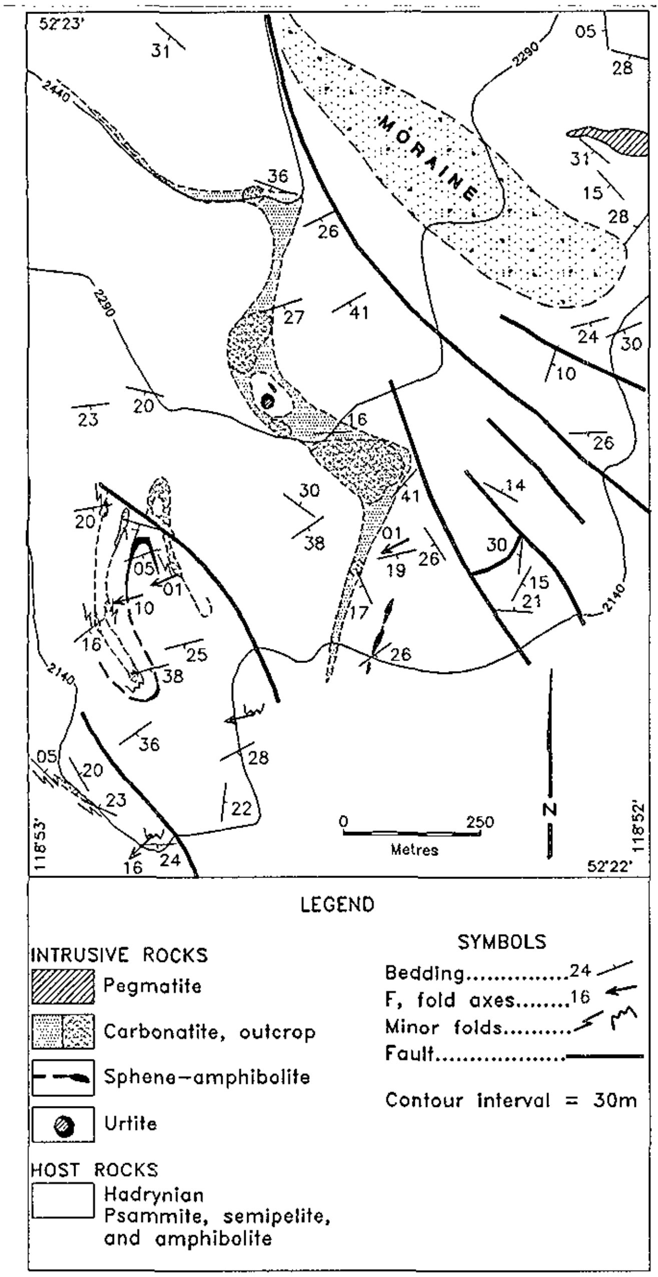


Figure 34. Geological map of the Howard Creek carbonatite occurrence.

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 (1951, 1953, 1955), Rowe (1958), Currie (1976a), Meyers (1977), Ahroon (1979, 1980), Aaquist (1981, 1982a, 1982b, 1982c), White (1982, 1985) and Pell (1987). 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. One is a whitish weathering olivine sovite which contains predominantly calcite (60-85%), olivine (3-20%) and apatite (2-20%). Accessory minerals which may be present are phlogopite (Plate 16), with either normal or reverse pleochroism (up to 8%), diopside (10% 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 long and magnetite clusters over 20 centimetres in diameter. Zircon crystals up to 3 centimetres long have also been found.

The second type is a buff-weathering dolomitic carbonatite (rauhaugite) with accessory amphibole (5-15%), apatite (2-10%), 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 (Plate 17). Pegmatitic segregations are not found in the rauhaugite, but coarse pyrochlore and zircon crystals (1-1.5 cm long) may be present. Separate bands of sovite and rauhaugite occur at Verity, Paradise Lake and Howard Creek. Rauhaugite is present at both the Mud Lake and Bone Creek localities.

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 (Figure 35). In general, the syenites comprise white to grey-weathering, medium-grained, layered and foliated gneisses, concordant with hostrocks of the Hadrynian Horsethief Creek Group. 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 (25-35%), plagioclase (An_{30} - An_{40}, 25-35%), nepheline (10-30%) and biotite (7-15%). 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 composed of either nepheline, microcline, plagioclase and sodalite or large perthite crystals (Plates 18 and 19).

MAFIC SILICATE ROCKS

Mafic and ultramafic silicate rocks are present at Howard Creek (Figure 34). The most common variety is

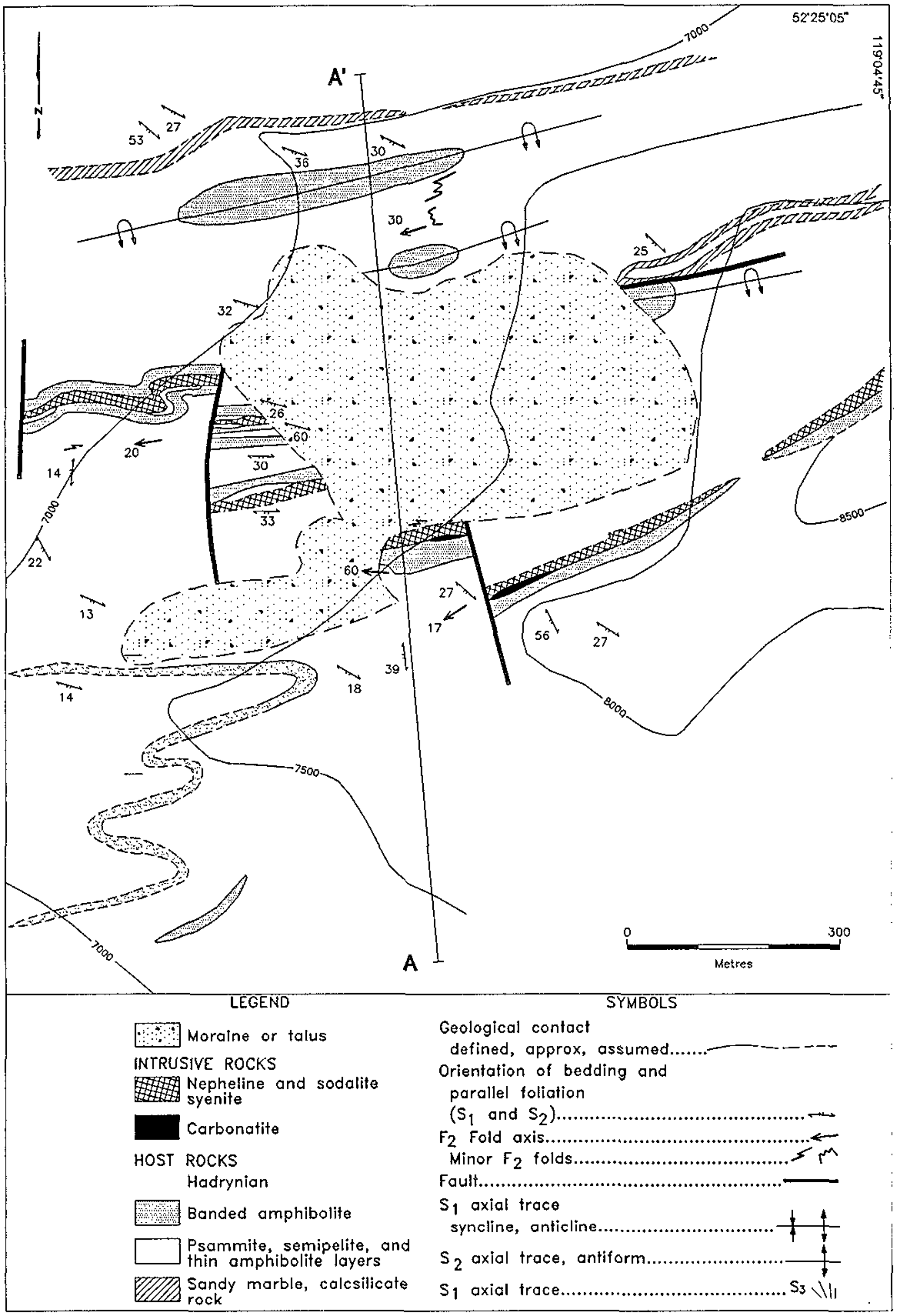


Figure 35. (A) Geology of the area south of Paradise Lake; (B) (Next page) Cross-section A-A', area south of Paradise Lake.

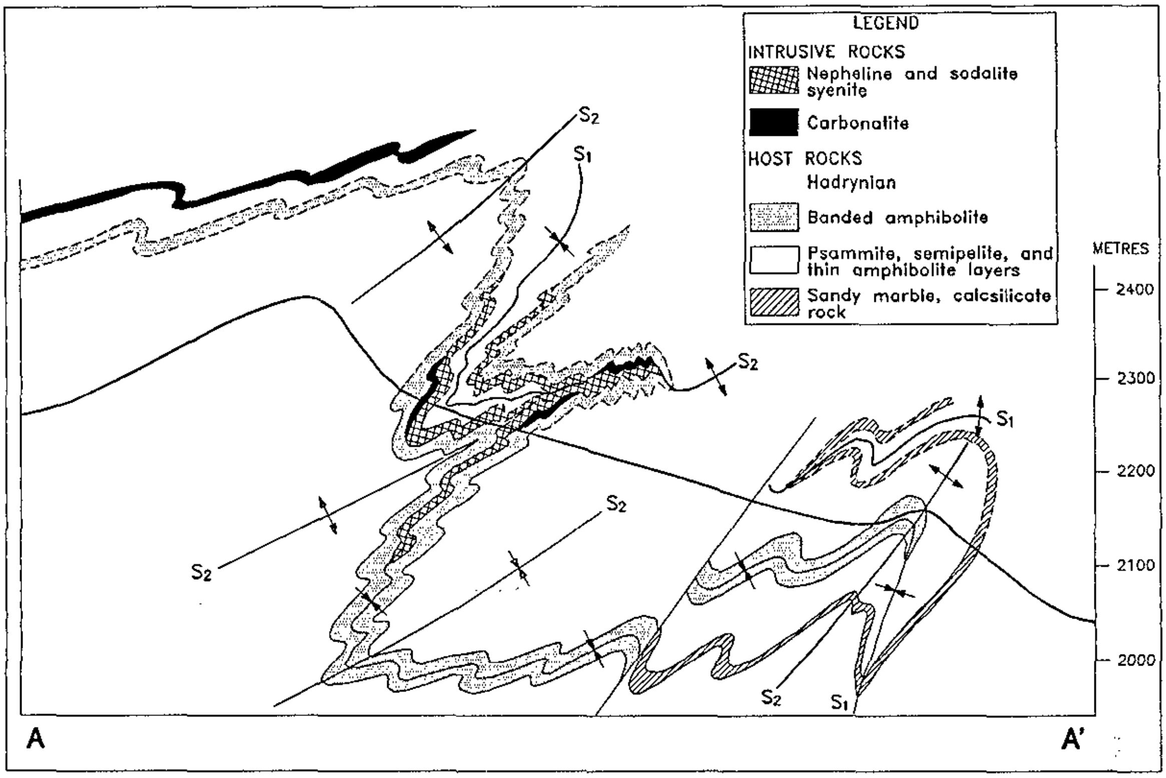


Figure 35B (continued)

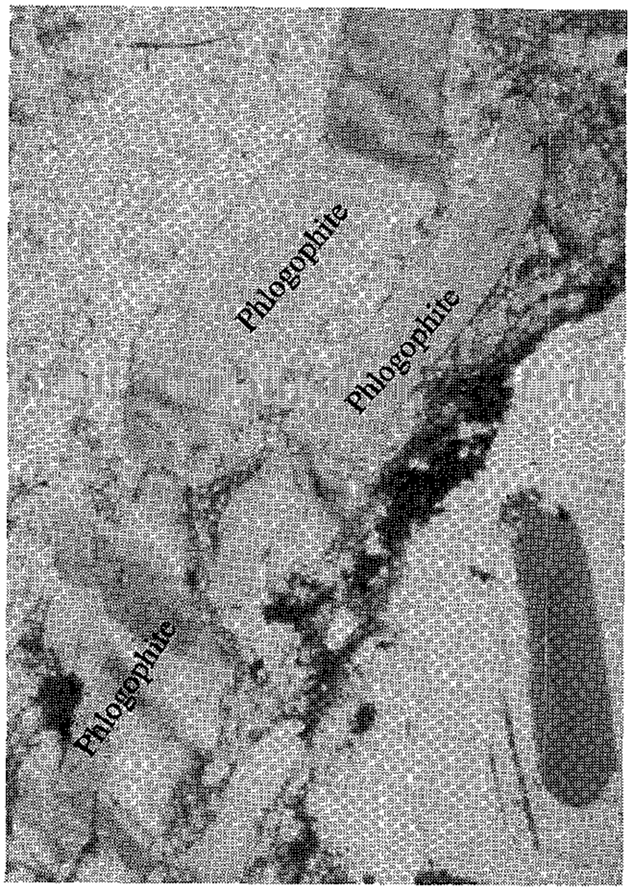


Plate 16. Phlogopite in carbonatite with reverse pleochroism and distinctive orange colour, from Verity. Long dimension of photomicrograph is 2.5 millimetres, *(colour photo, page 136).*

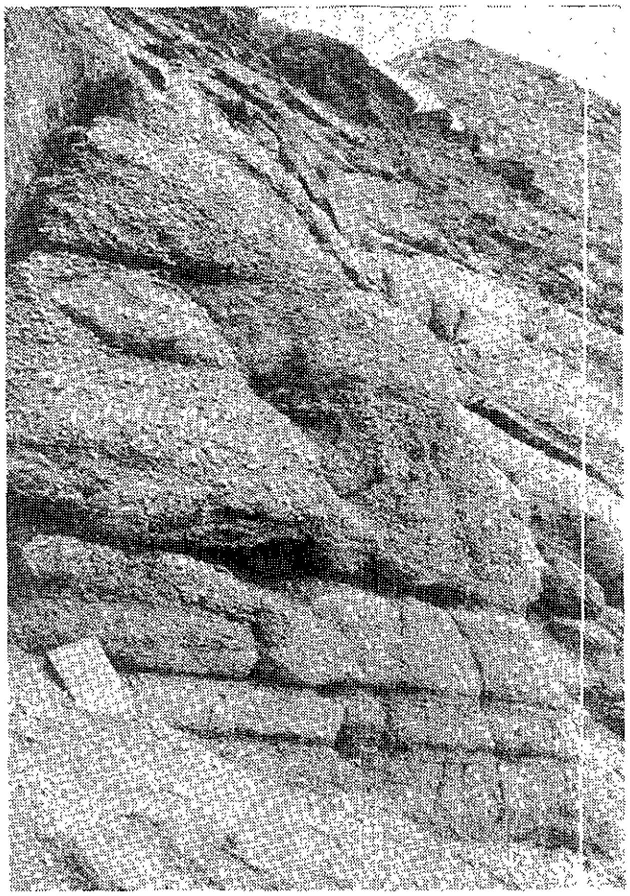


Plate 17. Well layered carbonatite, Howard Creek. Layering is produced by compositional variation within the carbonatite and is parallel to the margins of the layer, external sedimentary bedding and regional foliation.

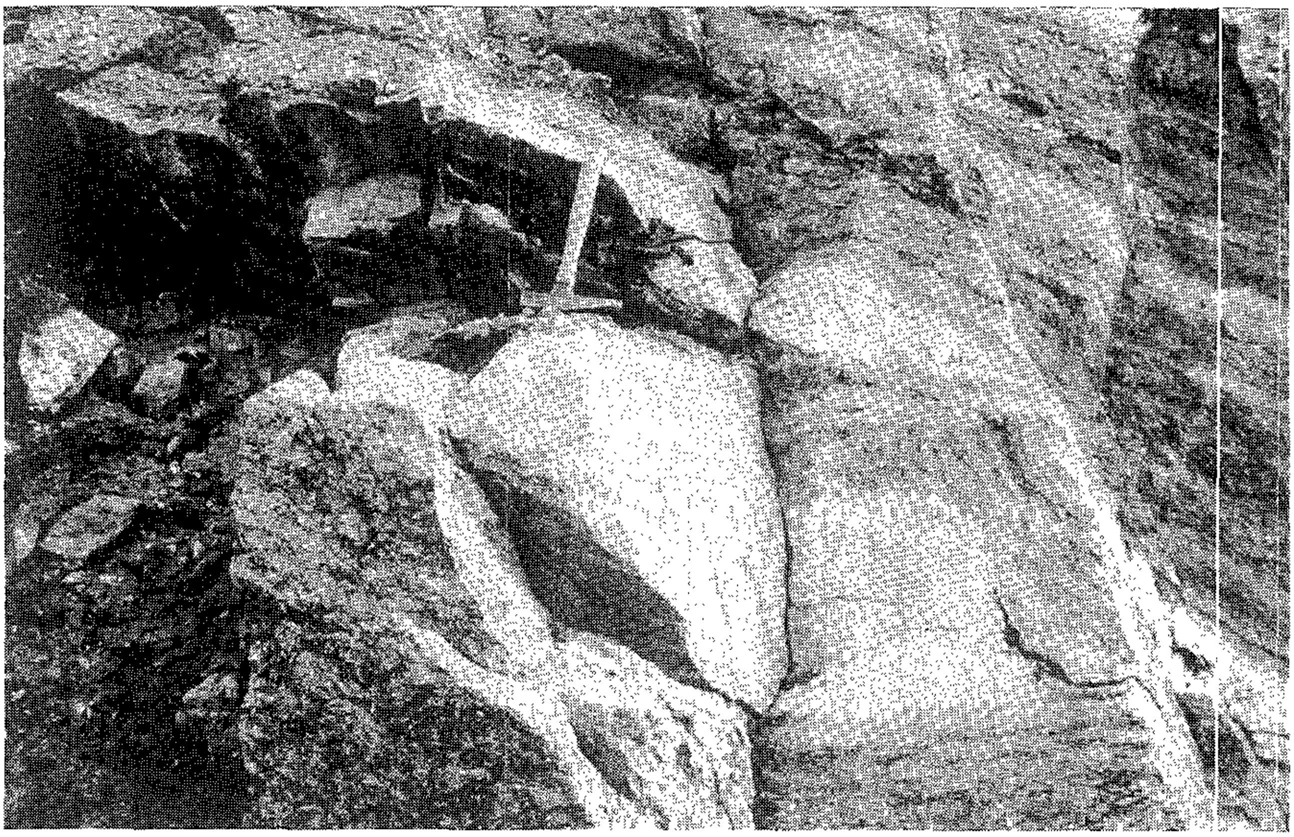


Plate 18. Migmatitic leucosome (fine-grained leucosyenite segregations) present in layered syenites, Paradise Lake.

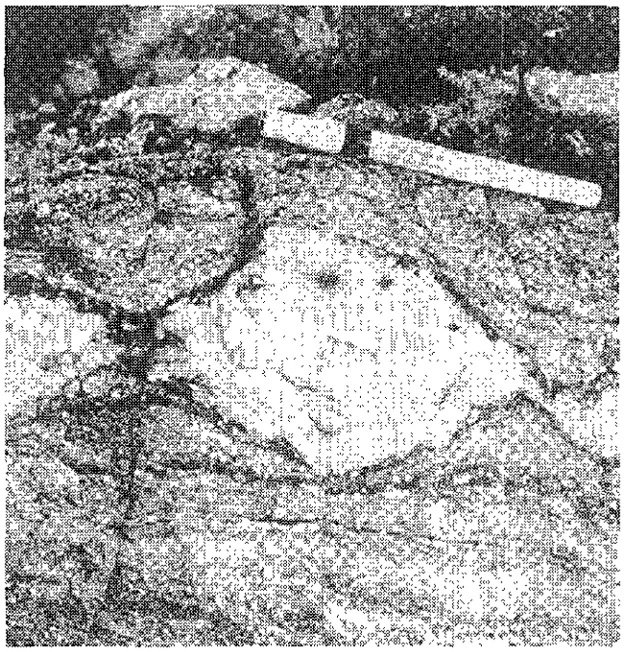


Plate 19. Migmatitic segregations of coarse perthite crystals in layered nepheline syenite gneiss, Paradise Lake.

sphene-pyroxene-amphibole rock or melteigite, which may be layered and foliated or massive. It consists of aegirine-augite (approximately 50%), strongly pleochroic hornblende (x - honey-yellow, y - dark bluish green, z - dark forest-green to opaque; 15-30%) and sphene (10-20%). Accessory minerals include nepheline, plagioclase, pyrite and calcite with or without 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 long. In the strongly foliated varieties, hornblende predominates (50-55%), with aegirine-augite, sphene and biotite abundant and calcite, plagioclase, apatite, pyrite and sometimes nepheline as trace constituents. At one locality, the melteigite is transitional to, and locally crosscut by, a coarse-grained, massive urtite composed of 25 to 40% nepheline, 10 to 15% potassium feldspar, 8 to 15% plagioclase, 8 to 15% aegirine, 15 to 20% 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. They are generally composed of amphiboles (hornblende-actinolite, 45-80%), clinopyroxene (generally diopside or augite, up to 35%), apatite and opaques. Accessory minerals which may be 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

The alkaline rocks in the Blue River area show distinct major element trends of increasing alkalis from carbonatites to syenites, with fenites most similar in composition to the carbonatites (Figure 36; Table 8). Carbonatites (both calcite

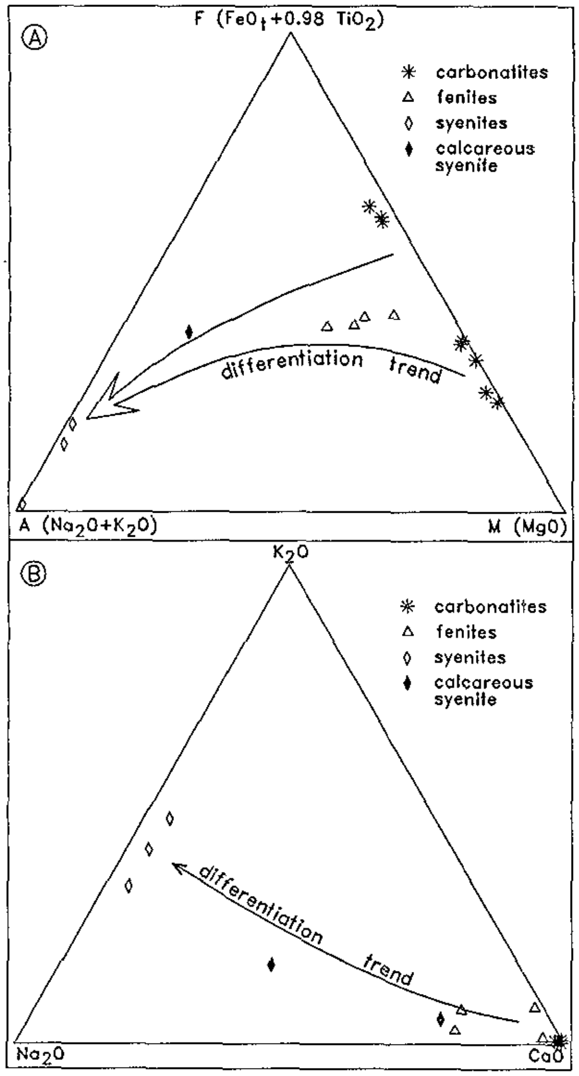


Figure 36. Major element ternary plots, Blue River area alkaline rocks.

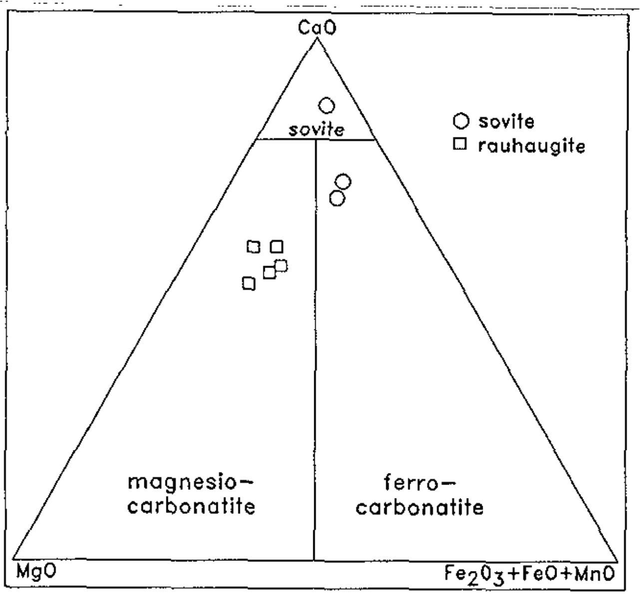


Figure 37. CaO-MgO-Fe_2O_3t+MnO carbonatite plot, Blue River area.

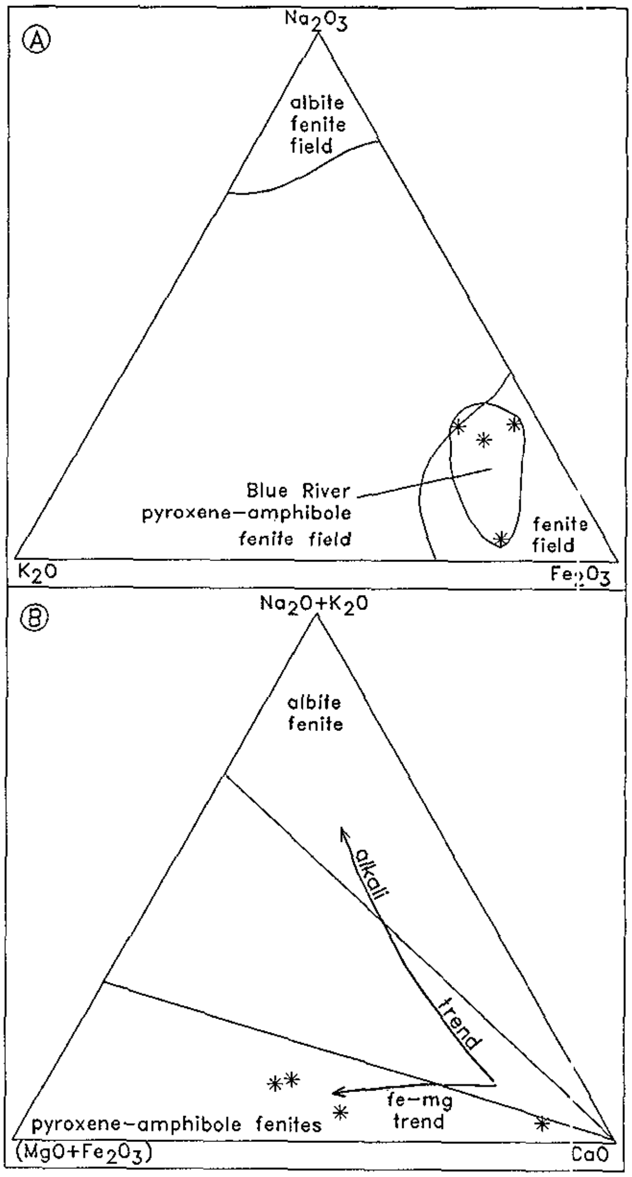


Figure 38. Ternary fenite plots, Blue River area rocks.

and dolomite-rich varieties) are distinct from marbles in the host Horsethief Creek Group; the carbonatites contain significantly less silica, aluminum and alkalis than the average *marble and are enriched in iron, phosphorus, strontium and* rare earths (Table 8). Enrichment in niobium and tantalum also occurs in the carbonatites (Table 8), Nb_2O_5 values of up to 0.46% (Aaquist, 1982b) and tantalum values to 2400 ppm (Aaquist, 1982c) have been reported. Calcite carbonatites range from true sovites to ferrocarbonatites, dolomitic carbonatites may be classified as magnesiocarbonatites (Figure 37). Fenites are all typical pyroxene-amphibole fenites, plotting within the pyroxene-amphibole fenite fields on both Na_2O-K_2O-Fe_2O_3 and CaO-Na_2O+K_2O-MgO+Fe_2O_3 plots (Figure 38a and b). Syenites from the Paradise Lake area are miaskitic, generally compositionally close to the 'average' nepheline syenite (Figure 39a and b). Alkaline rocks contain anomalous amounts of rare-earth elements, but not to the extent of many of the complexes in

TABLE 8
CHEMICAL ANALYSES, ALKALINE ROCKS, BLUE RIVER AREA

	Carbonatites								Fenites				Calcsyenite	Syenites			Other alkaline rocks			Non-alkaline rocks					
Wt %	1	2	3	4	5	6	7	8	9	10	11	12		14	15	16	17	18	19	20	21	22	23	24	25
Si02	3.82	6.60	5.26	2.73	2.03	7.60	12.30	3.10	12.00	44.12	35.86	47.04	42.30	58.20	58.20	59.20	41.03	45.30	41.80	47.10	31.80	46.60	55.80	50.80	60.50
Ti02	0.16	0.80	0.62	0.02	0.02	0.70	0.09	0.01	0.13	0.85	0.60	0.44	0.82	0.02	0.29	0.25	4.15	5.65	2.18	1.84	0.40	0.23	0.40	0.60	0.62
Al203	0.64	0.65	0.72	0.15	0.15	0.23	0.24	0.22	2.22	10.51	9.62	6.51	12.50	22.60	20.10	20.80	8.42	8.53	20.10	1.03	9.72	4.88	5.93	13.30	18.00
Fe203T	4.28	10.70	10.30	4.35	6.48	7.35	8.41	7.61	2.62	9.68	9.40	7.44	5.17	0.30	2.69	2.20	15.10	8.56	5.36	12.90	3.67	1.10	7.19	11.10	3.31
Mn0	0.21	0.23	0.24	0.31	0.38	0.21	0.41	0.37	0.24	0.27	0.20	0.22	0.18	0.01	0.04	0.03	0.41	0.23	0.12	0.34	0.06	0.15	0.19	0.20	0.03
Mg0	2.60	6.88	5.59	14.50	19.00	14.80	15.20	16.30	2.65	11.12	10.76	9.23	2.02	0.04	0.17	0.31	7.14	4.59	1.40	11.70	1.44	1.04	12.90	7.98	4.74
Ca0	45.40	39.80	40.90	28.10	28.70	32.90	30.60	29.10	42.90	15.26	16.81	20.09	14.40	0.83	0.56	0.69	13.58	16.80	8.20	23.10	28.70	23.50	14.90	11.50	5.35
Na20	0.10	0.15	0.15	0.10	0.27	0.11	0.05	<0.03	1.11	3.60	3.28	0.40	4.06	8.27	7.48	9.70	2.08	4.46	9.52	0.12	1.01	1.13	0.54	2.66	3.99
K20	<0.10	0.38	0.48	<0.10	0.25	0.29	0.12	0.12	0.59	0.60	1.53	1.66	3.78	8.07	5.49	5.08	1.71	1.20	3.50	<0.10	1.69	0.97	0.81	0.13	2.77
L0I	33.37	25.64	28.17	39.79	40.38	35.46	27.12	37.26	30.92	2.18	9.48	4.48	11.48	1.36	0.90	1.18	2.57	1.75	4.98	2.02	20.73	19.29	0.71	0.93	0.99
P205	4.12	5.93	5.45	2.52	2.12	0.21	3.44	2.98	1.32	1.92	1.18	2.12	0.94	<0.09	<0.09	<.09	0.98	1.11	0.44	0.23	<0.09	<0.09	<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	100.11	98.72	99.63	97.70	99.79	96.01	99.53	97.17	98.18	97.60	100.48	99.31	98.98	99.46	99.29	100.39
ppm																									
Ni	<2	<2	< 2	< 2	< 2	4	< 2	< 2	1	24	65	18	14	7	1	5	68	31	6	58	17	5	9	92	
Cr	< 20	< 20	< 20	< 20	< 20	2	< 20	< 20	< 20	75	88	37	44	79	43	90	83	65	43	52	104	124	127	300	
Co	10	18	16	16	28	32	18	22	8	22	25	23	12	2	4	4	39	21	13	36	11	9	7	46	
Sr	4223	2995	3372	4092	4459	1525	3276	3549	5312	534	1334	1641	3604	885	892	965	2020	3163	3965	78	2203	134	152	71	210
Ba	248	316	315	157	127	427	113	87	467	196	803	810	5310	4923	1846	3272	1573	2200	1697	12	238	161	319	36	445
Zr	159	934	712	27	30	1118	50	28	159	734	276	462	213	1266	1353	1388	842	761	313	63	119	155	303	37	430
Nb	96	41	42	470	720	109	491	117	< 5	181	185	303	119	3	275	68	403	563	276	160	3	6	16	1	
Y	76	68	67	15	9	25	22	16	68	32	33	48	34	13	12	14	85	110	46	36	19	26	42	17	
La	280	254	241	171	134	103	200	174	264	74	91	183	355	< 9	< 9	1	308	284	197	162	33	18	42	2	
Ce	539	548	530	371	279	208	415	339	470	169	187	370	561	25	< 12	4	555	664	363	302	70	32	164	15	
Nd		234	223	147	119	81	165	133					144			2		273	119	114					
Tb		4	4	1.4	1	1.8	2	1					3			1		7	3	3					
Sc	41	36	40	41	34	44	51	50	39	32	30	30	16	< 1	0.30	< 1	30	32	8	34	29	22	12	39	
Ta	19	< 2	< 2	125	178	8	82	37	< 2	11	12	38	7	6	16	7	15	33	15	10	< 2	< 2	< 2	< 2	
Th	< 6	0.11	6	< 6	< 6	< 6	0	< 6	< 6	4	17	9	4	7	15	0	22	9	< 6	< 6	5	13	20	1	

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 - V431.beforsite, Mud Lake
8 - V462B - beforsite, Mud Lake:
9 - P4328B - fenite, Paradise Lake;
10 - H4254B2 - fenite, Howard Creek;
11 - H4254 fenite with biotite, Howard Creed;
12 - H4298 - calcareous fenite, Howard Creek;
13 - P4345Fl - calcareous segregation in syenite, Paradise Lake;
14 - P4323F - white sodalite syenite, Paradise Lake;
15 - P4319 - syenite, Paradise Lake;
16 - P4323H - nepheline and sodalite syenite, Paradise Lake;
17 - S4349 - sphene amphibolite, Serpentine Creek
18 - H4273A - hornblende sphene aegirine amphibolite, meta-ijolite (?), Howard Creek;
19 - H4273B - hornblende sphene nepheline meta-urtite, Howard Creek;
20 - V467A - fine-grained basic sill, Mud Lake;
21 - P4340A - Horsethief Creek marble, Paradise Lake;
22 - LP4355C - Horsethief Creek marble, west of North Thompson River;
23 - LP4355A - Horsethief Creek, biotite amphibolite, west of North Thompson River;
24 - P4328B - Horsethief Creek amphibolite,
25 - JP4-38 - Horsethief Creek biotite schist

Samples 1 - 9, 13 - 16 and 18 - 25 had major elements analysed by ICAP, alkaline fusion, trace elements by XRF, and REE by INAA:
Samples 10 - 12 and 17 had major and trace elements analysed by XRF

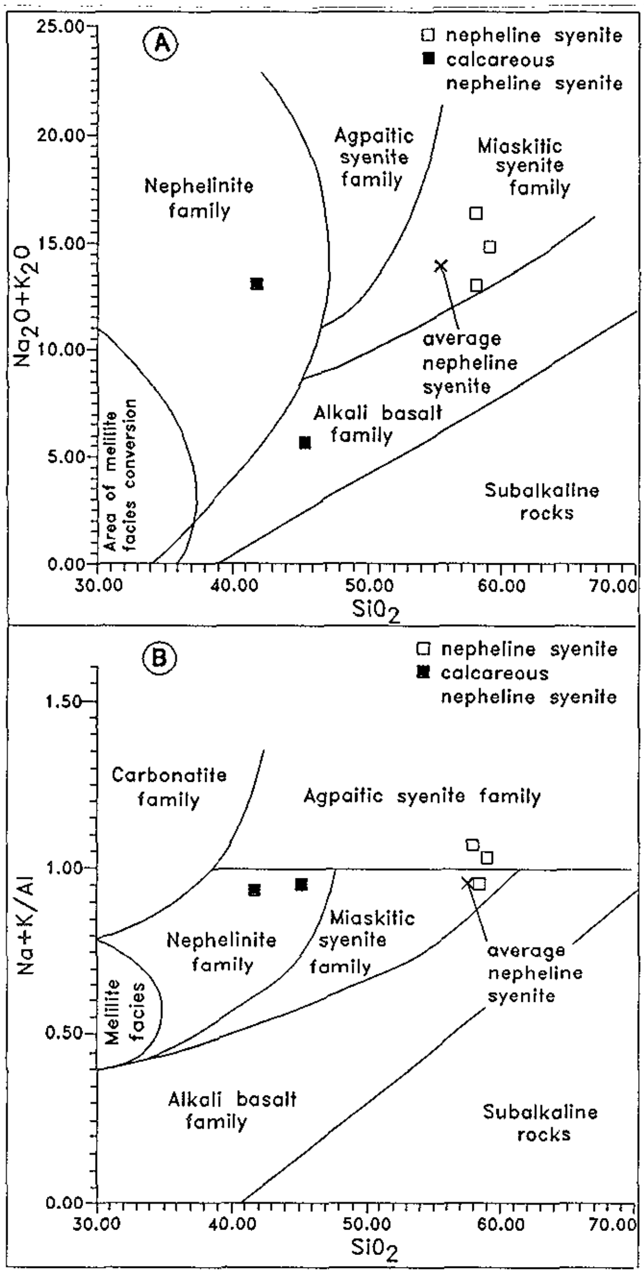


Figure 39. Alkali-silica and agpaitic index plots, Blue River area syenites.

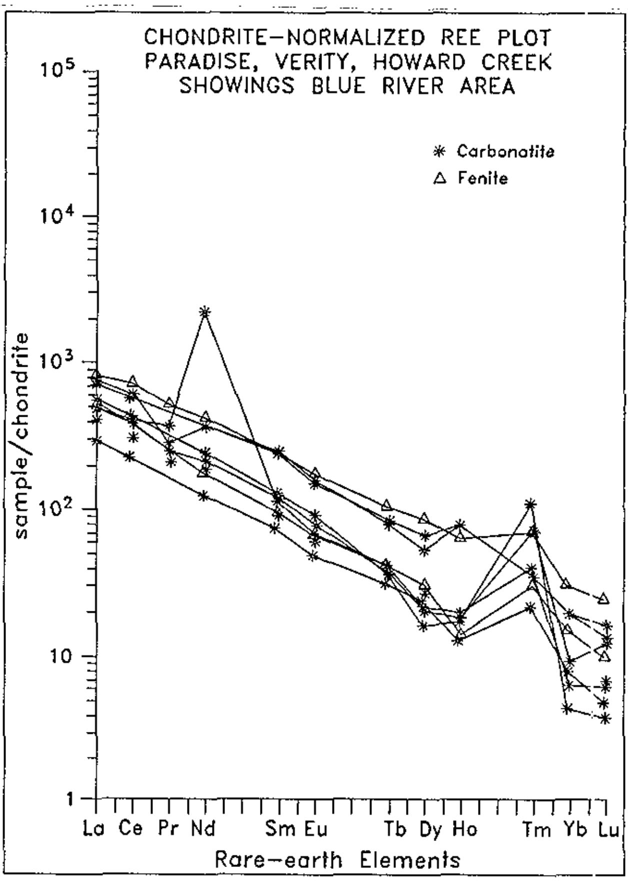


Figure 40. Chondrite-normalized REE plot - Paradise, Verity, Howard Creek showings Blue River area.

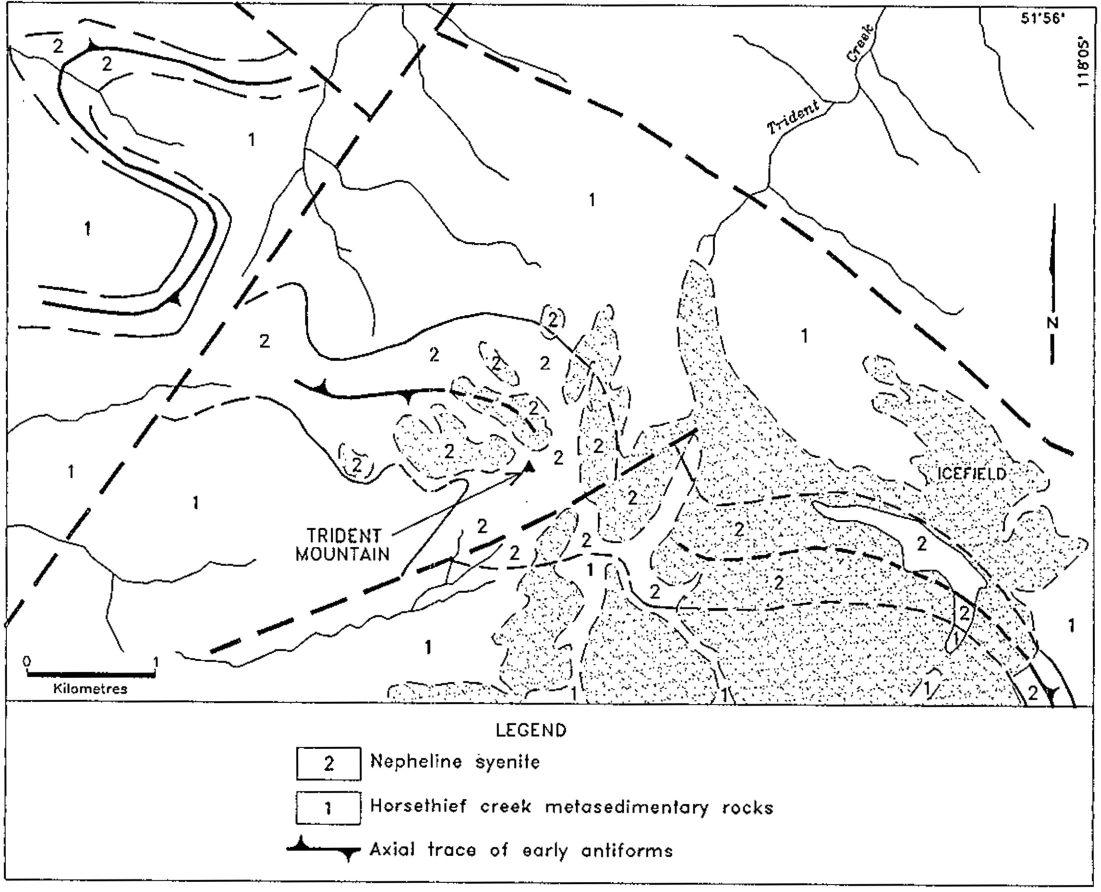


Figure 41. Geology of the Trident Mountain area, Selkirk Mountains (from Pell, 1986b; Perkins, 1983).

Plate 20. Coarse-grained ilmenite segregation in leucosyenite, Trident Mountain.

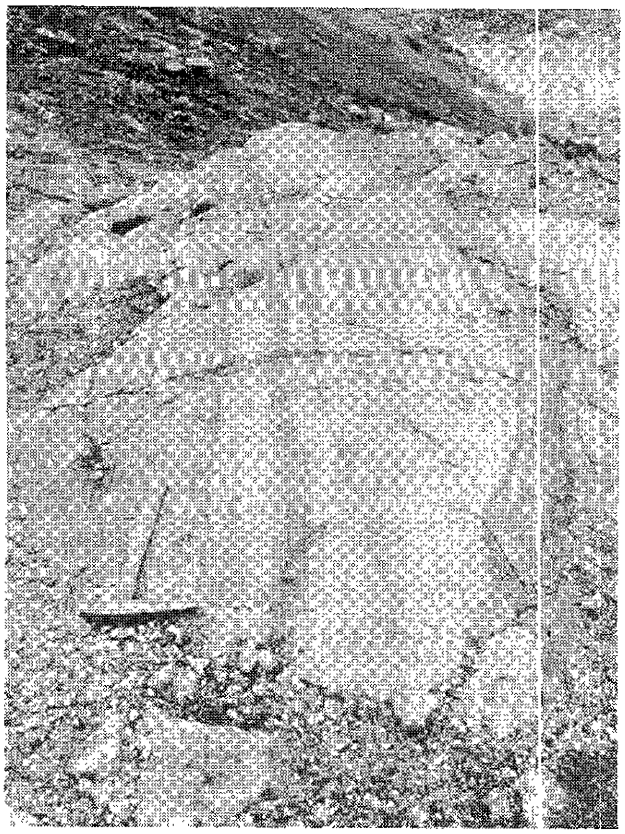


Plate 21. Typical banded nepheline syenites, Trident Mountain.

Plate 22. Leucosyenite dikes cutting mafic, biotite-amphibole gneiss, Trident Mountain.

Plate 23. Xenolith of mafic gneiss in biotite-rich syenite, Trident Mountain.

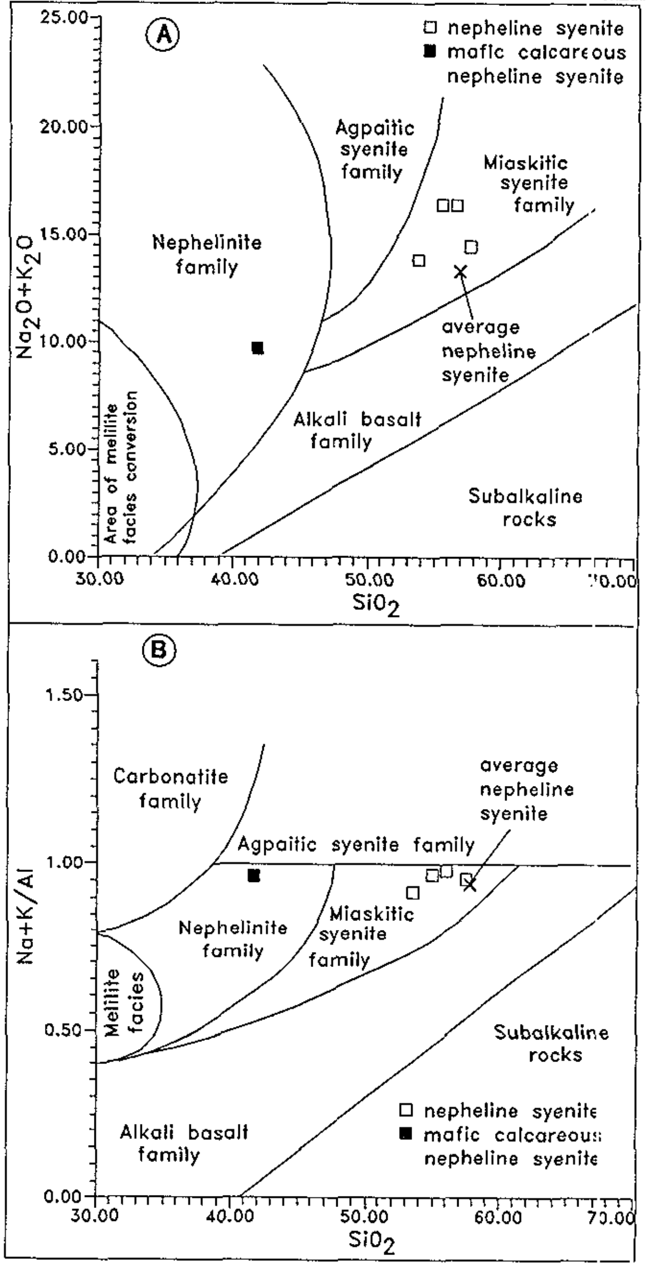


Figure 42. Alkali-silica and agpaitic index plots, Trident Mountain syenites.

the Rocky and Cassiar mountains (Appendix 1). Enrichment in light rare earths is greater than in heavy rare earths, as indicated by the shallow slope on the chondrite-normalized rare-earth element plot (Figure 40).

GEOCHRONOLOGY

Early attempts at dating did not provide definitive results on the age of the alkaline intrusions in the Blue River area. 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 (*circa* 80-90 Ma) are most likely representative of the timing of metamorphism and not the emplacement of the igneous rocks.

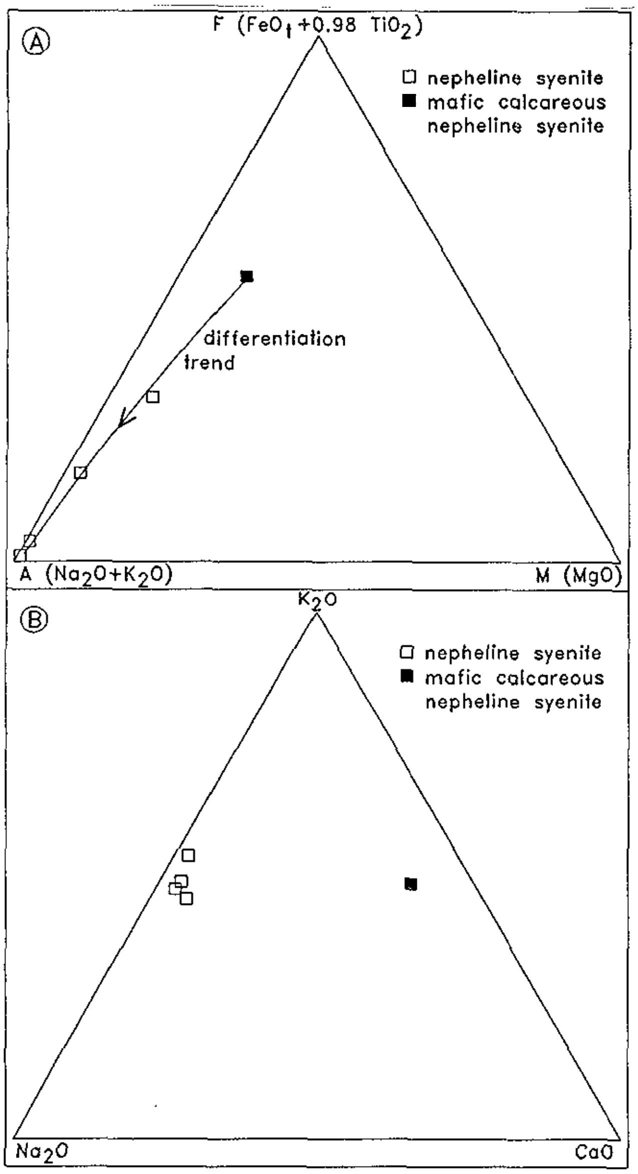


Figure 43. Major element ternary plots, Trident Mountain syenites.

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); a preliminary date of approximately 328±30 was obtained from Mud Lake samples (R.R. Parrish, personal communication, 1985). Zircons separated from Paradise Lake syenites, which were large, equant and clear, provided slightly discordant analyses which suggested a uranium-lead age of approximately 340 Ma and lead-lead ages of 351 and 363 Ma (Appendix 2).

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 (latitude 51°54′N, longitude 118°09′ west) 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 41). 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

TABLE 9
CHEMICAL ANALYSES OF TRIDENT MOUNTAIN SYENITES

wt %	1	2	3	4	5
Si02	56.66	41.76	53.72	57.64	55.59
Ti02	0.02	2.04	0.80	0.26	0.04
A1203	24.36	15.45	22.35	22.39	24.69
Fe203	0.17	13.15	6.24	2.71	0.59
Mn0	0.01	0.44	0.14	0.08	0.01
Mg0	0.05	3.10	1.59	0.46	0.07
Ca0	0.59	6.82	0.33	0.91	0.56
Na20	8.16	1.72	6.27	7.51	8.39
K20	8.22	7.96	7.52	6.94	7.98
L0I	0.99	5.46	0.66	0.97	1.55
P205	0.00	0.62	0.00	0.00	0.02
Total	99.23	98.52	99.62	99.87	99.49
ppm					
Ni	3	6	11	4	8
Cr	21	< 20	19	13	18
Co	16	18	13	14	18
Sr	1234	1713	625	730	1116
Ba	2992	1211	1156	584	1520
Zr	210	338	1562	57	43
Nb	< 5	358	229	249	33
Y	6	22	16	4	2
La	8	197	1	6	21
Ce	16	275	10	22	32
Nd	-	-	-	-	-
Yb	-	-	-	-	-
Sc	0.1	9.9	0.4	< 1	< 1
Ta	< 2	2	11	12	4
Th	3	8	5	7	7

1 - TM53A - very leucocratic syenite with sodalite
2 - TM53I - mafic, slightly calcareous phase with ~40% biotite
3 - TM5FLB - typical layered syenite
4 - TM53E - typical layered syenite with 10 - 15% biotite
5 - TM53G - leucocratic pink syenite
All analyses performed by XRF

(25-50%), albitic plagioclase (10-30%) and nepheline (10-40%). 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% of the rock. Locally, coarse-grained aggregates of randomly oriented biotite crystals are developed. Greenish acmitic pyroxene has also been reported from nepheline-rich phases (Currie, 1976a). Accessory minerals may include sodalite, cancrinite, calcite, apatite, sphene, ilmenite, pyrochlore and zircon (crystals up to 1.5 cm in size). Ilmenite segregations, 20 to 40 centimetres in size, are sometimes present (Plate 20). Local pegmatitic segregations are sporadically developed.

The syenites occur as a concordant lenticular mass high on the slopes of Trident Mountain and adjacent ridges. The hostrocks are psammitic and kyanite-bearing pelitic schists (with rare calcsilicate bands) of the Hadrynian 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%) and melanocratic (biotite 30-40%) phases (Plate 21) with occasional calcareous layers (sovitic sweats?). Leuococratic syenites are the most abundant phase.

Melanocratic syenite gneisses rich in amphibole, biotite and sphene are also present at Trident Mountain, but were not seen in outcrop. They are cut by dikes of leucosyenite. Contacts between the mafic gneisses and syenite dikes are sharp (Plate 22). Xenoliths of country rock or mafic orthogneiss were observed in the melanocratic syenites. The xenoliths have very diffuse contacts, suggesting reaction with, or partial digestion by, the syenitic magma (Plate 23). 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 intrusion were in the Sullivan River delta, which is now flooded by the Mica Dam reservoir.

GEOCHEMISTRY

The leucosyenites at Trident Mountain are miaskitic (Figure 42), and are compositionally similar to the 'average' nepheline syenite. Mafic calcareous phases plot within the nephelinite field. Melanocratic and leucocratic varieties apparently form a cogenetic sequence (Figure 43). The syenites are locally enriched in strontium, barium, zirconium and niobium (Table 9). Rare-earth element concentrations are generally low. Chemically (and mineralogically) they are very similar to those at Paradise Lake in the Blue River area.

GEOCHRONOLOGY

Two zircon fractions from the Trident Mountain syenite were collected and hand picked. They consisted of clear to slightly cloudy, equant, multifaceted roundish grains. The two analyses were somewhat discordant and, because of the low uranium content, it has been interpreted that both metamorphic and igneous zircons are present. This is also suggested by the fact that a number of the crystals have perfectly clear rims surrounding cloudy cores (*i.e.*, two generations of zircon growth). Also the morphology of the grains is typical of metamorphic zircon (R.R. Parrish, personal communication, 1987). On a concordia diagram (Appendix 2) a line joining the two analytical points has upper and lower intercepts of 378±7 Ma and 138±9 Ma). The 378 Ma date is consistent with the Devono-Mississippian age obtained from Paradise Lake syenites which resemble the Trident Mountain gneisses, and with interpreted ages of other carbonatite complexes in British Columbia. The 138 Ma date may be indicative of a period of resetting during a Jurassic metamorphic event. Uranium-lead data on pyrochlore yield a 60 Ma date (R.R. Parrish, personal communication, 1987) which may indicate a late metamorphic resetting.

CARBONATITES AND SYENITE GNEISS COMPLEXES ASSOCIATED WITH CORE GNEISSES IN THE OMINECA BELT

Intrusive and extrusive carbonatites and syenite gneiss bodies occur within a mixed paragneiss succession along the margin of Frenchman Cap gneiss dome (Figure 44), 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. Its depositional environment is interpreted as shallow marine or platformal (McMillan, 1973; Höy and McMillan, 1979; 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. Recent lead isotopic data from a syngenetic lead-zinc layer within the upper part of the succession support an Eocambrian to Early Cambrian age for that part of the sequence (Höy and Godwin, 1988). Uranium-lead systematics on a syenite intrusive into the lower part of the sequence suggest a late Precambrian (*circa* 770 Ma) age for the syenite (Okulitch *et al.*, 1981); this suggests that the lower part of the mantling gneiss succession must be younger than 780 Ma.

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. 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).

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 45) on the southeastern flank of the Frenchman Cap dome (latitude 51°05'N, longitude 118°25'W) approximately 25 kilometres northwest of Revelstoke. The alkaline rocks are readily accessible by an old mine road which leaves the TransCanada 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; much of what follows is summarized from that work.

The Mount Copeland syenites (Figure 45) are exposed in a large antiformal structure and have been subjected to more than one phase of folding. They are apparently concordant with metasedimentary hostrocks. All contacts within the igneous rocks appear to be gradational. Three alkaline rock units have been defined; 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 with a similar succession in the Perry River and Mount Grace areas (Höy and McMillan, 1979; Brown, 1980). Based on these correlations, it appears that the gneisses at Mount Copeland lie stratigraphically beneath the Mount Grace extrusive carbonatite. Postorogenic lamprophyre dikes are also present in the Mount Copeland area.

NEPHELINE SYENITE GNEISSES

The nepheline syenite gneisses (unit A1 of Currie, 1976b) contain nepheline in excess of 10%. They may be weakly to strongly foliated, and locally have a spectacularly developed augen texture with large porphyroblasts of nepheline and alkali feldspar in a fine-grained groundmass. The augen gneisses (unit A1a) are found in outlying areas and as lenticles within the calcsilicate hostrocks; they are mesocratic rocks with a faint purplish tinge and are predominantly composed of nepheline, alkali feldspar, perthite,

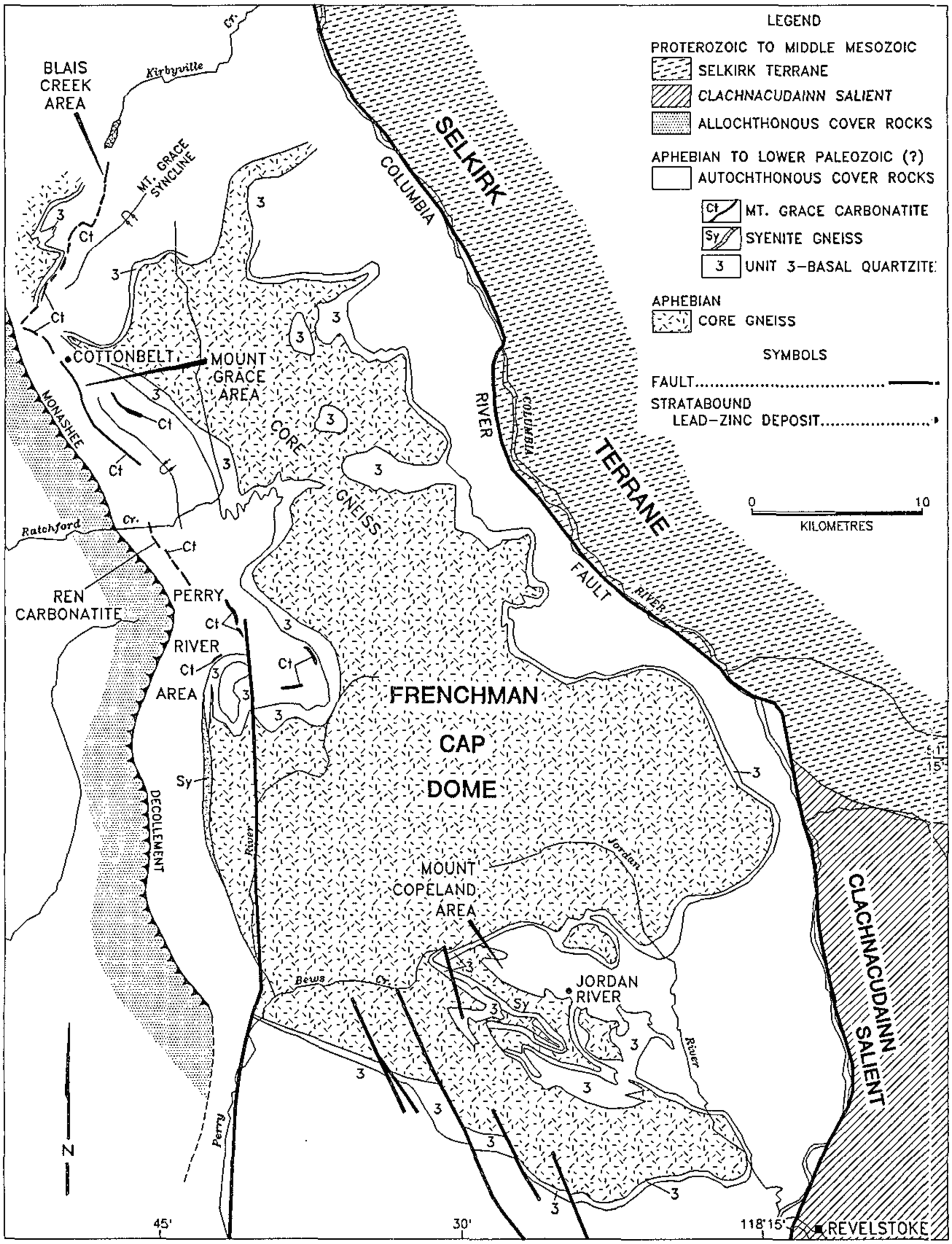


Figure 44. Geology of the Frenchman Cap area (from Höy and Kwong, 1986).

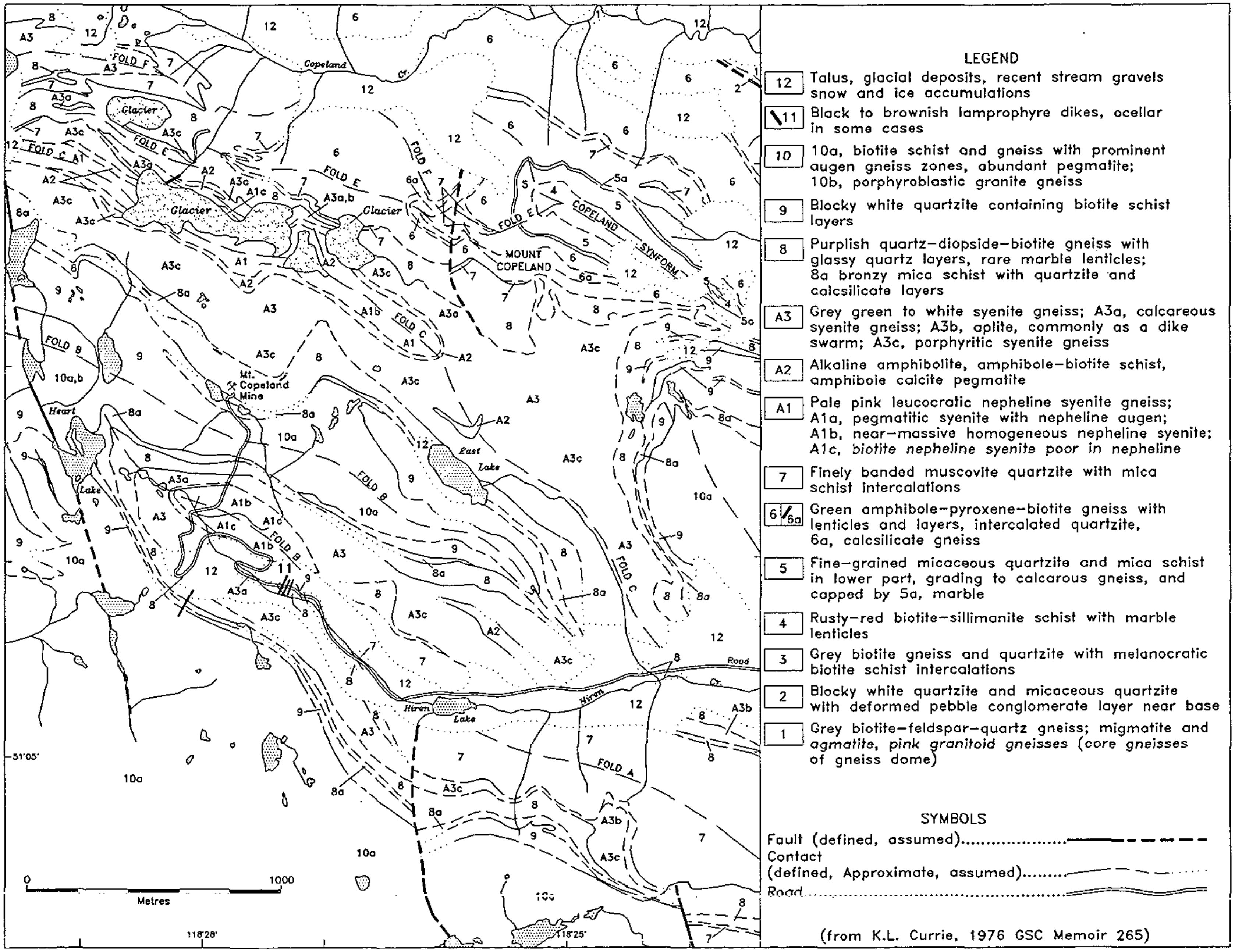


Figure 45. Geological map, Mount Copeland area.

calcite, biotite and fluorite. Cancrinite is often present marginal to nepheline grains. Accessory minerals include tourmaline, apatite, sphene, riebeckite and rarely, poikilitic aegirine.

The core part of the nepheline syenite (unit A1b) consists of a weakly foliated, pale pink leucocratic rock that contains 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.

The third type of nepheline gneiss (unit A1c), which may be transitional to the nepheline-free syenites, is creamy to buff weathering and exhibits the best-developed gneissic foliation of all the nepheline syenites. Microcline, perthite and fine-grained nepheline, commonly replaced by cancrinite and thompsonite, are the dominant constituents. Phlogopitic mica is the principal mafic mineral, although it is rarely present in amounts greater than 5%. Small amounts of aegirine and hastingsite may also be present. Accessory minerals include sphene, apatite, calcite and specularite.

ALKALINE AMPHIBOLITE

A thin lens, or numerous parallel lenses, of alkaline 'amphibolite' (unit A2) 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.

GREY SYENITIC GNEISS

The strongly alkaline rocks (units A1 and A2) are surrounded by a thick shell of less alkaline rocks. Three principal types are recognized: a fine-grained greenish grey syenite with slight gneissic banding (unit A3a); a white, aplitic leucosyenite (unit A3b); and a buff to pale pink, medium to coarse-grained syenite (unit A3c).

The fine-grained, greenish grey syenite 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.

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

wt %	A1a		A1b			A1c		A2		A3a	A3b		A3c	D	
Si02	48.78	47.23	54.92	52.00	56.90	55.05	54.11	44.18	48.90	49.09	57.97	53.60	54.97	39.70	39.73
Ti02	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	1.24
A1203	25.22	26.06	23.01	25.91	21.00	21.63	21.69	7.51	11.30	18.48	18.08	15.40	21.82	13.50	14.44
Fe203	3.46	3.64	2.57	0.89	2.60	1.07	2.48	8.06	1.30	0.22	0.04	2.60	3.81	2.60	2.71
Fe0	0.23	1.59	2.62	0.21	2.60	5.16	0.62	7.20	10.20	7.17	0.51	6.10	0.49	5.40	4.92
Mn0	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
Mg0	0.32	0.31	0.67	0.23	0.70	1.07	0.19	7.76	8.40	2.81	0.11	6.00	0.29	7.60	7.34
Ca0	3.08	1.52	1.53	1.32	1.60	0.29	3.01	9.68	10.10	11.57	6.53	4.80	2.51	11.00	9.41
Na20	9.89	12.61	6.06	5.40	6.10	2.31	5.85	3.69	2.30	2.63	9.32	2.50	4.33	1.90	1.32
K20	7.21	4.62	7.47	7.53	7.50	11.39	9.37	3.77	1.60	3.20	0.91	5.10	7.62	4.30	6.20
H20	0.30	0.88	0.49	4.72	0.50	1.11	1.26	1.21	2.20	0.82	0.18	1.70	2.29	1.90	2.03
C02	0.12	0.80	0.23	1.11	0.20	0.10	0.24	0.26	0.60	0.88	5.22	0.10	0.28	8.20	7.09
P205	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	1.77
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*	98.34
ppm															
Ni	20	< 10	-	33	-	80	64	220	-	98	-	-	100	-	-
Cr	-	-	< 10	-	-	-	-	240	-	4.3	-	-	-	-	-
Co	-	-	-	-	-	-	-	57	-	24	-	-	-	-	-
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	-	470	-	260	340	200	-	300	-	-	470	-	-
Y	230	41	39	100	-	-	5.8	6.8	-	9.5	-	-	15	-	-
La	590	710	110	360	-	-	44	270	-	34	83	-	500	-	-
Ce	99	1300	-	< 500	-	-	780	510	-	540	-	-	820	-	-
Nd	420	310	-	< 200	-	-	330	550	-	630	-	-	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	-	-	7.8	31	-	12	< 4	-	6.8	-	-

**From Currie (1976a)*
From Currie (1976b) - all other analyses

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 dike.

The aplitic leucosyenites 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.

The third group of syenites 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. Calcite or fine-grained aggregates of analcite and cancrinite are found in some specimens. Biotite, aegirine and a hastingsitic amphibole are the mafic minerals which may occur; they may be present in combination or separately. Zircon, magnetite and apatite are common accessory minerals; tourmaline and fluorite have also been noted.

GEOCHEMISTRY

The nepheline syenite gneisses show a marked increase in silica content from unit A1a to unit A1c (Table 10) that is proportional to a decrease in modal nepheline. Unit A1a is also 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. The syenites at Mount Copeland all tend to be enriched in incompatible elements (*e.g.* Sr, Zr, Nb, Y and REE, Table 10).

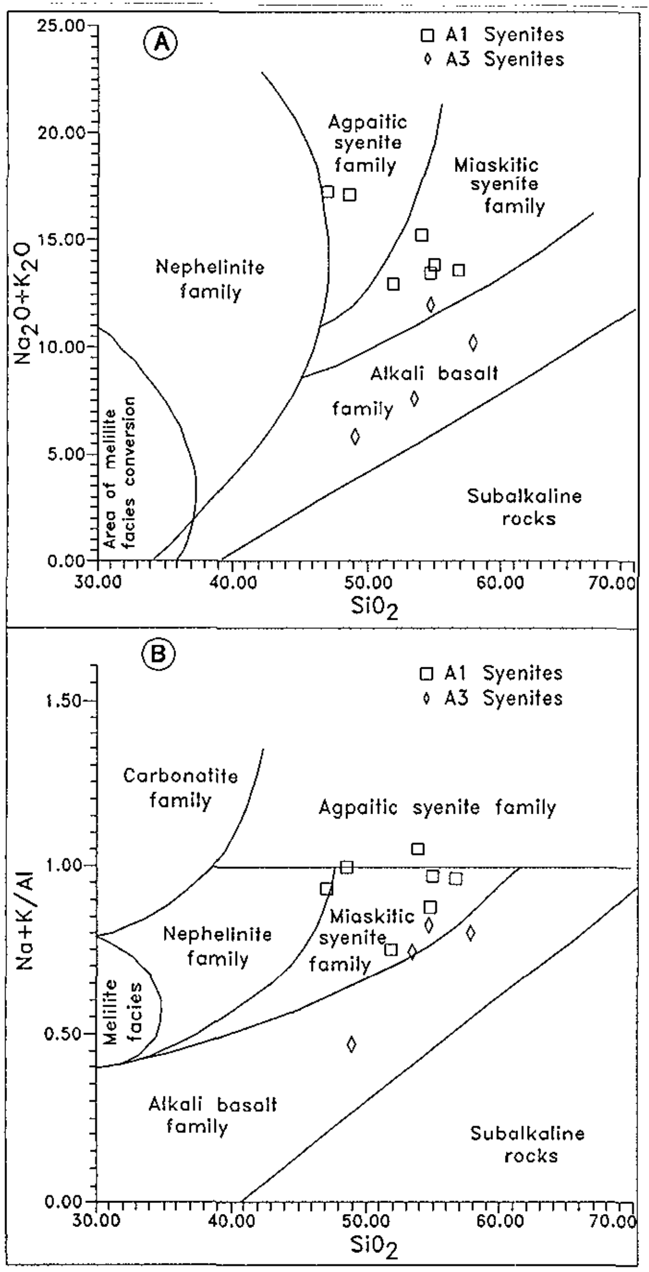


Figure 46. Alkali-silica and agpaitic index plots, Mount Copeland syenites.

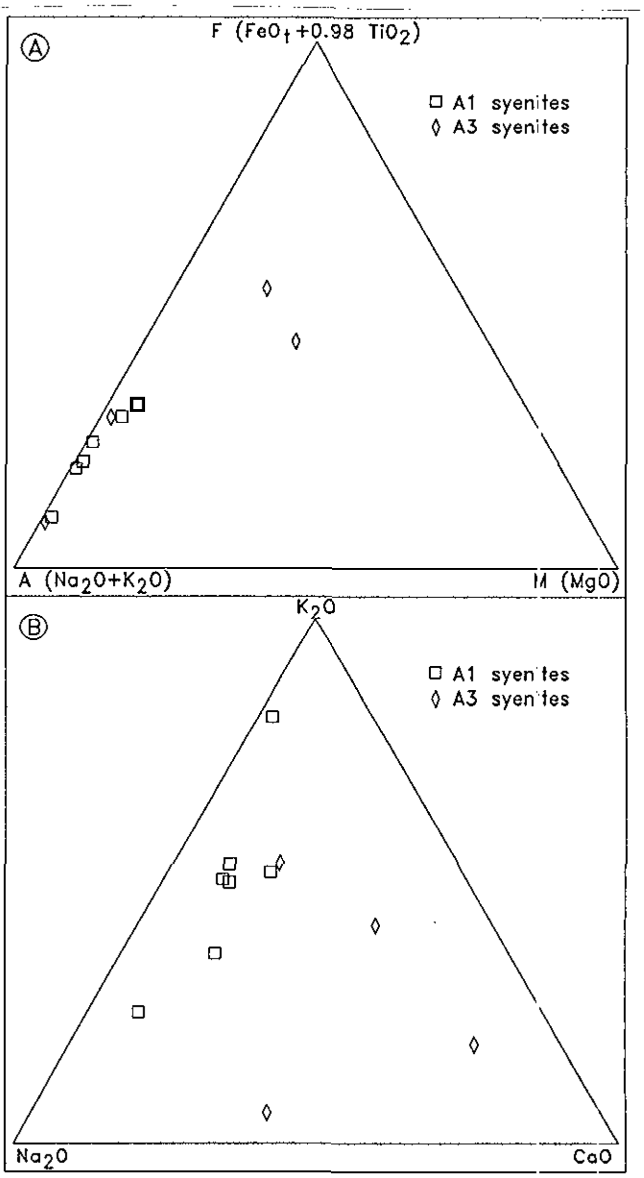


Figure 47. Major element ternary plots, Mount Copeland syenites.

On agpaitic index and alkali-silica plots, nepheline syenites (unit A1) predominantly plot within the miaskitic syenite field. The leucocratic nepheline augen syenites (unit A1a) fall within the agpaitic field on the alkali-silica plot, but are closer to the miaskitic field on the agpaitic index plot (Figure 46). The bordering syenites (unit A3) contain significantly less alkalis, and plot in the miaskitic syenite to alkali basalt (alkaline gabbro) fields. The border syenites are also somewhat enriched in calcium, magnesium and iron relative to the nepheline syenites (Figure 47).

GEOCHRONOLOGY

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

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 (latitude 51°15′N, longitude 118°41′W; Figure 44) were originally described by McMillan (1970) and McMillan and Moore (1974). Two types were recognized. Type 1 carbonatites are conformable with bedding in metasedimentary hostrocks and have metasomatic envelopes which may extend from 1 to more than 30 metres beyond the intrusive contacts. They are interpreted to be sills or dikes. Type 2 carbonatites are concordant bodies, associated with white marbles, which have no contact alteration zones. They crop out in strata which overlie those hosting Type 1 carbonatites. Detailed mapping in the Mount Grace area north of the Perry River (latitude 51°27′N, longitude 118°49′W; Höy and McMillan, 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 that it is an extrusive layer. More recent work (Pilcher, 1983; Höy and Pell, 1986; Höy, 1988) 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 (latitude 51°22′N, longitude 118°44′W). A detailed account of carbonatites on the west flank of the Frenchman Cap Dome is given in Höy (1988) and the reader is referred there for additional information.

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 (Figure 3 of McMillan and Moore, 1974) that is concordant with layering, but on a regional scale may cut up-section to the south. The carbonatites consist of discontinuous lenses associated with mafic (pyroxene-amphibole) and syenitic fenites. Within the volumetrically more abundant fenites, carbonatites may occur as relatively thick, buff-weathering, foliated and laminated layers (Plate 24); as swirled, discontinuous lenses (Plate 25); or as small, irregular coarse-grained pods.

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

FENITES – PERRY RIVER AREA

Fenites are well layered, probably reflecting original compositional variations in sedimentary strata. Three types are recognized; mafic pyroxene-amphibole fenite, syenitic albite – potassium feldspar fenite and albite fenite. The mafic fenite is by far the most abundant; it has gradational contacts with interlayered albite fenite and sharp contacts with syenitic fenites (Plate 26). Remnant metasedimentary calcsilicate gneiss, quartzofeldspathic paragneiss and minor

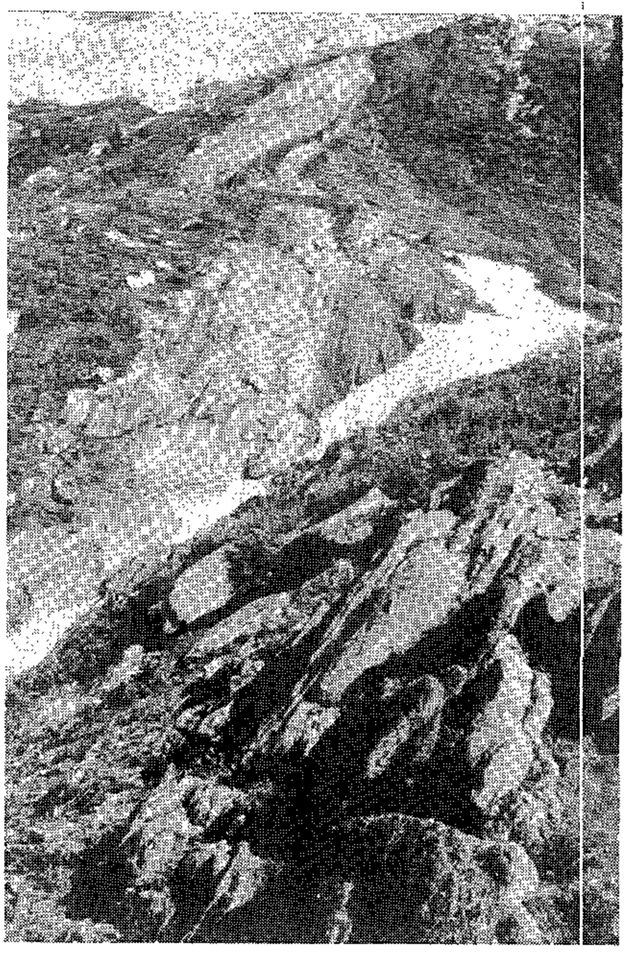


Plate 24. Intrusive carbonatite band (light grey) surrounded by dark amphibolite fenite and some grey syenitic fenite, Perry River area.

Plate 25. Swirled carbonatite (light colour) in amphibole fenite, Perry River area.

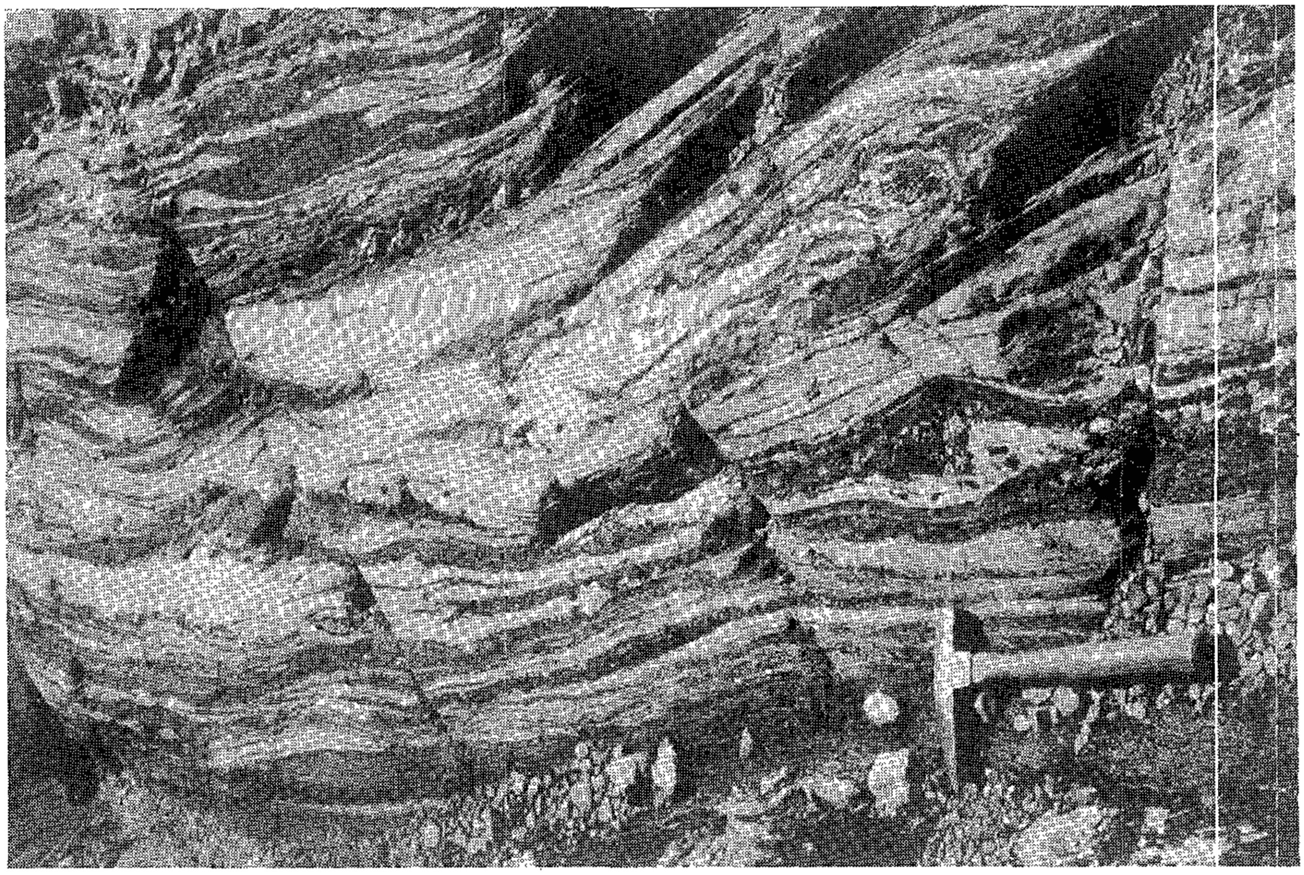


Plate 26. Interlayered amphibolitic fenite (dark) and syenitic fenite (light), Perry River area.

marble layers occur within the fenites. In general, the contacts between mafic fenites and quartzofeldspathic paragneisses are sharp, whereas those with more calcareous strata are gradational. Toward the centre of the 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, 1988).

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%. 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, 1988). Pegmatitic lenses consisting of calcite, amphibole, pyroxene, euhedral sphene, magnetite and ilmenite are common throughout the fenites. Individual crystals of these minerals may be in excess of 7 centimetres long. The mafic fenites are locally interlayered and gradational with leucocratic fenites (or albitites) consisting of approximately 90% 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% 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 with or without biotite. Calcite, muscovite, sphene, magnetite, apatite, chalcopyrite and allanite are common accessory minerals. Variable amounts of nepheline may also be present.

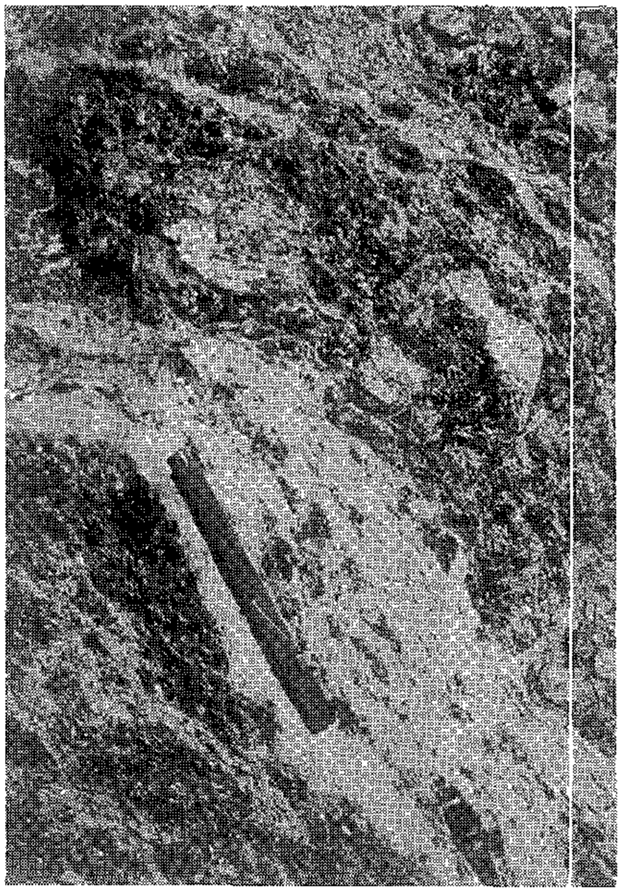


Plate 27. Ratchford Creek (REN) carbonatite (light grey) interlayered with amphibolitic fenite (dark grey) and containing fenitized country rock fragments (grey), *(colour photo, page 136).*

RATCHFORD CREEK (REN) INTRUSIVE CARBONATITE (82M/7)

The Ratchford Creek carbonatite is a concordant unit at least 3 kilometres in length and, on average, 10 to 30 metres thick. 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 44) 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 is intimately intermixed with pyroxene-amphibole fenites and locally contains weakly fenitized inclusions of country rock (Plate 27). The carbonatite comprises, on average, 60 to 80% carbonate minerals (calcite and dolomite) and 10 to 30% apatite, with accessory biotite, magnetite, amphibole, pyroxene and sphene, and minor pyrrhotite, pyrite, sphalerite, chalcopyrite, pyrochlore(?) and monazite(?) (Pilcher, 1983).

INTRUSIVE SYENITE – PERRY RIVER AREA (82M/7, 10)

A large intrusive syenite body crops out in the Perry River area (*see* Figure 44). It is a concordant unit, up to 300 metres thick and 12 kilometres long (McMillan, 1973), that is internally foliated and layered with alternating bands of syenitic and feldspathoidal rock. Country rocks along its margins are metasomatically altered; a rusty zone enriched in feldspar, pyroxene, muscovite and/or pyrrhotite is developed adjacent to the syenite. The syenite gneiss intruded strata which underlie those hosting the extrusive carbonatite.

The main minerals in the syenite are microcline, perthite, plagioclase (albite to labradorite) and nepheline. Approximately 60% of the rocks contain nepheline, with or without feldspars. 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).

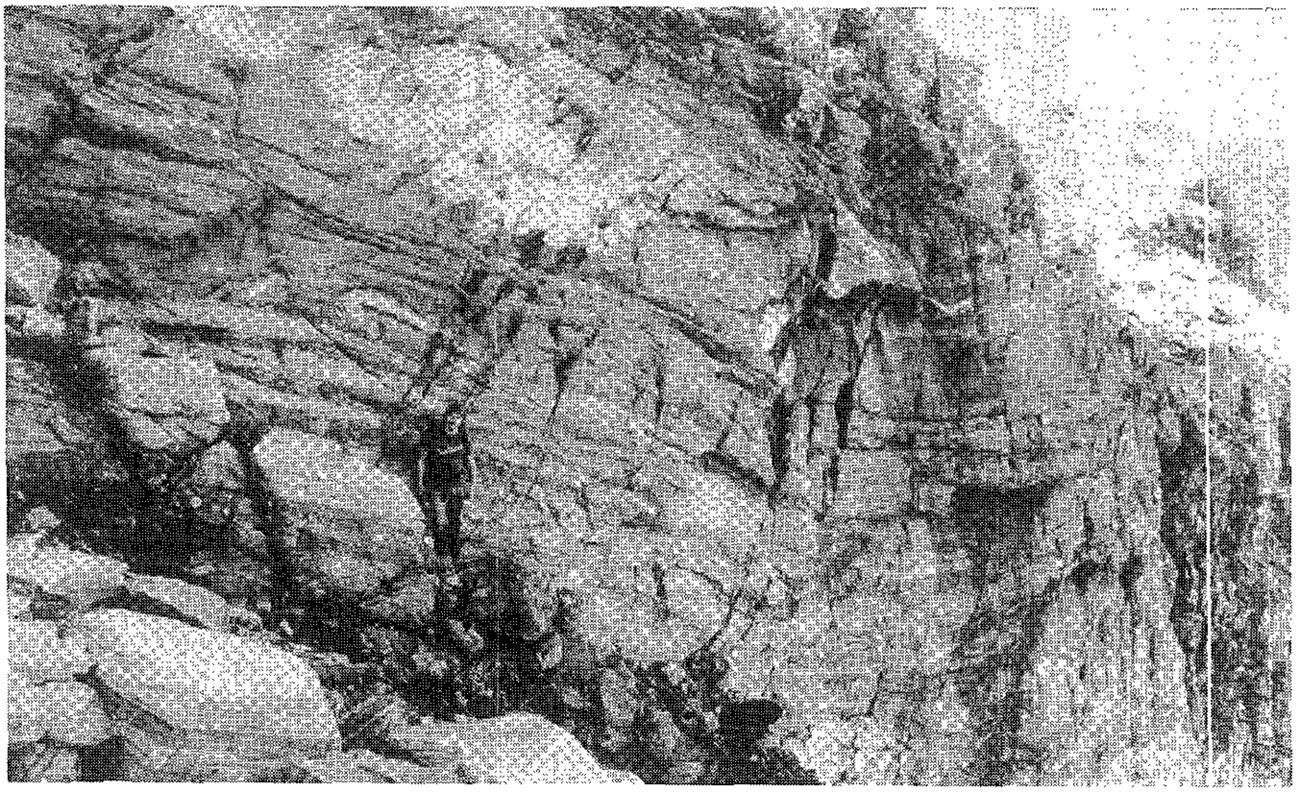


Plate 28. Part of the thickened section of the Mount Grace extrusive carbonatite; the whole cliff is part of the carbonatite zone; note large syenitic inclusions immediately above the person.

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 and near its mapped northern limit (Figure 44), it is estimated to be greater than 20 metres thick (Plate 28). An associated increase in clast sizes here indicates close proximity to a source or vent area. 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, 1988). 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 previously been published (Höy and Kwong, 1986; Höy and Pell, 1986; Höy, 1988) 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.

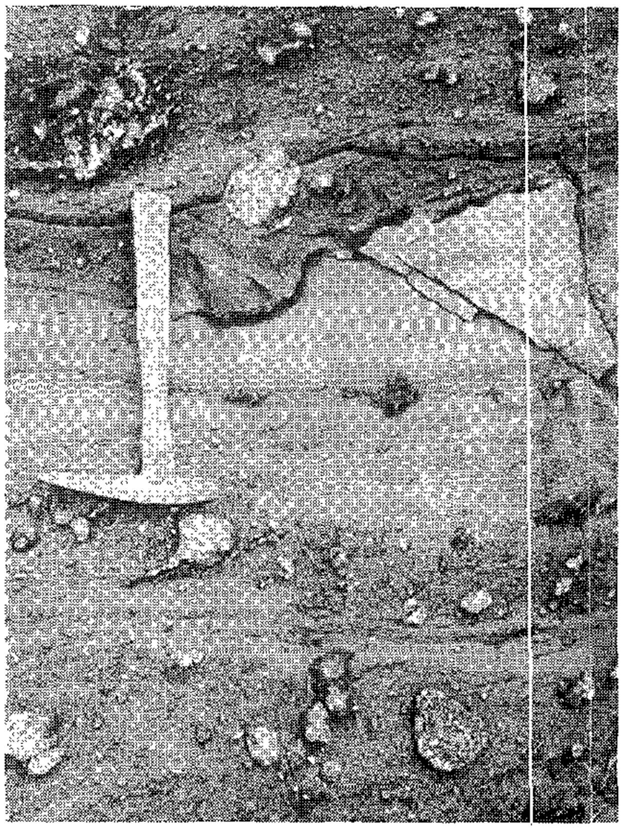


Plate 29. Interbedded grey sedimentary marble (light grey) with buff carbonatite agglomerate and tuff (darker greys) layers; Mount Grace carbonatite near Blais Creek.

TABLE 11
CHEMICAL ANALYSES OF ALKALINE ROCKS, WEST FLANK, FRENCHMAN CAP DOME

wt%	Nepheline syenite gneiss									Mount Grace carbonatite			Extrusive Carbonatite			Perry River intrusive carbonatites					Ren Intrusive carbonatite			
	2	*2*	*2*	*2*	*2*	*2*	*2*	*3*	*3*	*4*	*4*	*4*	*4, 1*	*4, 1*	*4,1*	*5, 1*	*5, 1*	*5, 1*	*5, 1*	*5, 1*	*5, 1*	*5, 1*	*5, 1*	*5, 1*
SiO	51.44	57.34	46.18	55.67	51.33	41.77	53.02	53.57	51.88	2.20	15.15	9.46	7.96	12.72	4.84	6.77	0.39	6.38	0.79	4.10	1.51	4.57	0.85	4.15
TiO2	0.27	0.30	0.94	0.28	0.38	0.52	0.21	0.60	0.88	< 0.02	0.70	0.14	0.08	0.21	0.07	1.32	<0.01	0.86	0.03	0.05	0.06	0.04	0.04	0.06
Al2O3	24.42	22.98	28.11	23.59	23.57	31.71	27.12	19.76	22.07	0.55	4.20	2.69	1.79	4.07	0.99	0.36	0.16	1.57	0.30	0.91	0.22	0.55	0.07	0.72
Fe2O3	1.40	0.59	4.08	0.63	0.44	0.29	1.14	4.10	1.27	2.64	4.87	4.47	3.39	5.01	4.19	4.14	0.38	4.66	0.68	1.20	3.45	2.87	2.71	3.29
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	0.34	0.40	0.39	0.38	0.44	0.44	0.17	0.99	0.31	0.43	0.41	0.43
MgO	0.15	0.24	1.12	0.15	0.79	0.46	0.31	0.37	0.26	3.47	4.54	4.60	5.42	5.72	5.10	2.38	0.46	1.85	0.62	0.10	6.30	17.30	16.69	15.40
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	41.33	35.21	43.79	45.34	51.04	42.72	52.44	45.29	43.82	31.05	33.83	32.86
Na2	9.44	5.06	3.00	4.12	7.51	12.23	4.24	6.04	5.07	0.36	2.30	1.16	0.85	1.05	0.33	0.37	0.13	0.64	0.14	0.37	0.08	0.24	0.04	0.16
K2O	3.55	10.18	5.80	8.99	6.69	4.70	6.41	10.90	10.30	<.03	0.38	0.69	0.68	1.73	0.75	0.21	< 0.01	0.85	0.09	0.04	0.02	0.12	0.01	0.17
H2O	1.08	0.97	0.63	1.41	1.74	1.23	1.53	0.50	1.42	0.36	0.50	0.34	0.43	0.76	0.10	0.06	< 0.05	0.08	0.03	-	-			
CO2	2.49	0.35	2.17	0.12	1.22	0.41	0.53	0.62	0.70	40.72	31.10	32.40	34.80	29.20	34.70	29.92	39.05	33.92	35.06	35.95	36.61	38.27	43.46	38.36
P2O5	0.16		0.60	0.10	0.36	0.16	0.31	<.08	<.08	0.06	0.06	0.53	0.07	0.07	1.60	0.21	< 0.01	0.85	0.09	0.34	4.20	3.60	2.16	3.60
Total	100.05	100.00	100.12	99.02	99.46	98.54	101.70	100.70	99.54	98.68	98.63	97.95	97.14	96.15	96.85	87.73	92.05	94.82	90.44	89.46	96.58	99.04	100.27	99.00
ppm																								
Ni	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	28	6	14	16	-	-	-	-	-
Cr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	37	< 25	25	25	-	< 10	36	< 10	38
C0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sr	-	-	-	-	-	-	-	-	-	3300	5700	4600	5400	6600	5800	1600	3100	2100	1000		5188	4628	4271	4828
Ba	-	-	-	-	-	-	-	-	-	3100	2800	3500	3200	3500	3600	1155	1217	2539	1205		213	1133	676	162
Zr	1400	1915	3700	2300	1150	2540	2185	-	-	-	-	-	-	-	-	-	-	-	-	208	297	96	92	108
Nb	1200	-	2380	-	1200	1200	-	-	-	<10	100	300	100	200	200	50	8	50	30	< 100	60	27	25	1516
Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	160	80	120	34	107	60	27	25	31
La	-	-	-	-	-	-	-	-	-	710	345	390	540	940	500	1470	704	> 2000	317	-	-	-	-	-
Ce	-	-	-	-	-	-	-	-	-	1050	560	660	810	1430	1020	2010	927	7630	614	-	-	-	-	-
Nd	-	-	-	-	-	-	-	-	-	350	230	290	230	405	430	654	271	3540	279	-	-	-	-	-
Yb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17.4	10	7.4	2.9	-	-	-	-	-

wt %	Syenitic fenites (albite-potassium-feldspar)							Albite fenite									Pyroxene-amphibole fenites					
								A	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*C*						
SiO2	55.70	63.96	62.29	63.23	59.02	62.81	62.62	49.19	53.76	56.58	57.45	64.31	57.66	61.26	55.91	62.87	35.66	38.44	41.94	38.88	37.24	35.64
TiO2	2.22	0.86	0.68	0.54	1.17	0.78	0.46	0.04	0.22	0.01	0.31	0.04	0.03	0.22	0.37	0.06	4.35	2.34	2.17	2.64	2.86	4.01
Al2O3	15.24	18.14	17.72	17.91	17.19	17.08	17.92	13.18	16.09	16.41	20.53	19.75	17.35	18.58	19.37	20.02	8.50	1.44	7.27	1.37	7.64	8.03
Fe2O3	*7.05*	*2.90*	*5.76*	*3.76*	*5.59*	*5.39*	*4.60*	*0.65*	*3.14*	*0.89*	*3.71*	*0.43*	*0.52*	*1.65*	*2.70*	*0.66*	*15.74*	*10.73*	*11.66*	*11.40*	*13.62*	*10.72*
MnO	0.22	0.07	0.16	0.13	0.15	0.15	0.12	0.12	2.22	0.28	0.14	0.04	0.10	0.06	0.10	0.02	0.31	0.15	0.23	0.15	0.27	0.25
MgO	1.61	0.56	0.19	0.37	0.91	0.35	0.50	1.02	3.16	0.33	1.76	0.08	0.16	0.41	0.66	0.36	8.20	12.41	6.82	12.37	9.52	7.91
CaO	3.72	2.81	1.90	1.58	2.50	1.68	1.99	15.79	9.14	8.12	2.24	3.16	6.93	3.58	3.55	3.48	13.66	21.70	16.70	21.80	12.05	14.63
Na2O	7.38	9.22	7.21	7.48	7.97	6.48	7.83	7.06	9.14	9.24	7.82	6.61	4.81	7.69	5.90	9.04	3.12	1.84	4.11	4.10	1.41	2.63
K2O	1.34	0.78	4.27	3.57	2.02	4.01	3.12	0.32	1.16	0.30	2.01	5.12	6.40	3.36	5.36	1.34	1.43	0.43	0.80	0.53	3.60	3.46
LOI	2.94	1.32	0.88	0.21	0.41	0.84	0.79	8.96	3.21	6.46	3.39	2.38	5.76	2.50	4.08	1.61	4.07	5.89	5.30	4.64	6.61	7.44
P2O5	0.37	0.07	0.03	0.02	0.06	0.02	0.03	2.68	0.24	0.75	0.08	0.36	0.16	0.05	0.35	0.05	2.12	3.32	1.81	3.19	0.99	1.82
Total	97.79	100.69	101.09	98.80	96.99	99.59	99.98	99.01	101.48	99.37	99.44	102.28	99.88	99.36	98.35	99.51	97.16	98.69	98.81	101.07	98.81	96.54
ppm																						
Ni	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cr	10	< 10	< 10	< 10	17	< 10	15	< 10	10	< 10	13	< 10	< 10	< 10	< 10	< 10	124	14	25	15	242	202
Co	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sr	2182	4235	2707	1288	3050	942	3208	6043	874	2267	837	1964	2251	1693	1674	1446	2616	2654	3120	2050	5307	6785
Ba	851	560	962	1074	613	628	996	183	1000	1060	830	5227	5732	2928	3990	995	521	187	423	229	2964	2701
Zr	476	352	713	1275	1613	569	818	117	22	28	675	30	286	79	815	38	1000	203	1142	220	1116	937
Nb	92	106	160	179	248	139	47	< 4	692	339	559	804	1166	200	403	9	138	22	24	33	74	117
Y	36	37	32	43	65	31	19	62	9	18	16	10	18	10	28	15	79	47	79	47	65	85

1 - total iron expressed as Fe2O3
2 - from McMillan and Moore (1974)
3 - from Höy and Pell (1986)
4 - from Höy and Kwong (1986)
5 - from Höy (1987)

A - Albite fenite associated with intrusive carbonatites, Perry River area;
B - Albite fenite (albitite) clasts in Mount Grace extrusive carbonatite;
C - Albite fenite associated with Ratchford Creek (Ren) intrusive carbonatite;

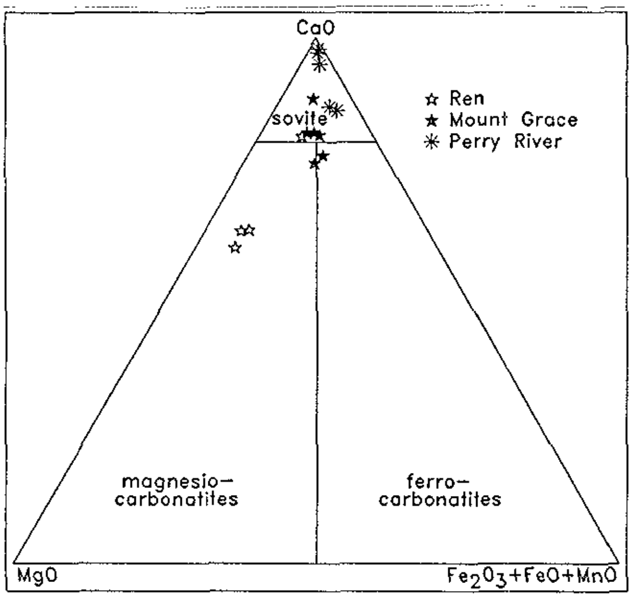
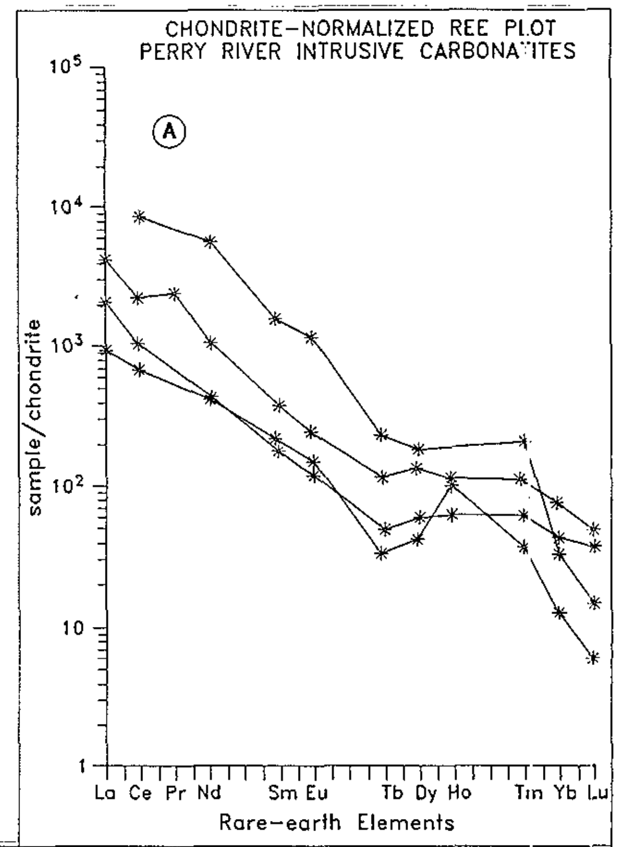


Figure 48. Carbonatite plot, Mount Grace and Perry River area.



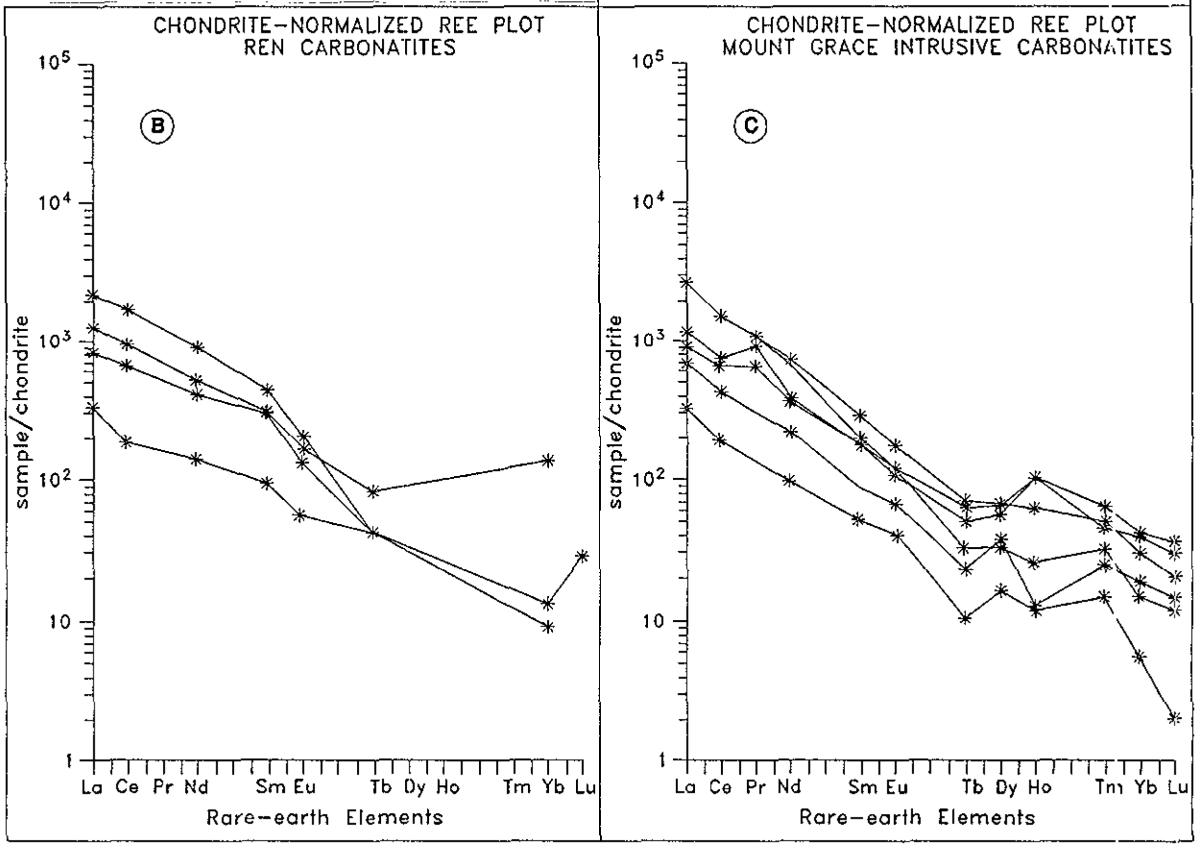


Figure 49. Chondrite normalized rare earth plots, carbonatites, west flank, Frenchman Cap Dome. (A) Chondrite-normalized REE plot - Perry River intrusive carbonatites; (B) Chondrite-normalized REE plot - Ren carbonatites; (C) Chondrite-normalized REE plot - Mount Grace extrusive carbonatites.

The carbonatite is commonly internally banded, with one or several layers of 'blocky' tephra interbedded with finer grained, massive or laminated carbonatite (Plate 29). The blocky tephra layers contain three types of matrix-supported clasts: small granular albitite clasts, commonly up to 3 centimetres in diameter, consisting of pure albite or albite with variable amounts of phlogopite; syenite clasts, generally 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. Near the northern mapped limit of the carbonatite layer, where it is thickest, unusually large syenitic clasts, over 1 metre in diameter, occur within it.

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 (Table 11; Appendix 1). The majority of the Mount Grace extrusive and Perry River intrusive carbonatites are sovites while at the Ratchford Creek showing magnesio-carbonatites predominate (Figure 48). All are highly enriched in strontium, barium, niobium and rare-earth elements relative to carbonates of sedimentary origin (Table 11). These high values are characteristic of carbonatites elsewhere (*e.g.*, Le Bas, 1981). All the carbonatites show typical light rare-earth element enrichment patterns on chondrite-normalized plots (Figure 49a, b, and c). 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 carbonatites hosted by Precambrian or Early Cambrian strata in the Omineca Belt.

The Mount Grace carbonatite has total rare-earth element concentrations ranging from approximately 600 ppm to greater than 8000 ppm (Appendix 1), significantly higher

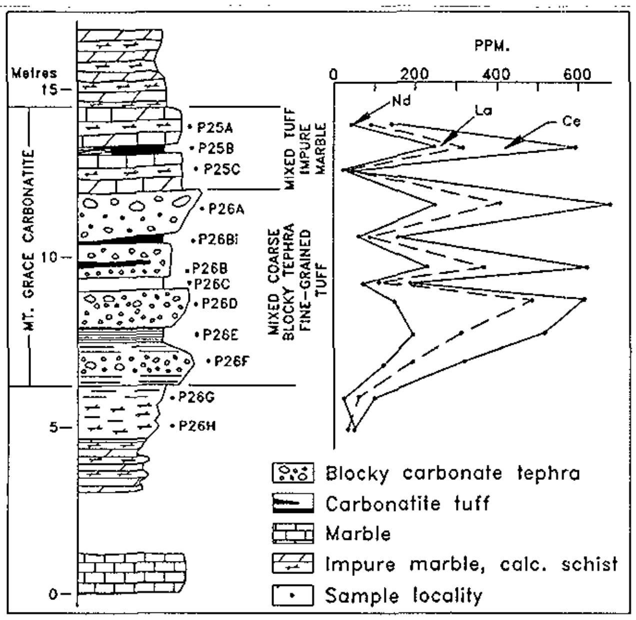


Figure 50. Detailed section of the Mount Grace carbonatite, Blais Creek showing. La, Ce and Nd values of selected samples from Höy (1988).

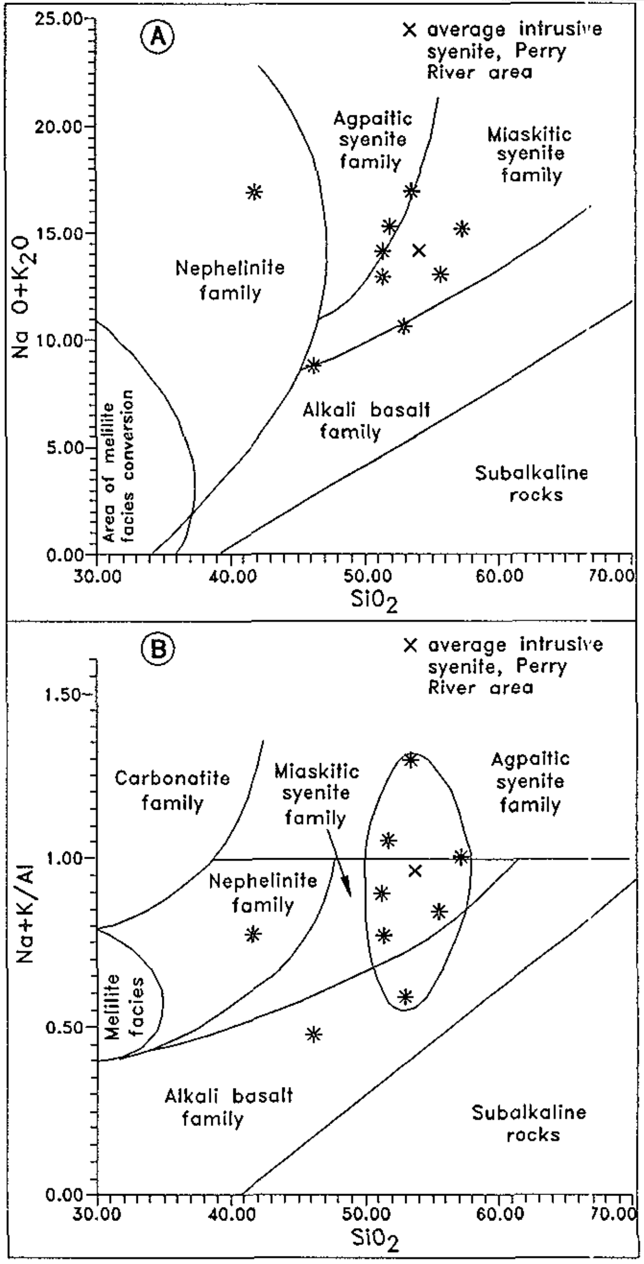


Figure 51. Alkali-silica and agpaitic index plots, Perry River syenites.

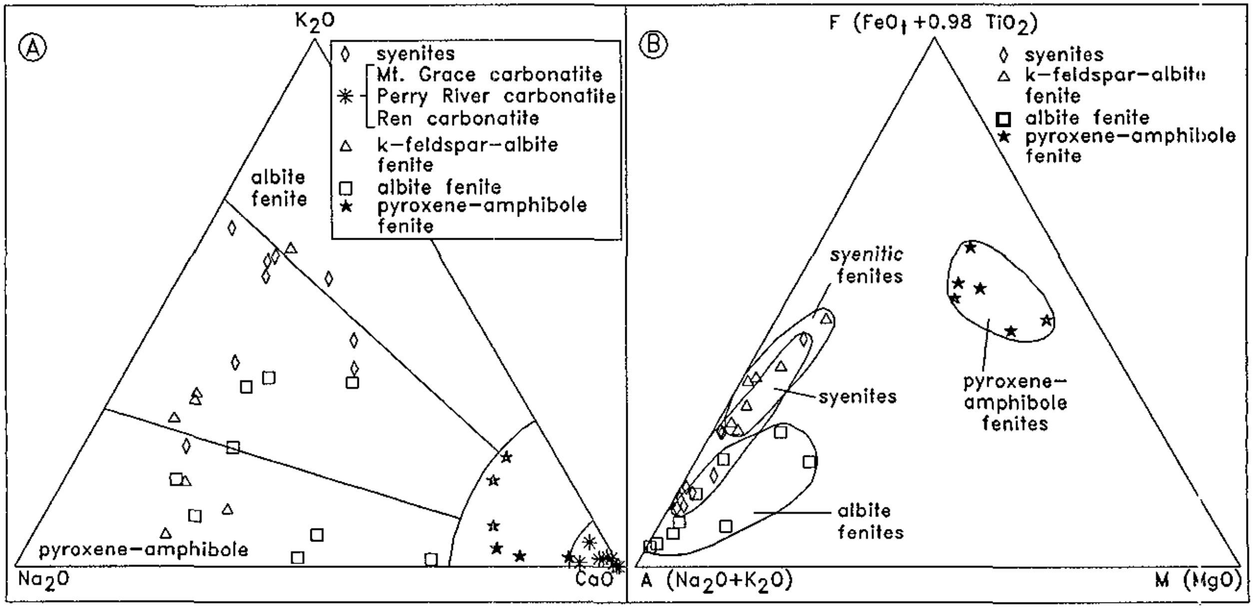


Figure 52. Major element ternary plots, Perry River and Mount Grace area alkaline rocks. (A) CaO-Na_2O-K_2O plot, Perry River and Mount Grace areas; (B) AFM diagram, Perry River syenites and fenites.

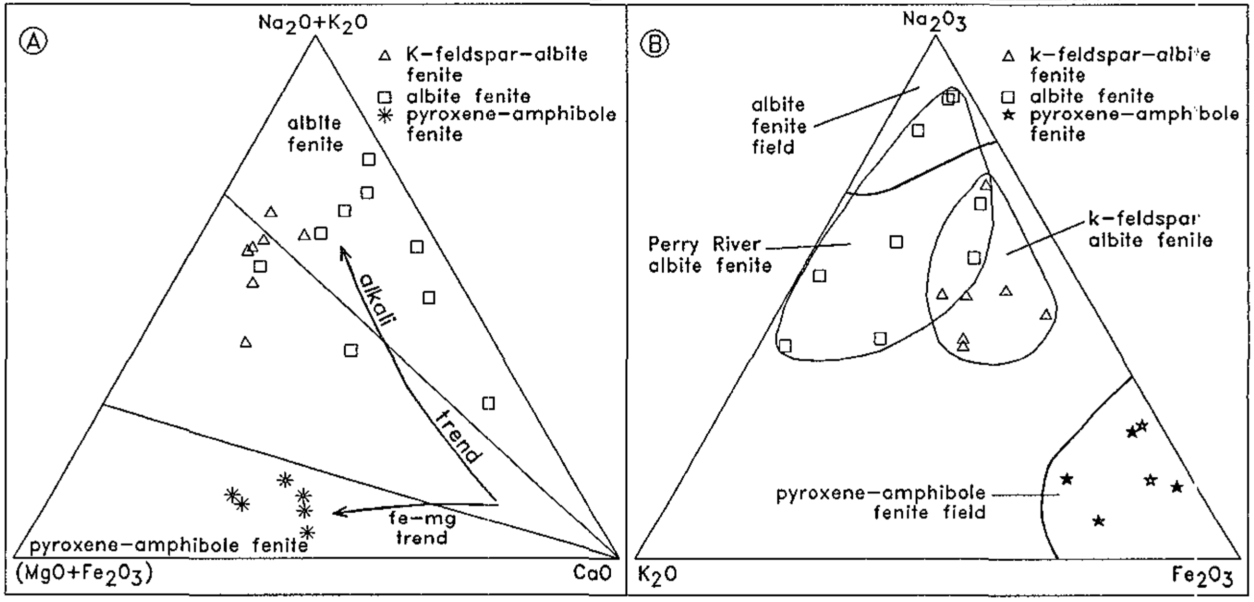


Figure 53. Fenite plots, Perry River area. (A) CaO-Na2O-K2O-MgO+Fe_2O_3 fenite plot, Perry River area; (B) Na_2O-K_2O-Fe_2O_3 fenite plot, Perry River area.

than sedimentary marbles; rare-earth element analyses can be used to differentiate the layered Mount Grace carbonatite from its hostrocks (Figure 50). Thin tuff layers, with high rare-earth element concentrations, are present within metasedimentary marble at the top of the carbonatite unit (sample H85P25B) and some of the fine-grained marble layers within the basal part of the carbonatite unit (those that have low REE concentrations, *e.g.*, 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.

Intrusive syenites are quite varied in major element composition (Table 1; Figures 51 and 52); both agpaitic and miaskitic varieties are present, but on average, the Perry River syenites are miaskitic in nature (Figure 51). Alkali and iron-magnesium fenites occur in the Perry River area, and can be clearly differentiated on ternary plots (Figure 53). The alkali fenites may be further subdivided into soda-rich (albite) fenites and soda and potash-rich (albite - potassium feldspar or 'syenitic') fenites; however, these two types are compositionally gradational (Figure 53). Syenitic fenites cannot be easily distinguished from igneous syenites on AFM or Na_2O-K_2O-CaO ternary plots (Figure 52). Albite fenites are most common as clasts in the Mount Grace carbonatite and Höy (1988) suggests that this may indicate that sodium fenitization is more important at depth adjacent to the parent magmas, and the more potassic and iron-magnesium fenitization occurs at higher structural levels.

GEOCHRONOLOGY

Uranium-lead analyses of zircons from the Mount Grace carbonatite produce nearly concordant ages of 70 to 100 Ma (R.R. Parrish, personal communication, 1987) which indicates that the zircons are mainly metamorphic in origin. Uranium-lead systematics on pyrochlore from the Mount Grace carbonatite yield a 60 Ma date, which is also indicative of metamorphism.

Because absolute dating methods have not been effective in establishing the age of Mount Grace and Perry River carbonatites, other methods must be attempted. The Mount Grace and Perry River carbonatites are hosted in the mantling gneisses of the Frenchman Cap dome, a rock sequence that also contains the Mount Copeland syenite gneiss (underlying the carbonatites) and the Cottonbelt stratiform lead-zinc layer (overlying the carbonatites). The Mount Grace carbonatite, which is extrusive, must be the same age as the sediments with which it is interbedded.

The date of approximately 770 Ma, obtained from zircons in the Mount Copeland syenite gneiss (Okulitch *et al.*, 1981) which intrudes the basal part of the succession in the Jordan River area, suggests that the basal part of the succession is Late Proterozoic (it must be at least as old as rocks which it is intruded by). A Lower Cambrian lead-lead date obtained from galena in the stratiform Cottonbelt lead-zinc deposit higher in the succession (Höy and Godwin, 1988) supports the interpretation that the age of the mantling gneiss succession spans Late Proterozoic to early Paleozoic time (Höy, 1988). The Mount Grace carbonatite also must be Late Proterozoic to early Paleozoic in age. It occurs high in the mantling gneiss stratigraphy, only 110 metres below the Cottonbelt deposit; and based on this, it is reasonable to assume that it is close in age to the Cottonbelt deposit, probably latest Hadrynian to Eocambrian (*circa* 570 Ma). Additional work on uranium-lead systematics is currently in progress in an attempt to verify these conclusions.

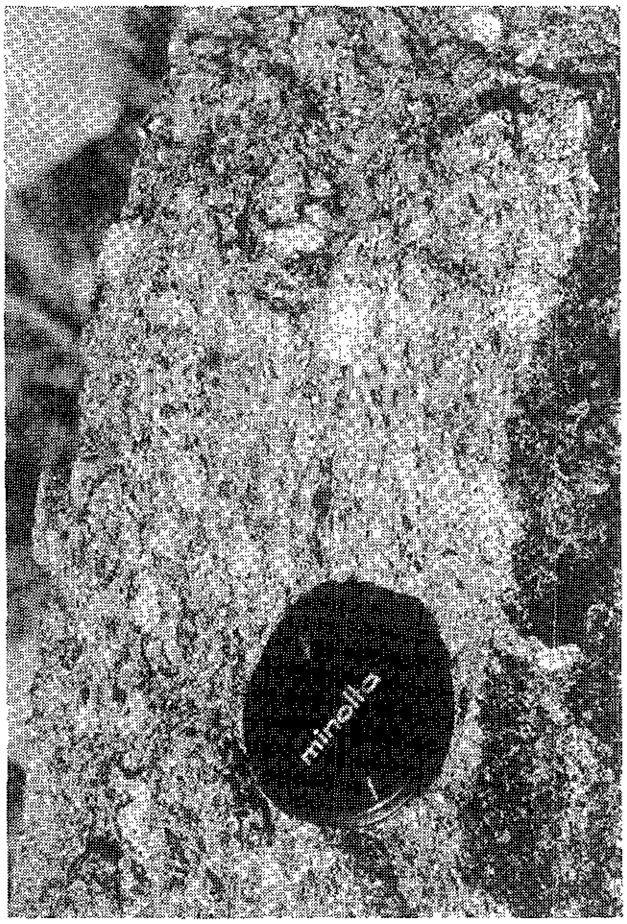


Plate 30. Large feldspar clots in biotite-rich carbonatite, Three Valley Gap area.

THREE VALLEY GAP (82L/16)

Carbonatites and leucosyenites are found along the Victor Lake Main logging road (latitude 50°55′34″N, longitude

TABLE 12
CHEMICAL ANALYSES, THREE VALLEY GAP
ALKALINE ROCKS

wt %	1	2	3	4	5	6
SiO2	18.70	21.60	33.40	46.50	50.96	61.38
TiO2	0.72	0.81	0.67	0.68	0.64	0.42
Al2O3	6.29	8.29	11.02	13.80	21.26	17.62
Fe2O3T	8.7	8.16	6.20	8.33	4.34	2.70
MnO	0.26	0.23	0.16	0.21	0.08	0.07
MgO	2.70	2.42	2.44	2.15	1.85	0.89
CaO	33.20	29.80	21.95	18.90	11.29	5.17
Na2O	0.92	1.60	1.93	2.18	3.35	3.64
K2O	2.85	3.26	3.59	2.40	2.37	6.76
LO1	22.25	20.75	14.63	2.26	1.29	0.07
P2O5	3.21	3.20	2.10	2.40	2.27	0.76
Total	99.80	100.1	98.09	99.81	99.7	99.48
ppm						
Ni	< 2	< 2	1	0	1	3
Cr	3	3	< 20	63	< 20	< 20
Co	14	13	15	12	20	28
Sr	3433	3135	3279	1418	1730	1313
Ba	1568	1726	2405	836	826	1643
Zr	207	296	79	217	177	31
Nb	429	114	110	96	33	92
Y	51	47	37	34	42	24
La	212	206	148	131	60	55
Ce	401	396	256	275	140	154
Nd	151	140	-	111	-	-
Yb	4.4	4.2	-	2.8	-	-
Sc	29	24	20	16	11.9	6 6
Ta	82	1	< 2	19	1	21
Th	0	10	6	< 6	4	7

1. - 3VG136A - biotite sovite; 2. - 3VG135A - sovite;
3. - 3VG139A - biotite sovite
4. - 3VG137 - border zone between carbonatite and associated syenitic rocks;
5. - 3VG137B - syenitic fenite, contact zone;
6. - 3VG139B - pegmatitic sphene-rich syenite.
Major elements analysed by ICAP, alkaline fusion, in samples 1,2,4; All trace elements analysed by XRF except REE in 1,2, & 4 which were analysed by INAA.

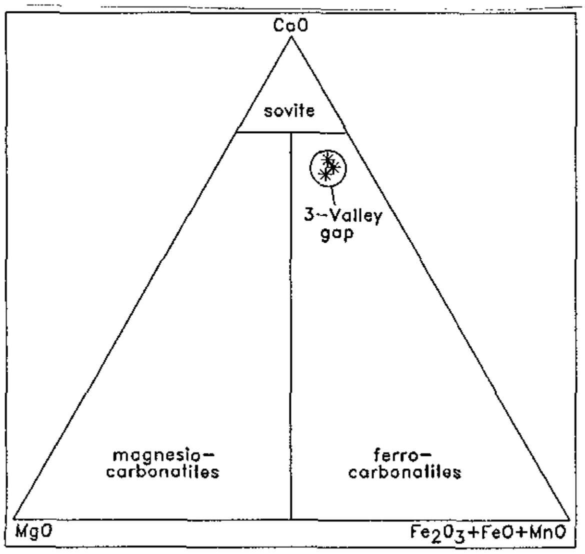


Figure 54. CaO-MgO-Fe_2O_3t+MnO carbonatite plot, Three Valley Gap.

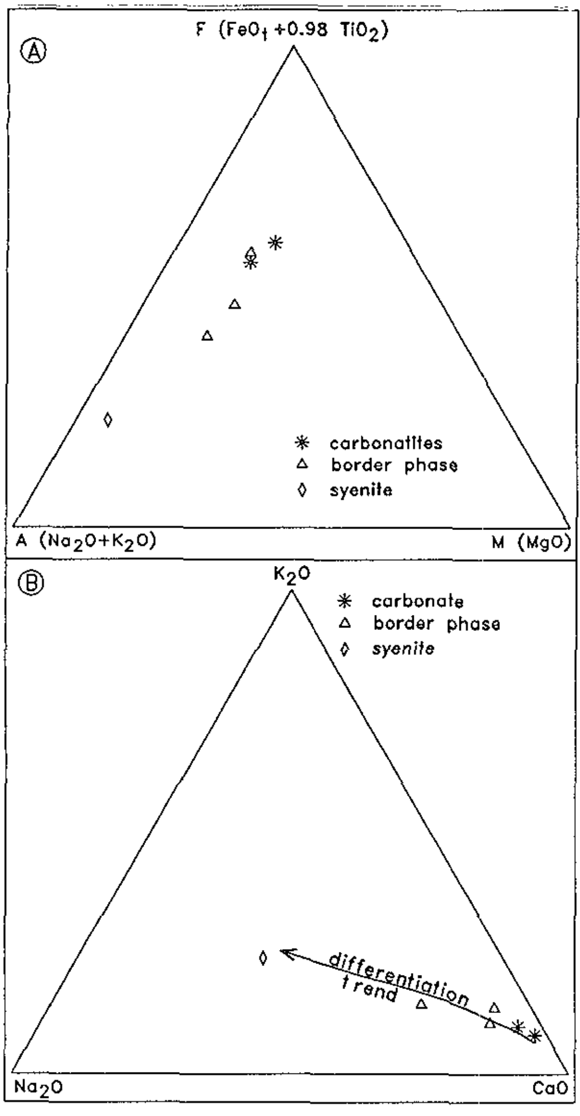


Figure 55. Major element ternary plots, Three Valley Gap.

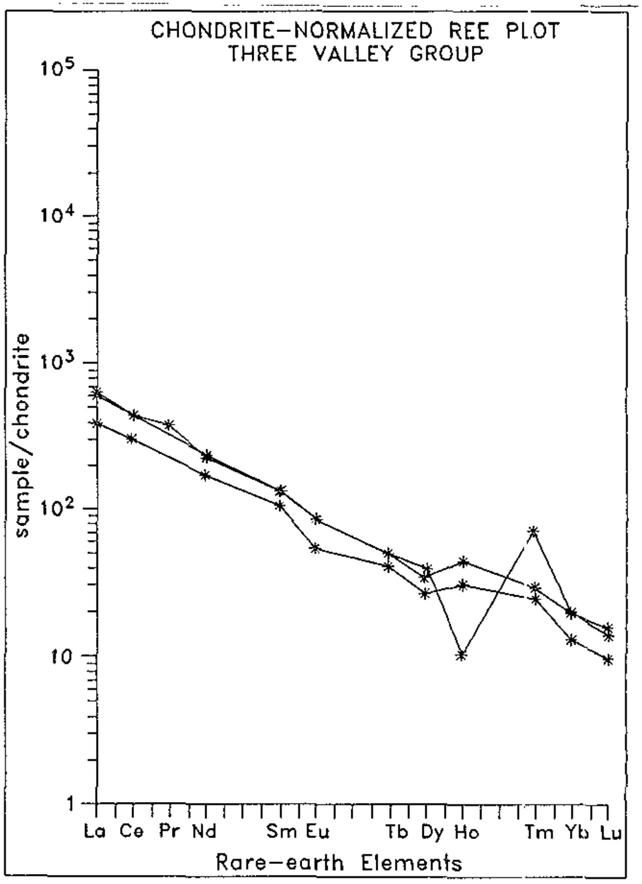


Figure 56. Chondrite-normalized REE plot - Three Valley Gap.

118°23'29"W) which joins the TransCanada 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 condition, passable by conventional vehicles.

The carbonatites and syenites occur as thin, discontinuous bedding-parallel lenses in pelitic metasedimentary rocks. Both the intrusions and hostrocks have been metamorphosed to upper amphibolite facies (sillimanite zone) and the pelites have been extensively migmatized. The hostrocks 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 they are assigned to the mantling gneisses. Carbonatite lenses are generally 20 to 60 centimetres in width and have envelopes of mafic fenites, 10 to 30 centimetres thick, 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 buff to brown-weathering rocks that are primarily composed of calcite (45-50%), biotite (5-20%), apatite (5-15%), perthite (up to 10%), hornblende (5-30%), augite (1-10%) and traces of sphene. In places they contain feldspathic lenses or augen (Plate 30), 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 are green on weathered and fresh surfaces and generally contain abundant augite, hornblende, calcite (25% 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 are massive, white, medium to coarse-grained rocks that generally contain potassium feldspar>plagioclase±augite±sphene. Their origin is unclear; unambiguous field relationships are not exposed. These syenites may actually be syenitic fenites, rather than intrusive phases.

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 12). They are also relatively enriched in iron and plot within the ferrocarbonatite field on a CaO-MgO-Fe_2O_3+MnO ternary plot (Figure 54). Samples collected adjacent to the carbonatites have major element concentrations intermediate between the carbonatites and the 'syenitic' rocks (Figure 55). Rare-earth element contents are low, relative to Perry River, Ren and Mount Grace carbonatites (Appendix 1) and slopes on chondrite-normalized rare-earth plots (Figure 56) are flatter than for carbonatites on the west flank of the Frenchman Cap dome (less light rare-earth enrichment).

GEOCHRONOLOGY

Uranium-lead analyses of zircons separated from the Three Valley Gap carbonatite produce nearly concordant ages of 70 to 100 Ma, as was the case with the Mount Grace carbonatite, indicating that the zircons are mainly metamorphic in origin.

ULTRABASIC DIATREMES IN NORTHERN BRITISH COLUMBIA

Only two breccia pipes have so far been recognized in British Columbia north of Prince George (Figure 2); the Ospika pipe near the Peace Reach, east of Williston Lake and a small diatreme in the Kechika River area of the Cassiar Mountains, west of the Rocky Mountain Trench. Both are hosted by middle Paleozoic carbonate rocks and are associated with carbonatite/alkaline rock complexes. The diatreme in the Kechika River area is the only one documented west of the Rocky Mountain Trench.

THE KECHIKA RIVER DIATREME AND RELATED ROCKS (94L/12, 13)

A suite of alkaline igneous rocks in the Kechika Ranges of the Cassiar Mountains is intermittently exposed in a northwest-trending zone in excess of 20 kilometres long, the centre of which is approximately latitude 58°42′ north and longitude 127°30′ west. Trachytes, syenites, malignites, carbonatites and related tuffs and agglomerates are present in this suite (*see* Chapter 2); a diatreme breccia pipe and related dikes and tuffs are also exposed in this area. The igneous rocks are hosted by middle Paleozoic (Silurian?) carbonate strata and have been deformed and metamorphosed to greenschist facies.

A complex diatreme containing a number of breccia phases, related tuffs and breccia dikes crops out near the centre of the belt of alkaline igneous rocks (Figures 21 and 22). These rocks weather greenish silver to rusty orange and are weakly to extremely well foliated. The main diatreme is exposed in a creek at approximately 1560 metres elevation; dikes and tuffs are present on the slopes and ridges to the north and west of the diatreme, at elevations of up to 2230 metres. Exposure in the area is moderate to excellent; buckbrush and scattered trees are present in the valley bottoms, while the upper slopes are barren. Access to the area is by helicopter from Watson Lake, Yukon or Dease Lake, B.C., 150 and 160 kilometres distant, respectively.

LITHOLOGY

The main diatreme (Figure 22) comprises very inhomogeneous, heterolithic tuffisitic breccias with rounded to angular xenoliths up to 7 centimetres in diameter. Quartzite and carbonate rock fragments dominate the xenolith population; some autoliths, rare syenite fragments and some black argillite clasts were also noted. Quartz xenocrysts, rare chrome spinels, juvenile and vesiculated glass lapilli, and crystal fragments (predominantly potassium feldspar and minor phlogopite) are also present. The breccia matrix consists of carbonate minerals, potassium feldspars, minor muscovite and locally, chrome micas. In places near its outer contacts, the breccia is intensely deformed and has the appearance of a stretched-pebble conglomerate. The northern and central parts of the diatreme have been cut by fluorite-calcite and fluorite-calcite-pyrite stockwork veins containing minor amounts of galena and molybdenite. Similar breccias (minus the phlogopite) are present in the Bull River – White River area of the southern Rocky Mountains (Pell, 1987).

Associated dikes are quite common peripheral to the main diatreme and on the ridges to the north (Figures 21 and 22). They crosscut both the carbonate hostrocks and the mottled phyllites. The dikes, in general, are extremely well foliated and average 1 to 2 metres in thickness. They are similar in composition and appearance to the matrix of the main diatreme, comprised predominantly of iron and mag-

TABLE 13
GEOCHEMISTRY OF SELECTED DIATREME BRECCIAS AND RELATED DIKES AND TUFFS, KECHIKA AREA

wt %	Dikes		Diatreme breccia			Tuffs	
SiO2	33.34	34.35	35.68	37.04	36.75	19.82	41.46
TiO2	1.18	1.14	0.85	1.12	0.95	0.81	0.74
Al2O3	6.07	6.32	10.35	10.42	10.07	5.39	8.87
Fe2O3	9.78	9.48	5.96	7.13	6.92	7.47	6.81
MnO	0.14	0.12	0.38	0.39	0.48	0.44	0.26
MgO	13.65	15.11	8.45	10.68	10.01	9.37	5.11
CaO	9.55	5.44	12.55	9.89	11.27	20.21	11.7
Na2O	0.06	2.13	2.10	2.74	2.96	0.25	0.72
K2O	4.80	1.71	7.74	6.04	4.20	4.02	3.76
LOI	16.87	23.31	14.79	13.05	14.22	28.47	15.88
P2O5	0.24	0.19	0.26	0.21	0.21	1.31	0.18
Total	95.68	99.30	99.11	98.71	98.04	97.56	95.49
Ni	600	514	210	270	689	78	162
Cr	1100	1108	510	720	-	328	641
Co	-	82	-	-	269	27	56
Rb	390	95	230	320	314	105	127
Sr	295	212	790	610	708	899	420
Ba	970	179	500	430	412	417	174
Zr	105	106	225	440	181	56	175
Nb	9	60	20	< 5	92	433	80
Y	32	23	32	55	50	385	46
La	15	26	440	360	199	317	341
Ce	33	35	560	440	270	423	510
Nd	-	47	-	-	75	201	204
Yb	< 5	< 3	< 5	< 5	9	23	5
Sc	18	18.5	12	9	18.5	31.9	22.2
Ta	1.2	5	3.9	4.2	9	5	5
Th	3	32	15	16	29	322	5
U	< 0.5	42	2.4	7.5	35	46	29
V	-	161	-	-	132	370	149
F	18000	1800	19000	18000	14500	2650	3700

nesium-rich carbonate minerals, feldspars, muscovite and serpentine. Some quartz and apatite may also be present. The dikes locally contain chrome spinels, small lithic fragments and fragments of devitrified glass. Some contain chrome-green (chrome mica) or dark green (chlorite and biotite) elliptical patches which probably represent sheared and altered fragments or crystals. One dark green weathering dike contains abundant small rock fragments and altered olivine macrocrysts.

Tuffs outcrop on ridges near the centre of the property, immediately north of the main diatreme and at the north end of the property, south of Boreal Lake (Figures 21 and 22). These pyroclastic rocks are rusty orange to silver-green weathering with a pale green fresh surfaces, very similar in appearance to some of the dikes. They are conformable with the host carbonate succession and are interbedded with brown, blocky weathering agglomerates and aplitic trachytes. Chrome spinels are present locally. In thin section, these rocks are seen to contain plagioclase laths, siderite spots and altered, six-sided crystals (clinopyroxenes) in a fine-grained matrix of carbonate, sericite or talc, feldspar and opaques. These rocks may be the extrusive

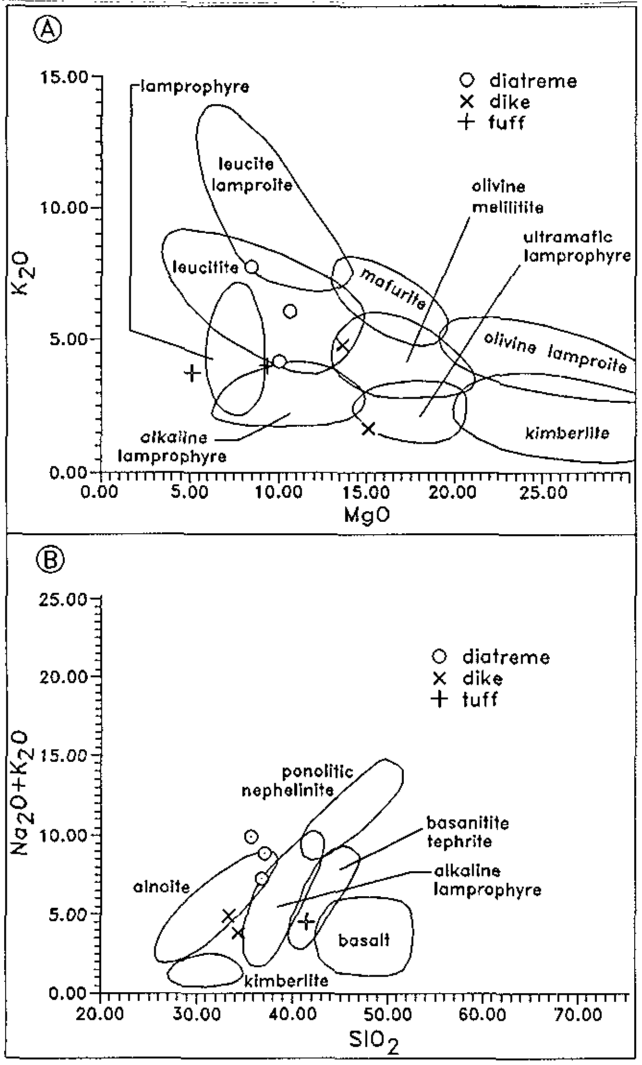


Figure 57. Major element discriminant plots, Kechika diatreme and related dikes and tuffs.

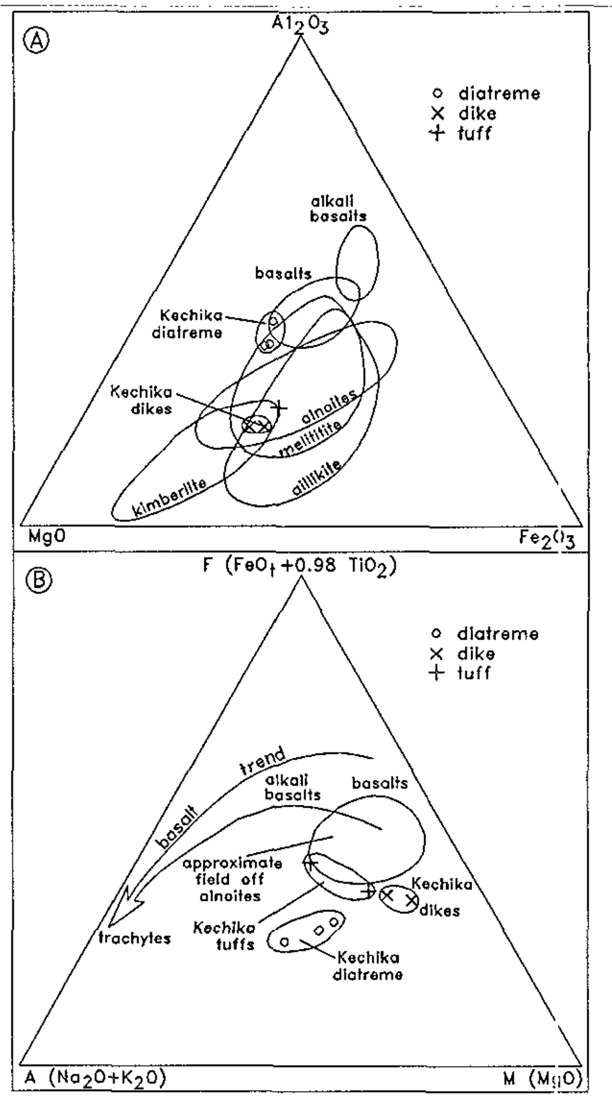


Figure 58. Major element ternary plots, Kechika diatreme and related rocks.

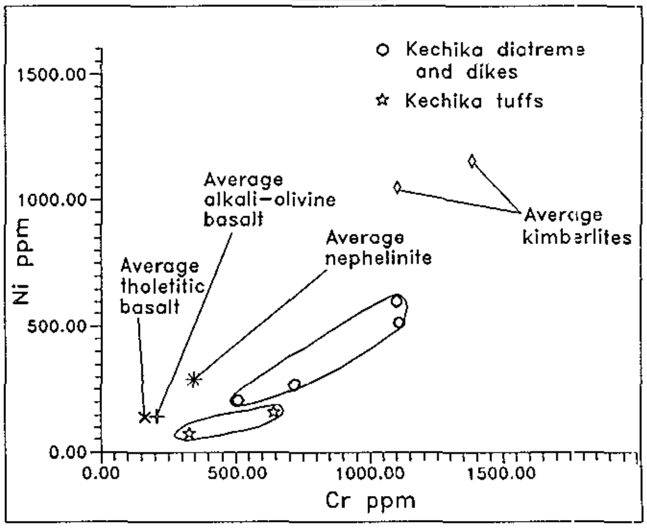


Figure 59. "Average" compositions from Wederhal and Maramatsu, 1979. Ni vs Cr plot, Kechika diatreme, dikes and tuffs.

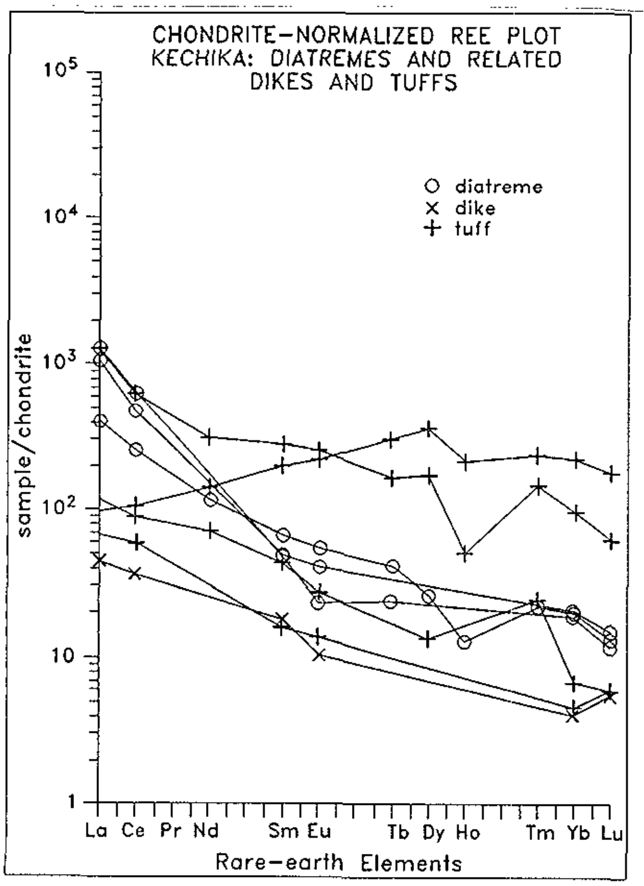


Figure 60. Chondrite-normalized REE plot - Kechika: diatremes and related dikes and tuffs.

Based on modal mineralogy (olivine, clinopyroxene, plagioclase and/or potassium feldspar and minor phlogopite) it is difficult to classify these rocks; they show some similarities to alkaline basalts (basanites).

GEOCHEMISTRY

Major element analyses of samples from the Kechika diatreme and related dikes and tuffs (Table 13) indicate that these rocks are relatively low in silica and aluminum and moderately enriched in calcium and magnesium. On a K_2O-MgO discriminant plot samples from the Kechika pipe and related rocks fall predominantly within or near the leucitite field (Figure 57a), while on an alkali-silica discriminant plot they fall between the alkaline lamprophyre and alnoite field (Figure 57b). On the ternary Fe-Al-Mg plot, samples fall within the melilitite (alkaline lamprophyre) field (Figure 58a). On an AFM plot, samples plot closer to the base (the A-M side) than alnoites or typical basalts (Figure 58b); the diatreme samples are similar, in this respect, to samples of other rock types in the Kechika area (*see* Figure 24b). Based on major element chemistry, it is difficult to classify these rocks although they do show some chemical affinity to alkaline lamprophyres (nephelinites) or leucitites. Alteration may have affected major element chemistry enough to preclude definitive classification.

Diatreme and dike samples show a fair range of nickel and chrome values; some are moderately enriched, containing up to 0.11% chrome and 0.07% nickel. They contain higher concentrations of these two elements than do the related tuffs, in which the igneous component has been diluted (Figure 59). Diatreme and dike samples are also moderately enriched in fluorine, containing between 0.18 and 1.9% (Table 13). They contain low to moderate amounts of rare earths

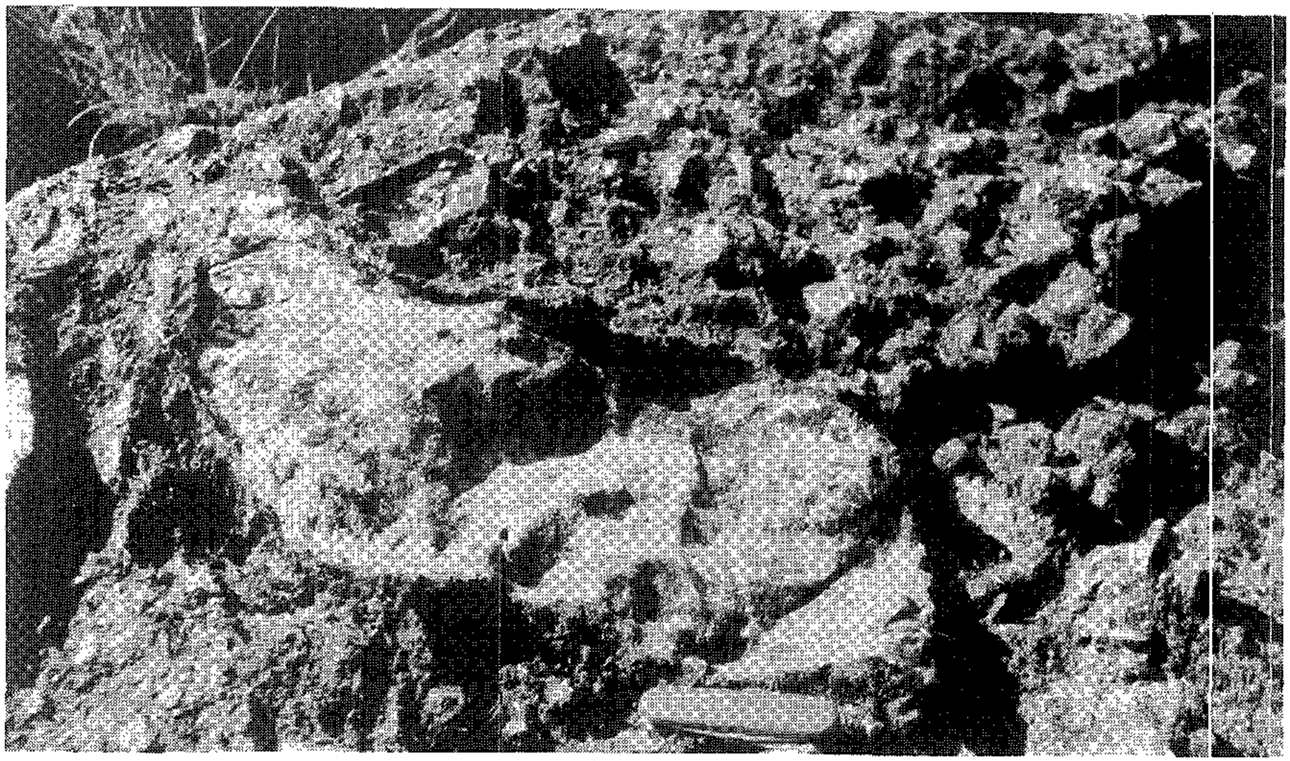


Plate 31. Dolostone clast with reaction rim, Ospika pipe.

(up to 510 ppm La) and, on chondrite-normalized rare-earth plots, generally display shallow, negatively sloping curves (Figure 60) which are indicative of a low to moderate degree of light rare-earth enrichment. The diatreme and related rocks are anomalously enriched in rubidium and have very low total strontium:rubidium ratios that average around 2:1 (Table 13).

GEOCHRONOLOGY

No radiometric dating has been done on alkaline rocks from the Kechika area. Field relationships suggest that they are similar in age to the host strata, Silurian or slightly younger.

TABLE 14
CHEMICAL ANALYSIS - OSPIKA PIPE

wt %	1	2	3	4	5	6	7
SiO2	27.90	24.18	32.09	30.59	26.66	28.65	0.99
TiO2	2.76	2.15	2.76	1.67	2.25	2.58	0.38
Al2O3	5.43	4.77	6.25	5.01	5.19	5.61	0.25
Fe2O3T	9.47	7.94	9.25	9.56	7.61	8.67	5.21
Mn	0.20	0.19	0.17	0.22	0.16	0.17	0.55
MgO	12.72	10.04	14.65	10.62	12.47	14.07	14.69
CaO	15.63	17.26	13.40	17.20	17.52	14.84	27.53
Na2O	0.01	1.23	0.95	2.29	1.55	1.85	0.00
K2O	1.43	4.01	5.55	3.80	4.01	4.02	0.12
LOI	21.51	24.79	10.83	14.32	18.07	17.05	41.59
P2O5	1.12	0.84	0.09	1.80	0.99	0.95	0.09
S	0.08	0.28	0.12	0.16	0.01	0.80	0.41
Total	98.25	97.67	96.93	97.25	97.50	99.26	91.81
ppm							
Ni	230	190	360	220	290	330	40
Cr	455	331	481	185	409	387	232
Co	48	24	46	39	40	47	10
Rb	48	42	160	115	148	118	<8
Sr	514	1257	1134	1650	1448	837	1601
Ba	788	1163	1248	1741	1737	1290	20138
Zr	300	53	263	682	261	303	4
Nb	241	625	180	245	147	168	226
Y	36	72	32	51	26	26	34
La	183	177	124	170	96	199	3858
Ce	322	332	217	369	85	166	6298
Nd	-	-	-	-	-	-	-
Yb	<-2	2	<-4	0	<-7	<-1	6
Sc	29	33.2	32.1	29	32.6	31.5	28.8
Ta	13	15	10	16	6	8	16
Th	36	90	21	40	16	17	1731
U	16	13	16	19	5	16	8
V	317	398	353	261	342	320	253
Cu	109	74	119	73	103	112	80

All analyses by XRF, B.C. Geological Survey Analytical Laboratory.

1. - AL6-4: lamprophyre dike, located in a thrust sheet to the northeast of the Ospika pipe;

2. - AL6-3B5b: rusty weathering fine-grained phlogopite-clinopyroxene-rich clast-poor breccia phase, Ospika pipe;

3. - AL6-3mi: massive phase, Ospika pipe, inclusion-poor ;

4. - AL6-3F: clast-rich breccia phase, Ospika pipe;

5. - AL6-Bl: accretionary lapilli breccia phase;

6. - AL6 2B3: mica-rich breccia phase;

7. - AL6-01: carbonate dike crosscutting breccias of the Ospika pipe

OSPIKA PIPE (94B/5)

The Ospika pipe is a small diatreme located on Cominco's Aley claims (latitude 56°27′N, longitude 123°45′W) 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* Chapter 2), but the relationships between the carbonatite and the diatreme are unclear.

LITHOLOGY

The Ospika pipe is a composite diatreme (roughly 20 by 50 metres in area) 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

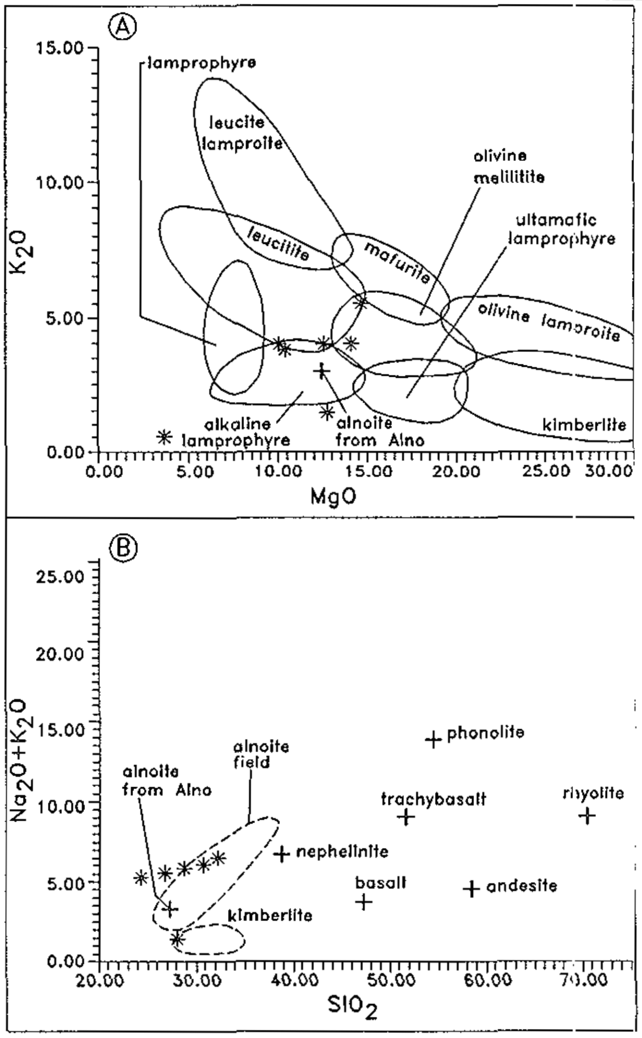


Figure 61. Major element discriminant plots, Ospika pipe.

on the pipe. The phases are differentiated by size and percentage of fragments of sedimentary rock, macrocrysts and pelletal lapilli. Contacts between phases may be sharp or gradational. Locally, narrow dolomitic dikes crosscut diatreme breccias.

The breccias contain 2 to 25% subangular to subrounded fragments of sedimentary rock. These range from a few millimetres to 50 centimetres across, with most in the 2 to 10-centimetre range. Larger fragments are dolomitic with prominent reaction rims (Plate 31). Rare cognate xenoliths are present, but no exotic xenoliths were found. One distinct phase is composed of abundant small pelletal lapilli (50-60%), macrocryptic phlogopite (5-10%) and small fragments of sedimentary rock (less than 10%) in a fine to medium-grained carbonate matrix.

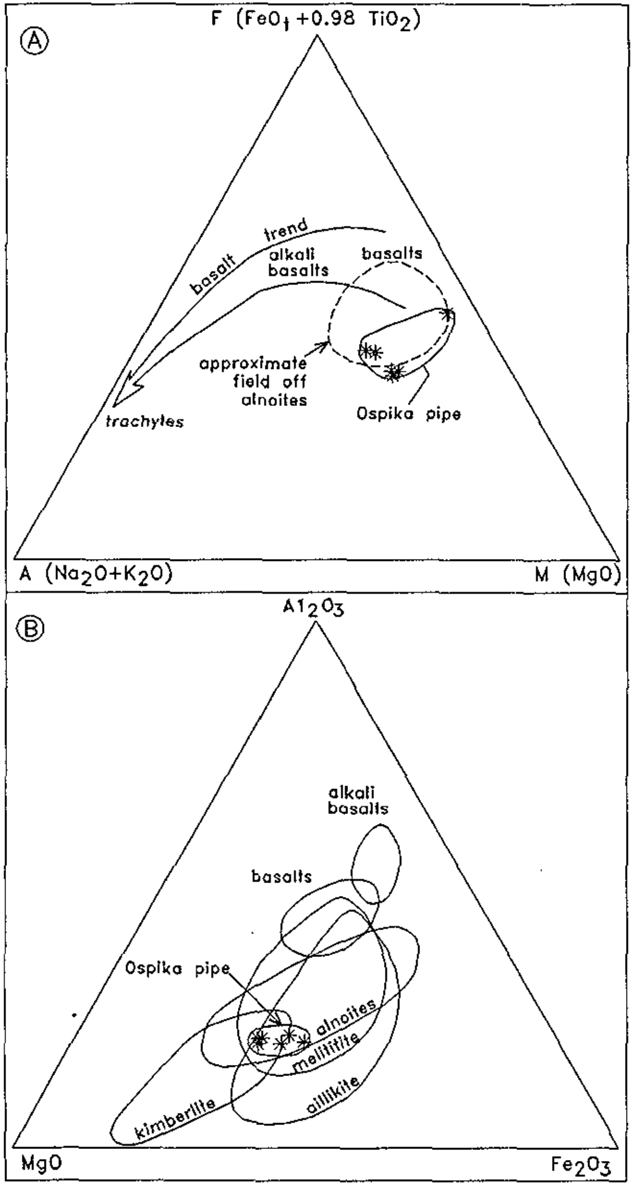


Figure 62. Major element ternary plots, Ospika pipe.

Phlogopite dominates the macrocryst assemblages, comprising 5 to 20% of the rock, with titaniferous augite, rare altered olivine and bright green diopside also present locally. 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, the 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 dolomite and felted phlogopite, chlorite, amphibole with or without talc. It contains abundant fine-grained opaque oxides and, in some places, pyrite.

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

The Ospika pipe and related dikes may be classified, on the basis of petrography, as ultramafic lamprophyres using 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.

GEOCHEMISTRY

Major element analyses of samples from the Ospika pipe and related dike rocks (Table 14) indicate that the pipe is low in silica and high in calcium, magnesium and iron. On a K_2O-MgO discriminant diagram (Figure 61a) analyses group in an area which is overlapped by the leucitite, olivine melilitite and alkaline lamprophyre fields. It should be noted, however, that on this diagram, alnoites from Alno fall

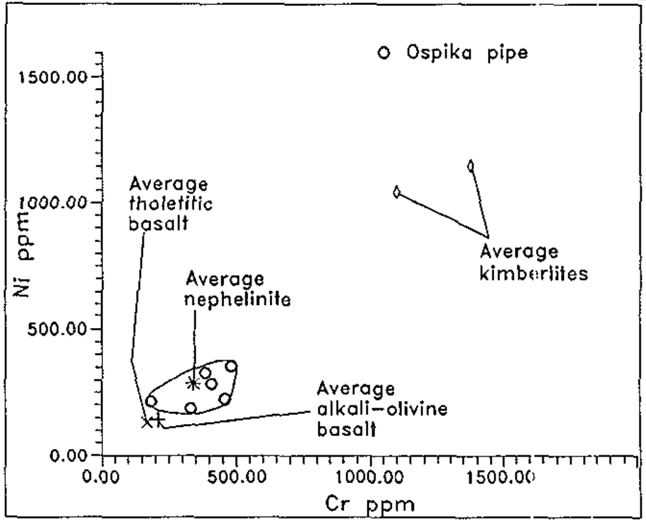


Figure 63. Ni-Cr plot, Ospika pipe.

within the alkaline lamprophyre field, which suggests that the ultramafic lamprophyre field should be extended; this plot is not strictly adhered to in attempting a chemical classification. Analyses from the Ospika pipe plot relatively close to the type alnoite. The same is true on an alkali-silica plot (Figure 61b). Ternary AFM and MgO-Al_2O_3-Fe_2O_3 plots (Figure 62) show that analyses from the Ospika pipe plot in or near the alonite and/or aillikite (a melilite-free alnoite) fields.

The Ospika pipe has a restricted range of nickel and chrome values and contains relatively low concentrations of these elements, similar to the 'average' nephelinite (Figure 63). It is somewhat enriched in titanium, barium, strontium and niobium, and has a fairly restricted range of total strontium:rubidium ratios, averaging around 13:1 (Table 14).

The geochemical data do not conflict with the petrographic classification of the pipe as an aillikite, or melilite-free variety of alnoite, which, according to Rock (1986) is a member of the ultramafic lamprophyre family.

GEOCHRONOLOGY

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 (Appendix 2). These data suggest that the pipe is very similar in age to the Aley carbonatite complex, which it flanks. The temporal and spatial association between carbonatites and alnoites or aillikites is well documented (Rock, 1986).

ULTRABASIC DIATREMES IN THE GOLDEN - COLUMBIA ICEFIELDS AREA

Numerous diatremes are located along the Alberta – British Columbia border (82N, 83C) between 50 and 90 kilometres north of Golden (Figures 2 and 64). 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 dikes are also present.

Microdiamonds have reportedly been recovered from heavy mineral separates taken from two of the pipes in this swarm (Northcote, 1983a, b; Dummett *et al.*, 1985; George Cross News Letter, Jan. 23, 1990). Preliminary investigation suggests that these rocks are neither kimberlites nor lamproites, the two lithologies currently known to contain economic concentrations of diamonds.

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

Near the headwaters of the Bush River (latitude 52°04′20″N, longitude 117°23′50″W; Figure 64) a suite of dikes and small diatremes intrudes Upper Cambrian strata. Three diatremes were examined in this study (Figure 65), revealing two breccia types. The breccias appear quite different in the field, but the division is somewhat arbitrary.

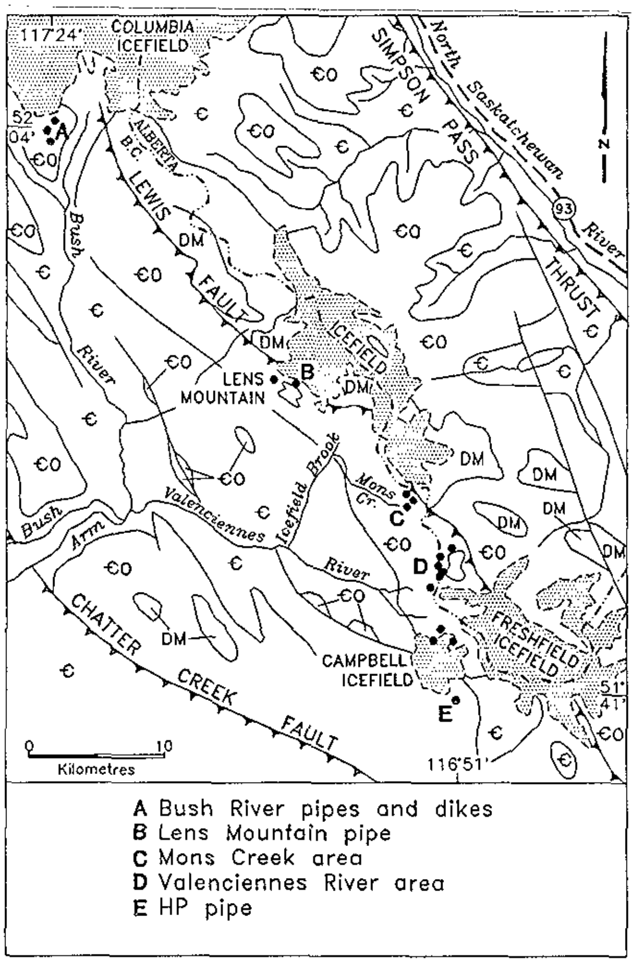


Figure 64. General geology and diatreme locations in the Golden - Columbia Icefields area. • indicates diatremes or dike swarms. Geology modified from Wheeler (1962) and Price (1967a, 1967b). For legend *see* Figure 73.

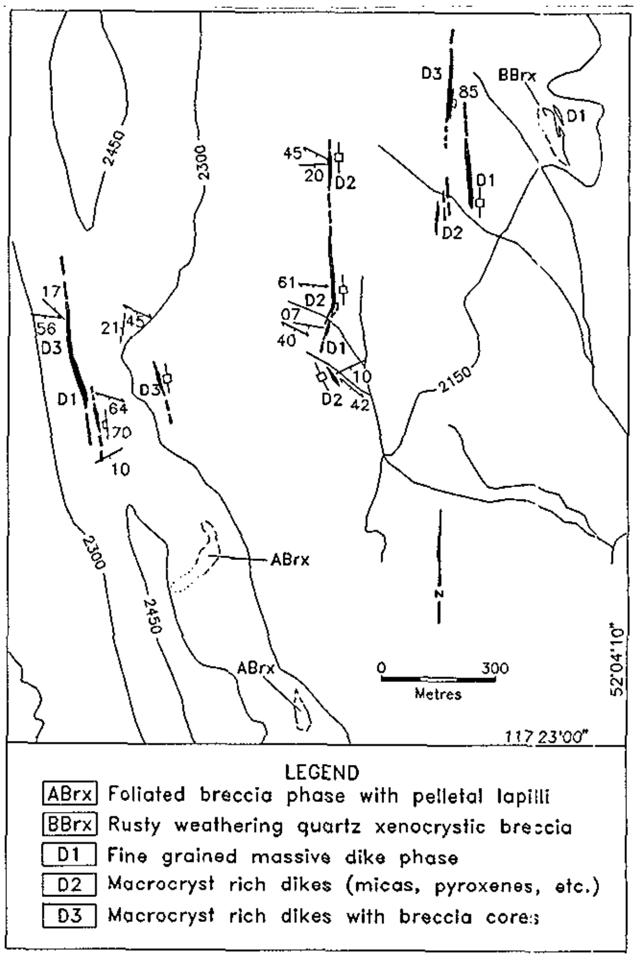


Figure 65. Diatreme breccias and dikes, Bush River area (83C/3).

Plate 32. Rusty weathering, clast-supported megabreccia, Bush River area.

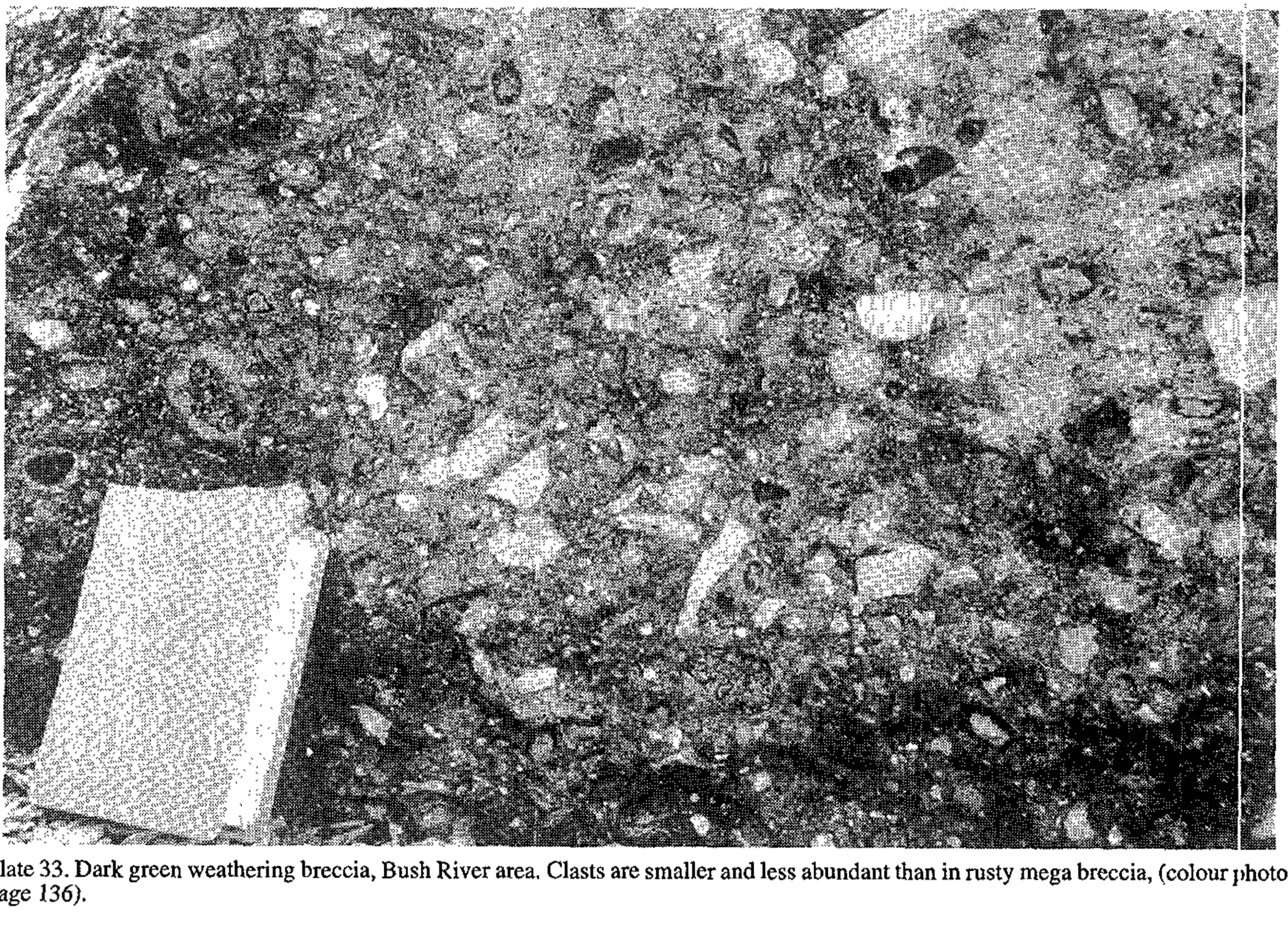


Plate 33. Dark green weathering breccia, Bush River area. Clasts are smaller and less abundant than in rusty mega breccia, (colour photo, page 136).

Plate 34. Limestone-cored armoured xenolith in diatreme breccia, Bush River area.

Plate 36. Boulder from a dike, Bush River area. Dike has a breccia core containing abundant fragments of sedimentary rock and a finer grained, macrocryst rich rim.

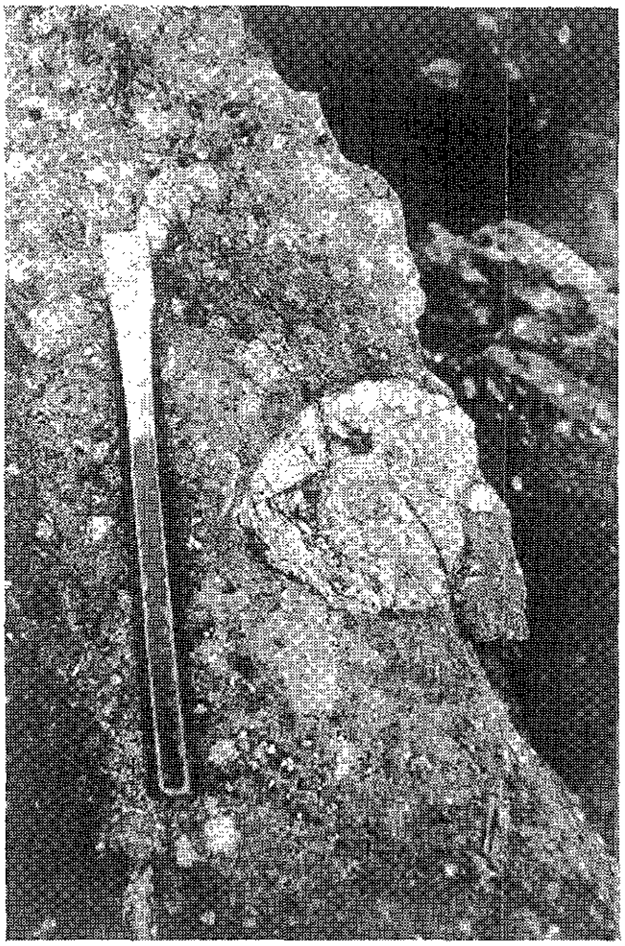


Plate 35. Altered mica macrocryst in diatreme breccia, Bush River area.

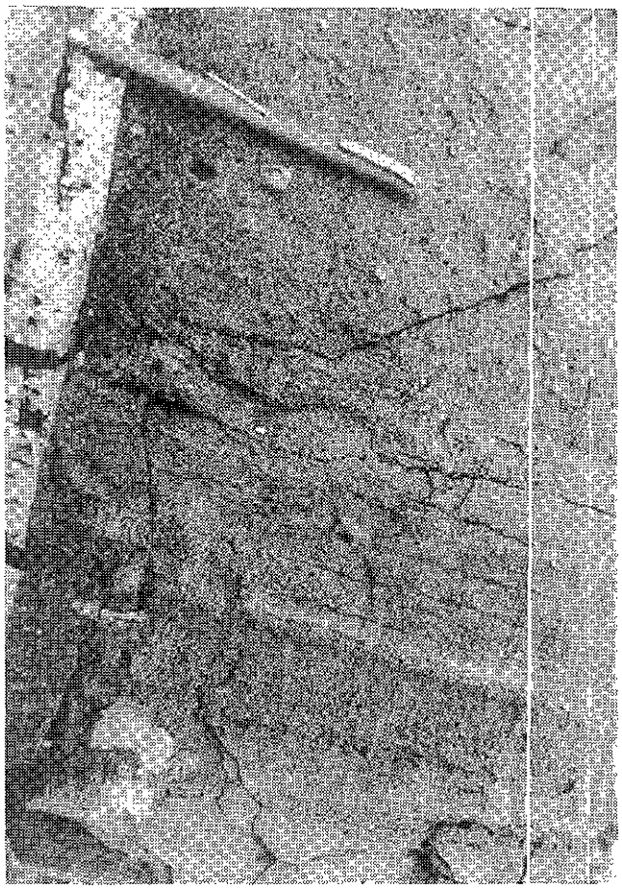


Plate 37. Laminated (flow-banded) margin of a fine-grained dike, Bush River area.

The pipes are massive; only the southeastern diatreme has a margin that is foliated, with the foliation subparallel to the contacts (Pell, 1987; Ijewliw and Schulze, 1989).

The northeastern pipe comprises rusty orange weathering, clast-dominated megabreccia (Plate 32). The clast:matrix ratio is approximately 3:2. Over 99% of the clasts are subrounded to subangular fragments of the hosting carbonate lithologies, ranging in size from 1 to 75 centimetres, 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 type of breccia, exhibited by the central and southern pipes, is also clast dominated and generally massive, but is rusty to dark green weathering (Plate 33) rather than orange in colour. The clast:matrix ratio is greater than in the first breccia type and the clast population more varied. Approximately 50% of the clasts are subangular fragments of sedimentary rock, carbonates, shales and some orthoquartzites. Two to five percent 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 fragments of altered igneous-looking material comprise 10 to 20% of the xenoliths. These clasts consist of coarse, randomly oriented carbonate grains,

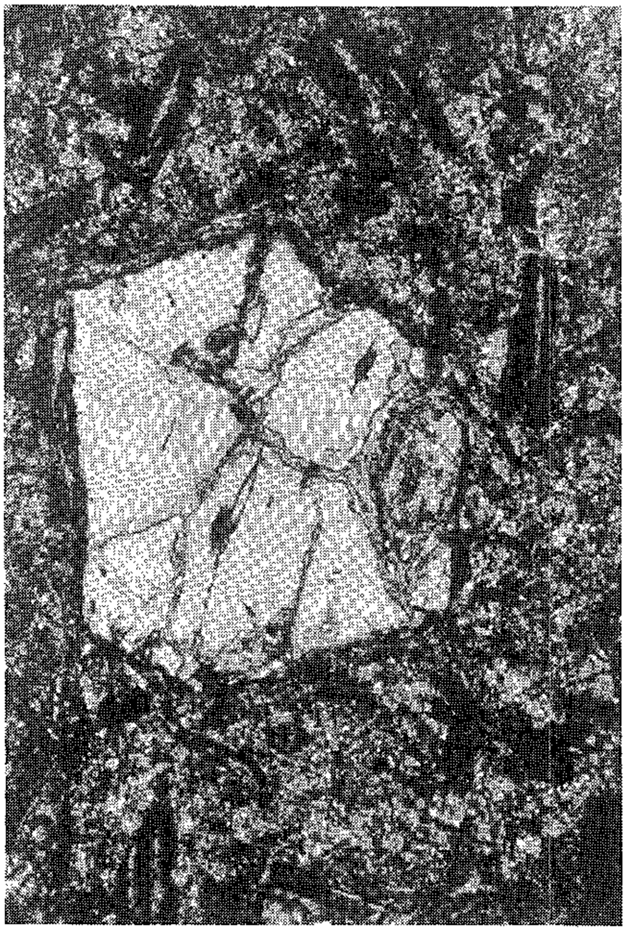


Plate 38. Photomicrograph of an altered pyroxene crystal in a matrix containing abundant altered mica; dike, Bush River area. Long dimension of photograph is 2.5 mm.

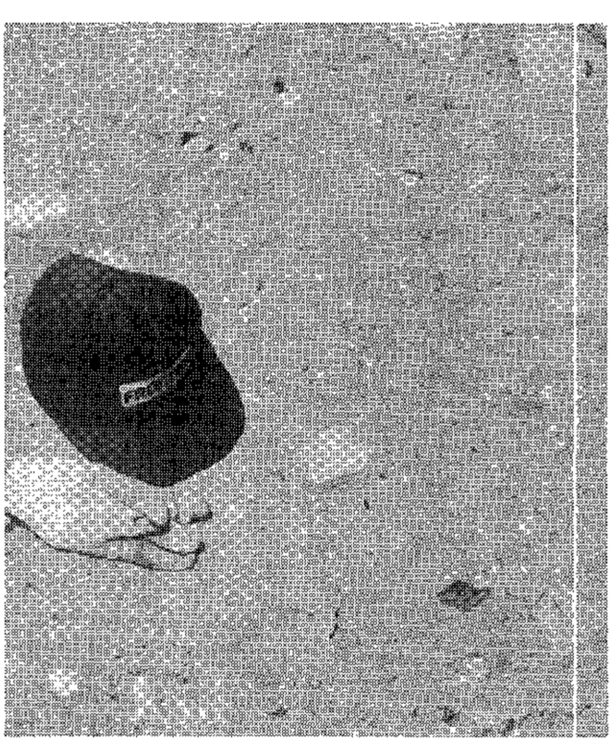


Plate 39. Fragments of sedimentary rocks in a buff-weathering, quartz xenocryst-rich breccia, Mons Creek area.

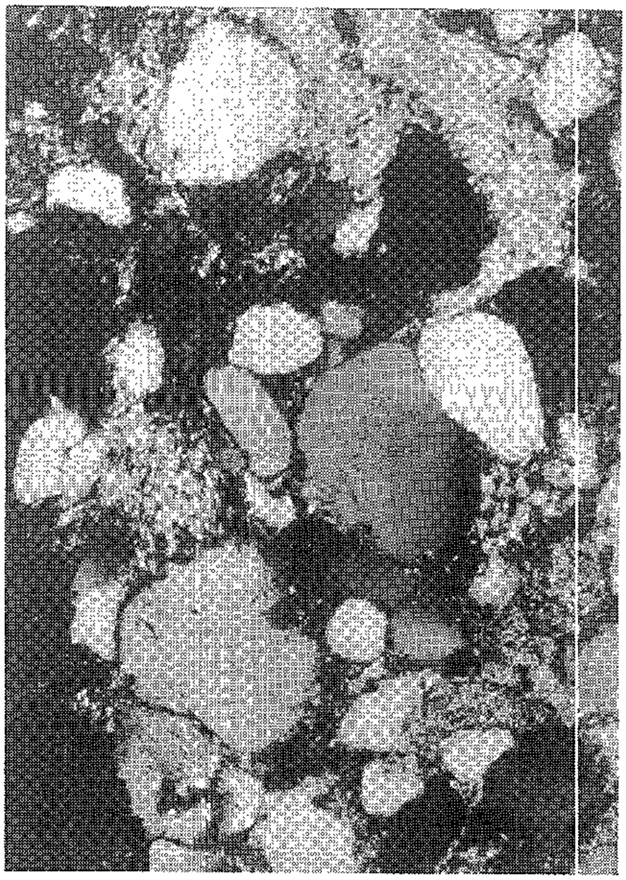


Plate 40. Photomicrograph of quartz xenocryst-rich breccia, similar to that shown in previous photograph. Quartz xenocrysts are enclosed in a matrix of carbonate, chlorite and iron-oxides. Long dimension of photograph is 2.5 mm.

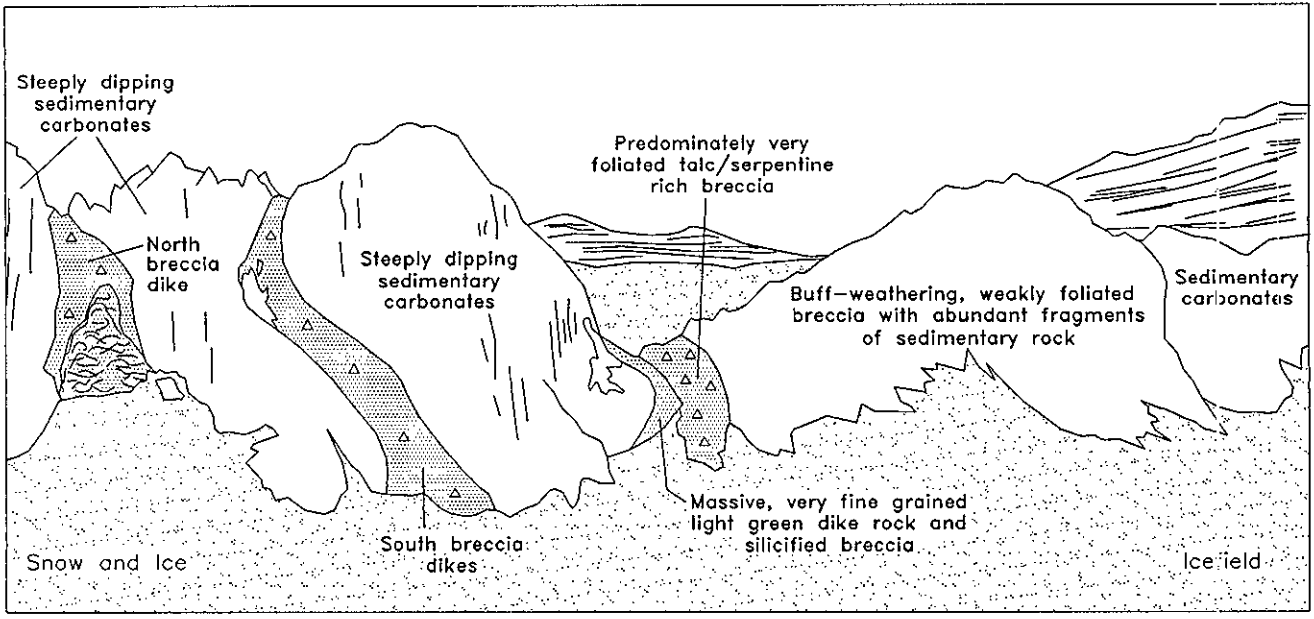


Figure 66. Sketch showing distribution of diatreme related rocks on the Jack claims Lens Mountain area; sketch drawn from photograph taken by C. Fipke. View is of the ridge southeast of Lens Mountain, facing northeast.

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 mica-rich igneous material similar to the breccia matrix. An additional 5 to 10% of the breccia fragments are cognate xenoliths. The remainder of the clast population is made up of spherical structure (also referred to as accretionary lapilli or globular segregations) ranging from a few millimetres to 3 centimetres in size and frequently cored by small fine-grained limestone fragments (Plate 34). Armoured xenoliths and accretionary lapilli are features common to pyroclastic rocks (Fisher and Schmincke, 1984). Silvery, altered mica macrocrysts, up to 3 centimetres in diameter, are abundant (Plate 35); they were, most likely, originally biotites. The matrix of the breccia consists of chlorite≥calcitequartz>trace apatite. In thin section, it is seen to comprise 25% euhedral to subhedral olivine crystals that have been pseudomorphed by either serpentine, or calcite and quartz with magnetite rims, cloudy, brown plagioclase, biotite, euhedral calcite and trace amounts of magnetite and apatite phenocrysts in a fine-grained aggregate of dusty carbonate, quartz, serpentine, magnetite, chlorite, felsic microlites and unidentifiable material (Ijewliw and Schulze, 1989).

Numerous subparallel dikes are present in the Bush River area, some of which crosscut the diatreme breccias; they range in length from 50 to 600 metres and in width from 0.5 to 2.5 metres. Bifurcation and remerging occurs along the length of some dikes and narrow, fine-grained apophyses are common. Both homogeneous and zoned dikes are seen (Figure 65). The homogeneous dikes are fine grained and medium to dark green in colour. They may contain up to 10% small, silvery, mica phenocrysts and minor amounts of spinel or other opaque oxides. A dike with unaltered phlogopite megacrysts was observed in one locality. The zoned dikes are rusty to dull green on weathered surfaces and fresh surfaces are generally a dull greenish grey colour. They have coarse xenolith and/or macrocryst-rich cores and finer grained margins (Plate 36). Contacts within the dikes may be gradational or distinct and often the margins have a strongly flow-banded texture (Plate 37). In thin section, the dikes are porphyrytic with altered macrocrysts, phenocrysts and glomerocrysts of olivine, pyroxene (Plate 38) and biotite. The olivine crystals, some of which contain inclusions of red-brown spinel, are altered to calcite, serpentine and talc. The groundmass consists of a network of altered biotite with dusty secondary calcite, minor serpentine, spinels and opaques (Ijewliw and Schulze, 1989).

Based on modal mineralogy, including the pseudomorphed phases (olivine, pyroxene, biotite, plagioclase), the dikes and diatremes in the Bush River area can be classified as lamprophyres of either alkaline or calcalkaline affinity. The best designation appears to be as olivine-kersantites, which are part of the calcalkaline lamprophyre family (Ijewliw and Schulze, 1989) or biotite-camptonites, which are alkaline lamprophyres.

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

At both Lens Mountain (latitude 51°54'30"N, longitude 117°07'30"W) and Mons Creek (latitude 51°49'30"N, longitude 117°00'30"W; Figure 64) the dominant intrusive lithology consists of a buff-weathering, weakly foliated breccia with a low clast:matrix ratio (approximately 1:3 or 1:4). The 'Jack diamond' (Northcote, 1983b) was recovered from this lithology and two additional microdiamonds have recently been recovered from drill core (George Cross News Letter, Jan. 23, 1990, p. 2). Clasts are small subangular fragments of sedimentary rock, predominantly carbonates, in the 2-millimetre to 2-centimetre size range (Plate 39). The 'matrix' is pale green to buff in colour and consists of abundant rounded quartz grains (xenocrysts), carbonate, chlorite and iron oxides (Plate 40). Relict lapilli, with a preferred orientation, have also been observed (Ijewliw and Schulze, 1989). At Mons Creek, this breccia grades into a clast-poor (5 to 10% 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.E. 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. The subhorizontal fabric locally displayed in the breccias would have originally been steeply dipping (prior to deformation), which would favour the latter hypothesis.

At Lens Mountain, two additional small breccia pipes or dikes and light green, clast-free aphanitic rock are also present (Figure 66). The breccias are very coarse, weather dark red and have dark grey fresh surfaces. They consist of subangular clasts of limestone and relict phenocrysts in a carbonate matrix. The matrix consists of 15% phenocrysts that are entirely pseudomorphed by fine-grained quartz and/or calcite. Some of the phenocrysts retain traces of simple twinning, with a morphology suggestive of sanadine. Altered crystals of titanamphibole or sphene are also present; they have been replaced by calcite but retain a rim of inclusions of very fine grained sphene. The groundmass is extremely fined grained and contains calcite patches (Ijewliw and Schulze, 1989).

At Mons Creek, a small, light green, strongly foliated, fine-grained breccia crops out to the north of the main sandy diatreme. It contains fragments of sedimentary rock less than 1 centimetre across and opaque oxides in a matrix consisting of dolomite>quartz≥pyrophyllite±minor chlorite, calcite, muscovite and trace apatite. In thin section, these rocks have a porphyrytic texture, but are highly altered. Calcite replaces some phenocrysts, which may have been olivine, many of which have red-brown spinel inclusions. The original composition of other pseudomorphed phenocrysts is undeterminable (Ijewliw and Schulze, 1989).

At Mons Creek, one small, altered dike cutting the main diatreme and a second parallel dike outside the diatreme

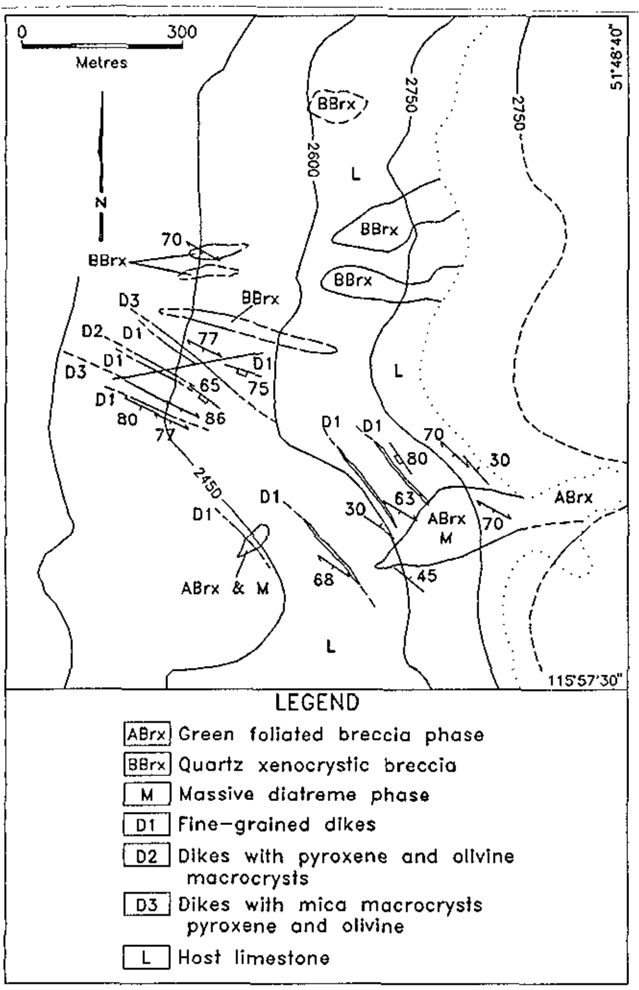


Figure 67. Diatreme breccias and dikes, Valenciennes River.

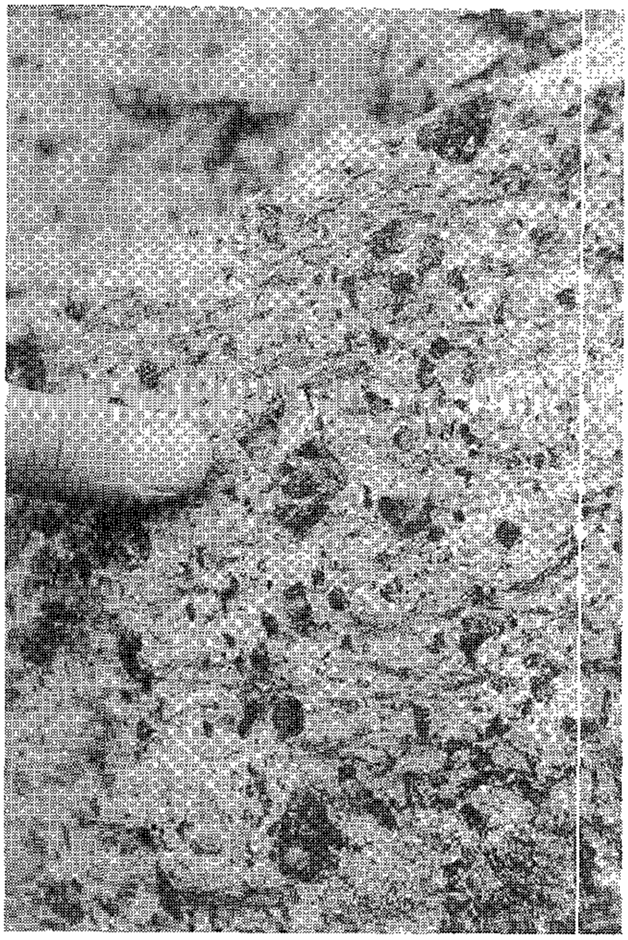


Plate 41. Serpentinized olivine macrocrysts in a fine-grained, massive diatreme phase, Valenciennes River area.

were observed. One unaltered porphyrytic dike and abundant unaltered float of porphyrytic dike-rock are present elsewhere on the property. The altered dikes contain quartz aggregates replacing a lath-shaped, twinned mineral that may have been feldspar, some minute plagioclase grains (An_{25}) that are partly replaced by calcite, and a phyllosilicate mineral, partially replaced by calcite, with sphene inclusions and rims in a fine-grained groundmass of carbonate, chlorite and minor quartz and pyrite (Ijewliw and Schulze, 1989). The unaltered dike material contains 5% primary phenocrystic clinopyroxene, commonly augite or diopsidic augite with pinkish brown titaniferrous rims. Some grains also have titanium-rich cores, and an intermediate, nonpleochroic zone. Other phenocrysts present include biotite, some amphiboles and olivine, completely pseudomorphed by calcite or chlorite, with red-brown spinel inclusions. The matrix contains microphenocrysts of clinopyroxene, biotite, sphene and plagioclase (An_{25}) in a groundmass of carbonate, chlorite, interstitial quartz, fine-grained serpentine and opaque oxides.

The main diatremes 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 dikes at Mons Creek, however, have a preserved mineralogy (titanaugite, plagioclase, biotite, amphibole, olivine) which allows classification as alkaline lamprophyres, or more specifically, biotite camptonites (Ijewliw and Schulze, 1989).

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

Four or more diatremes and numerous dikes intrude Upper Cambrian rocks near the headwater of Valenciennes River (latitude 51°47′00″N, longitude 116°58′00″W; Figures 64 and 67). Two distinctly different diatreme types are present. The first are rusty brown to pale green weathering, weakly to well-foliated, composite pipes with both massive and breccia phases. Two such diatremes are exposed at the southern end of the area examined. Serpentinized olivine macrocrysts (Plate 41), coarse nonmagnetic oxides (green spinels) and altered spinel peridotite xenoliths are present in some phases. Typical breccias contain 30 to 40% clasts, most of which are small (1-5 cm, with a mode of 2 cm), with rare xenoliths up to 15 centimetres across. Limestone, dolostone, shale and minor quartzite 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 seen in hand sample (chrome-rich muscovite?). Chromite and ilmenite have been identified in heavy mineral separates and a microdiamond is reported to have been recovered from the largest diatreme (Northcote, 1983a).

Associated dike rocks are fine to medium grained, rusty to dark green weathering, with a light greenish grey to medium green fresh surfaces. They occur in a number of orientations, varying from almost concordant to discordant to bedding. Dikes which are nearly parallel to bedding and

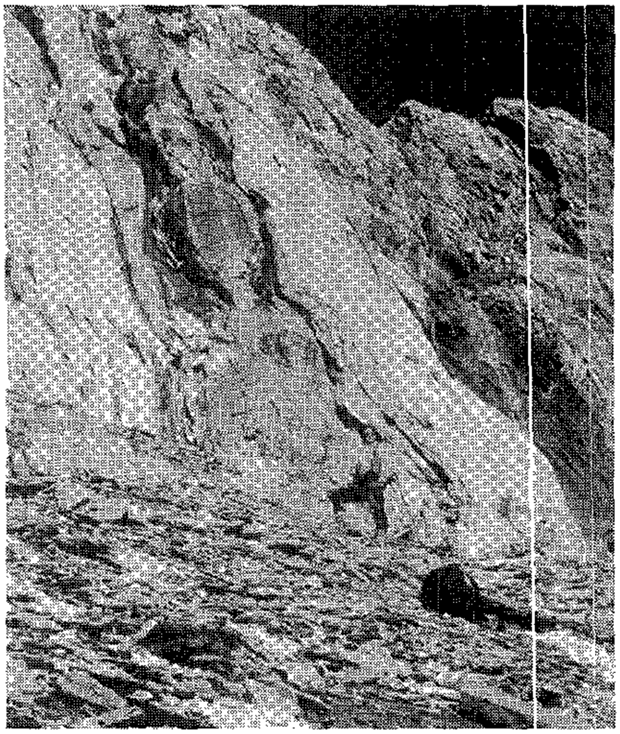


Plate 42. Fine-grained boudinaged dike subparallel to bedding in buff-coloured carbonates. Diatreme breccia in the right background. Valenciennes River area.

Plate 43. Altered phenocrysts (zoned pyroxenes±olivine±mica) in a dike, Valenciennes River area. The degree of alteration in this sample is typical. Long dimension of the photograph is 2.5 mm.

cleavage are strongly boudinaged (Plate 42). Some of the dikes are porphyritic and all are altered. The phenocryst assemblage, so far as can be recognized, consists of sieve-textured olivine pseudomorphs, altered euhedral clinopyroxene with relict zoning, mica and rare spinels. Plagioclase phenocrysts have also been observed (Ijewliw and Schulze, 1989). In some phases, olivine appears to be more abundant than pyroxene (olivine±pyroxene≥mica) and in others pyroxene is far more abundant (pyroxene±olivine≥mica). Some dikes are predominantly micaceous. It is difficult to accurately estimate proportions of phenocrysts as they are altered and only morphology can be used (Plate 43). The groundmass generally consists of very fine grained carbonate, chlorite, serpentine and altered biotite (Ijewliw and Schulze, 1989). Oxides are also a common groundmass constituent. The dikes are generally peripheral to the diatremes, but locally crosscut them.

The second type of breccia is present in the diatremes in the northern part of the area examined (Figure 67). They are brown weathering and moderately well foliated with angular to subangular fragments of sedimentary rock set in a matrix of quartz grains, chlorite and carbonate. Clasts average 1 to 5 centimetres across, with some up to 20 centimetres. The clast:matrix ratio is 2:3. These diatremes are similar to the orange-weathering pipe in the Bush River area (the first type described).

Intense alteration makes petrological classification difficult. The rocks in the Valenciennes River area, as evidenced by phenocryst assemblages in dikes (olivine, clinopyroxene, mica, plagioclase) also bear a strong resemblance to those in the Bush River area and probably belong to the calcalkaline or alkaline lamprophyre clans. The best designation appears to be as olivine kersantites, which are part of the calcalkaline lamprophyre family or, alternatively, biotite camptonites, which are alkaline lamprophyres.

THE HP PIPE (82N/10)

The HP pipe (latitude 51°41′30″N, longitude 116°57′W) is the most southerly diatreme so far recognized in the Golden – Columbia Icefields area (Figure 64). 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 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% exposure and is therefore ideal for study.

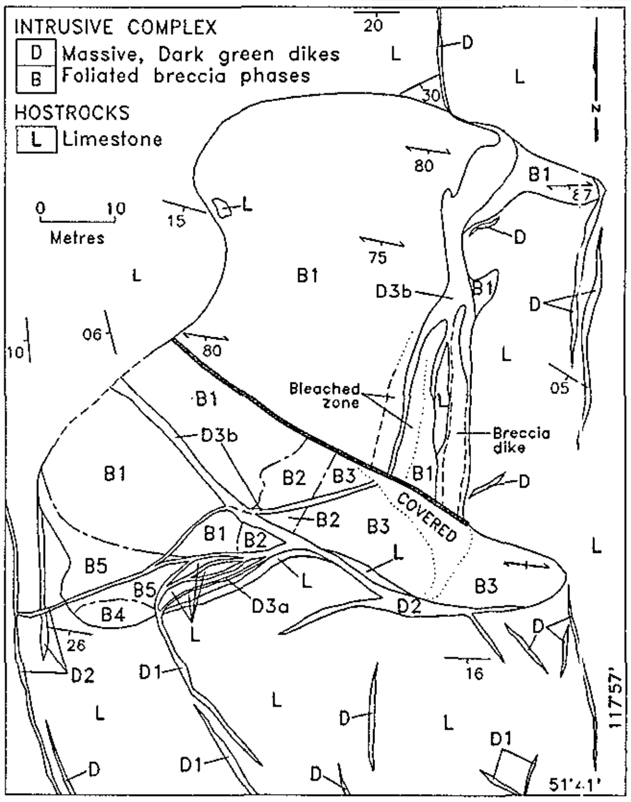


Figure 68. Geology of the HP pipe, south of the Campbell Icefield. Details on breccia and dike phases supplied in Table 15. *See* text for geographic coordinates.

The pipe has sharp, steeply dipping contacts with the horizontal to shallow-dipping grey Cambrian limestone beds which it intrudes (Figure 68). It is a composite dia-

TABLE 15
FIELD CHARACTERISTICS OF HP PIPE BRECCIA PHASES

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

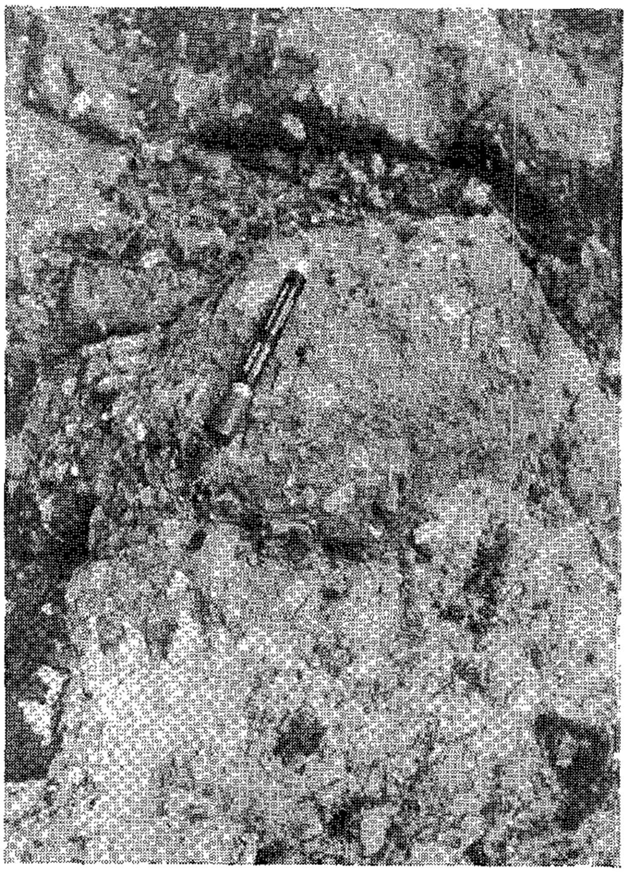


Plate 44. Sharp contact between breccia phases (B2 & 3), HP pipe.

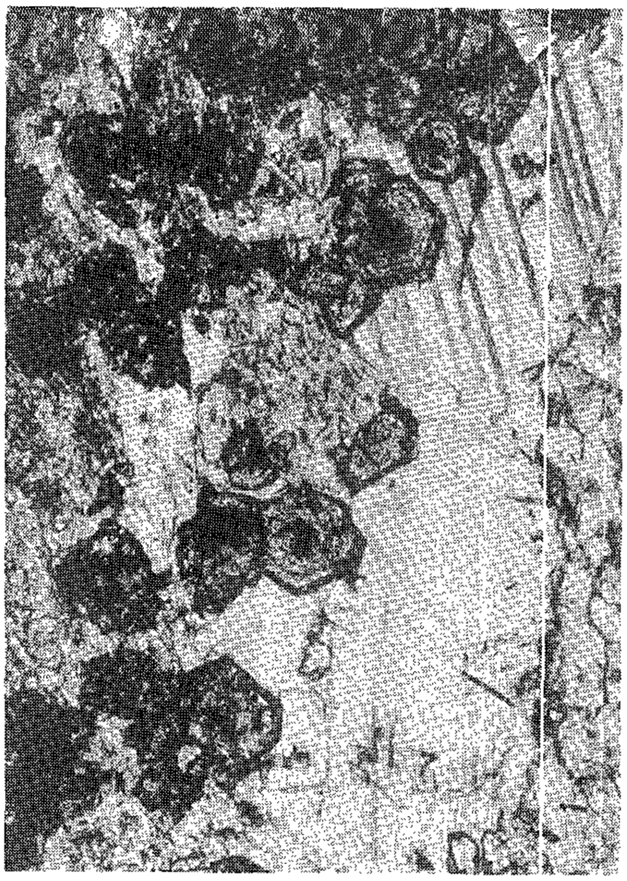


Plate 46. Optically zoned andradite garnets, HP pipe. Long dimension of the photomicrograph is 2.5 mm. Carbonate segregation forms matrix.

Plate 45. Large gabbroic xenolith in a strongly foliated breccia (BI phase), HP pipe.

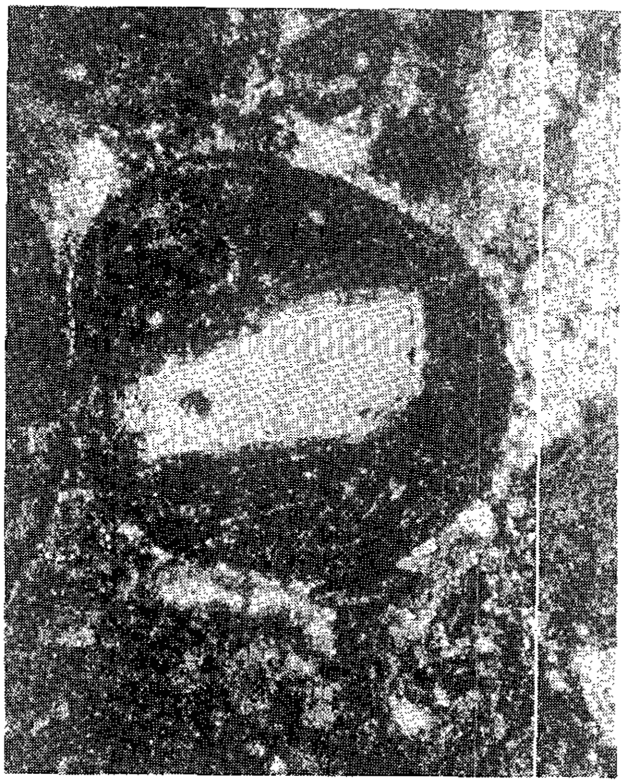


Plate 47. Biotite macrocryst coring spherical structure, HP pipe. Long dimension of the photomicrograph is 7 mm.

TABLE 16
CHEMICAL ANALYSES - GOLDEN AREA DIATREMES

	HP			**Bush River**				**Mons Creek**		**Valenciennes River**				
Wt %	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SiO2	36.12	33.04	37.18	35.01	32.85	30.20	37.20	39.14	40.85	40.52	44.85	39.93	36.97	43.4
TiO2	1.36	1.30	1.41	1.83	2.08	2.31	1.98	1.00	1.39	1.24	0.89	1.12	1.29	0.8
Al2O3	7.70	7.43	9.97	12.42	7.95	11.06	11.32	10.77	11.16	10.18	12.00	11.43	11.58	11.61
Fe2O3T	8.11	7.66	8.28	6.51	8.79	10.31	8.56	9.52	9.51	9.98	7.95	8.44	6.91	8.48
MnO	0.14	0.13	0.18	0.06	0.17	0.12	0.13	0.18	0.18	0.06	0.12	0.12	0.06	0.16
MgO	13.21	11.79	8.67	5.18	9.69	14.67	11.03	12.27	12.79	6.16	6.51	9.48	5.02	7.25
CaO	19.92	20.39	17.41	17.74	16.15	13.28	9.48	16.11	13.36	14.51	11.28	12.36	15.61	12.77
Na2O	0.29	0.27	1.65	1.87	0.25	0.06	0.42	1.32	1.60	0.06	2.73	0.29	0.01	0.18
K2O	4.47	4.18	4.13	1.01	0.06	0.01	4.03	0.53	1.36	0.93	0.21	0.70	3.70	0.60
LOI	6.44	10.70	7.27	16.29	19.88	16.02	14.05	7.71	5.84	14.50	11.73	14.08	16.11	13.90
P2O5	0.58	0.61	1.40	0.95	0.79	0.74	0.58	0.81	0.91	0.77	0.47	0.88	0.65	0.42
S	0.11	0.04	0.09	0.07	0.02	0.11	0.16	0.08	0.07	0.08	0.20	0.04	0.31	0.05
Total	98.45	97.54	97.63	98.95	98.66	98.89	98.93	99.43	99.02	98.99	98.93	98.88	98.21	99.63
ppm														
Ni	240	210	110	140	150	330	200	200	270	230	200	270	230	200
Cr	786	904	313	335	301	805	386	493	527	849	399	589	744	387
Co	40	40	38	30	42	55	43	45	42	48	38	36	56	40
Rb	137	121	130	39	< 8	3	112	17	40	24	< 8	12	85	5
Sr	995	1121	1189	579	881	1191	528	513	1410	595	640	1026	821	781
Ba	1933	1868	3131	390	202	3791	1975	514	2136	360	91	227	322	589
Zr	244	191	128	337	188	345	361	160	229	265	112	198	312	96
Nb	175	156	237	350	172	301	294	204	262	200	140	229	338	111
Y	24	17	31	34	20	22	22	26	25	29	24	24	26	18
La	90	78	261	92	121	91	78	120	197	119	162	165	145	123
Ce	181	169	449	193	208	171	149	206	321	247	267	291	278	220
Nd	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Yb	<-1	<-8	<-4	<-3	<-4	3	1	<-2	1	0	0	0	<-2	<-1
Sc	45	43.3	37.4	26.5	33	28.2	26.1	34.3	35	31.3	25	28.8	31.1	25.1
Ta	8	3	10	17	6	18	17	6	10	9	3	11	11	3
Th	11	11	42	24	7	41	4	17	28	14	0	23	33	6
U	9	6	5	20	4	21	10	15	14	12	7	12	16	3
V	288	269	270	353	356	305	339	232	306	322	206	221	278	189
Cu	57	49	67	8	83	7	69	65	80	109	110	73	215	30

All analyses by XRF, British Colombia Geological Survey Branch Analytical Laboratory

1. - HP6-08 Macrocryst-rich dike, HP pipe;

2. - HP6 - D8rim Fine-grained, macrocryst-poor border phase of dike, HP pipe;

3. - HP6 -D12 Fine-grained, micaceous dike, HP pipe;

4. - LA6 - 19F Fine-grained massive dike cutting diatreme breccia Larry claims , Bush River area;

5. - LA6 - 3B Fine-grained dike hosted in carbonates, Larry claims Bush River area;

6. - LA6 - 19FL Red-weathering breccia containing abundant accretionary lapilli;

7. - LA6 - 19G Biotite macrocryst-rich dike, Larry claims, Bush river area;

8. - MZ6 - Titanaugite-olivine-phlogopite dike, Mike claims, Mons Creek area;

9. - MZ6 FLC Titanaugite-olivene-phlogopite dike, Mike claims, Mons Creek area;

10. - MK6 - 5C Olivine - clinopyroxene porphry dike, olivine and clinopyroxene crystals completely pseudomorphed, Mark claims, Valenciennes River area

11.- MK6 - 5B Fine-grained dike, Mark claims, Valenciennes River area;

12. - MK6 - 7A Fine-grained, foliated dike, Mark claims, Valenciennes River area;

13. - MK5 - 1B Fine-grained, light green dike, Mark claims, Valenciennes River area;

14. - MK5 - 3A Dike, Mark claims, Valenciennes River area.

treme, comprising five distinctly different breccia phases and numerous dikes. 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 spherical structures (Table 15). Contacts between breccia phases may be gradational or sharp (Plate 44). A well-developed foliation, at high angles to the pipe's eastern and western margins, is present in phases B1 and B2 (Plate 45). The other phases are moderately to weakly foliated.

The matrix of breccia phases B1, B2 and B3 is composed of calcite±biotite≥colourless clinoamphibole (tremolite?)≥chlorite. Serpentine, talc and pyrite are also reported to be present (Ijewliw and Schulze, 1989). 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 (Plate 46). 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). In addition to small disseminated garnets, larger garnets commonly occur in dikes and associated with calcite segregations in clast and spherical structure-supported breccias. 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 spherical structure-rich breccias is predominantly calcite with or without amphibole (colourless to slightly bluish). Euhedral garnets commonly form rims on the spheres. The spheres are composed of material similar to the matrix of the other breccia phases and are commonly cored by pyroxene or mica megacrysts (Plate 47).

Black clinopyroxene (salite; C.E. Fipke, personal communication, 1987) bright green chrome diopside and biotite are the dominant megacrysts. The black clinopyroxenes are rich in titanium (up to 2.6%) and aluminum (up to 14.5%). The clinopyroxenes are compositionally similar to those found in the Isle Bizard alnöite and in South African olivine melilitites. Biotite x-ray spectra show high iron:magnesium ratios and occasional zoning to iron-rich rims. Red-brown chrome spinels with minor amounts of aluminum, magnesium and titanium have also been identified. The spinels have a very limited compositional range; $Fe^{2+}/(Fe^{2+}+Mg)$ values of 0.34 to 0.38, Cr/(Cr+Al) values of 0.54 to 0.68 and TiO_2 of less than 1%. The spinels are also compositionally similar to those from Isle Bizard. Euhedral apatite phenocrysts are also present (Ijewliw, 1987; Ijewliw and Shulze, 1988).

The breccia pipe and surrounding sediments are cut by numerous dikes (Figure 68). The dikes are generally fine grained and massive, but are variable with respect to xenolith, macrocryst, spherical structure and obvious garnet content. D1 dikes are massive and free of inclusions. They contain biotite and spinel phenocrysts; the biotites are often aligned (flow foliation?). D2 dikes have some (less than 5% total) small limestone xenoliths and macrocrysts; they may also contain minor amounts of spherical structures. D3a dikes are megacryst rich (15-20%); D3b dikes are also megacryst rich and contain spherical structures and visible garnet. In thin section, all phases contain some, generally fine-grained, garnet.

The HP pipe is unique, in many respects, from the other pipes in the Golden area. Petrography and mineral chemistry suggest that it is an ultramafic lamprophyre with aillikitic affinity. There also appears to be a significant metasomatic or metamorphic overprint introducing phases such as melanite/andradite and clinoamphibole.

GEOCHEMISTRY OF DIATREMES AND RELATED DIKES

Diatreme breccias and dikes in the Golden area are ultrabasic; silica values predominantly range from 30 to 40% (Table 16) with the exception of dikes from the Valenciennes River area which contain from 40 to 45% silica. Analyses are varied with respect to the other major elements (Figure 69; Table 16) and chemical classification is difficult. Alteration is intense, and may have affected some elements more than others (*e.g.* potassium, as is suggested by the fact that most micas have been strongly altered and potassium may have been removed). In general, analyses plot in or near the alkaline to ultramafic lamprophyre fields (Figures 69 and 70); the HP pipe borders on alnöitic in composition, dikes from the Bush River area and from Mons Creek fall more within the alkaline lamprophyre range and dikes from the Valenciennes River area (all strongly altered) trend toward a basaltic composition.

As is the case with major element compositions, trace element abundances in diatremes and dikes from the Golden area are quite varied. There is a fairly wide range in elements such as chrome (Figure 71), strontium, rubidium and barium (Table 16). The HP pipe, in general, shows more restricted compositions than the others, has higher average rubidium, strontium and barium concentrations and has much more restricted total strontium:rubidium ratios (Figure 72). Rocks from the Valenciennes River and Bush River areas generally show the most variation and have large ranges in total strontium:rubidium ratios, which may be indicative of higher degrees of alteration. Rocks collected from Bush River were more enriched in titanium than those from elsewhere in the Golden area (Figure 72).

Although chemistry alone is not sufficient grounds to classify rocks, especially altered rocks, it does back up petrographic observations. The HP pipe appears to share many characteristics with ultramafic lamprophyres; the other pipes and dikes in the Golden area are slightly different, in general more similar to alkaline lamprophyres.

GEOCHRONOLOGY

In the Golden area, the HP pipe and some of the dikes in the Bush River area are relatively unaltered and contain abundant micas. These two locations were sampled, mica separates obtained and potassium-argon and rubidium-strontium analyses performed in order to establish the age of the intrusions. Elsewhere, the rocks are either too altered or too poor in mica to attempt to date. Biotites from the HP pipe yield potassium-argon dates of 391±12 and 396±10 Ma (Appendix 2). Initial rubidium-strontium analyses yielded a date of 348±7 Ma; these analyses were rerun, using a more accurate ion-exchange technique and a new date of approximately 400 Ma was obtained (Appendix 2). Close agreement of potassium-argon and rubidium-strontium dates suggests that the HP pipe was emplaced at approximately 400 Ma. Recent paleomagnetic work (Symons and Lewchuk, in press) established that samples from the HP pipe, after tilt corrections, give a concordant Mississippian pole, which is slightly younger than the isotopic age.

Preliminary results of rubidium-strontium ion exchange analyses of micas from alkaline dikes in the Bush River area suggest an age of 410 Ma (Appendix 2), which is in close agreement with results from the HP pipe.

Zircon separates were obtained from rocks in the Valenciennes River, Lens Mountain and Mons Creek areas. In all cases, the zircon populations are very heterogeneous. Zircons from the Mons Creek area vary from rounded, frosted, colourless to pale yellow spheres, to clear, equant fragments. In the Valenciennes River samples zircons vary in shape from round to rounded prisms. Some grains are rounded and broken. Colours range from clear to colourless, frosted to pink. In the Lens Mountain sample both clear and

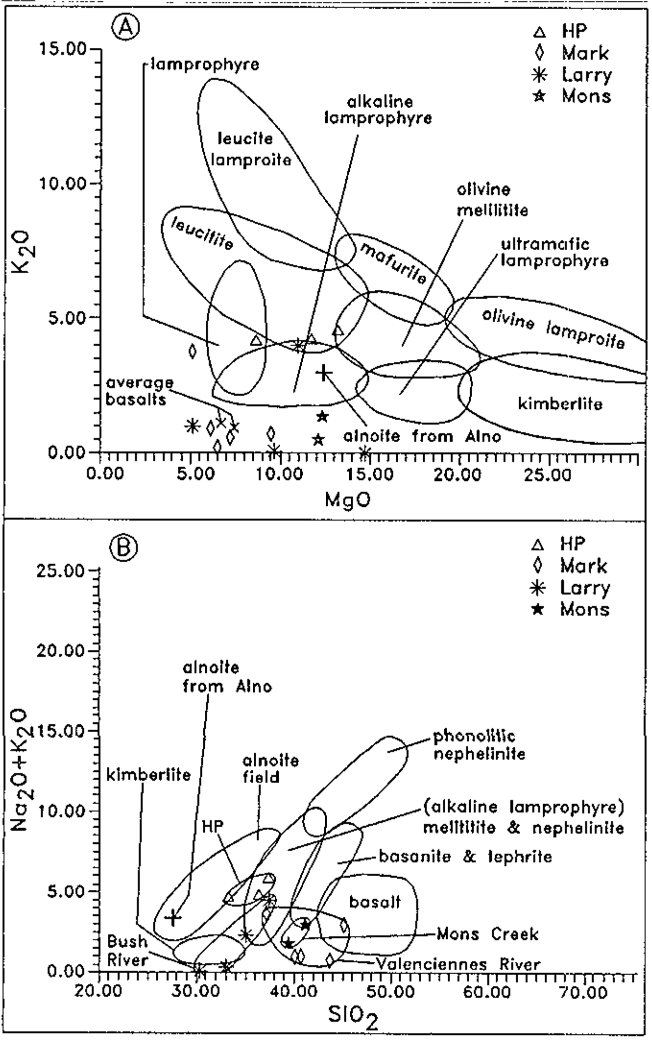


Figure 69. Major element discriminant diagrams, Golden diatreme swarm.

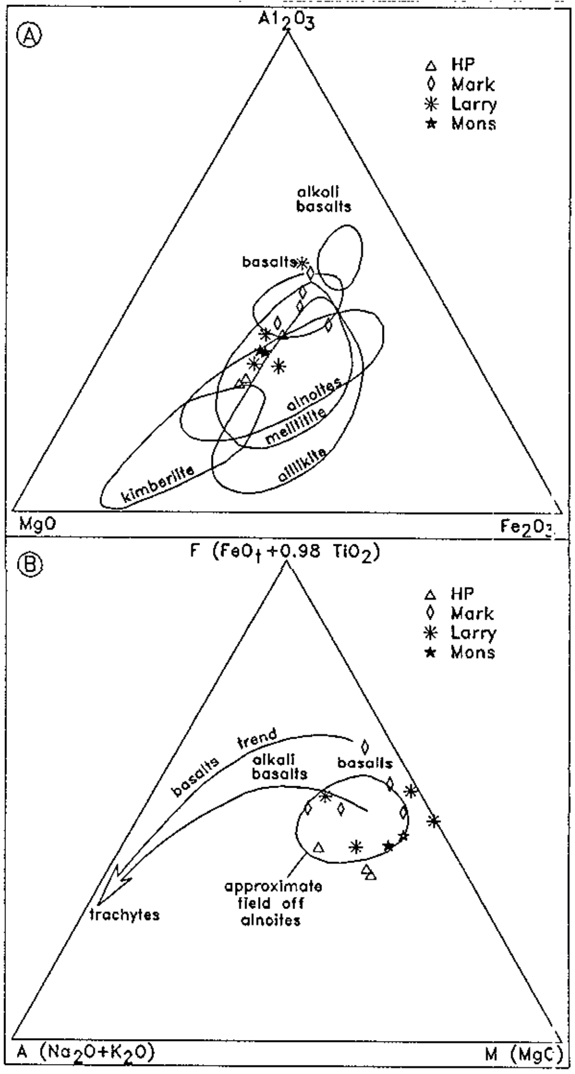


Figure 70. Major element ternary plots, Golden diatremes.

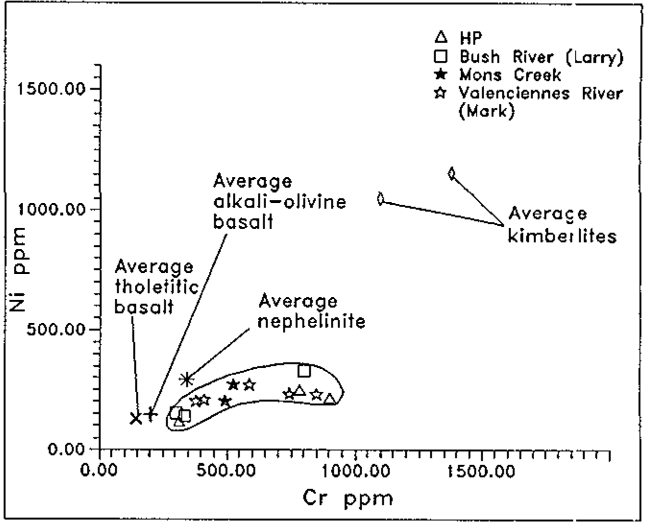


Figure 71. Ni vs Cr plot, Golden diatremes.

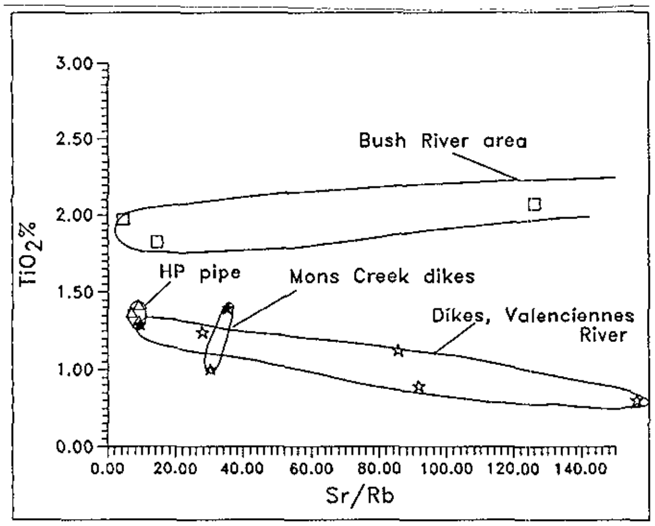


Figure 72. Sr/Rb vs TiO_2, Golden diatremes and related dikes.

pink rounded zircons are present, as well as clear, frosted to clear, colourless, rounded prisms.

Euhedral zircons from Mons Creek yielded a concordant lead-lead age of 469±17 Ma (Appendix 2), which possibly represents the age of zircon crystallization in the lamprophyric magma. This may be equivalent to, or slightly older than, the actual age of emplacement. This date is consistent with the fact that the igneous rocks are hosted by Lower to Middle Cambrian strata. Rounded zircons from the same sample gave ages of 1917 to 1907 Ma (Appendix 2); these zircons are clearly xenocrystic and the dates may be representative of the age of the basement.

Zircons separated from a diatreme in the Valenciennes River area are all xenocrystic in origin and gave lead-lead ages of approximately 1525, 1825, 2550 and 2565 Ma (Appendix 2). All analyses are discordant. Zircons separated from the Lens Mountain sample were also all xenocrysts. Resultant lead-lead ages are approximately 1790, 2050 and 2685 Ma (Appendix 2).

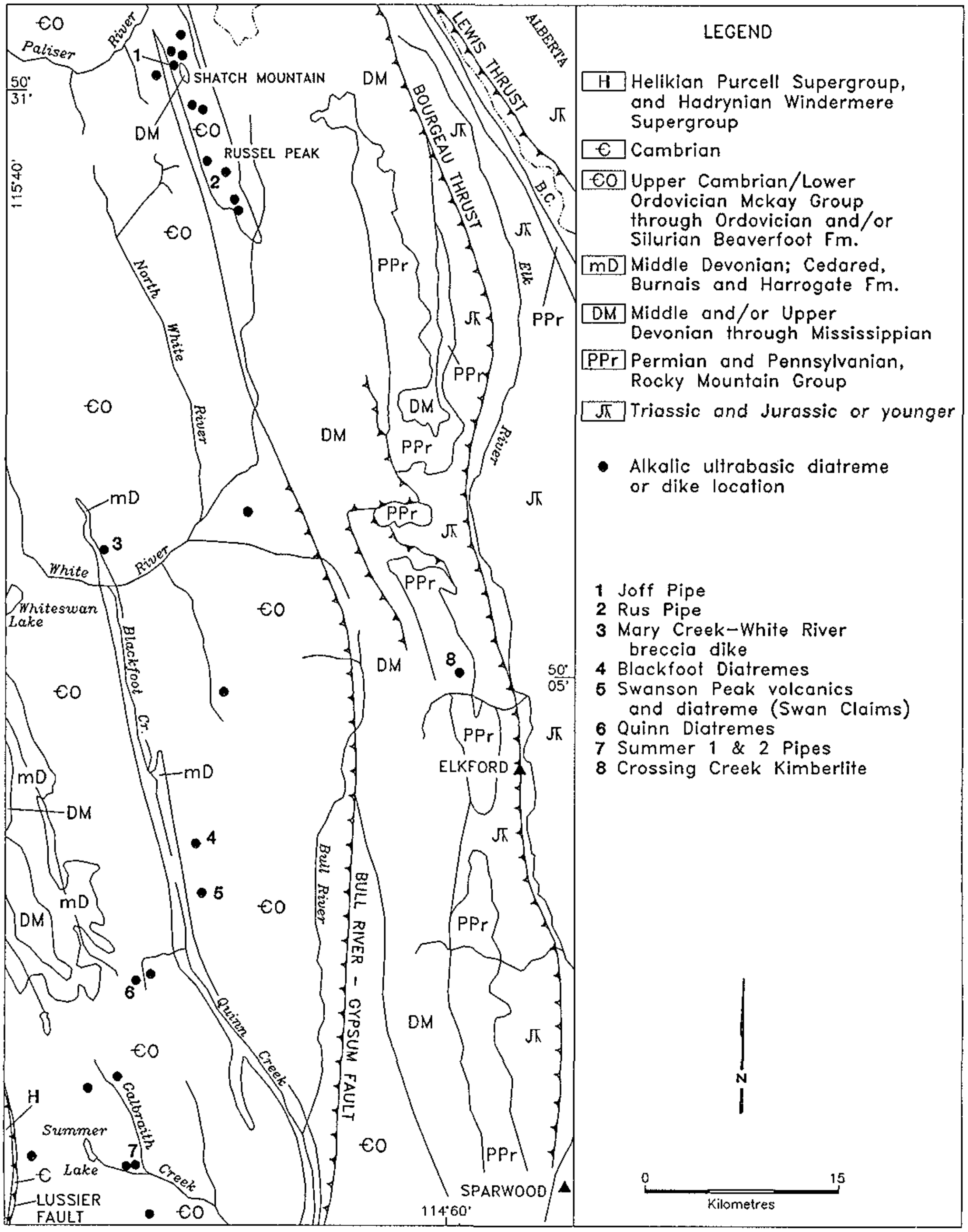


Figure 73. General geology and diatreme locations in the Bull River - White River area. Geology modified from Leech (1960, 1979) and Price (1981).

ULTRABASIC DIATREMES IN THE BULL RIVER - ELK RIVER AREA, SOUTHERN BRITISH COLUMBIA (82G, J)

Forty or more breccia pipes and related dike-rocks occur within the Bull, White and Palliser river drainages (Figures 2 and 73) 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 and dikes have been reported (D.L. Pighin, personal communication, 1984) south of the Palliser River on the ridges around Shatch Mountain, west of Joffrey Creek (latitude 50°31′07″N, longitude 115°16′33″W) approximately 55 kilometres east of Invermere (Figure 73). 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 74) 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 xenoliths and rare pyroxenite nodules are present. In thin section, honey-coloured altered vesicular glass lapilli are the predominant constituents; locally the glass is completely devitrified. 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. This is a tuffisitic crater-infill breccia.

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 agglomerate layers locally display moderate to well-developed graded bedding (Plate 48). Elsewhere, 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 (Plate 49).

South of the main tuffisitic breccia, a medium to fine-grained, massive igneous intrusive crops out (Figure 74), that is medium to dark green in colour with intensely brecciated and hematized margins. It contains 10 to 15% altered clinopyroxene and olivine phenocrysts in a matrix containing fine-grained altered clinopyroxene and some feldspar. Microprobe analyses indicate that the feldspar is essentially pure albite; the albite, however, may be secondary, having replaced an earlier, more calcic plagioclase or potassium feldspar. Some feldspar laths have been partially altered to white mica or clay minerals. Some mafic phenocrysts have been pseudomorphed by quartz and chlorite. Opaque oxides are abundant.

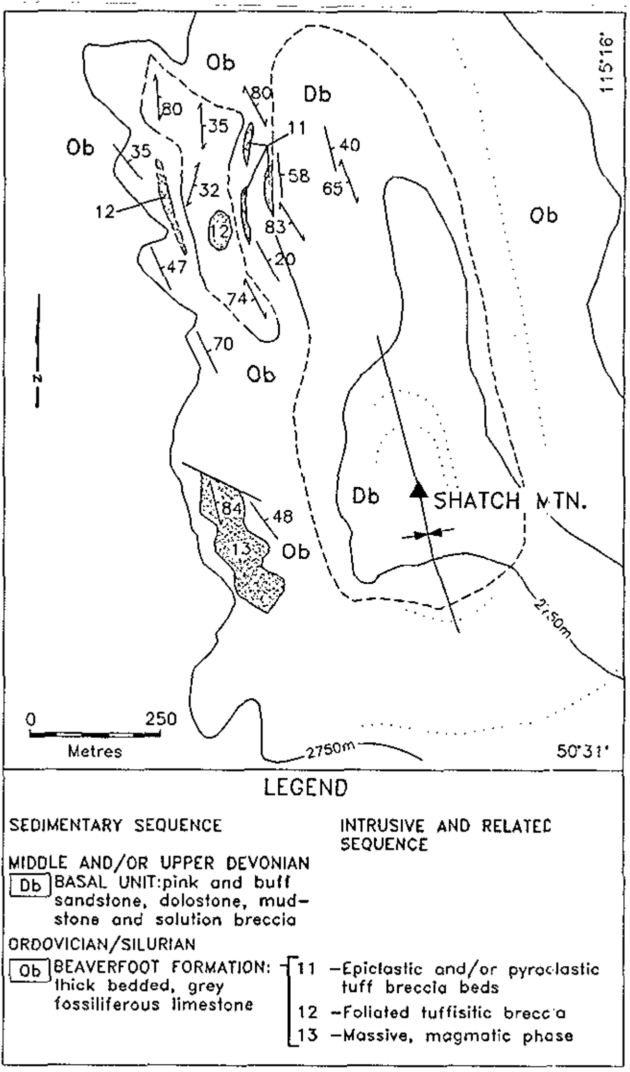


Figure 74. Geology of the Joff pipe, Shatch Mountain area (modified from Pell, 1986a). *See* text for geographic coordinates.

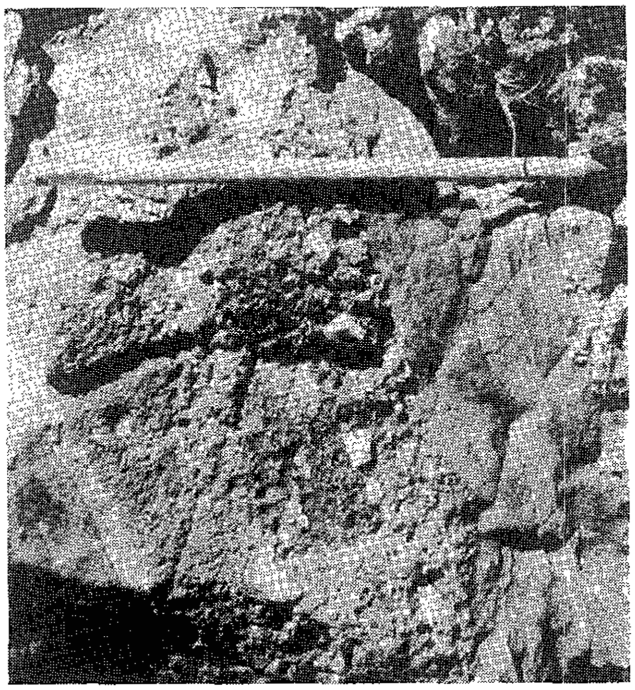


Plate 48. Graded bedding in extrusive epiclastic layer, Joff pipe.

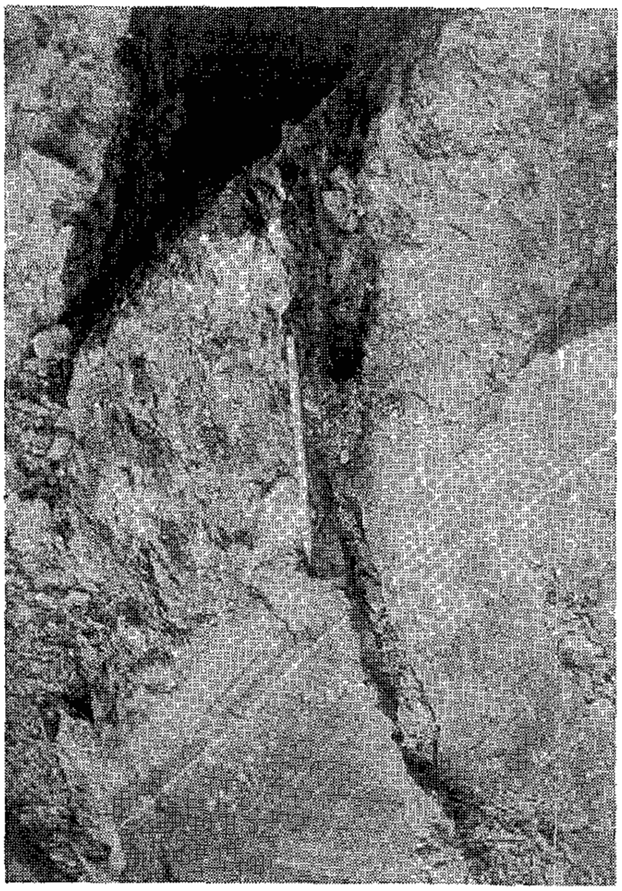


Plate 49. Epiclastic crater-infill breccia, Joff pipe, immediately overlain by well-bedded, pink and buff-weathering strata of the basal Devonian Unit, *(colour photo, page 136).*

Due to intensity of alteration, classification is difficult. The presence of glass lapilli and absence of biotite/phlogopite exclude these rocks from the ultramafic lamprophyre clan. The phenocryst and microphenocryst assemblage of olivine, two generations of clinopyroxene and a small amount of feldspar (albite) in the groundmass of the porphyritic dike-rocks suggest that they may share some affinity to limburgites or alkaline basalts.

THE RUSSELL PEAK DIATREMES (82J/6)

Diatremes in southern British Columbia are typified by those near Russell Peak (latitude 50°25′40″N, longitude 115°13′30″W; Figure 73). There are at least three small pipes in the immediate vicinity of Russell Peak; two more small intrusions crop out approximately 7 kilometres to the north (latitude 50°29′15″N, longitude 115°15′40″W). All of these pipes can be reached by helicopter from Fairmont Hot Springs. One, immediately south of Russell Peak, is particularly well exposed on a cliff face and displays many features of pipe morphology (Figure 75). The lower portion of the exposed pipe comprises well-foliated, tuffisitic breccia containing abundant subangular fragments of sedimentary rock

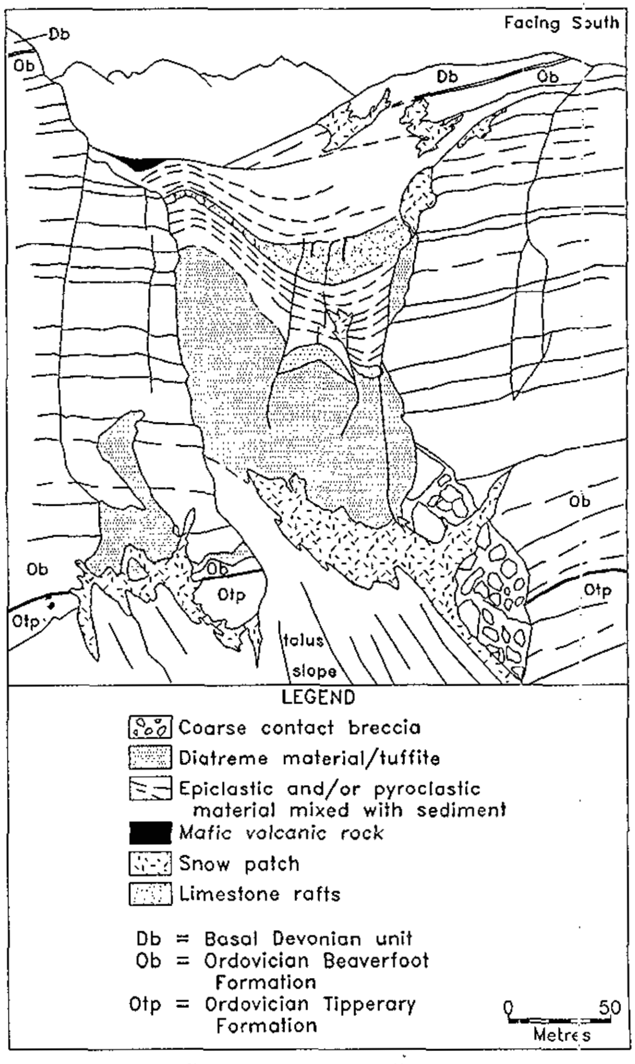


Figure 75. Geology of the Russell Peak diatreme.

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 across 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. It contains large (up to 4 or 5 m), chaotic fragments of angular wallrock and subordinate matrix.

Between 50 and 100 metres of well-bedded, greenish weathering pyroclastic and/or epiclastic material (Plate 50) is exposed overlying the tuffisitic breccia. At the base of this zone, the material is similar in composition to the tuffisitic breccia, with increasing amounts of sedimentary material and interbeds of dolomitic siltstone or silty dolostone, upsection. Thin layers of igneous material are apparently interbedded with, or injected into, the Ordovician-Silurian Beaverfoot Formation carbonate rocks, near the top and margins of the exposed pipe. The succession is unconformably overlain by Middle and/or Upper Devonian strata.

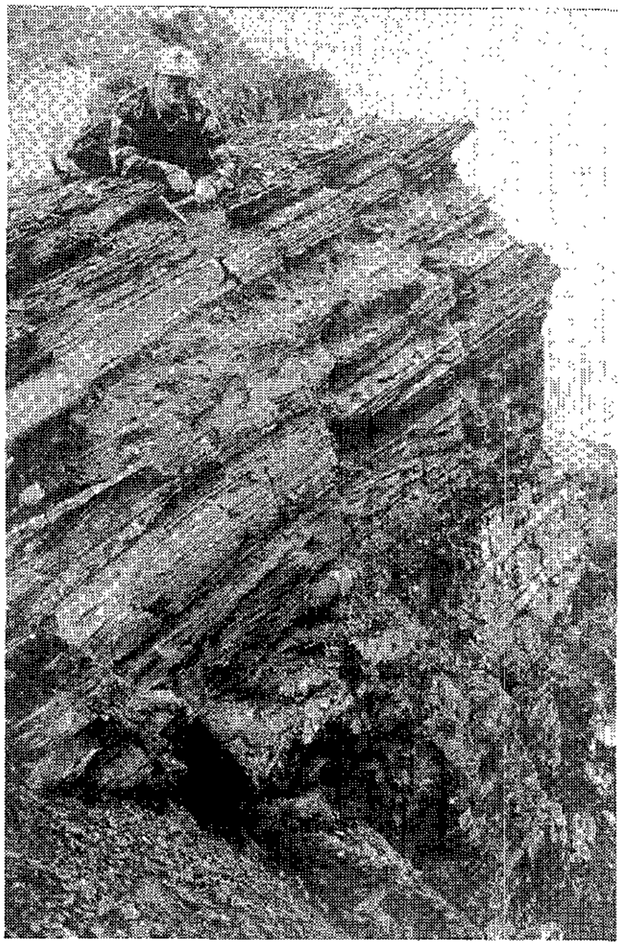


Plate 50. Well bedded crater infill material, Russell Peak diatreme.

A small, black-weathering, mafic body (flow?) outcrops near the exposed top of the crater zone (Figure 75) and represents the only unaltered material present in the diatreme complex (Plate 51). It is extremely porphyritic and comprises 5 to 20% titanaugite (Appendix 3) and approximately 10% altered olivine phenocrysts set in a matrix of 35 to 40% titanaugite microphenocrysts, 0 to 5% olivine, approximately 10% altered feldspar and 5 to 10% opaque oxide microphenocrysts with 15 to 25% fine-grained groundmass. The groundmass, in part, consists of fine-grained material of essentially albitic composition. Some quartz and calcite are present as alteration minerals. Microprobe analyses indicate that some essentially unaltered labradorite is present (Appendix 3) together with trace amounts of chrome spinel. In a nearby diatreme, similar material occurs as small dikes crosscutting diatreme-zone tuffisitic breccia, suggesting that this phase was emplaced late in the intrusive sequence.

The modal mineralogy of the magmatic phase (titanaugite and olivine phenocrysts, titanaugite, olivine, labradorite and opaque oxide microphenocrysts in a fine-

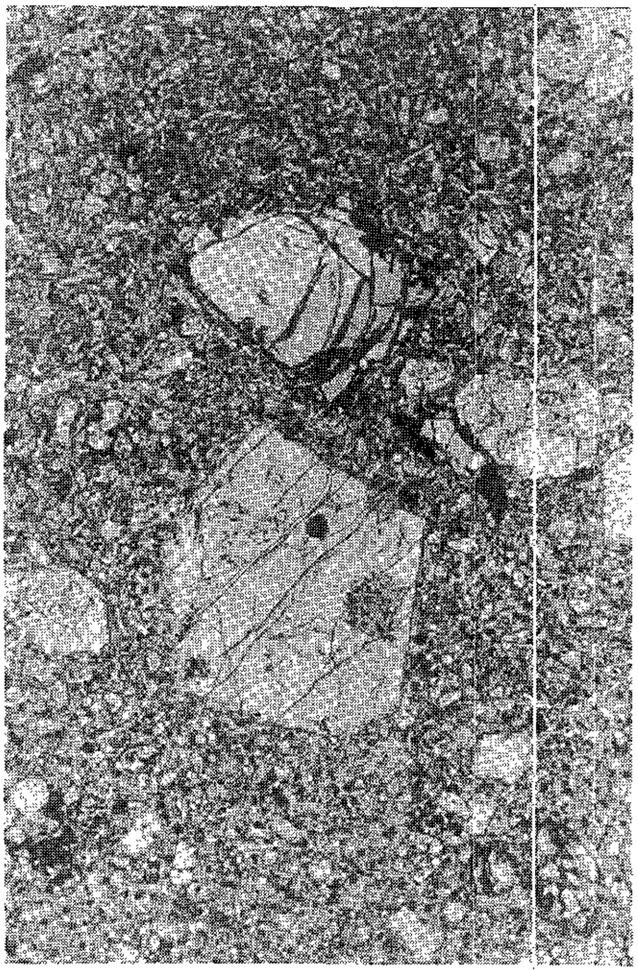


Plate 51. Porphyritic volcanic rock, Russell Peak diatreme. Large euhedral grains are zoned, titaniferious clinopyroxene phenocrysts; the large anhedral crystal is an altered olivine phenocryst; the microphenocryst population consists of titaniferous clinopyroxenes, feldspar laths and opaque oxides. Long dimension of the photo micrograph is 7 mm.

grained groundmass) suggests that these rocks have affinity to limburgites or alkaline basalts, but do not fit exactly into either category. They differ from limburgites in that the feldspar present is calcic (labradorite) rather than sodic. They exhibit some mineralogic similarities to basanites or tephrites (alkaline basalts), but lack modal feldspathoids and contain considerably less feldspar than commonly present in these rock types.

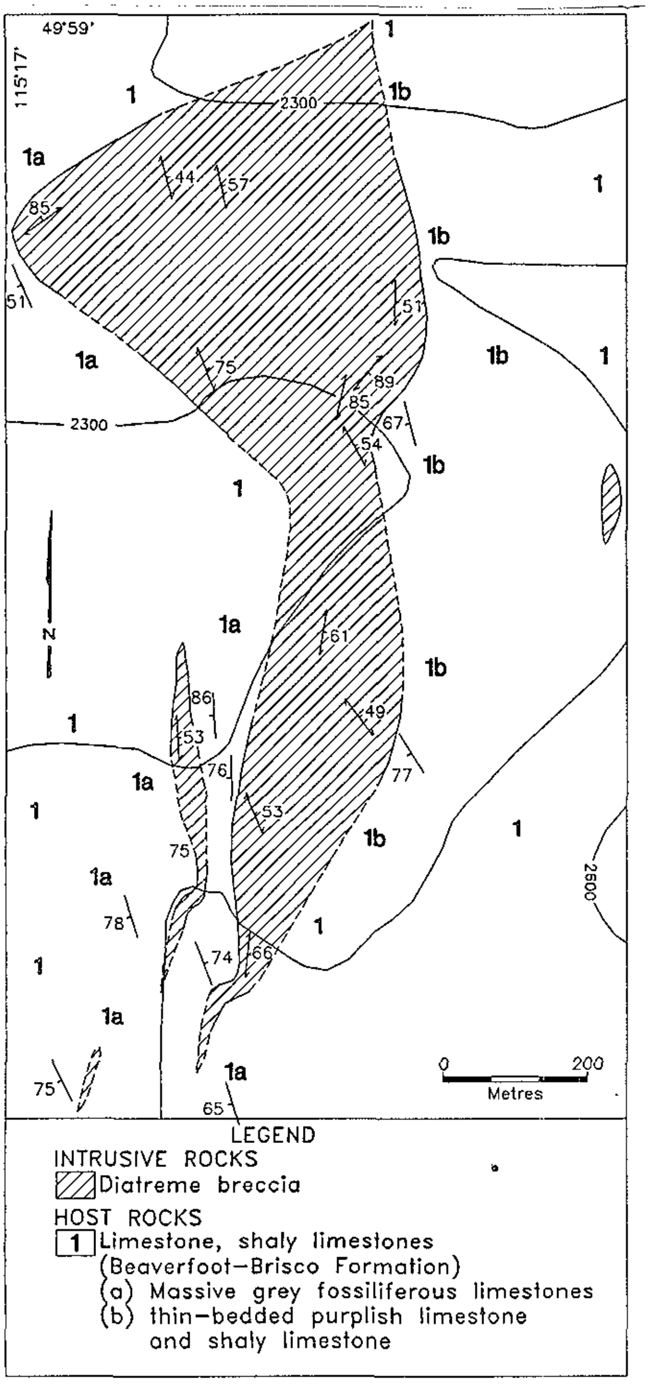


Figure 76. Geology of the Blackfoot diatreme.

BLACKFOOT AND QUINN DIATREMES (82G/14)

The Blackfoot diatreme crops out at 2650 metres elevation on ridges east of the headwaters of Blackfoot Creek (latitude 49°58'23"N, longitude 115°16'45"W) approximately 65 kilometres northeast of Cranbrook (Figure 73). Access is by helicopter or on foot from a logging road in the Blackfoot – Quinn Creek valley. Two small diatremes (the Quinn pipes) are present near the head of Goat Creek, a tributary of Quinn Creek (latitude 49°53'05"N, longitude 115°20'30"W). One is exposed west of Goat Creek, at approximately 1980 metres elevation and can be reached by hiking along Goat Creek for slightly less than a kilometre from the end of a logging road. The other is exposed east of Goat Creek, in a saddle at 2315 metres elevation and is best reached by helicopter. These pipes are very similar to the Blackfoot diatreme and will be discussed together with it.

The Blackfoot pipe 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 hostrocks near the diatreme, where there is a deviation from the regional steep westerly dips (Figure

Plate 52. Vesiculated glass lapilli in diatreme breccia, Quinn Creek. Long dimension of photo micrograph is 2.5 mm.

76). 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, nonfossiliferous, purplish weathering limestones and shaly limestones are present in the footwall. The contacts between the diatreme and the limestones are well exposed and no thermal metamorphic effects are evident.

The Blackfoot diatreme is a composite or branching pipe-like body that is intensely foliated near its margins and contains fragments that 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 (Figure 76). This was apparently a site of localized shearing during deformation. This pipe contains approximately 30% 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 cm in diameter). The largest xenoliths are purple-grey to buff-weathering carbonates probably derived from the Beaverfoot-Brisco Formation. The Quinn pipes are very similar in appearance and composition, but somewhat less deformed.

Exotic xenoliths, predominantly clinopyroxenites, hornblendites and dunites, are relatively common and remarkably fresh. Eclogite nodules have also been reported (C.I. Godwin, personal communication, 1984). Clinopyroxenite nodules consist of 30 to 57% green diopside, 0 to 15% enstatite, 0 to 40% olivine plus serpentine, 0 to 22% hornblende with calcite, talc and minor ilmenite, spinel and pyrite. Hornblendites contain approximately 75% hornblende, 10% clinopyroxene and 10% ilmenite, with calcite, serpentine and traces of pyrite. Dunites contain 63% olivine, 14% clinopyroxene and 17% talc with accessory orthopyroxene and hornblende (Ijewliw, 1986). Exotic xenoliths were not found in the Quinn pipes.

Altered vesicular glass lapilli, yellow in colour, are present in the breccias (Plate 52), as are juvenile lapilli. The glass lapilli are extremely well preserved in the Quinn pipes. Lapilli constitute about 25 to 30% 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 from tuffisitic material in the western Quinn pipe.

Massive, fine-grained, dark green dikes cut the breccias at both the Blackfoot and Quinn diatremes. These dikes are intensely altered. The Blackfoot and Quinn diatremes are extremely similar to both the Shatch Mountain and Russell Peak pipes and are therefore probably also of limburgitic or alkaline basaltic affinity.

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

The Swan claims are located approximately 5 kilometres south of the Blackfoot pipe (Figure 73) in the Mount Haynes – Swanson Peak area (latitude 49°56′20″, longitude 115°16′30″W). Igneous rocks outcrop at approximately 2400 metres elevation and can be reached by helicopter.

Extrusive flows and a small diatreme are exposed within a few hundred metres of each other. The main flow is approximately 3 metres thick. It overlies an orange-weathering, coarse, intraformational limestone conglomerate that, in turn, overlies graptolitic shale. The volcanics are 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, at its base, contains small (centimetre-size) greenish clasts of the underlying volcanic rocks. 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 77). Thin to thick-bedded grey carbonates of the Beaverfoot Formation, containing abundant fossil corals, overlie the quartzite. The stratigraphic position of this flow, which un-

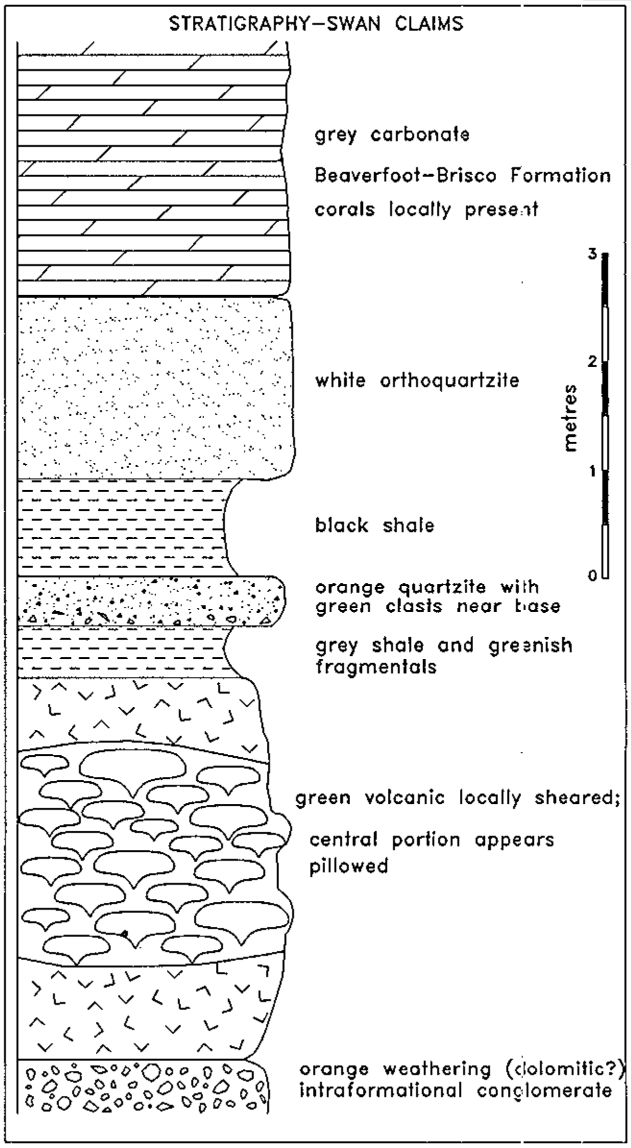


Figure 77. Stratigraphy, Swanson Peak area.

Plate 53. Pillowed flow, Swanson Peak.

derlies a quartzite (Tipperary Formation?) beneath the Beaverfoot Formation, indicates that it is of probable Late Ordovician age.

The flow is fine grained and dark green in hand sample. Spherical pillow structures are preserved in the centre of the unit (Plate 53). In thin section, the rock displays a fine porphyritic texture consisting of approximately 10% altered olivine (±pyroxene?) phenocrysts and 2 to 5% feldspar phenocrysts in a fine-grained altered groundmass that contains approximately 40% feldspar microphenocrysts and a few percent opaque oxides. Microprobe analyses indicate that the feldspars, both phenocrysts and microphenocrysts, are very pure potassium feldspars (Appendix 3).

The diatreme is exposed on a small ridge, approximately 200 metres south of where the volcanics outcrop. It is light greenish to buff weathering, massive, and has a greyish to buff fresh surface. It consists of a matrix-supported breccia that predominantly contains small, subrounded fragments of sedimentary rock.

Based on the modal mineralogy (olivine±clinopyroxene and two generations of potassium feldspar), the volcanic rock is difficult to classify; it exhibits similarities to the trachybasalt or the nephelinite family of rocks, but contains potassium feldspar alone rather than with plagioclase in the former, or feldspathoids, in the latter case. It is impossible to say, however, if the potassium feldspar is primary or pseudomorphing a pre-existing phase.

THE MARY CREEK - WHITE RIVER BRECCIA DIKE (82J/3W)

A narrow dike crops out at the head of Mary Creek, a small tributary of the White River, east of Whiteswan Lake (latitude 50°10′30″N, longitude 115°22′15″W; Figure 73). It is exposed at the 2010-metre elevation and is most easily accessed by helicopter.

The dike is 1 to 2 metres wide, steeply dipping and slightly discordant to bedding. It mainly consists of a massive, fine-grained, dark green weathering phase that locally grades into a red and green-weathering, strongly foliated phase that contains small round globular segregations or accretionary lapilli. The massive phase locally contains clasts of host sedimentary strata. In thin section, accretionary lapilli were observed to be cored by olivine macrocrysts with large red-brown spinel inclusions; some fine-grained biotite was also noted.

THE SUMMER PIPES (82G/11)

Two small intrusive bodies are exposed at the confluence of Galbraith and Summer creeks (latitude 49°44′50″ longitude 115°20′32″W; Figures 73 and 78) approximately 40 kilometres northeast of Cranbrook. Outcrops occur between 1250 and 1350 metres 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

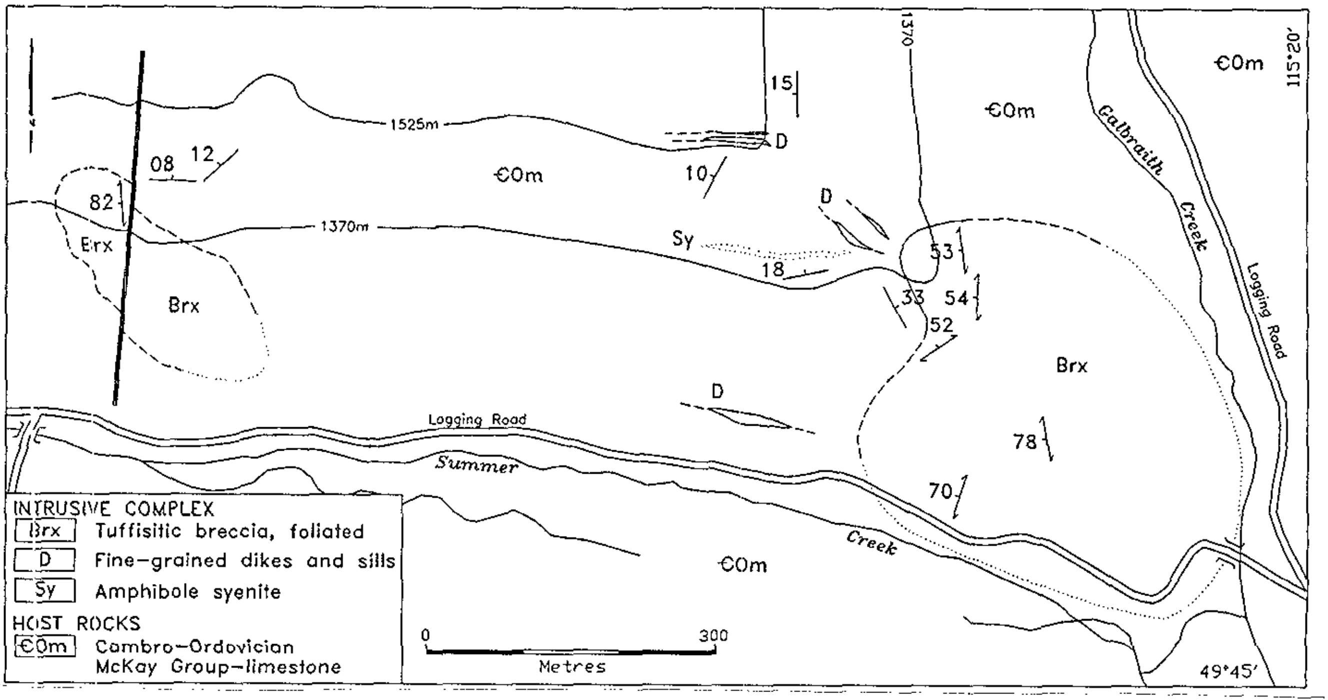


Figure 78. Diatreme breccias, Summer and Galbraith creeks area.

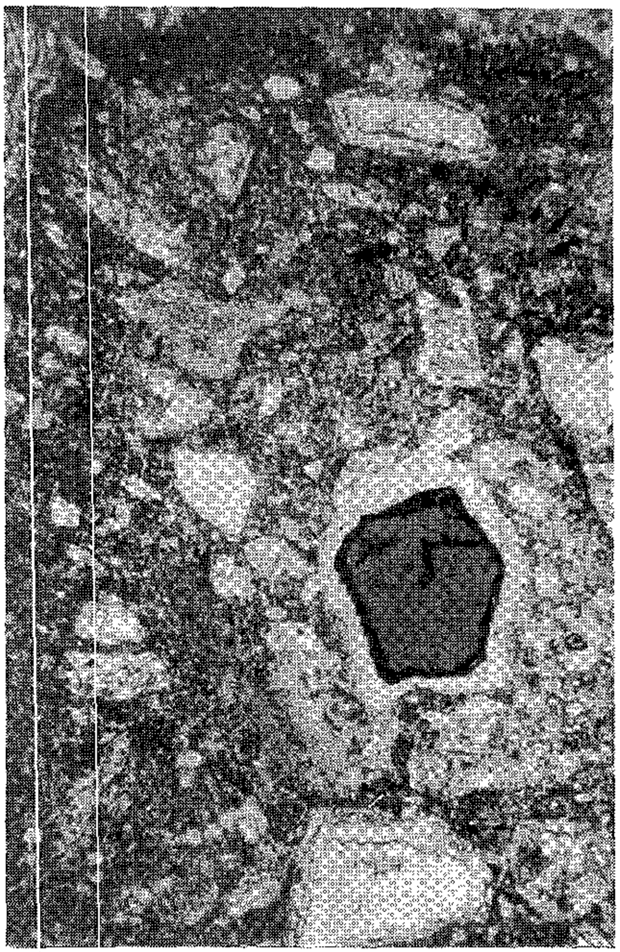


Plate 54. Chrome spinel macrocryst (dark crystal rimmed by light coloured to transparent minerals - mainly carbonates), Summer diatreme breccia. Long dimension of the photograph is 2.5 mm.

have been previously reported on by Grieve (1981) and Pell (1987).

The Summer diatremes form rusty weathering resistant knolls and are hosted by 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 is the contact between limestone and breccia exposed 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 strongly 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 inclusions are angular limestone, limestone conglomerate and shale fragments, up to 70 centimetres across, which comprise 90% of all the clasts. The remaining 10% 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 sedimentary clasts.

The matrix is predominantly chlorite, serpentine and carbonate (Grieve, 1981). Abundant juvenile lapilli (20-40%) and altered olivine and clinopyroxene macrocrysts are evident in thin section; some of the lapilli are cored by altered feldspar or clinopyroxene grains. Minor chrome spinel may also be present (Plate 54). No vesicular glass lapilli were observed.

TABLE 17
CHEMICAL ANALYSES BULL RIVER - ELK RIVER DIATREMES AND RELATED ROCKS

	Joff	Quinn	Black Foot						Rus				Scat		Summer				Swan				Gabbro Haynes Ck.
						Nodules																	
wt %	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
SiO2	36.41	45.76	36.81	36.93	44.89	35.10	44.67	47.05	41.89	40.69	44.17	39.93	38.15	40.43	39.02	40.22	30.87	28.49	38.69	41.99	37.85	30.94	45.62
TiO2	1.50	0.80	0.77	0.78	2.43	3.62	1.60	0.29	1.85	1.59	2.28	1.95	2.34	2.22	2.12	1.97	0.77	1.70	2.65	2.43	2.57	1.18	1.80
Al2O3	7.92	6.73	5.82	6.03	15.36	11.14	9.77	3.40	11.05	10.00	12.68	12.42	12.89	12.45	10.82	9.96	5.30	10.17	15.81	16.06	14.93	7.74	16.12
Fe2O3T	9.11	4.32	5.49	5.38	10.99	10.09	8.43	3.11	11.27	10.11	11.75	10.64	12.08	10.35	9.64	9.93	6.49	8.47	11.62	5.31	11.31	5.98	11.18
MnO	0.08	0.10	0.15	0.14	0.08	0.17	0.17	0.08	0.09	0.08	0.17	0.05	0.05	0.05	0.10	0.11	0.09	0.17	0.04	0.03	0.03	0.09	0.19
MgO	18.05	4.44	12.32	12.34	6.43	12.43	12.8	14.31	12.96	16.27	10.37	10.52	15.91	12.98	11.80	13.61	12.43	12.08	5.00	3.94	4.88	10.72	5.85
CaO	9.48	16.35	18.37	18.51	6.59	15.30	18.78	21.14	9.29	6.56	10.18	6.12	4.22	5.00	9.94	8.98	16.40	14.12	5.39	6.64	6.10	20.36	7.11
Na2O	0.07	0.02	1.12	1.14	2.12	1.03	0.40	1.03	0.95	0.59	1.12	0.51	0.47	0.40	0.54	0.13	0.05	2.11	0.27	0.11	0.16	0.02	4.92
K2O	0.30	2.95	0.46	0.49	1.95	1.31	0.32	0.17	1.93	1.38	2.67	3.23	2.07	3.49	0.25	0.03	0.77	0.27	6.49	9.34	6.51	1.08	0.04
LOI	15.48	15.73	17.34	17.28	7.23	6.76	1.26	3.51	6.97	11.42	3.13	12.94	10.10	10.93	13.01	12.90	26.01	21.28	9.94	11.52	13.32	20.52	5.01
P2O5	0.39	0.20	0.40	0.42	0.89	0.24	0.02	0.01	0.45	0.32	0.48	0.37	0.62	0.59	0.72	0.67	0.19	0.78	0.81	0.76	0.78	0.36	0.51
S	0.01	0.22	0.19	0.13	0.03	0.07	0.10	1.29	0.04	<.01	0.01	<0.01	<0.01	<0.01	0.07	0.10	0.02	0.08	0.02	<0.01	<0.01	0.03	0.01
Total	98.80	97.61	99.25	99.58	98.99	97.27	98.32	95.39	98.73	99.02	99.01	98.69	98.89	98.90	99.03	98.60	99.40	99.72	96.72	98.12	98.39	99.02	98.35
ppm																							
Ni	480	140	420	420	80	160	140	490	400	480	200	300	210	158	380	520	430	280	200	85	116	340	50
Cr	754	236	579	564	176	201	476	8115	592	1050	542	709	508	450	898	994	1454	471	134	237	131	540	178
Co	40	32	33	30	30	51	42	34	45	47	48	56	50	42	43	52	40	39	36	8	32	43	32
Rb	8	22	5	11	21	16	6	<8	26	11	40	33	18	46	4	<8	20	12	73	68	77	27	<8
Sr	157	152	438	457	681	901	108	2440	538	135	818	115	574	270	490	490	239	450	212	96	354	395	1415
Ba	106	553	2050	2158	1335	1016	443	<7	1109	425	990	630	1461	676	140	67	88	73	2002	1320	1983	999	126
Zr	147	82	116	127	166	73	35	26	212	131	182	125	186	186	173	157	70	216	191	214	180	101	205
Nb	63	34	60	67	63	44	5	10	72	50	82	54	100	98	84	77	27	131	73	70	67	63	98
Y	21	20	15	20	30	22	16	<5	25	21	29	17	25	24	25	22	14	29	28	29	28	16	25
La	8	9	27	23	35	24	<7	<7	33	6	39	12	40	42	42	32	<7	59	24	22	20	27	46
Ce	50	54	77	68	70	38	14	63	88	60	84	63	90	91	95	101	32	139	61	69	56	61	122
Nd	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Yb	0	2	<-4	0	2	<-8	<-7	<5	0	0	<-2	<-2	0	0	<-2	0	0	<-2	0	2	0	<-2	1
Sc	19.3	24.0	21.6	22.8	21.4	38.4	59.9	43	23.3	24.00	29.9	25.6	26.0	26.1	28.0	27.5	23.5	27.9	20.5	22.6	20.4	31.5	20.3
Ta	3	0	0	3	3	2	<-5	<7	1	1	3	0	6	8	4	5	3	4	4	4	6	3	7
Th	6	6	0	12	16	1	12	1	3	9	26	<-8	3	2	1	1	0	22	15	<-5	9	4	5
U	7	12	4	10	17	7	10	7	8	10	20	<5	3	8	4	5	9	12	4	5	4	3	13
V	188	156	129	130	261	650	511	286	280	258	319	313	338	335	325	292	143	219	331	296	323	215	263
Cu	36	15	24	22	52	51	54	15	76	61	68	22	6	4	62	55	39	49	7	4	6	57	38

All analyses by XRF, British Columbial Geological Survey Branch, analytical laboratory
1. - JF5 - BR Typial foliated breccia, Joff pipe Shatch Mountain area;
2. - QU5 - 1B Fragmental dike, cutting diatreme breccia, Quinn pipe, Quinn Creek;
3. - BF5 - 8B Typical foliated breccia, Blackfoot pipe;
4. - BF5 - 8B duplicate;
5. - BF5 - 19 Fine-grained macrocriptic dike, Blackfoot pipe;
6. - BF5 - 1B Hornblendite nodule, Blackfoot pipe
7. - BF5 - N1 Pyroxenite nodule; Blackfoot pipe;
8. - BF5 - N2 Chrome diopside pyroxenite nodule, Blackfoot pipe;
9. - RS6 - D Black dike crosscutting breccia associated with flow in the crater, Rus pipe, Russell Peak;
10. - RS6 - 15E Black volcanic flow located in crater, Rus pipe, Russell peak, contains altered negacrysts;
11. - RS6 - 9B Unaltered black volcanic, located in the crater, Rus pipe, Russell Peak;
12. - RS6 - 2A Fine - grained light green dike, Russell Peak;
13. - SC6 - GR Massive dike, Scat claims, Mary Creek/White River area;
14. - SC6 - GR5 Foliated dike phase with inclusions, Scat claims, Mary Creek/White Ri
15. - SM6 - FL2 Dike assiciated with Summer 2 diatreme, Summer and Galbraith creek
16. - SM6 - FL1 Dike associated with Summer 2 diatreme, Summer and Galbraith Cree
17. - SM6 - 3B Summer 2, diatreme breccia with abundant spinels, Summer and Galbr
18. - SM5 - 7A Fine-grained, light green dike, crosscutting Summer 1 diatreme, Summe
19. - SD6 - 2C1 Ultrapotassic pillowed volcanic flow, Swan claims, Swanson Peak
20. - SD6 - 2C2 As above;
21. - SD6 - 2C3 As above;
22. - SD6 - 3 Typical diatreme breccia, Swan claims, Swanson Peak;
23. - HC6 - 1 Gabbroic sill, part of White River sill complex, Haynes Creek

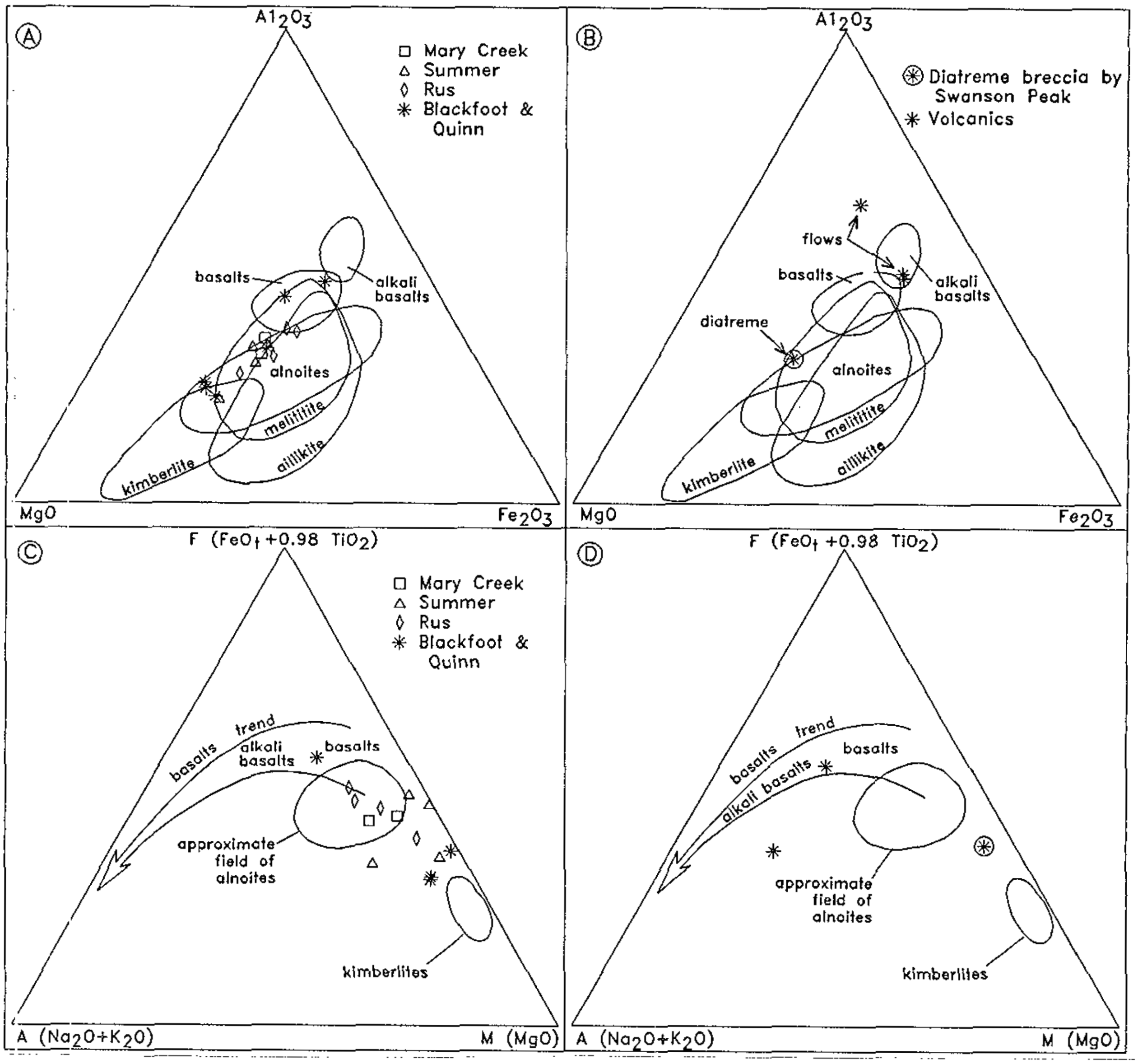


Figure 79. Major element ternary plots. (A) Fe_2O_3-MgO-Al_2O_3 plot, southern diatremes; (B) Fe_2O_3-MgO-Al_2O_3 plot, Swan volcanics; (C) AFM diagram, southern pipe swarm; (D) AFM diagram, Swan volcanics.

Related dikes and sills occur peripheral to the diatremes. The dikes are fine grained, porphyritic and strongly altered. They are texturally similar to dikes and flows in the Russell Peak area. They contain what appear to be altered olivine, clinopyroxene and feldspar phenocrysts and microphenocrysts. These dikes 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: they are hosted by Late Cambrian McKay Formation strata, not by Ordovician-Silurian formations; they are massive, brown-weathering, weakly foliated breccias as opposed to dominantly green-weathering, well-foliated tuffisitic breccias; and they are devoid of volcanic glass lapilli. These rocks may represent slightly deeper level intrusions or blind diatremes of alkaline basalt affinity that did not breach the surface.

GEOCHEMISTRY OF DIATREMES AND DIKES

Alkaline rocks in the Bull River – Elk River area are varied in composition. Silica contents are in the ultrabasic range to marginally basic, from 28 to 45% and the aluminum to alkali ratios place them in the metaluminous fields (Table 17). Other major elements vary significantly (Table 17; Figures 79 and 80). On the Fe_2O_3-MgO-Al_2O_3 ternary discriminant plot, these rocks generally fall in or peripheral to the alkaline lamprophyre (melilitite) fields (Figure 79), while on the AFM ternary plot they plot in the ultramafic lamprophyre field and between it and the kimberlite field, generally removed from the area of typical basaltic compositions (Figure 79c). Relatively unaltered dike and flow material from the Russell Peak area plot in the alkaline lamprophyre field on a K_2O-MgO discriminant plot; dikes from Mary Creek plot in the alkaline and ultramafic lamprophyre fields (Figure 80a). Samples from other areas generally have MgO values in the alkaline to ultramafic lamprophyre range, but are depleted in potassium. On the alkali-silica plot, relatively fresh dike material from the Russell Peak and Mary Creek areas plots peripheral to the melilitite-nephelinite and basanite fields; the other samples are quite varied, some plotting in the typical basalt field and others exhibiting a depletion in alkalis relative to alkaline lamprophyres (Figure 80b). Much of the scattering of chemical compositions may, in part, be due to alteration or to dilution from incorporation of foreign material. The chemistry suggests that these rocks are more basic than typical alkaline basalts and may be transitional to nephelinites, but have not developed modal feldspathiods.

The volcanic rocks at Swanson Peak have an unusual composition; like other igneous rocks in southern British Columbia, they are ultrabasic, but are peraluminous and extremely potassic. They do not fall consistently into one category on the various discriminant plots: on the Fe_2O_3-MgO-Al_2O_3 ternary plot they fall on the aluminous side of the alkali basalt fields (Figure 79b); on an AFM diagram they plot along the basalt trend and closer to the AM side of the triangle than typical basalts (Figure 79d); on a K_2O-MgO plot they fall within or marginal to the leucitite field (Figure 80a); and, on an alkali-silica plot they fall well within the melelitite-nephelinite field (Figure 80b). Major element chemistry and conventional plots do not help in unequivocally classifying the Swanson Peak volcanics; they do, however, suggest that these rocks share some chemical similarities with members of the nephelinite family, although lacking in modal feldspathoids.

Trace element concentrations of rocks from the southern diatreme swarm are somewhat variable, particularly in terms of elements such as strontium, barium, nickel and chrome (Table 17). Swanson Peak volcanics have nickel and chrome concentrations similar to typical basalts, while diatremes and dikes from elsewhere in the southern swarm are enriched in these elements (particularly in chrome) relative to basalts or nephelinites (Figure 81), with dikes generally more enriched than breccia phases. Most ultrabasic rocks in this area contain low concentrations of rubidium and low to moderate amounts of strontium, relative to the others examined from the Golden, Ospika and Kechika areas. Total strontium:rubidium ratios for diatreme breccias throughout the area, and for dikes from the Summer area, are quite variable (3 to 122:1), while dikes and flows from Russell Peak and the Blackfoot area have restricted ranges, averaging around 22:1. The volcanics from the Swanson Peak area have higher than average rubidium concentrations and lower than average strontium concentrations compared to other members of the southern diatreme swarm, resulting in low total strontium:rubidium ratios (around 2:1). On average, dikes and flows in the Bull River - Elk River area are significantly more enriched in titanium than related breccias; the Swanson Peak volcanics contain more titanium, on

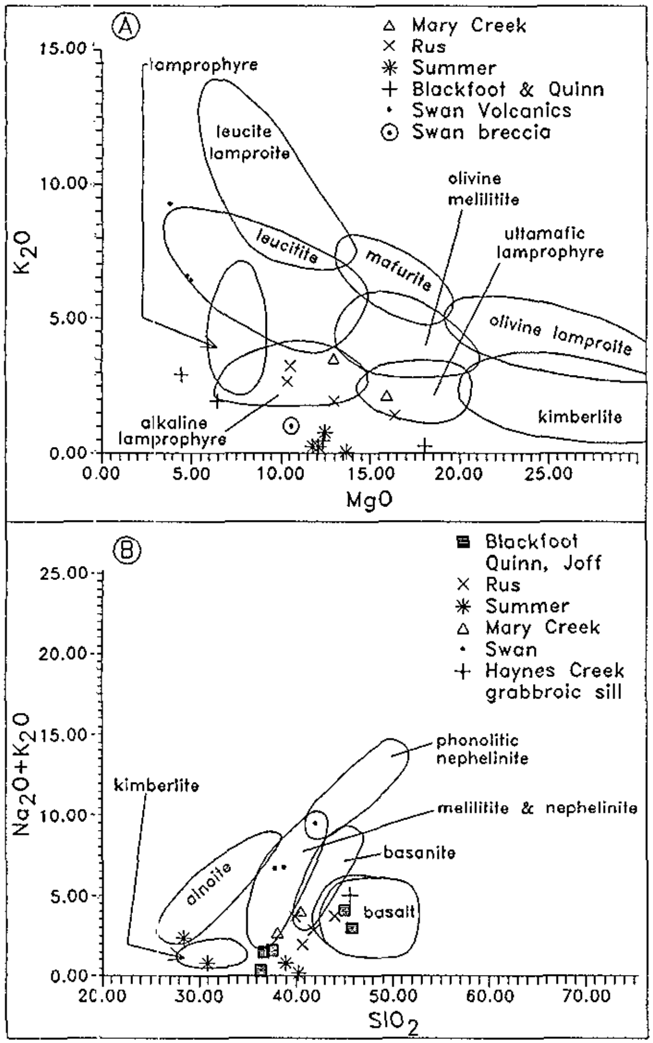


Figure 80. Major element discriminant plots, southern diatreme swarm. (A) South diatreme swarm: (B) Alkali-silica plot, southern pipes.

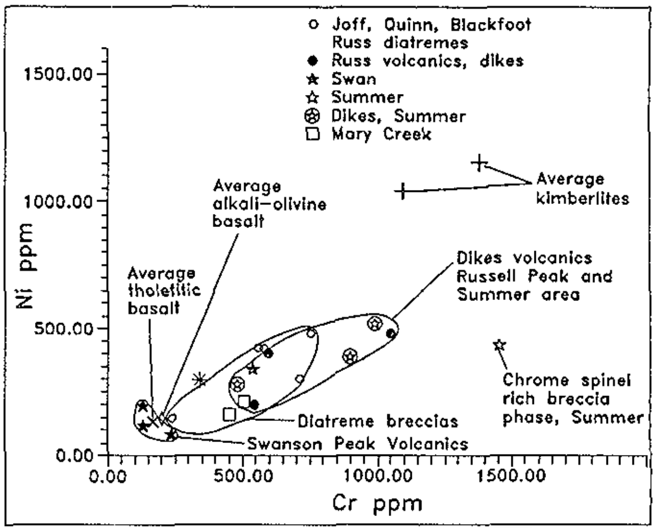


Figure 81. Ni vs Cr plot, southern diatremes.

average, than the other ultrabasic rocks in the area (Table 17).

GEOCHRONOLOGY

Diatreme breccias and related rocks in the Bull River – Elk River area for the most part do not contain mica or other minerals amenable to Rb-Sr or K-Ar radiometric dating. In lieu of this, other methods have been attempted in order to establish the ages of emplacement of these rocks. Crater-infill material from the Rus pipe on Russell Peak was sampled for conodonts. It was barren. Samples were collected from the Joff pipe on Shatch Mountain and from the Blackfoot pipe and zircon separates were obtained. Zircons recovered from the Joff pipe were colourless and rounded, with an oblate to prismatic shape. Results of analyses indicate that the zircons are xenocrystic in origin (Appendix 2), giving lead-lead ages of 1046, 1780, 1820 and 2085 Ma. Two of the analyses, which yielded the oldest and youngest ages, plotted very close to concordia (Appendix 2).

Zircons obtained from the Blackfoot diatreme are of four different types: round and colourless; round and pinkish; clear, colourless, euhedral and abraided; and clear, euhedral, multifaceted. The rounded zircons gave lead-lead ages of 1918 and 2052 Ma (Appendix 2). The other two fractions plotted on concordia, yielding Paleozoic ages of 529 and 532±2.5 Ma. Although tantalizingly young, it is unlikely that these ages are related to diatreme emplacement; the Blackfoot pipe is hosted by the Ordovician to Silurian (*circa* 440 Ma) Beaverfoot Formation carbonate rocks.

As radiometric dating methods have not yet proved useful, age determinations must rely on relative methods. In the case of the Swanson Peak volcanics, this task is not too difficult. The volcanics clearly underlie a quartzite unit immediately beneath the Late Ordovician to Early Silurian Beaverfoot Formation. A diatreme in the North White River valley is of apparently the same age. It cuts Middle Ordovician Skoki Formation strata and contains bedded epiclastic crater-infill material in the upper portion of the pipe (Helmstaedt *et al.*, 1988). The crater-fill sediments are overlain by a quartzite unit which underlies the Beaverfoot Formation, suggesting an age of emplacement of *circa* 450 Ma. A majority of the other pipes in the area cut through part or all of the Beaverfoot Formation, but do not breach the basal Devonian unconformity surface; they are, therefore, post-Late Ordovician to Early Silurian and pre-Middle Devonian in age, probably *circa* 400 Ma.

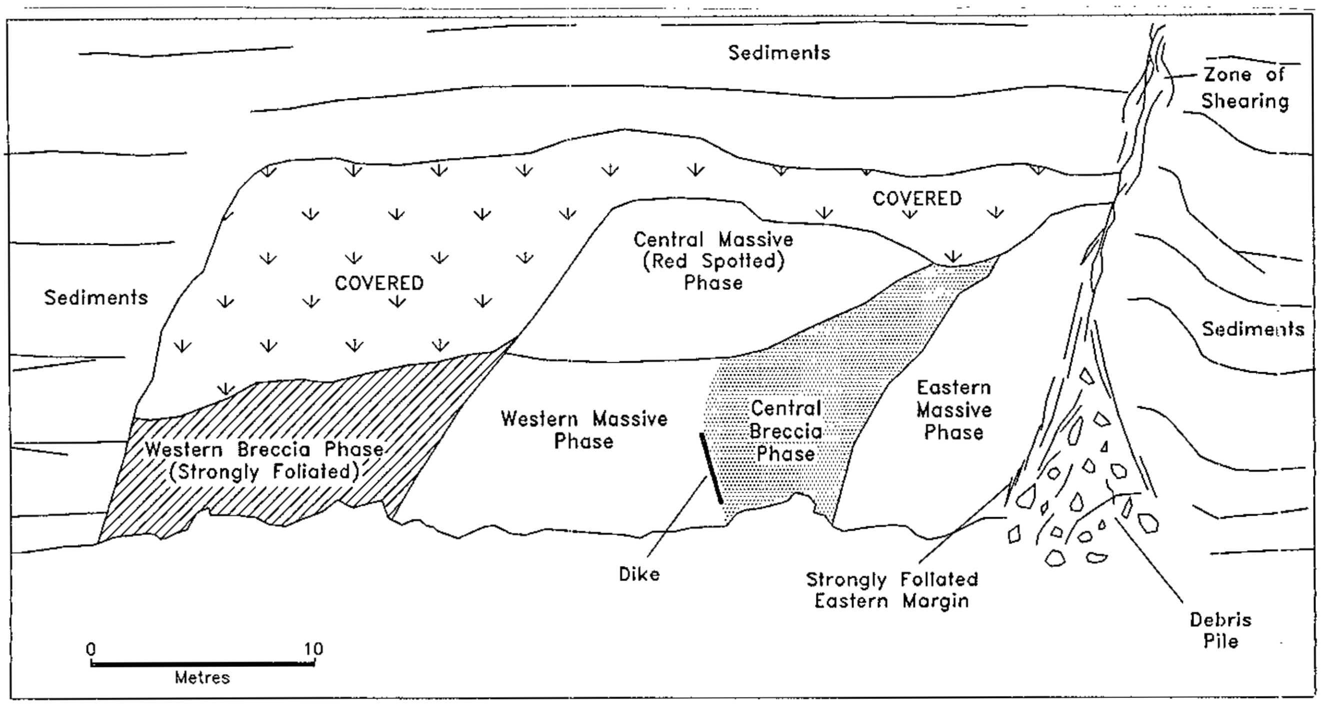


Figure 82. Sketch of the Crossing Creek kimberlite pipe, facing north.

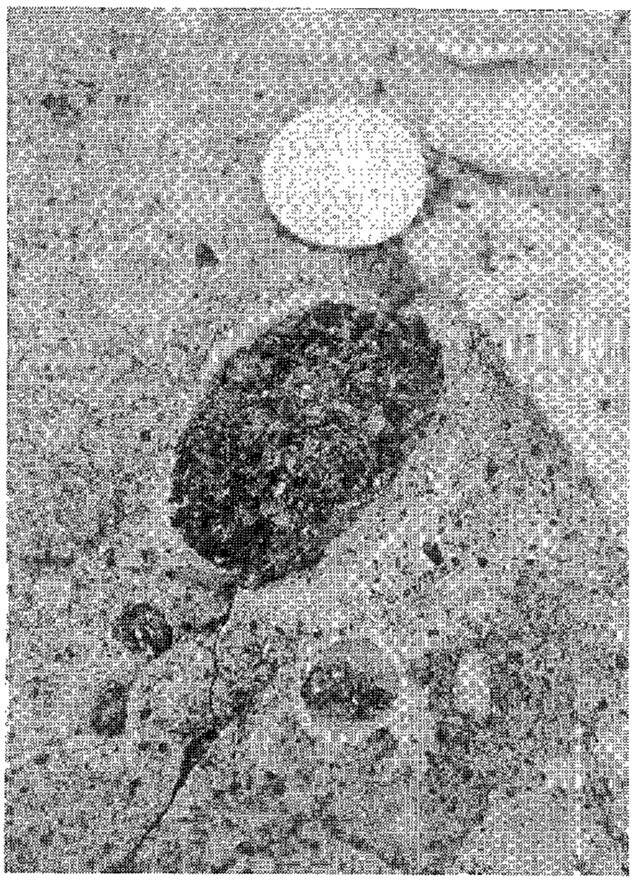


Plate 55. Pyroxenite inclusion forming the core of an accretionary lapillus, central breccia phase, Cross kimberlite.

Plate 56. Altered olivine macrocrysts and phenocrysts, phlogopite phenocrysts and opaque oxides in a magmatic matrix, Cross kimberlite.

KIMBERLITES IN BRITISH COLUMBIA

THE CROSS KIMBERLITE (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 (latitude 50°05′24″N, longitude 114°59′48″W). 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 73). It represents the only true kimberlite known in the province to date. Access is by helicopter or by four-wheel-drive vehicle and a hike along an undriveable road. It has previously been reported on (Meeks, 1979; Roberts *et al.*, 1980; Grieve, 1981, 1982; Hall *et al.*, 1986; Ijewliw, 1986, 1987; Pell, 1987) and the reader is referred to those works for additional details.

The Cross diatreme intrudes Pennsylvanian-Permian Rocky Mountain Supergroup 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 (Figure 82). A minor shear zone forms the eastern contact. No thermal effects on the wallrocks were observed.

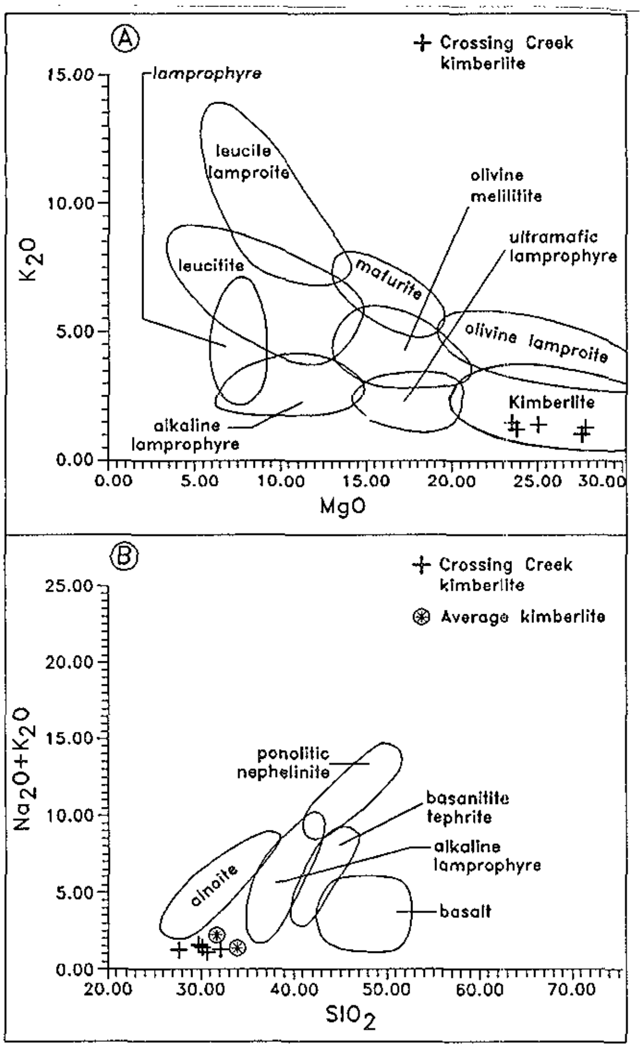


Figure 83. Major element discriminant plots, Cross kimberlite.

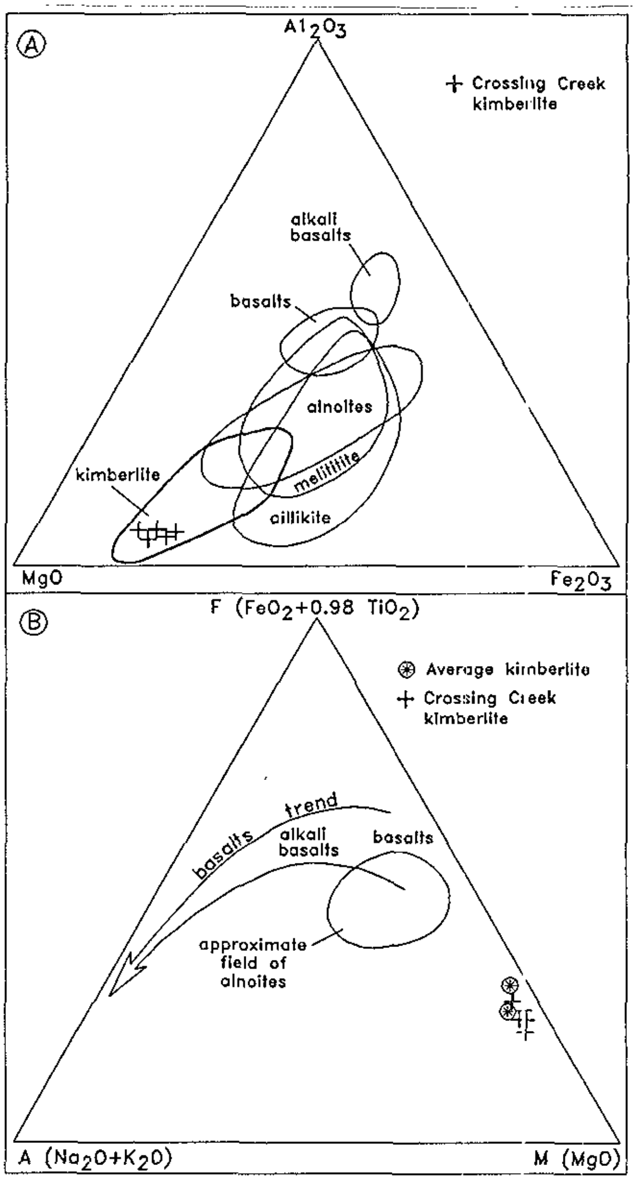


Figure 84. Major element ternary plots, Cross kimberlite.

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 in alkaline rocks. 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. Molybdenum, zirconium, copper, fluorite, wollastonite 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, a metal which is used in the production of high-temperature speciality steels and superalloys for nuclear, aerospace, heavy equipment and pipeline applications. Niobium also has important potential as a superconductor of electricity at cryogenic temperatures (Cunningham, 1985a). The principal niobium mineral in carbonatites is pyrochlore, although other niobium-bearing species such as columbite and fersmite may also be present. The majority of the world's niobium, approximately 85% of total production, comes from Araxa, Brazil, where pyrochlore has been concentrated by residual weathering and grades are in the order of 3% Nb_2O_5. In Canada, niobium is mined by Niobec Inc. (Teck Corporation and Cambior Inc.) at St. Honoré, near Chicoutimi, Quebec, where grades are 0.5 to 0.67% Nb_2O_5.

Tantalum is a relatively rare, heavy, inert metal that is used in electronics, chemical processing equipment, metal-cutting tools and high-temperature steel alloys. It is recovered principally as a coproduct of other metal mining, associated with tin lodes, tin placers and beryllium-tin-niobium pegmatites (Cunningham, 1985b). Tantalum may also be present in significant amounts in carbonatites, generally in the mineral pyrochlore. In alkaline rocks the Nb:Ta ratios commonly exceed 100, whereas in granitic rocks they average 4.8 (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 complexes so far discovered. Work by Cominco Ltd. since 1982, which includes surface exploration and diamond drilling, has defined extensive zones in both the rauhaugite core and sovites, containing between two-thirds and three-quarters of a percent Nb_2O_5 (K.R. Pride, personal communication, 1986) and grades which easily rival the St. Honoré complex in Quebec. Local areas containing greater than 2% Nb_2O_5 have been outlined in the Aley complex. At Aley, the niobium is present mainly in the minerals fersmite and pyrochlore; columbite is also present in minor amounts (Pride *et al.*, 1986). The other British Columbia carbonatite complexes which have been examined all have average Nb_2O_5 values of 0.30% or less, but there is excellent potential for the discovery of other carbonatites with potential ore-grade niobium concentrations.

Tantalum is not abundant in British Columbia carbonatites. Most of the complexes have Nb:Ta ratios typical of carbonatites, approaching 100:1 or more and niobium grades are never sufficient to result in significant concentrations of tantalum. Carbonatites in the Blue River area have anomalous Nb:Ta ratios, in the order of 4:1 and tantalum analyses of up to 2400 ppm are reported (Aaquist, 1982b). On average, however, the niobium grades at Blue River are low, ranging between 0.06 to 0.1% Nb_2O_5 and, therefore, even with anomalous Nb:Ta ratios, currently subeconomic 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. A considerable concentration of rare-earth elements may be contained in common minerals such as calcite, dolomite, pyrochlore, fluorite, apatite, sphene and zircon. Rare-earth carbonate and fluorocarbonate minerals such as bastnaesite and parisite, or phosphate minerals such as monazite or xenotime, may also be present in alkaline suites and contain rare-earth elements. Yttrium, although not strictly a rare earth, 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, iron, steel and other metal-alloying agents, glass-polishing compounds and glass additives, permanent magnets and phosphors for television and lighting (Hendrick, 1985). The rare earths also have important potential in the manufacture of superconductors and applications in advanced ceramics and lasers, particularly yttria (Wheat, 1987). The U.S.A., Australia and China are the major producers of rare earths (Griffiths, 1984; Hendrick, 1985). Most of the economic recovery in the U.S.A. comes from the Mountain Pass carbonatite in California, which grades 7 to 8% total rare-earth oxides, predominantly of the cerium subgroup. Bastnaesite is the principal ore mineral. In Australia rare earths are recovered from monazite placers; in China rare earths are recovered from tabular magnetite iron ores, fluorite-quartz-carbonate and tungsten-quartz veins, pegmatites and tin placers (Lee, 1970). Recently, the greatest demand has been for samarium and neodymium to be used in the magnet industry and for yttrium in phosphors, The diatreme is lithologically heterogeneous and, locally, 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, inclusion-poor light green unit (western massive phase) which in turn grades into a rock with 40% inclusions, 5 to 10% of which are ultramafic xenoliths (central breccia phase). The inclusions often form the cores of accretionary lapilli (Plate 55). Farther 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). Contacts between phases may be gradational or sharp. A thin dike, 10 to 30 centimetres wide, 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; the grains, however 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).

The macrocryst population (0.5 to 5.0 mm in size) consists 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% 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 (Plate 56). Phlogopite grains vary in size, 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.

TABLE 18
CHEMICAL ANALYSIS
CROSSING CREEK KIMBERLITE

wt %	1	2	3	4	5
SiO2	30.04	30.74	30.02	32.11	27.67
TiO2	1.28	1.45	1.29	1.44	1.54
Al2O3	2.23	2.31	2.21	2.10	2.11
Fe2O3T	6.89	8.28	5.31	7.48	7.70
MnO	0.12	0.16	0.09	0.11	0.15
MgO	25.03	27.72	23.54	27.75	23.84
CaO	13.48	9.78	14.94	9.55	14.21
Na2O	0.07	0.09	0.03	0.02	0.05
K2O	1.37	1.01	1.47	1.26	1.22
LOI	17.04	15.38	17.87	15.4	17.37
P2O5	0.99	1.06	1.03	0.99	1.05
S	0.14	0.23	0.09	0.12	0.18
Total	98.68	98.22	97.88	98.35	97.09
ppm					
Ni	1000	1000	1000	1300	890
Cr	1398	1369	1294	1747	1728
Co	60	56	54	70	55
Rb	56	40	53	57	54
Sr	1177	1073	1171	1452	1492
Ba	3237	2642	3497	2648	3442
Zr	292	322	301	313	367
Nb	187	207	200	199	230
Y	18	22	21	22	21
La	134	157	126	132	197
Ce	258	300	239	266	363
Nd	na	na	na	na	na
Yb	1	3	2	0	<-1
Sc	23.1	20.3	23.7	20	25.1
Ta	7	14	9	11	11
Th	18	19	24	18	41
U	14	14	15	14	22
V	196	196	208	222	230
Cu	54	73	50	51	54

All analyses by XRF, B.C. G.S.B. analytical laboratory
1. - CX5-6 Kimberlite, western massive phase;
2. - CX5-7B Hematite-spotted kimberlite; red-spotted phase;
3. - CX5-8A Kimberlite, eastern massive phase;
4. - CX6-D1 Fine-grained crosscutting, inclusion-free dike;
5. - CX5-7 Micaceous kimberlite, red-spotted phase.

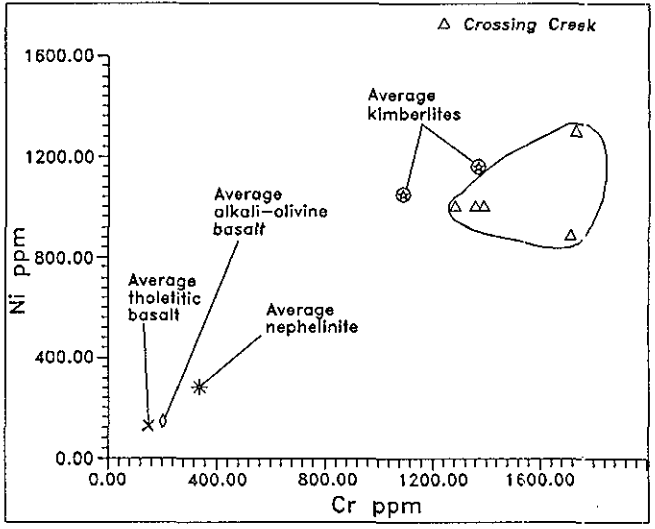


Figure 85. "Average" values from Wederhal and Maramatsu 1979. Ni vs Cr plot, Cross kimberlite.

GEOCHEMISTRY

The Cross diatreme is the only true kimberlite so far recognized in the province. It fits both the petrologic and geochemical definitions of a kimberlite (Figures 83 and 84; Table 18). Although it appears to be quite a heterogeneous intrusion, samples analyzed were all very similar geochemically. It is characterized by low silica, high magnesium, high strontium and high nickel and chrome (Figure 85; Table 18).

GEOCHRONOLOGY

Rubidium-strontium dating of mica separates has yielded Permo-Triassic ages of 240 and 244 Ma for the Cross kimberlite (Grieve, 1982; Smith, 1983; Hall *et al.*, 1986). Both the Cross kimberlite and its hostrocks are significantly younger than other British Columbia diatreme suites.

engineering ceramics and superconductors (Roskill Information Services, 1988).

Significant enrichment in rare-earth elements is reported from five localities in British Columbia, the Aley complex and Rock Canyon Creek, both in the Rocky Mountains; the Wicheeda Lake area along the Rocky Mountain Trench near Prince George; the Kechika River area in the Cassiar Mountains; and the Mount Bisson area in the Omineca Mountains. At Aley narrow dikes enriched in rare-earth elements, and locally fluorite, cut the altered sediments peripheral to the main complex. Samples containing in excess of 2.1% total rare-earth oxides are present. The rare earths are contained in carbonate minerals such as bastnaesite, burbankite, cordylite and huanghoite (Mäder, 1987). These dikes are thin and sporadically developed and, although worthy of note, not of major economic interest.

At Rock Canyon Creek a metasomatically altered (fenitized) zone rich in rare earths and fluorite, measuring approximately 1000 by 100 metres, has been identified. Samples containing in excess of 2.7% total rare-earth oxides (predominantly cerium and lanthanum oxides) have been obtained from outcrops of this zone. The rare-earth fluorocarbonate minerals bastnaesite and parisite, and gorceixite, a phosphate mineral, have been identified. At Rock Canyon Creek, locally high rare-earth values at surface, the size of the zone and the lack of extensive work suggest that further work is warranted.

In the Wicheeda Lake area a series of alkaline rocks including carbonatites, syenites and leucitites are exposed. Work by Teck Corporation has indicated that one carbonatite plug locally contains in excess of 4% total rare-earth elements and one trench, across part the carbonatite, exposed material grading 2.60% total rare earths over its 42-metre length (Betmanis, 1988). These values are predominantly in light rare earths, in particular cerium and lanthanum, however, the results are favourable and this area might warrant further work in the future, particularly if the demand for cerium and lanthanum increases.

In the Kechika River area, alkaline rocks consisting of syenites, malignites, breccias and fenites are intermittently exposed along a northwest-trending zone in excess of 15 kilometres in strike length. During a recent exploration program, samples containing in excess of 3.77% total rare-earth oxides (mainly cerium subgroup elements) were collected from carbonatite dikes; other samples containing up to 1.13% Y_2O_3, 0.30% Nd_2O_3, 0.11% Sm_2O_3 and 0.14% Dy_2O_3 were taken from phosphate-rich segregations, containing up to 19.3% P_2O_5, in a mylonitized syenite/trachyte (Pell *et al.*, 1990). Rare-earth elements and yttrium in the Kechika River area are present mainly in monazite, xenotime and other phosphate minerals. The size of this zone, lack of detailed work and presence of anomalous concentrations of heavy rare-earth elements suggest that additional work is warranted.

Light rare-earth elements, particularly cerium and lanthanum, are concentrated in allanite pegmatites and allanite-bearing mafic syenite dikes that are associated with large fenite zones in the Mount Bisson area. Some of the pegmatites reportedly contain up to 14.5% total rare earths and can be 1 to 4 metres wide and over 30 metres long. Mafic syenite dikes in the area generally contain lower concentrations of rare earths than the pegmatites; local concentrations up to 4.26% total rare earths have been found (Halleran and Russell, 1990). Very little work has been done in the Mount Bisson area and preliminary results indicate some potential; this area might warrant further work in the future, particularly if the demand for cerium and lanthanum increases.

The presence of these five 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%. The main zirconium minerals present in these rocks are zircon, eudyialite (Na-Zr silicate) and baddeleyite (ZrO_2), with alkaline rocks being the only known source of substantial amounts of baddeleyite.

The major application of zirconium 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 heat-resistant tiles, sensors and automobile exhausts. The principal sources of zirconium are zircon recovered as a byproduct from titanium placer deposits and baddeleyite produced as a coproduct from apatite mining of the Palabora carbonatite, South Africa and of niobium mining at Araxa and Pocos de Caldas carbonatites in Brazil (Adams, 1985).

Zircon is a ubiquitous phase in carbonatite and nepheline syenite gneiss complexes in British Columbia and crystals often exceed 1 centimetre in length. The Aley complex, Paradise Lake syenite, Verity carbonatite, Trident Mountain syenite and Lonnie and Vergil complexes all contain coarse zircon in excess of 1%. In the Lonnie and Vergil complexes, the syenitic rocks may contain 3 to 15% 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 of niobium or rare-earth mining and should be tested for.

PHOSPHATES

Ultrabasic alkaline igneous complexes commonly contain high concentrations of phosphate, largely in the form of the mineral apatite and approximately 18% of all phosphates mined come from igneous complexes. Apatite from carbonatites is mined at Palabora, South Africa; Dorowa, Zimbabwe; the Kola Peninsula in the U.S.S.R.; and Araxa and Jacupiranga in Brazil (Currie, 1976a; Russell, 1987; Fernandes, 1989). Grades as low as 4% P_2O_5 are currently recovered. Approximately 90% of all the phosphate mined is used in the fertilizer industry; other uses include organic and inorganic chemicals, soaps and detergents, pesticides, insecticides, alloys, animal-food supplements, ceramics, beverages, catalysts, motor lubricants, photographic materials and dental cements.

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 of the other carbonatites, containing, on average, 5 to 15% apatite, with P_2O_5 contents up to 11% (Tables 1 and 9) and averaging 3.5 to 5%. The Ren carbonatite also has an average P_2O_5 content of approximately 3.5%, with maximum values of 4.2% (Table 12). Carbonatite dikes cutting ultramafic rocks of the Ice River complex locally contain up to 8% P_2O_5 (Table 3). Syenitic mylonites in the Kechika area contain small zones which assay as high as 19.3% P_2O_5 and have apatite as one of the major rock-forming minerals. The continuity of these phosphate zones is unknown and it is unlikely that they would be exploited for phosphate alone.

It has been estimated that the Aley complex may contain as much as 15 billion tonnes of 5% P_2O_5, while other carbonatites probably contain only a few million tonnes of phosphate reserves (Butrenchuk, in preparation). 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, particularly in the case of Aley, if niobium were to be mined.

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; these elements act as a flux which affects the rate and temperature of melting, the fluidity of the melt and the physical properties of the finished product. 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.

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 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 (Table 11; Currie, 1976a). In general, the Mount Copeland syenites are medium to coarse grained and it was considered that many of the impurities (ferromagnesian minerals – in particular biotite) could potentially be removed by crushing and magnetic separation techniques; however, beneficiation tests failed to produce a product with a low enough iron content to meet industry specifications (White, 1989). Some of the other syenites, such as the Paradise syenite or the large body on Trident Mountain, are quite similar in composition to those being mined in Ontario. Beneficiation tests run on samples from Trident Mountain indicate that this syenite is low in magnetic impurities, has a high recovery rate of nonmagnetic materials and, therefore, has good potential to produce a commercial-grade nepheline syenite product with a brightness of 85% (White, 1989). The remote location of this body, however, severely limits its economic potential.

VERMICULITE

Vermiculite is a mineral which expands when heated. It is formed from alteration of biotite or phlogopite and is a characteristic accessory in 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 from carbonatites 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 the Mount Copeland showings were the focus of significant exploration and development work in the late 1960s (Fyles, 1970). Current economics, however, do not favour exploitation of molybdenum from such deposits.

WOLLASTONITE

Wollastonite is an important mineral filler used primarily in the paint and ceramics industries. It can be found in two main geological environments: contact metamorphic or metasomatic (skarn) deposits and in carbonatites, as a primary, magmatic mineral. Most world production comes from contact deposits (Harben and Bates, 1990).

Wollastonite has not been recognized in any carbonatites in British Columbia; however, it is worth looking for in future discoveries.

TITANIUM

Titanium-bearing minerals are present in a number of the carbonatite and alkaline rock complexes in British Columbia. Sphene, perovskite and ilmenite have all been recognized. As well, knopite, a rare-earth enriched variety of perovskite, has been reported from the Ice River area (Ellsworth and Walker, 1926). In most cases, these titanium minerals are present in relatively low concentrations; at Howard Creek, however, sphene is a rock-forming mineral in a melteigite of limited spatial distribution. It is unlikely that titanium could be produced from any of these occurrences.

DIAMOND

Diamonds were traditionally considered to be present in economic concentrations in kimberlites only. Recent studies have shown that they may also be recovered from lamproites, and they have also been reported from such diverse rock types as peridotites and even carbonatites. Only one true kimberlite has been discovered in British Columbia, the Cross diatreme, but no results of laboratory research on mineral composition or diamond recovery have been re-

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ported by industry. Microdiamonds have, however, reportedly been recovered from two of the lamprophyre diatremes in the Golden – Columbia Icefields area. One of the pipes reported to have yielded microdiamonds from concentrates collected and processed at two different times, from different laboratories. A significant amount of additional research is necessary to establish if economic concentrations are present.

GEMSTONES

Corundum (sapphire, ruby) is a common accessory mineral in silica-undersaturated, alumina-rich rocks such as nepheline syenites and nepheline-feldspar pegmatites. In the Bancroft area of Ontario, corundum occurs in nepheline-bearing rocks and marginal zones of nepheline syenite intrusions at Blue Mountain and elsewhere. Nepheline syenites at Cabonga Reservoir, Quebec contain blue corundum crystals mantled by biotite (Currie, 1976a). Sapphires have also been reported from alkaline lamprophyre dikes in Montana.

Nepheline syenites are known from a few localities in B.C. (*e.g.*, Paradise Lake, Ice River, *etc.*). These areas have not been evaluated for their potential to contain gem corundum. Alkaline lamphrophyres are present in the Rockies (*e.g.*, Golden cluster) and could also be prospected for gem corundum varieties.

Blue corundum crystals (star sapphires) up to 1 to 2 centimetres in size, have recently been discovered in the Slocan Valley within a syenitic phase of the Valhalla Gneiss Complex, part of the Passmore Dome. These gneisses also contain sphene and amphibole and, in outcrop, resemble fenites in the Blue River and Perry River areas (Z.D. Hora, personal communication, 1993). Fenites are widespread, associated with carbonatites and syenite gneiss complexes within metamorphosed rocks or the Ominica Belt and should be prospected for gem corundum.

SUMMARY AND CONCLUSIONS

CARBONATITES AND SYENITE GNEISSES

Carbonatites and syenite gneisses crop out in three belts parallel to the Rocky Mountain Trench. The intrusions in the eastern Rocky and Cassiar Mountain belt are middle Paleozoic, predominantly Devono-Mississippian in age, hosted by lower to middle Paleozoic strata and therefore are relatively high-level intrusions. They can be large and elliptical in shape and have significant alteration halos (*e.g.*, Aley carbonatite), consist simply of metasomatic alteration zones (*e.g.*, Rock Canyon Creek showing), or be extensive linear belts comprising numerous and lithologically varied sills, dikes and plugs (*e.g.* the Wicheeda Lake and Kechika River showings). The carbonatites in the eastern belt can be significantly enriched in niobium, fluorine, yttrium and rare-earth elements.

The central belt 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 by Precambrian strata; they were not emplaced as high in the stratigraphic succession as those in the eastern belt. The carbonatites in the Omineca Mountains are thin, discontinuous, sill-like intrusions generally with narrow fenite alteration halos. With one exception (the Mount Bisson intrusions), they are not as enriched in niobium, fluorine or rare-earth elements as their eastern counterparts.

The western belt, also within the Omineca Mountains, comprises intrusive and extrusive carbonatites and nepheline syenite gneisses hosted by the autochthonous cover sequence of the Frenchman Cap gneiss dome. The enclosing metasedimentary rocks are of uncertain age, however, recent studies suggest that they may have been deposited in a period which spans late Precambrian to Eocambrian time (Höy and Godwin, 1988). A single radiometric date, obtained on one of the alkaline intrusive bodies (Mount Copeland syenite) which occurs near the base of the mantling gneiss succession, indicates an age of emplacement of *circa* 770 Ma for that intrusion (Okulitch *et al.*, 1981). This gives a minimum age for the basal part of the succession. Much higher in the mantling gneiss stratigraphy, overlying the carbonatite horizons, a stratabound lead-zinc deposit has yielded an Eocambrian to early Cambrian lead-lead date. This suggests that the highest stratigraphic levels of the mantling gneiss succession are Early Cambrian and the intervening stratigraphy was deposited between Late Proterozoic and early Paleozoic time. The extrusive carbonatites are located relatively high in the mantling gneiss stratigraphy, approximately 100 metres below the lead-zinc layer and, like the lead-zinc deposit, are probably Eocambrian in age.

The carbonatites in the western belt comprise high-level intrusions and extrusives. The carbonatite 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 such as niobium or rare earths. All of these factors are probably related to the original volatile content of the magma. The most favourable areas for additional exploration for these elements would appear to be those underlain by lower to middle Paleozoic strata of North American affinity. The western Rocky Mountains and some regions of the eastern Omineca Belt, close to the Rocky Mountain Trench, have the best potential. Byproduct recovery of apatite and zircon should also be considered when assessing the niobium or rare-earth potential of any prospects.

Commercial-grade nepheline syenite could potentially be produced from the Trident Mountain syenite, however, current inaccessibility precludes immediate exploitation. If this area were ever to become more accessible, through the development of good logging roads, the nepheline syenite potential of this body would warrant serious examination. Other compositionally similar syenites are present in British Columbia, but are also in remote locations and remain untested.

KIMBERLITES, LAMPROPHYRES AND OTHER ULTRABASIC DIATREMES

Ultrabasic diatremes have been recognized in five areas of British Columbia; the Kechika River and Ospika River areas of northern British Columbia, the Golden, Bull River – Elk River and Elkford areas of the Kootenays. In the Ospika River area north of Mackenzie, and in the Columbia Icefields area north of Golden (Figure 2), the diatremes are characterized by macrocryst-rich breccias and dikes. The macrocryst population consists of clinopyroxene, phlogopite, green diopside, spinel and olivine, with either pyroxene or phlogopite as the most abundant phase. In some cases, microphenocrystic feldspars are present in small amounts. These rocks are tentatively classified as lamprophyres; the HP pipe in the Golden area and the Ospika pipe can be classified as aillikites, which are members of the ultramafic lamprophyre clan based on their modal mineralogy and, to a lesser extent, the chemistry. The other ultrabasic intrusions in the Golden area are more difficult to classify; they appear to be most similar to amphibole-free alkaline lamprophyres. In all cases the breccia pipes commonly contain multiple phases of intrusion characterized by variable proportions of xenoliths, macrocrysts and accretionary lapilli or spherical structures. The breccia matrix in some cases is clearly magmatic. These pipes are characteristic of the diatreme facies material, as described from kimberlite pipes and/or hypabysal-facies (Clement and Reid, 1986).

They formed from extremely volatile-rich magmas, so rich, in some cases, that as they reached the surface and vesiculated, the magmatic phase exsolved from the volatiles and actually formed the 'bubbles', as indicated by the spherical structures (or globular segregations) and armoured xenoliths. At Lens Mountain, Mons Creek and Valenciennes River sandy tuffisitic or gas-stream breccias, with an insignificant recognizable igneous component, are also present.

Rubidium-strontium and potassium-argon dates of 338±3 and 323±10 Ma have been obtained from phlogopite separates from the Ospika pipe. These dates indicate that emplacement occurred in Devono-Mississippian time, as is the case for the most of the carbonatites in the eastern and central belts. Aillikites and alnoites are noted for their affiliation with carbonatites (Rock, 1986). Pipes and dikes from two areas north of Golden have also been dated. In that area, most of the diatremes were emplaced slightly earlier, in Early Devonian time (*circa* 400 Ma). Zircons from ultrabasic rocks in the Mons Creek area yielded concordant lead-lead ages of 469 Ma; if these zircons are not xenocrystic, it may indicate that there was a third period of emplacement in the Late Ordovician to Early Silurian.

Intrusions in the Bull River and Kechika areas are distinctly different than those in the Golden or Ospika areas. They are characterized by chaotic breccias containing abundant vesiculated glass lapilli, juvenile lapilli and rare altered olivine, altered pyroxene, feldspars and chromian spinel macrocrysts and by the absence of primary micas. The matrix of these breccias is not magmatic; they are crater and diatreme-facies tuffisitic breccias. Some pipes breached the paleosurface and the upper parts of the crater zone contain bedded epiclastic or pyroclastic rocks. A number of the pipes in the Bull River – Elk River area intrude Ordovician-Silurian Beaverfoot carbonate rocks and contain bedded crater-facies material which is unconformably overlain by the basal Devonian unit (Middle Devonian) suggesting an Early Devonian age of emplacement of approximately 400 Ma. Other pipes and flows apparently underlie and predate the Beaverfoot Formation, but cut middle Silurian rocks and, therefore, must be approximately 455 Ma in age. The Kechika pipe is also hosted by Ordovician to Silurian strata and associated with bedded tuffs which must be of the same age as the host strata (possibly *circa* 450 Ma.).

The craters containing these breccias are envisaged to have a 'champagne glass' structure, similar to that of lamproite or basaltic craters, with no extensively developed root zone. The breccias are commonly associated with crosscutting porphyritic dikes and flows, characterized by the presence of phenocrystic olivine and titanaugite, with abundant feldspar (plagioclase or potassium feldspar), titanaugite and opaque oxide microphenocrysts in a fine-grained groundmass. These rocks are extremely difficult to classify; they are ultrabasic, and locally quite potassic, feldspar-bearing rocks that can contain vesiculated glass lapilli and are generally devoid of hydrous mafic minerals and feldspathoids. They may have originated in volatile-enriched systems, but not to the extent of the previous diatremes; as they neared the surface the volatiles exsolved from the magma and not

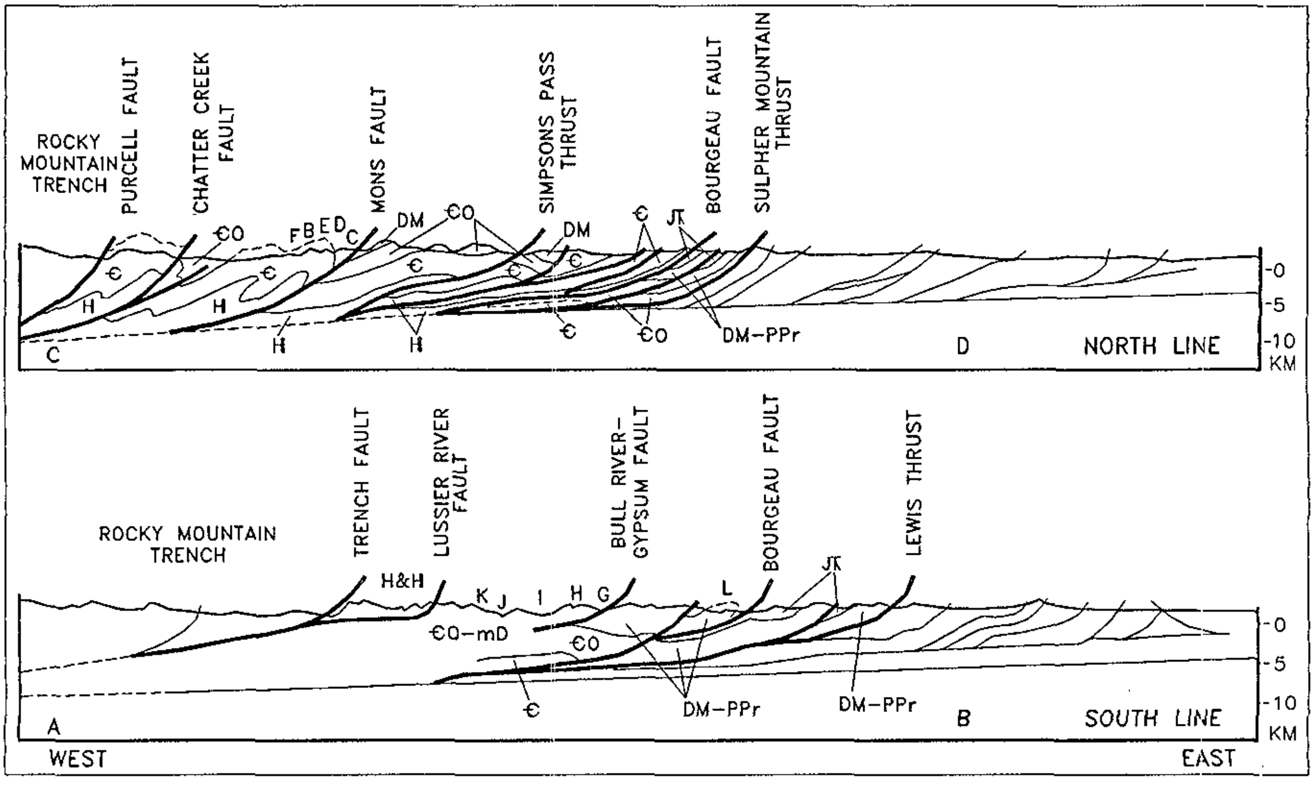

Figure 86. Structural position of diatremes, B - Bush River; C - Lens Mountain; D - Mons Creek; E - Valenciennes River ; F- HP pipe; G - Shatch Mountain; H - Russell Peak; I - Blackfoot; J - Quinn Creek; K - Summer ; L - Crossing Creek, Geology modified from Wheeler (1963), Wheeler *et al.*, (1972), Leech (1979), Price (1981).

the reverse. In some cases they may be tentatively classified as limburgites, in others they appear to be most similar to members of the alkaline basalt family, but generally are more basic than typical alkaline basalts which suggests that they are verging towards nephelinites.

The last distinct rock type is represented by one example, the Cross kimberlite, located at Crossing Creek, north of Elkford. As the name implies, it is a true kimberlite, the only one so far recognized in the province. It is apparently a deeply eroded pipe remnant and contains two generations of olivine, 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 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. The Crossing Creek kimberlite apparently originated deep in the mantle, it contains abundant pyrope garnets and has sampled mantle lithologies including garnet lherzolites. This suggests that it may have originated at depths generally considered sufficient to be in the diamond field; however, diamond genesis apparently depends on oxygen fugacity as well as pressure and depth of origin alone is not sufficient to predict the diamond potential of a pipe (Haggerty, 1986). The pipes in the other areas of British Columbia do not appear to have originated as deep in the mantle as the Crossing Creek kimberlite. They contain no good evidence of deep mantle xenoliths; the xenolith and xenocryst populations are generally confined to crustal material: rare eclogites, spinel lherzolites, chrome spinels and very rare pyrope garnets (Northcote, 1983a, 1983b). This suggests an origin in the spinel lherzolite field of the upper mantle, which is generally considered to be at pressures below those required for diamond formation. Microdiamonds reportedly found in two of the pipes in the Golden swarm suggest that these pipes may have sampled the uppermost levels of the diamond field.

When compared to current models, it appears that the probability of British Columbia diatremes containing economic concentrations of diamonds is low. From craton to margin, a sequence of kimberlite with diamond, kimberlite without diamond (*e.g.*, Cross) and diamond-free ultrabasic diatremes (nonkimberlitic) 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 86). If these sections were restored to predeformational configurations, the pipes contained in the most westerly thrust sheet would have been the farthest outboard. The Cross kimberlite is in the Bourgeau thrust sheet and is the easternmost of the diatremes. The ultrabasic diatremes in the Bull River area are carried by the Bull River – Gypsum fault (Figure 86), 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 and alkaline lamprophyres north of Golden are carried on a thrust (the Mons fault) which lies west of the Simpsons Pass thrust and apparently originated the farthest outboard of the continent. If Haggerty's model is applicable to western North America, it is unlikely that significant concentrations of diamonds can be found in nonkimberlitic rocks originating so far from the stable craton; however, the western continental margin at the time of diatreme emplacement was probably significantly more complex than the one proposed in Haggerty's model for South Africa. The location of the western edge of the continental mass at that time is unknown and the depth to the lithosphere-asthenosphere boundary is also uncertain, therefore, the proposed constraints on diamond genesis may be not directly applicable.

TECTONIC IMPLICATIONS

The emplacement of carbonatites, kimberlites and other alkaline rocks in the Canadian Cordillera appears to be related, in part, to extension and rifting along the western continental margin that produced and deepened the basin into which the miogeoclinal succession was deposited. Sedimentological and stratigraphic evidence indicate that the western continental margin was tectonically active throughout much of the Proterozoic and Paleozoic eras. It does not appear to have behaved entirely in a passive manner and therefore may not be strictly analogous to the present day Atlantic margin, as earlier workers proposed (Stewart, 1972; Stewart and Poole, 1974); rather it appears that several superimposed 'passive margin-type' sequences are present as a result of periodic extensional activity (Pell and Simony, 1987; Thompson *et al.*, 1987). During these periods of extension, deep faults and fractures in the crust may have released pressure and triggered partial melting, which ultimately resulted in alkaline magmatism (Table 19).

The earliest event recorded by alkaline activity in western Canada is represented by the Mount Copeland syenite of Late Proterozoic in age (*circa* 770 to 750 Ma); it may record extension or rifting of the North American craton and the initiation of the Late Proterozoic Windermere basin. Diabase dikes and sills of similar age (770 Ma) in northern Canada also record extension preceding Windermere deposition (Armstrong *et al.*, 1982). Slightly younger dates of 728 and 741 Ma (U-Pb, zircons) have been obtained from granitic gneisses which appear to be basement for Windermere Supergroup strata in north-central and central British Columbia (Parrish and Armstrong, 1983; Evenchick *et al.*, 1984). This implies that rifting began as early as 770 Ma in some areas, but that the event spanned a period of time and, locally, Windermere sedimentation did not begin until after 730 Ma.

Sedimentary loading and synsedimentary faulting (Lis and Price, 1976; Eisbacher, 1981; Root, 1983; Bond and Kominz, 1984; Devlin and Bond, 1984) accounted for the deepening of the basin and the continuation of deposition into the early Paleozoic. Minor extensional activity is also indicated by the presence of acid to basic volcanic and intrusive rocks throughout the Hadrynian to early Paleozoic sedimentary wedge (Simony and Wind, 1970; Raeside and Simony, 1983; Pell and Simony, 1987; Sevigny, 1987).

Extrusion of the Mount Grace carbonatite and intrusion of shallow-level carbonatites, accompanied by the formation of extensive zones of fenitization, probably occurred in Eocambrian to Early Cambrian time (Höy and Godwin,

TABLE 19
TIMING OF ALKALINE INTRUSIONS AND OROGENESIS

Million Years	Period	ALKALIC INTRUSIVES	TECTONIC EVENTS PACIFIC MARGIN	TECTONIC EVENTS ATLANTIC MARGIN
	Tertiary		**CIRCUM-PACIFIC SUBDUCTION SYSTEM** ***(Columbia Orogeny)*** ***(Laramide & Nevadian in USA)***	**ATLANTIC OCEAN SPREADING**
100	Cretaceous			
	Jurassic			
200	Triassic	▮ Cross Kimberlite	▮ Sonoman Orogeny	
	Permian			▮ Alleghenian Orogeny
300	Pennsylvanian			
	Mississippian	▮ Majority of Carbonatites Ospika Pipe	▮ Middle Paleozoic Extension Antler Orogney	
400	Devonian	▮ Diatremes, Golden & Cranbrook Areas	▮ Rifting & Discordances	▮ Acadian Orogeny
	Silurian			▮ Taconic Orogeny
	Ordovician	▮ Some Diatremes Cranbrook Area	Minor Unconformities & ▮ Subsidence	
500	Cambrian	▮ Mount Grace Carbonatite	▮ Rift to Drift Transition	
600	Precambrian			
700				
800		▮ Mount Copeland Syenite Frenchman Cap Area	▮ Pre-Windermere Rifting	▮ Pre-Appalachian Rifting
900				

Several 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.

(modified from Dickinson, 1977)

1988). These rocks occur in a relatively thin cover-succession above core gneisses of the Frenchman Cap dome, which suggests that the dome may reflect a tectonic high in late Precambrian to Early Cambrian time. Emplacement of the alkalic rocks may have coincided with foundering of an extensive Lower Cambrian platform to the east. This period is also interpreted by many workers as the time of the rift-to-drift transition along the western continental margin (Bond and Kominz, 1984; Devlin and Bond, 1984; Thompson *et al.*, 1987). In the southwestern United States, carbonatites of Eocambrian to Early Cambrian age are reported from a number of localities (Figure 87); for example, the McClure Mountain carbonatite-alkalic complex, the Gem Park and the Iron Hill carbonatite complexes in Colorado and the Lobo Hills syenite and carbonatite in New Mexico (Fenton and Faure, 1970; Olson *et al.*, 1977; Loring and Armstrong, 1980; Armbrustmacher, 1984; McLemore, 1984; 1987;). Although these intrusions are structurally inboard of the Mount Grace carbonatite, their emplacement may be related to the same large-scale extensional tectonic event.

A number of periods of Paleozoic extension are inferred along the western continental margin; however, additional dating is necessary to clearly define these periods and eliminate possibilities of overlap. The earliest event is Late Ordovician to Ordovician-Silurian in age (*circa* 450 Ma) and is recorded by the emplacement of some ultrabasic diatremes and alkaline lamprophyres in the southern Rocky Mountains and the Golden area of British Columbia. The Bearpaw Ridge sodalite syenite (eastern belt, Figure 1) may also prove to be Ordovician to Early Silurian in age as was originally proposed by Taylor and Stott (1980), who believed it to be a subvolcanic pluton related to alkaline basalt flows in the Silurian Nonda Formation. Syenites, trachytes, carbonatites and ultrabasic diatremes and tuffs in the Kechika area may also be of a similar age. Carbonatites of approximately the same age are found in the Lemitar Mountains of New Mexico (McLemore, 1987).

A second period of alkaline igneous activity along the western margin of North America occurred in Early Devonian time (*circa* 400 to 410 Ma). Most of the ultrabasic and alkaline lamprophyres in the Golden area and some ultrabasic diatremes in southern British Columbia were emplaced at this time. Diatreme breccias in the Yukon Territory (*e.g.*, Mountain diatreme, R.L. Armstrong, personal communication, 1988) are of the same age. In a more continental setting (Figure 87), Early Devonian kimberlites are reported from the Colorado-Wyoming State-Line district (McCallum *et al.*, 1975; McCallum and Marbarak, 1976; Hausel *et al.*, 1979).

A third Paleozoic extensional event at the end of the Devonian (*circa* 350 to 370 Ma) resulted in the intrusion of carbonatites into the miogeoclinal succession in the Foreland and Omineca belts. Aillikite diatremes (ultramafic lamprophyres) and dikes in the Ospika River area were also emplaced at this time. The tectonic instability resulting from this major Devono-Mississippian extensional event is also evident in the stratigraphic record (Thompson *et al.*, 1987); 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 and central Canadian Cordillera (Gordey, 1981; Mortensen, 1982; Gordey *et al.*, 1987) as well as in the southern Canadian Cordillera (Wheeler, 1965).

The Devono-Mississippian extension was synchronous with, or slightly postdated, compression to the south that was associated with the Antler orogeny. Devono-Mississippian granites and granitic gneisses have also been documented in the Canadian Cordillera and Alaska (Okulitch *et al.*, 1975; Dillon *et al.*, 1980; Montgomery, 1985; Okulitch, 1985; Mortensen 1986; Mortensen *et al.*, 1987). These rocks crop out west of the alkaline intrusions and are believed to have intruded near the western edge of the Paleozoic Cordilleran miogeocline (Okulitch *et al.*, 1975). Also during Devono-Mississippian time, a mixed volcanic and sedimentary sequence, termed the Eagle Bay assemblage, was forming off the western contintental margin; these rocks record a change from an island arc environment at the base of the sequence, where calcalkaline volcanics were forming above a subducting plate, to a rift environment in which alkaline volcanism and sedimentation took place (Schiarizza and Preto, 1987).

These data suggest that a complex tectonic regime must have pertained at the end of the Devonian and that it was not simply a time of extension. A more complex model is necessary to explain westerly sources for Devono-Mississippian miogeoclinal sediments, obduction at the latitude of present-day northern California and southern Oregon, and emplacement of granites in southern British Columbia, the Cariboo and Alaska at approximately the same time as extension and alkaline intrusion were taking place near the eastern margin of the Canadian Cordilleran miogeocline. A sequence of events may have occurred which culminated in the development of an incipient continental back-arc rift at a complex, attenuated margin (*see* Struik, 1987), as localized obduction (and possibly subduction) occurred to the south and outboard. Subduction probably resulted in partial melting and genesis of granite and calcalkaline volcanic rocks; this compressional regime was apparently superceded by an extensional regime. Alternatively, extensional basins may have resulted from strike-slip faulting outboard of the preserved margin of the miogeocline, as proposed by Eisbacher (1983) and Gordey *et al.* (1987); however, this scenario does not explain the intrusion of granites.

The last Paleozoic extensional event is inferred from the presence of Permo-Triassic kimberlite in the Rocky Mountains. Although only one example is known, it is possible that other alkaline intrusions of similar age exist and that other evidence for extension may be discovered. As with the previous event, Permo-Triassic extension occurred approximately synchronously with compression in the southern Cordillera (Sonoman orogeny).

In Late Jurassic to Early Tertiary time, orogenesis occurred when a compressional regime was established on the Pacific margin while rifting and the opening of the Atlantic took place on the opposite side of the continent. During orogenesis the continental margin prism was telescoped and the alkaline igneous rocks were deformed, metamorphosed and

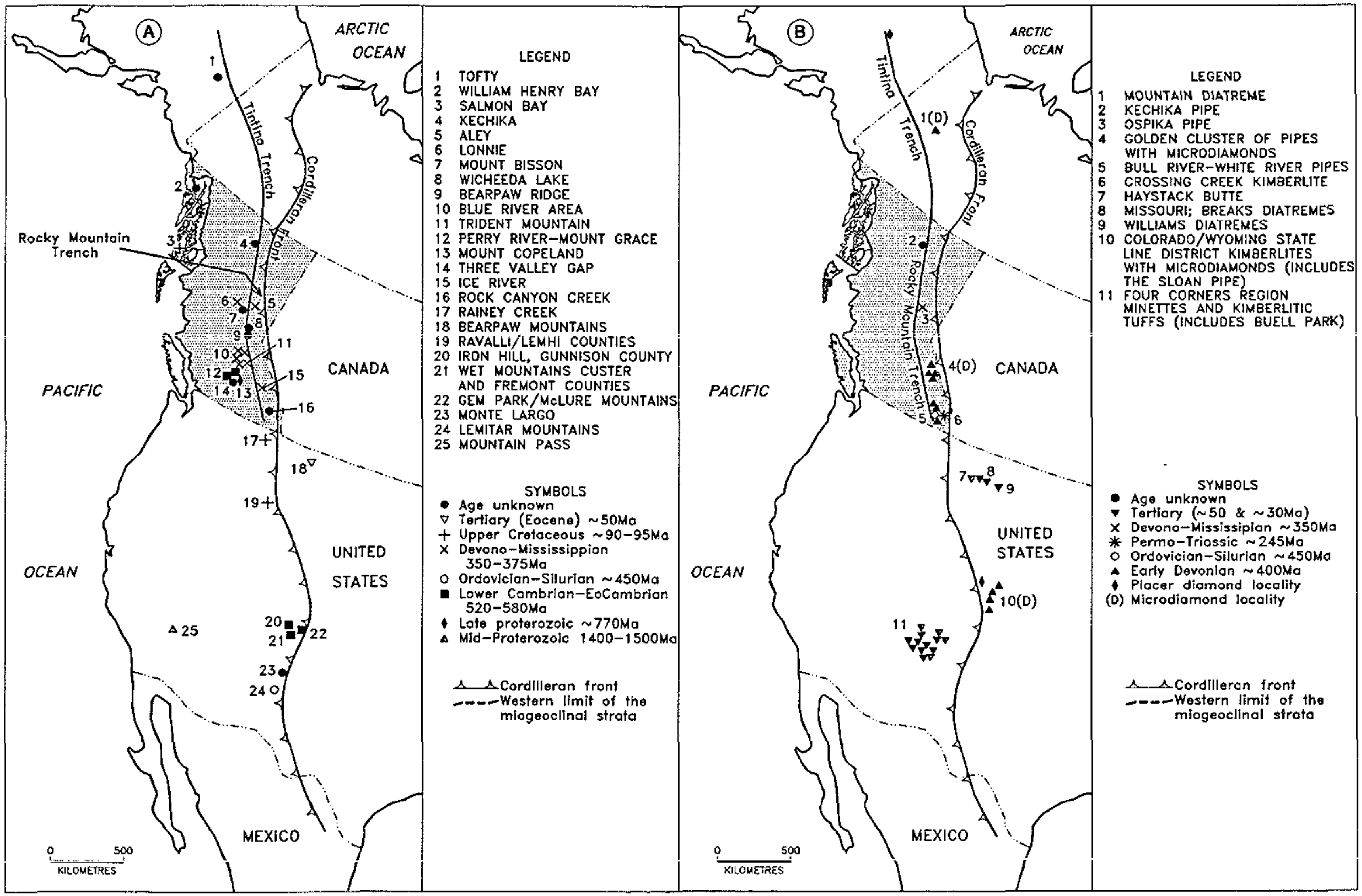

Figure 87. (A) Carbonatites and related rocks in western North America; (B) Diamonds and diatremes in western North America.

transported eastwards in thrust sheets. Their present distribution near the Rocky Mountain Trench is due to original location along a rifted continental margin, not to later tectonics. No syn or postorogenic carbonatites or alkaline ultramafic diatremes have been discovered in the Canadian Cordillera, however, young calcalkaline lamprophyres, strongly alkaline basalts and miaskitic syenite complexes such as Kruger Mountain, Copper Mountain and the Coryell intrusions are present.

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APPENDICES

APPENDIX 1
RARE EARTH ELEMENT ANALYSES FROM SOME CARBONATITE SUITES

Sample No.	Rock Type	La	Ce	Pr	Nd	Sm	Eu	Tb	Dy	Ho	Tm	Yb	Lu	Gd	Sc	Y
Kechika River Area - RAR Claims (selected samples)																
K1267	Syenite with fluorite veining	1550	3050	260	1220	209	47	9	34	5	6.3	15.8	0.9	-	4.35	350
K1268	Calcareous mylonite with fluorite	> 2000	3300	< 200	862	53.6	16	5	24	< 2	22.2	39	< 0.6	-	5.52	200
K1269	Fluorite veining	1040	1180	< 91	260	24.4	8	3	17	< 1	2.6	9	0.7	-	12.80	100
K1270	Quartz-fluorite vein	> 2000	7990	< 530	1800	149	56	15	53	< 3	18.8	44.1	1.5	2300	7.39	550
K1651	Fenitized sedimentary carbonatite	> 2000	2870	< 170	504	55.1	19	5	22	< 1	4.7	18.2	0.9	-	8.13	110
K1656	Fenitized sedimentary carbonate	39.2	130	< 50	140	38.1	16	25	219	36	20.2	118	12.0	310	4.60	1600
K1658	Fenitized sedimentary cabonate	406	508	< 54	166	36.9	11	3	13	< 1	1.6	4.1	0.4	-	3.74	50
K1660	Apatite - quartz- muscovite - carbonate rock (altered mylonite?)	142	427	< 52	402	331	138	114	755	76	39	142	11.4	-	6.32	3800
K1661	Apatite - quartz- muscovite - carbonate rock (altered mylonite?)	100	364	< 55	319	313	122	119	744	94	41.6	168	14.6	1100	3.38	4400
K1666	Crystal and lapilli tuffisitic breccia	33.7	96	< 50	90	38.9	16	14	110	17	7.6	49.7	6.1	-	7.99	755
K1667	Fluorite in quartz-carbonate mylonite	289	405	< 50	128	19.7	6	1	7	<1	1	3.2	0.3	-	4.32	34
K1673	Mafic syenite dike	450	738	< 80	248	23.9	6	1	15	<1	4.3	8	0.4	-	15.30	94
K1676	Mafic syenite dike	133	167	< 89	46	5.9	1	<1	3	<1	< 0.6	3.1	0.4	-	3.89	41
K1688	Quartz-carbonate mylonite	1820	4310	360	2540	509	125	40	149	< 3	26.2	30.4	< 0.6	-	2.45	495
K1733	Dolomite-quartz-muscovite mylonite	626	835	< 88	204	20.8	5	2	6	< 1	< 0.7	4.1	0.2	-	11.70	27
K1738	Carbonate-fluorite vein in syenite?	> 2000	3340	< 240	761	111	31	5	27	< 2	6.3	17	< 0.3	-	9.42	89
K1739	Fragmental tuffisitic breccia?	431	577	< 75	201	56.5	19	8	59	4	4.8	21.3	2.2	-	13.90	365
K1750	?Apatite-quartz-carbonate mylonite	196	616	< 98	557	505	206	189	1240	100	59.9	244	21.3	-	12.90	7100
Aley Carbonatite Complex																
AL5-12A	REE-enriched carbonatite dike	> 2000	12100	< 670	2940	139	31	3	15	< 3	3.7	11.6	0.5	-	2.61	65
AL5-12B	REE-enriched carbonatite dike	> 2000	12500	< 770	3260	190	46	3.5	9	< 4	4.5	10	< 0.2	-	2.63	26
AL5-12C	REE-enriched carbonatite dike	> 2000	4000	< 370	1080	65.4	17	1.3	7	< 2	1.7	3.5	< 0.1	-	1.67	8
AL5-12D	alkaline amphibolite (fenite?)	1020	2070	260	941	137	86	6.7	51	10	4.5	20.9	2.6	-	5.63	227
Wicheeda Lake Area - Prince and George Group Claims																
W10732	*calcite carbonatite with aegirine and biotite*	*1290*	*1750*	*107*	*505*	*59.1*	*18.4*	*6.1*	-	*1.5*	*< 0.5*	*9.9*	*1.4*	*16*	-	*34*
W10733	calcite carbonatite with aegirine and biotite	858	1220	168	256	30.5	9.3	1.5	-	4	1	3.7	0.5	36	-	91
W10734	calcite carbonatite with aegirine and biotite	1540	1970	202	480	51.3	15.9	3.5	-	2.5	0.5	4.1	0.5	26	-	54
W10735	calcite carbonatite with aegirine and biotite	712	976	105	263	40.1	10.5	2.3	-	2	0.5	4.2	0.6	20	-	50
W10736	calcite carbonatite with aegirine and biotite	964	1750	133	357	48.2	16	5.5	-	3	1	5.5	1.1	28	-	60
W10737	calcite carbonatite with aegirine and biotite	1090	1530	151	390	57.2	17.8	5.6	-	3.5	1	6.4	1.0	31	-	85
W10738	melanotype microsyenite (composite sample)	64	218	14	39	7.1	1.4	0.4	-	< 0.5	< 0.5	0.8	< 0.1	3	-	7
W10739	Syenite	4980	5090	700	1140	169	75.5	16.8	-	3.5	< 0.5	6.3	0.8	126	-	59
W10740	calcitecarbonatite with accessory feldspar, pyrite and apatite	157	382	27	89	13.3	2.3	0.7	-	< 0.5	< 0.5	1.2	< 0.1	6	-	12
W10741	calcitecarbonatite with accessory feldspar, pyrite and apatite	371	516	48	117	14.8	4.5	1.1	-	1	< 0.5	2.2	0.31	9	-	24
W10742	calcitecarbonatite with accessory feldspar, pyrite and apatite	241	342	30	83	14.6	4.9	1.0	-	1	< 0.5	2.1	0.52	9	-	21
W10743	calcitecarbonatite with accessory feldspar, pyrite and apatite	344	478	43	119	27.4	10.5	3.7	-	2	0.5	4.8	0.95	22	-	48
W10744	calcitecarbonatite with accessory feldspar, pyrite and apatite	65	115	10	32	11	3.9	1.7	-	1	0.5	5.5	1.2	8	-	24
Rock Canyon Creek																
R85DP-1A	brown altered carbonate with fluorite	9800	10000	-	3000	300	76	-	-	-	-	11.0	1.4	-	57	190
R85DP-1B	brown altered carbonate with fluorite	3900	5100	-	1200	140	34	-	-	-	-	8.2	1.3	-	56	120
R85DP-2A	carbonate breccia with pyrite & fluorite	1600	3800	-	2000	240	60	-	-	-	-	7.6	1.4	-	60	190
R85DP-2B	carbonate breccia with pyrite & fluorite	1900	4600	-	2500	260	68	-	-	-	-	7.5	0.9	-	40	180
R85DP-3	altered carbonate with fluorite	2900	5000	-	2000	240	55	-	-	-	-	9.0	1.04	-	58	210
R85DP-6	massive dark purple fluorite	102	163	-	61	173	4.3	-	-	-	-	1.7	0.2	-	3.8	40
R85DP-8	altered carbonate with fluorite	3500	4900	-	1500	273	78	-	-	-	-	5.5	0.62	-	00	130
Manson Creek Area - Lonnie and Vergil Calims																
L4-179C	aegirine sovite	347	600	29	179	29.7	7.1	2.9	15.5	4.8	1.6	7.7	1.0	-	0.50	62
L4-242B	biotite sovite	401	741	57	245	39.5	9.1	3.2	16.7	5.3	1.5	6.2	0.74	-	0.61	69
L4-184	biotite sovite	371	673	46	206	31.0	8.4	3.0	13.0	3.0	1.1	5.2	0.62	-	0.15	54
L4174B	fenite	87.6	172	< 49	56	8.4	2	0.9	3.1	1.8	0.6	2.1	0.38	-	12.60	16
L4-197B	syenite	135	286	< 35	102	17.0	4.5	1.7	7.6	5.6	1.2	3.78	0.55	-	0.27	46
L4-240B	syenite	43.2	107	< 38	35.2	4.9	1.8	0.6	3.6	7.8	0.7	3.46	0.77	-	0.43	78
Blue River Area - Verity, Mud Lake, Paradise Lake and Howard Creek Areas																
HA-260	sovite - Howard Creek	254	548	35	234	49.2	11.7	3.9	19.5	6.1	1.1	4.18	0.44	-	3.30	68
HA-297A	sovite - Howard Creek	241	530	< 59	233	46.0	11.1	3.8	16.7	6.1	1.1	4.10	0.55	-	6.80	67
V4-120	rauhaugite - Verity	171	371	45	147	22.7	5.7	1.7	6.1	1.4	2.3	1.40	0.21	-	20.30	15
V4-BEF	rauhaugite - Verity	134	279	25	119	17.7	4.5	1.6	4.9	1.4	3.5	1.00	0.13	-	13.70	9
V4-740	rauhaugite - Mud Lake	103	208	< 16	81	14.8	3.7	1.5	7.3	1.0	0.7	1.77	0.17	-	19.30	25
V4-31A	rauhaugite - Mud Lake	200	415	< 24	165	25.6	6.8	1.6	8.2	4.7	2.2	2.00	0.41	-	34.80	22
V4-62B	rauhaugite - Mud Lake	174	339	30	133	22.5	5.1	2.0	6.6	1.5	1.3	1.40	0.22	-	34.70	16
P4-323H	syenite - Paradise Lake	0.9	3.9	< 44	1.9	< 0.2	0.1	< 0.2	< 0.6	< 0.3	0.2	0.60	0.11	-	0.14	14
P4-345FL	calcareous segregation in syenite	355	561	< 41	144	18.1	4.4	1.6	7.9	1.2	1.1	3.22	0.4	-	2.97	34
H4-273A	meta-ijolite - Howard Creek	284	664	63	273	48.3	13.0	5.0	26.6	4.95	2.3	6.70	0.84	-	19.10	110
H4-273B	meta-ijolite - Howard Creek	197	363	< 56	119	19.4	5.0	2.0	9.6	1.1	1.0	3.39	0.34	-	1.40	46
V4-67A	basic sill - Mud Lake	162	302	< 16	114	20.3	4.8	1.4	7.4	1.99	1.1	2.54	0.32	-	22.20	36
Three Valley Gap Carbonatites																
3VG-136A	biotite sovite	212	401	< 24	151	25.9	6.30	2.4	11.4	0.80	2.22	4.35	0.52	-	1.10	51
3VG-135A	*biotite sovite*	*206*	*396*	*45*	*140*	*25.2*	*6.18*	*2.4*	*10.2*	*3.46*	*0.90*	*4.21*	*0.48*	-	*0.65*	*47*
3VG-137	carbonatite contact	131	275	< 25	111	20.9	3.99	1.9	8.0	2.39	0.78	2.75	0.32	-	1.73	37
Carbonatites, West Flank, Frenchman Cap																
H85P1-5	intrusive carbonatite	1470	2010	290	654	73.8	18	5.4	41	9	3.4	17.4	1.7	-	8.45	160
H85P1-8	intrusive carbonatite	704	927	< 99	271	35.6	9	2.4	18	5	2.0	10.0	1.3	-	0.12	80
H85P1-3B	intrusive carbonatite	> 2000	7630	< 550	3540	313.0	83	11.0	55	< 3	6.7	7.4	0.5	-	0.58	120
H85P4-3C	Mount Grace Carbonatite	317	614	< 71	279	41.4	11	1.6	13	8	1.2	2.9	0.2	-	0.12	34
H85P3-2E	Mount Grace Carbonatite	93.9	155	< 64	65	8.2	2	0.8	4	< 1	< 0.5	1.6	0.3	-	7.42	-
H85P3-3	Mount Grace Carbonatite	957	1430	< 130	469	56.0	13	3.3	20	5	1.6	6.6	0.7	-	3.78	-
H85P7	Mount Grace Carbonatite	736	1170	< 120	380	33.2	8	1.4	8	2	1.0	3.4	0.2	-	7.19	-
H85P9	Mount Grace Carbonatite	722	1190	170	424	42.7	12	2.2	15	3	1.6	4.9	0.5	-	6.89	-
H85P10	Mount Grace Carbonatite	505	875	110	345	43.6	12	2.3	15	4	1.9	4.9	0.5	-	6.70	-
H85P11	Mount Grace Carbonatite	937	1410	< 130	433	38.2	9	1.5	10	2	1.0	3.3	0.4	-	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	-	5.37	-
MG5-8	Mount Grace Carbonatite	131	235	< 68	88	14.6	4	1.4	11	2	0.7	3.3	0.4	-	4.42	-
H85P26A	Mount Grace Carbonatite	400	670	110	247	34.4	8	2.4	17	8	1.5	8.7	1.0	-	2.35	-
H85P26B	Mount Grace Carbonatite	362	605	< 96	224	28.6	7	1.8	14	5	1.8	6.1	0.9	-	2.17	-
H85P26D	Mount Grace Carbonatite	479	611	< 100	149	13.4	4	0.8	7	< 1	0.5	2.6	0.3	-	4.67	-
H85P26E	Mount Grace Carbonatite	151	289	< 60	123	15.1	5	0.8	7	1	0.7	1.6	0.1	-	2.14	-
H85P26F	Mount Grace Carbonatite	310	512	< 89	188	23.2	6	1.3	9	2	0.6	2.5	0.3	-	5.51	-
H85P29	Mount Grace Carbonatite	242	398	< 100	139	17.8	5	1.1	11	1	0.8	4.1	0.5	-	5.22	-

All analysis by neutron activation (INAA), listed in ppm, Xby XRF.
Rock Canyon Creek data from Graf (1985); Frenchman Cap data from Hoy and Pell (1986); Kechika River data from Fox, 1987; Wicheeda Lake data from Betmanis, 1987.
Analyses, with the exception of those from Graf (1985) and Betmanis (1987) performed by Bondar-Clegg.

Blank

APPENDIX 2A
U-Pb ZIRCON DATA, BRITISH COLUMBIA CARBONATITES AND NEPHELINE SYENITES

Analysis No. Size[1]	wt.* (mg)	U ppm	Pb[2] ppm	$^{206}Pb/^{204}Pb$ [3]	Pbc[4] (pg)	^{206}Pb[2] (%)	$^{206}Pb/^{238}U$ ±1SEM%[5]	$^{207}Pb/^{235}U$ ±1SEM%[5]	$^{207}Pb/^{206}Pb$ ±1SEM%[5]	$^{207}Pb/^{206}Pb$	age, error[6] (Ma)
Trident Mountain nepheline syenite, PCA-307-83 NSY											
1.+149ceu	1.674	45.34	5.39	2999	75	64.0	0.4698 (.06)	0.3454 (.10)	0.5332 (.06)	342.6	(1.2)
2.+149cdeu	2.295	124.6	13.56	1224	496	72.2	0.03327 (.08)	0.2373 (.18)	0.05172 (.13)	273.2	(2.9)
Paradise Lake nepheline syenite, P4-323											
3.+149ceu	1.988	40.98	8.035	2458	11.4	74.7	0.05440 (.18)	0.4036 (.21)	0.05382 (.10)	363.3	(2.2)
4.+149cup	1.872	92.84	15.47	6702	89	70.4	0.05421 (.18)	0.4000 (.19)	0.05352 (.05)	350.7	(1.2)
Lonnie carbonatite, L4-191											
5.+149ceui	1.673	44.28	4.488	461	484	58.7	0.04599 (.20)	0.3416 (.41)	0.05386 (.36)	365.2	(8.2)
Vergil carbonatite, L4-241											
6.+149cf	2.714	75.36	7.676	2969	236	51.7	0.05414 (.18)	0.3996 (2.0)	0.05354 (.07)	351.6	(1.6)

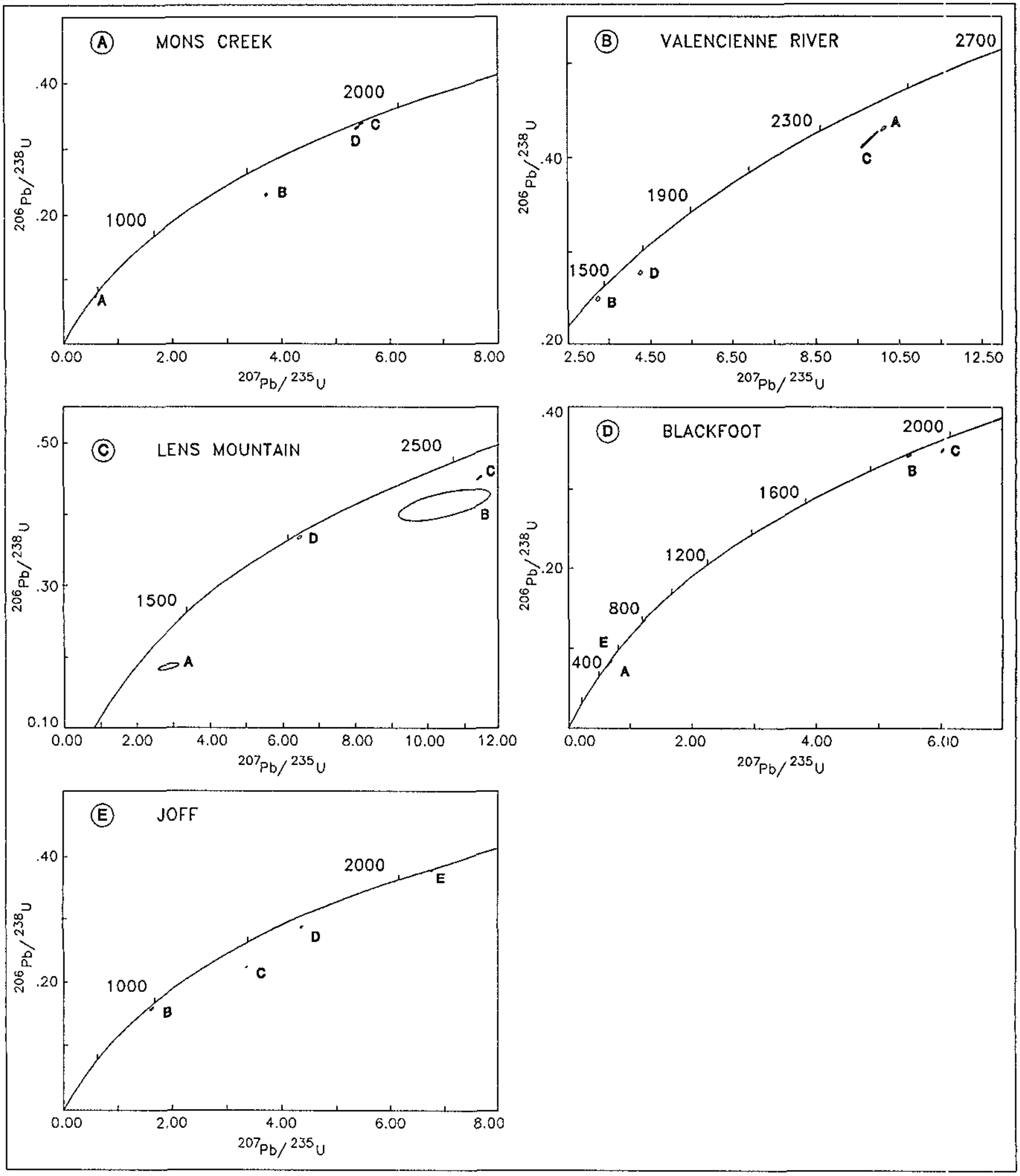
Notes:
[1] sizes (i.e., +1495) refer to length aspect of zircons in microns, e=equant, cd=somewhat cloudy, c=clear, u=euhedral, p=pink, i=contains inclusions, f=fragments and shards;
[2] radiogenic Pb;
[3] measured ratio, corrected for spike and fractionation;
[4] total common Pb in analysis corrected for fractionation and spike;
[5] corrected for blank Pb an U, common Pb, errors quoted are 1 standard error of the mean in percent;
[6] corrected for blank and common Pb, errors are 1 standard error of the mean in Ma;
**weighing error 0.002 mg.*

APPENDIX 2B
URANIUM-LEAD ANALYTICAL DATA, B.C. DIATREMES

Mineral Fraction (zircon)	wt. (mg)	U, ppm	Pb*1 ppm	$\frac{^{206}\text{Pb}}{^{204}\text{Pb}}$ measured	Total common Pb (pg)	% ^{208}Pb*	S-K Common Pb age used	Corr. coeff	$\frac{^{206}\text{Pb}}{^{238}\text{U}}$	$\frac{^{206}\text{Pb}}{^{238}\text{U}}$ % error	$\frac{^{206}\text{Pb}^{1}}{^{238}\text{U}}$ age	$\frac{^{207}\text{Pb}^{1}}{^{235}\text{U}}$	$\frac{^{207}\text{Pb}}{^{235}\text{U}}$ % error	$\frac{^{207}\text{Pb}^{1}}{^{235}\text{U}}$ age	$\frac{^{207}\text{Pb}^{1}}{^{206}\text{Pb}}$	$\frac{^{207}\text{Pb}}{^{206}\text{Pb}}$ % error	$\frac{^{207}\text{Pb}^{1}}{^{206}\text{Pb}}$ age	$^{207/206}$Pb age error
Mons Creek																		
A euh, clear 306.9	0.007	72.92	5.44	500.7	5.3	7.64	500	0.69	0.0758	0.44	471.2	0.5899	0.52	470.8	0.0564	0.39	469.2	+16.9 -17.1
B frosted, rnd 306.10	0.011	213.05	51.34	3855	8.9	7.43	1950	0.93	0.2322	0.09	1346.1	3.7378	0.10	1579.5	0.1167	0.04	1906.9	±1.9
C frosted prism 306.11	0.004	1016.6	394.70	13480	6.4	15.79	1910	0.99	0.3401	0.17	1887.3	5.4794	0.18	1897.4	0.1168	0.03	1908.3	±1.6
D colorless, rnd abr 312.6	0.016	103.23	44.6	2356	14.9	25.17	2000	0.96	0.3358	0.15	1866.6	5.44	0.16	1890.6	0.1174	0.05	1917.0	+1.7 -1.6
Valencienne River																		
A colorless rnd 291.17	0.131	76.84	41.11	22910	11.8	18.73	2700	0.96	0.4313	0.115	2311.6	10.1505	0.132	2448.6	0.1707	0.038	2564.4	±1.3
B rnd, pink 291.18	0.067	75.51	23.66	6664	11.9	24.92	1600	0.93	0.2495	0.094	1435.9	3.2601	0.114	1471.6	0.0948	0.044	1523.5	+1.7 -1.6
C pink, prism 306.2	0.009	209.18	97.15	5751	8.7	8.68	2600	0.998	0.4216	0.662	2267.8	9.8307	0.665	2419.0	0.1691	0.041	2548.8	±1.4
D clr, rnd 306.3	0.010	56.17	17.99	581.3	17.6	17.03	1850	0.76	0.2776	0.147	1579.3	4.2746	0.221	1688.5	0.1117	0.146	1826.9	±5.3
Lens Mountain																		
A clr, prism 306.6	0.004	72.015	17.51	59.75	80	26.85	1800 Ma	0.717003	0.186009	±1.021	1099.7	2.808292	4.793	1357.8	0.109498	4.073	1791.1	+141.4 -156.3
B clr, rnd 306.7	0.008	67.691	39.74	28.98	931	28.04	2700 Ma	0.65	0.414069	±2.692	2233.5	10.4799	5.997	2478.1	0.183562	4.713	2685.3	+147.9 -165.0
C rnd, pink 306.8	0.006	159.8	90.63	1246	22	18.76	2700	0.96	0.451944	0.179	2403.9	11.4326	0.192	2559.1	0.183467	0.056	2684.5	+1.8 -1.9
D clr, abr 312.5	0.008	65.2	26.89	1471	8.4	13.44	2100	0.89	0.368040	0.125	2020.2	6.4303	0.134	2036.4	0.126718	0.060	2052.9	±2.1
Blackfoot																		
A pink, euh 291-14	0.061	100.17	9.50	1877	17.1	20.83	550	0.92	0.0824	0.118	510.4	0.6595	0.145	514.3	0.0581	0.058	531.9	±2.5
B pink, rnd 291-15	0.019	559.08	221.9	15080	15.1	17.41	2100	0.95	0.3408	0.096	1890.4	5.5191	0.116	1903.6	0.1175	0.038	1918.0	±1.4
C rnd, colorless 291-16	0.055	119.12	49.1	11500	12.4	18.35	2100	0.95	0.3470	0.095	1920.0	6.0582	0.115	1984.3	0.1266	0.038	2051.8	±1.3
E clr, euh, abr 312:1	0.068	100.26	9.86	2716	13.5	21.12	550	0.89	0.0851	0.088	526.5	0.6804	0.121	527.0	0.0580	0.058	529.0	±2.5
Joff																		
B colorless, ellipse 306.5	0.010	49.24	10.60	651	8.0	31.45	1050	0.95	0.1593	0.58	953.3	1.6294	0.576	981.6	0.0742	0.17	1045.6	+6.9 -7.0
C colorless prism 312.2	0.005	454.57	106.70	4944	6.4	8.94	1800	0.94	0.2242	0.10	1304.0	3.3624	0.111	1495.7	0.1088	0.04	1779.0	±1.3
D colorless, abr 312.3	0.011	285.71	82.50	7485	7.5	5.47	1900	0.96	0.2857	0.09	1619.8	4.3825	0.101	1709.1	0.1113	0.03	1820.3	±1.1
E colorless, abr 312.4	0.020	240.42	107	12870	8.9	16.88	2100	0.95	0.3806	0.08	2078.9	6.7729	0.096	2082.2	0.1291	0.03	2085.5	+1.1

Notes: *numbers refer to sizes of mineral fractions expressed in microns*
abr = abraded
rnd = rounded
clr = clear
euh = euhedral
1 = is corrected for blank and common Pb

APPENDIX 2B *(continued)*



APPENDIX 2C
SUMMARY OF Rb/Sr ANALYTICAL DATA, B.C. DIATREMES

Lab Number	Mineral	Sample Name	ppm Sr	ppm Rb	87Rb/86Sr	87Sr/86Sr	Age	Assumed Initial Ratio
Ospika Pipe								
33008	phlogophite	AL 6-4	103.0±0.3	432.4±2.7	12.22±0.08	0.7646±1	351±2 Ma	0.7036
30239	phlogophite	AL 5-20	134.9±0.4	407.5±2.3	8.7±0.08	0.7471±1	351±3 Ma	0.7036
30238	phlogophite	AL 5-16	166.8±0.5	387.7±2.2	6.75±0.04	0.7361±1	338±3 Ma	0.7036
HP Pipe								
30240	phlogophite	HP - 5	159.9±0.5	429.4±2.4	8.01±0.06	0.749±1	391±5 Ma	0.7040
Bush River (Larry)								
32961	phlogophite	LA 6-196	156.1±0.5	475.9±5.6	8.86±0.11	0.7556±1	409±6 Ma	0.7040

APPENDIX 2D
SUMMARY OF K-Ar ANALYTICAL DATA, B.C. DIATREMES

HP Pipe
Sample Number(s)
HP-5
Analytical Data: (list duplicate analyses or indicate n=2, n=3, etc.)

$K=\bar{X}=8.20\pm0.01$ % ;(Ar^{40*} = 139.297×10^{-6} cc/gm) ;(94.6 $\%\Sigma Ar^{40*}$)
K_2O= n=2 % 62.159×10^{-10} mol/gm)

material	date	1σ error
(Biotite)	391	±12 Ma

$K=\bar{X}=8.20\pm0.01$ % ;(Ar^{40*} = 139.297×10^{-6} cc/gm) ;(94.6 $\%\Sigma Ar^{40*}$)
K_2O= n=2 % 62.159×10^{-10} mol/gm)

material	date	1σ error
(Biotite)	391	±12 Ma

Ospika Pipe
Sample Number(s)
AL-5-16
Analytical Data: (list duplicate analyses or indicate n=2, n=3, etc.)

$K=\bar{X}=7.20\pm0.08$ % ;(Ar^{40*} = 108.496×10^{-6} cc/gm) ;(95.8 $\%\Sigma Ar^{40*}$)
K_2O= n=3 % 48.414×10^{-10} mol/gm)

material	date	1σ error
(Biotite)	323	±10 Ma

decay constants
4.96/.581/1.167

Plate 3. Chocolate brown-weathering, REE-enriched dikes in carbonate host rocks, Aley complex.

Plate 12. Typical trachyte, Kechika area, note feldspar phenocryst in a matrix predominantly consisting of felted feldspar laths with minor disseminated carbonate and opaques.

Plate 14. Blue pleochroic amphibole (magnesio-arfvedsonite) and finer grained aegirine (light green) in ultrafenite, Lonnie area. Long dimension of photomicrograph is 2.5 millimetres.

Note: Colour plates are produced by colour photocopying technology.

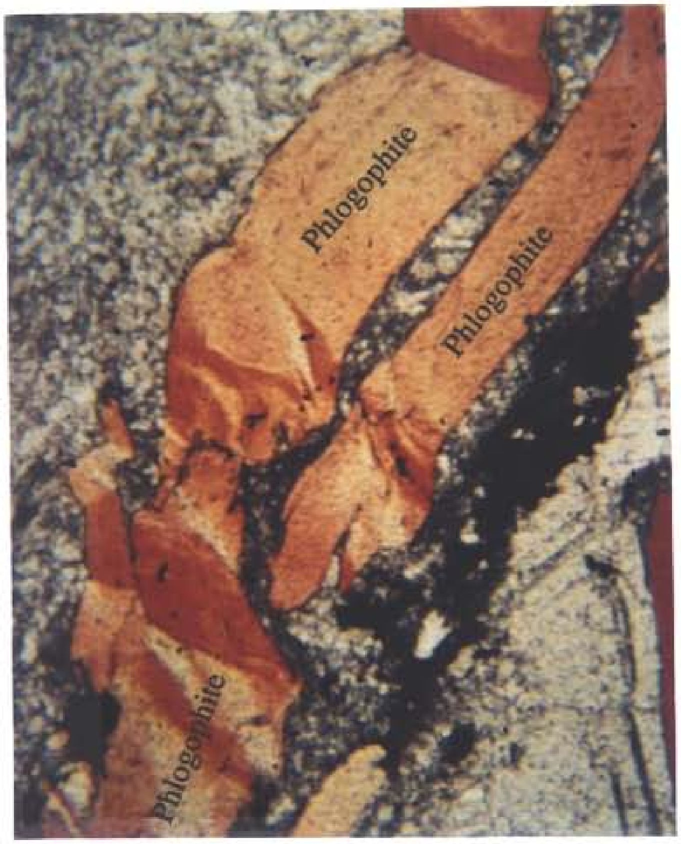


Plate 16. Phlogopite in carbonatite with reverse pleochroism and distinctive orange colour, from Verity. Long dimension of photomicrograph is 2.5 millimetres.

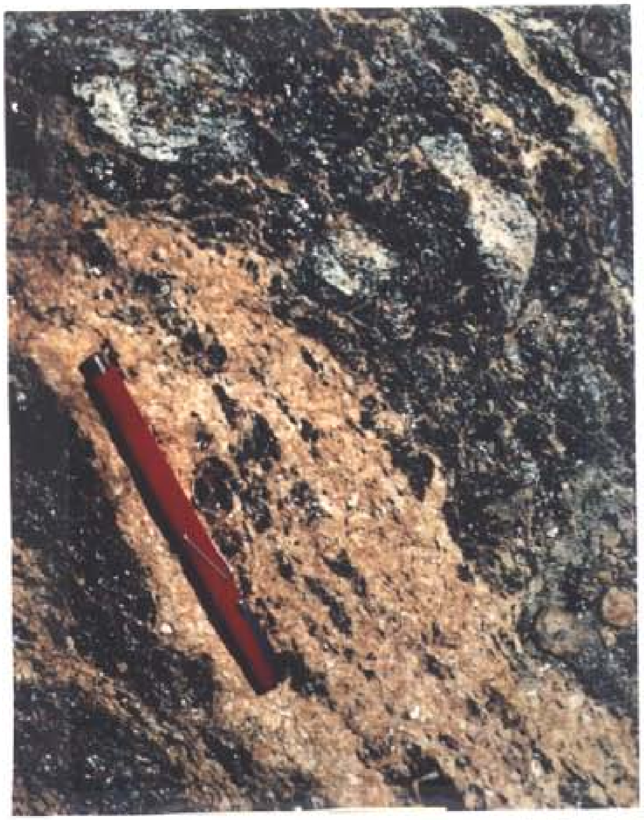


Plate 27. Ratchford Creek (REN) carbonatite (buff colour) interlayered with amphibolitic fenite (dark green) and containing fenitized country rock fragments (grey).

Plate 33. Dark green weathering breccia, Bush River area. Clasts are smaller and less abundant than in rusty mega breccia.

Plate 49. Epiclastic crater-infill breccia, Joff pipe, immediately overlain by well-bedded, pink and buff-weathering strata of the basal Devonian Unit.

Note: Colour plates are produced by colour photocopying technology.