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 Osrika 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 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 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. The diatreme in the Kechika River area is the only one documented west of the Rocky Mountain Trench. 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; buck-brush 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 hostrock 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>
<thead>
<tr>
<th>Table 13 Geochemistry of Selected Diatreme Breccias and Related Dikes and Tuffs, Kechika Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>wt %</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>SiO2</td>
</tr>
<tr>
<td>TiO2</td>
</tr>
<tr>
<td>Al2O3</td>
</tr>
<tr>
<td>Fe2O3</td>
</tr>
<tr>
<td>MnO</td>
</tr>
<tr>
<td>MgO</td>
</tr>
<tr>
<td>CaO</td>
</tr>
<tr>
<td>Na2O</td>
</tr>
<tr>
<td>K2O</td>
</tr>
<tr>
<td>LOI</td>
</tr>
<tr>
<td>ZrO5</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

Ni | 600 | 514 | 210 | 270 | 689 | 711 | 78 | 162 |
Cr | 1100 | 1108 | 510 | 720 | - | - | 328 | 641 |
Co | - | 82 | - | 269 | 27 | 56 |
Rb | 390 | 95 | 230 | 320 | 314 | 103 | 127 |
Sr | 295 | 212 | 790 | 610 | 708 | 499 | 840 |
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 | <5 | <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 |
P | 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

\[ A \]
\[ B \]
\[ C \]

**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 Wederhi1 and Maramatsu, 1979. Ni vs Cr plot, Kechika diatreme, 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 K2O-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.
(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**

<table>
<thead>
<tr>
<th>wt %</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<tr>
<td>SiO₂</td>
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<td>24.18</td>
<td>32.09</td>
<td>30.59</td>
<td>26.66</td>
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<td>TiO₂</td>
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<td>2.15</td>
<td>2.76</td>
<td>1.67</td>
<td>2.25</td>
<td>2.58</td>
<td>0.38</td>
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<tr>
<td>Al₂O₃</td>
<td>5.43</td>
<td>4.77</td>
<td>6.25</td>
<td>5.01</td>
<td>5.19</td>
<td>5.61</td>
<td>0.25</td>
</tr>
<tr>
<td>Fe₂O₃T</td>
<td>9.47</td>
<td>7.94</td>
<td>9.25</td>
<td>9.56</td>
<td>7.61</td>
<td>8.67</td>
<td>5.21</td>
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<tr>
<td>Mn</td>
<td>0.20</td>
<td>0.19</td>
<td>0.17</td>
<td>0.22</td>
<td>0.16</td>
<td>0.17</td>
<td>0.55</td>
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<tr>
<td>MgO</td>
<td>12.72</td>
<td>10.04</td>
<td>14.65</td>
<td>10.62</td>
<td>12.47</td>
<td>14.07</td>
<td>14.69</td>
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<tr>
<td>CaO</td>
<td>15.63</td>
<td>17.26</td>
<td>13.40</td>
<td>17.20</td>
<td>17.52</td>
<td>14.84</td>
<td>27.53</td>
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<tr>
<td>Na₂O</td>
<td>0.01</td>
<td>1.23</td>
<td>0.95</td>
<td>2.29</td>
<td>1.55</td>
<td>1.82</td>
<td>0.00</td>
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<tr>
<td>K₂O</td>
<td>1.43</td>
<td>4.01</td>
<td>5.55</td>
<td>3.80</td>
<td>4.01</td>
<td>4.02</td>
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<td>LOI</td>
<td>21.51</td>
<td>24.79</td>
<td>10.83</td>
<td>14.32</td>
<td>18.07</td>
<td>17.85</td>
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<tr>
<td>P₂O₅</td>
<td>1.12</td>
<td>0.84</td>
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<td>1.80</td>
<td>0.99</td>
<td>0.95</td>
<td>0.09</td>
</tr>
<tr>
<td>S</td>
<td>0.08</td>
<td>0.28</td>
<td>0.12</td>
<td>0.16</td>
<td>0.01</td>
<td>0.80</td>
<td>0.41</td>
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<tr>
<td>Total ppm</td>
<td>98.25</td>
<td>97.67</td>
<td>96.93</td>
<td>97.25</td>
<td>97.50</td>
<td>99.26</td>
<td>91.81</td>
</tr>
</tbody>
</table>

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 weatherting finte-grained phlogopite-clinopyroxene-rich clast-poor breccia phase, Ospika pipe;
3. - AL6-3mt: massive phase, Ospika pipe, inclusion-poor;
4. - AL6-3P: clast-rich breccia phase, Ospika pipe;
5. - AL6-8l: accumulation lapilli breccia phase;
6. - AL6 2B3: mica-rich breccia phase;
7. - AL6-01: carbonate dite 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.
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 sub-rounded 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.

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 fine 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 melilitite.

**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 K2O-MgO discriminant diagram (Figure 61a) analyses group in an area which is overlapped by the leucite, olivine melilitite and alkaline lamprophyre fields. It should be noted, however, that on this diagram, alnoites from Alno fall
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-Al₂O₃-Fe₂O₃ 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 35. Altered mica macrocryst 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 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, quartz xenocrysts, and 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 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 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>calcite>quartz>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 magnetic 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).

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 porphyritic with altered macrocrysts, phenocrysts and glomerocrysts of olivine, pyroxene (Plate 33) 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 ophites (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-karsantites, 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)**

At both Lens Mountain (latitude 51°54'30"N, longitude 117°07'30"W) and Mons Creek (latitude 51°49'00"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).
'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 sodalite. 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 sphenic. 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 porphyritic 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...
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 (An25) 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 (Ijewiwi and Schulze, 1989). The unaltered dike material contains 5% primary phenocrystic clinopyroxene, commonly augite or diopside 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 (An25) 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 (Ijewiwi 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. Serpentinitized 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
cleavage are strongly boudinaged (Plate 42). Some of the dikes are porphyritic and all are altered. The phenocrypt assemblage, so far as can be recognized, consists of sieve-textured olivine pseudomorphs, altered euhedral clinopyroxene with relic 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.

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>
<thead>
<tr>
<th>Breccia Phase</th>
<th>Xenolith characteristics</th>
<th>Site</th>
<th>Percent</th>
<th>Megacryst characteristics</th>
<th>Size</th>
<th>Percent</th>
<th>Other comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>subangular to subrounded marmorealized limestones - 80%</td>
<td>range 0.5-5.0 cm</td>
<td>50%</td>
<td>saline 70%</td>
<td>0.2 - 8.0</td>
<td>5 - 6%</td>
<td>megacrysts and cognate xenoliths</td>
</tr>
<tr>
<td></td>
<td>rounded cognate xenoliths - 5-10%</td>
<td>modally 3.5 cm</td>
<td>50%</td>
<td>biotite 25-25%</td>
<td>0.4 - 3.0</td>
<td></td>
<td>often conical structures; abundant pyrite, minor oxides.</td>
</tr>
<tr>
<td>B2</td>
<td>subangular, marmorealized limestones - 70%</td>
<td>range 0.5-20 cm</td>
<td>50%</td>
<td>saline 25%</td>
<td>0.2 - 2.0</td>
<td>4 - 5%</td>
<td>saline megacrysts core-xenolithic structures; trace amounts of pyrite present.</td>
</tr>
<tr>
<td></td>
<td>rounded to angular xenoliths - 20-25%</td>
<td>modally 3.5 cm</td>
<td>50%</td>
<td>diopside 5-10%</td>
<td>0.5 - 2.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>quartz, glimmerite, granite or gneiss, shale</td>
<td></td>
<td>50%</td>
<td>biotite trace</td>
<td>0.2 - 1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B3</td>
<td>angular to subangular</td>
<td>range 0.03-1 cm</td>
<td>15%</td>
<td>saline 90%</td>
<td>0.2 - 2.0</td>
<td>5 - 6%</td>
<td>no obvious lapilli; veins with calcite and epidote.</td>
</tr>
<tr>
<td></td>
<td>cognate xenoliths, shale, chert, sandstone</td>
<td>modally 3.5 cm</td>
<td>15%</td>
<td>diopside 4-5%</td>
<td>1.0 - 1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B4</td>
<td>subrounded to subangular marmorealized limestones - 100%</td>
<td>range 0.5-15 cm</td>
<td>12 - 16%</td>
<td>saline 97%</td>
<td>0.2 - 2.0</td>
<td>2 - 5%</td>
<td>abundant (&gt;50%) spherical structure; no obvious fragments in core; abundant subhedral oxides, 1.2 mm size.</td>
</tr>
<tr>
<td>B5</td>
<td>marmorealized limestones - 75%</td>
<td>range 0.5-5.0 cm</td>
<td>25%</td>
<td>diopside 2%</td>
<td>0.2 - 1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>cognate xenoliths, chert, sandstone</td>
<td>modally 1-3 cm</td>
<td>25%</td>
<td>biotite 5%</td>
<td>0.1 - 4.0</td>
<td>4 - 5%</td>
<td>abundant (&gt;50%) spherical structures in 2.5 mm size range; some pelletal textures caused by megacrysts.</td>
</tr>
</tbody>
</table>
Plate 44. Sharp contact between breccia phases (B2 & 3), HP pipe.

Plate 45. Large gabbroic xenolith in a strongly foliated breccia (B1 phase), HP pipe.

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

Plate 47. Biotite macrocryst coring spherical structure, HP pipe. Long dimension of the photomicrograph is 7 mm.
### TABLE 16
CHEMICAL ANALYSES - GOLDEN AREA DIATREMES

<table>
<thead>
<tr>
<th>Wt %</th>
<th>HP</th>
<th>Bush River</th>
<th>Mons Creek</th>
<th>Valenciennes River</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>SiO2</td>
<td>36.12</td>
<td>33.04</td>
<td>37.16</td>
<td>35.01</td>
</tr>
<tr>
<td>TiO2</td>
<td>1.36</td>
<td>1.37</td>
<td>1.41</td>
<td>1.83</td>
</tr>
<tr>
<td>Al2O3</td>
<td>7.70</td>
<td>7.43</td>
<td>9.97</td>
<td>12.42</td>
</tr>
<tr>
<td>Fe2O3</td>
<td>8.11</td>
<td>7.66</td>
<td>8.28</td>
<td>6.51</td>
</tr>
<tr>
<td>MnO</td>
<td>0.14</td>
<td>0.13</td>
<td>0.18</td>
<td>0.06</td>
</tr>
<tr>
<td>MgO</td>
<td>13.21</td>
<td>11.79</td>
<td>8.67</td>
<td>5.18</td>
</tr>
<tr>
<td>Na2O</td>
<td>0.29</td>
<td>0.27</td>
<td>1.65</td>
<td>1.87</td>
</tr>
<tr>
<td>K20</td>
<td>4.47</td>
<td>4.18</td>
<td>4.13</td>
<td>1.01</td>
</tr>
<tr>
<td>LOI</td>
<td>6.44</td>
<td>10.70</td>
<td>7.27</td>
<td>16.29</td>
</tr>
<tr>
<td>P2O5</td>
<td>0.58</td>
<td>0.61</td>
<td>1.40</td>
<td>0.95</td>
</tr>
<tr>
<td>S</td>
<td>0.11</td>
<td>0.04</td>
<td>0.09</td>
<td>0.07</td>
</tr>
<tr>
<td>Total</td>
<td>98.45</td>
<td>97.54</td>
<td>97.63</td>
<td>98.95</td>
</tr>
</tbody>
</table>

All analyses by XRF, British Columbia Geological Survey Branch Analytical Laboratory
1. HP6 - 08 Macrocryst-rich dike, HP pipe;
2. HP6 - D8m Fine-grained, macrocryst-poor border phase of dike, HP pipe;
3. HP6 - D12 Fine-grained, microcrys 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 - 19F Red-weathering breccia containing abundant accretionary lapilli;
7. LA6 - 19G Biotite macrocyrst-rich dike, Larry claims, Bush River area;
8. MSZ - Titanolite-olivine-phlogopite dike, Mike claims, Mons Creek area;
9. MZS FLG Titanolite-olivine-phlogopite dike, Mike claims, Mons Creek area;
10. MKZ - 5C Olivine - clinopyroxene porphyry dike, olivine and clinopyroxene crystals completely pseudomorphed, Mark claims, Valenciennes River area;
11. MKZ - 5B Fine-grained dike, Mark claims, Valenciennes River area;
12. MKZ - 7A Fine-grained, foliated dike, Mark claims, Valenciennes River area;
13. MKZ - 1B Fine-grained, light green dike, Mark claims, Valenciennes River area;
14. MKZ - 5A 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 calcic biotite/colourless clinohumite (tremolite) schlorite. Serpentinite, 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 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 chromite diopside and biotite are the dominant megacrysts. The black clinopyroxenes are rich in titanium (up to 2.6%) and aluminium (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 aluminium, 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 TiO2 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 Schulze, 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 aillikite affinity. There also appears to be a significant metasomatic or metamorphic overprint introducing phases such as melanite/andradite and clinohumite.

**GEOCHEMISTRY OF DIATREMES AND RELATED DIKES**

Diatreme breccias and dikes in the Golden area are ultrabasic; silica values predominantly range from 50 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 aulonitic 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 approxi-
mately 400 Ma was obtained (Appendix 2). Close agree-
ment of potassium-argon and rubidium-strontium dates
suggests that the HP pipe was emplaced at approximately
400 Ma. Recent palaeomagnetic work (Symons and Lew-
chuk, 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 ex-
change 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

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

Euhedral zircons from Mons Creek yielded a concor-
dant lead-lead age of 469±17 Ma (Appendix 2), which possi-
bly 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 con-
sistent 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 Valentine-
cennes River area are all xenocrystic in origin and gave lead-lead
ages of approximately 1525, 1825, 2550 and 2565 Ma (Ap-
pendix 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).
British Columbia

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.
Due to intensity of alteration, classification is difficult. The presence of glass lapilli and absence of biotite/hlogopite 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.
and subrounded cognate xenoliths (autoliths) in a matrix of vesicular altered glass lapilli, monocry stalline 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, up-section. 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.

A small, black-weathering, mafic body (?) 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 albite 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-
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.

**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

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*Figure 76. Geology of the Blackfoot diatreme.*

*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 (favorites 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 dunes, are relatively common and remarkably fresh. Eclogite nodule 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. Dunes contain 63% olivine, 14% clinopyroxene and 17% talc with accessory orthopyroxene and hornblende (Ijewiwi, 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 tuffitic 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-
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 (?) 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 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 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 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
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 autobrecia 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>
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<th>Table 17</th>
<th>Chemical Analyses Bull River - Elk River Diatremes and Related Rocks</th>
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All analyses by XRF, British Columbia Geological Survey Branch, analytical laboratory.

1. JFS - BK Typit foliated breccia, Joff pipe Thatch Mountain area
2. QVS - GR Folicated dike, cutting diatreme breccia, Quinip pipe, Quinian Creek
3. BFF - Black foliated breccia, Blackfoot pipe
4. BFF - Black dyke, Blackfoot pipe
5. BFF - 19 FSS dyke, cutting diatreme breccia, Blackfoot pipe
6. BFF - Black foliated breccia, Blackfoot pipe
7. BFF - ND Proximate nodule, Blackfoot pipe
8. BFF - ND Chromite diopside pyroxenite, Blackfoot pipe
9. BFF - Black dike crosscutting breccia associated with flow in the crater, Russ pipe, Russell Peak
10. BFF - 19S Black volcanic flow located in crater, Russ pipe, Russell peak, contains altered nodules
11. BFF - 19B Unbanded volcanic breccia in crater, Russ pipe, Russell Peak
12. RSF - 2A Fine-grained light green dike, Russell Peak
13. RSF - GR Massive dike, Scat clasts, Mary Creek/White River area
14. SCF - GRS Foliolated dike with inclusions, Scat clasts, Mary Creek/White River
15. FSS - FL2 Dike associated with Summer 2 diatreme, Summer and Gullmarth Creek
16. FSS - FL1 Dike associated with Summer 2 diatreme, Summer and Gullmarth Creek
17. FSS - 2 Sa Summer 2, diatreme breccia with abundant spilites, Summer and Gullmarth Creek
18. FSS - 7A FSS spilite, light green dike, crosscutting Summer 1 diatreme, Summer
19. FSS - 2C1 Ultramafic pillow volcanoc, Scat clasts, Swanov Peak
20. FSS - 2C2 As above
21. FSS - 2C3 Above
22. SCF - 3 Typical diatreme breccia, Swain clasts, Swanov Peak
23. SCF - 1C4 Gabbro-tili, part of White River sill complex, Haynes Creek
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 alkali 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 Fe₂O₃-MgO-Al₂O₃ 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 compo-
sitions (Figure 79c). Relatively unaltered dike and flow material from the Russell Peak area plot in the alkaline lamprophyre field on a K$_2$O-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 feldspathoids.

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$_2$O$_3$-MgO-Al$_2$O$_3$ 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$_2$O-MgO plot they fall within or marginal to the leucite field (Figure 80a); and, on an alkali-silica plot they fall well within the melilitite-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 nephelinites, 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 Palaeozoic 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 lapillius, central breccia phase, Cross Kimberlite.

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