# COMPARATIVE MINERALOGY OF THREE ULTRAMAFIC BRECCIA DIATREMES IN SOUTHEASTERN BRITISH COLUMBIA CROSS, BLACKFOOT AND HP* (82J, 82G, 82N)

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## INTRODUCTION

A series of ultramafic breccia diatremes occurs along a northwest trend line east of the Rocky Mountain Trench in British Columbia (Figure 4-4-1). Three of these, Cross, Blackfoot and HP diatremes, were selected for comparative study. All three were intruded into Paleozoic miogeoclinal sediments prior to deformation associated with the Columbia Orogeny (Pell, 1986) and have been considered to have kimberlitic affinity (Dummett *et al.*, 1985; Grieve, 1981 and 1982).

The purpose of this study is to classify the diatremes where possible, and to compare and contrast their petrography, mineralogy and chemistry.

## THE CROSS DIATREME (82J/2)

### INTRODUCTION

The Cross diatreme lies north of Crossing Creek about 10 kilometres northwest of the village of Elkford at latitude 50°05′25″N, longitude 114°59′30″W. Access is by helicopter or by four-wheel-drive vehicle and a three-hour hike. The outcrop is a steep bluff some 15 metres high and 50 to 60 metres long. The slope below is covered with natural diatreme talus and material derived from road construction.

### DESCRIPTION

The diatreme is lithologically heterogenous and very friable. The west end of the outcrop is a light green, strongly foliated rock containing some red hematized clasts. Foliation is at a high angle to bedding in adjacent sediments. This grades eastwards to a massive, light green unit with 40 per cent inclusions including 5 to 10 per cent ultramafic xenoliths. Further east the rock is a dark green, massive, unfoliated unit with fewer clasts but containing abundant, randomly distributed phlogopite books and ultramafic xenoliths. 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.

The several distinct lithologies may reflect separate intrusive pulses. A shear zone cuts the diatreme vertically with the eastern third being downdropped slightly.

Inclusions comprise 15 to 20 per cent of the rock volume and consist of angular fragments of country rock, rounded, dark green serpentinized xenoliths and black pyroxenite xenoliths. The rounded xenoliths range in size from a few millimetres to 6 centimetres in diameter.

### DETAILED PETROGRAPHY

Xenoliths are almost entirely serpentinized pseudomorphs of olivine and pyroxene (Plate 4-4-1). Serpentine is markedly finer grained at the xenolith margins. Talc replaces pyroxene to a limited extent and also rims and veins serpentinized grains. The original presence of olivine is indicated by the typical olivine outline and fracture pattern. Olivines are completely serpentinized. Some relict pyroxene with characteristic cleavage and birefringence is preserved. The degree of alteration in the pyroxenes often makes the identification difficult. Interstitial spinels are also present in minor amounts. The xenoliths may therefore be broadly classified as spinel lherzolites.

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 $(Fe,Mg)(Cr,Al)_2O_4$.

Macrocrysts (0.5-5.0 millimetres) consist of completely serpentinized olivines (Plate 4-4-2), partially altered garnets, garnets with kelyphitic rims (Plate 4-4-3) and phlogopites (Plate 4-4-2). They may be round, oval or lath-shaped in random orientation and make up 10 to 20 per cent of the rock volume. Garnets show a moderate to high degree of alteration or dissolution in reaction with the matrix. None are euhedral. They are rounded and irregular in shape and surrounded by kelyphitic rims or reaction coronas of opaque iron oxides (Plate 4-4-3). Fracturing is common, with serpentine forming in the fractures. Occasionally, calcite rimmed with phlogopite and sitting in serpentine, is nested in a garnet. In plane polarized light, the garnets exhibit a range of colours from clear to light pinkish brown and pale green. X-ray spectra of clear and brown garnets show roughly similar compositions in the pyrope-almandine-grossular range with minor amounts of titanium and chromium.

Phlogopites are occasionally zoned. Many grains are bent and show undulating extinction. Occasionally grains are intergrown. Alteration, which is relatively rare, occurs as embayments, pockets and central sieving. X-ray spectra confirm that the micas are phlogopite and contain appreciable amounts of titanium.

Xenocrystic quartz grains, singly and in aggregates, occur in the eastern part of the diatreme, probably representing mixing with the intruded sedimentary rocks.

The phenocryst population is comprised of completely serpentinized olivine, together with phlogopite and spinel. Phlogopite grains vary in size and are randomly oriented, square to rectangular in shape and relatively unaltered (Plate 4-4-2). Zoning is rare but grains may be intergrown. Reddish brown translucent spinels are disseminated in the groundmass and show magnetite reaction rims. Spinels may also be surrounded by phlogopite.

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Plate 4-4-1. Cross diatreme xenolith showing serpentinized olivine with characteristic fracture pattern (top half) and serpentinized pyroxene with relict cleavage and birefringence (bottom half); field of view = 1.80 millimetres. XPL

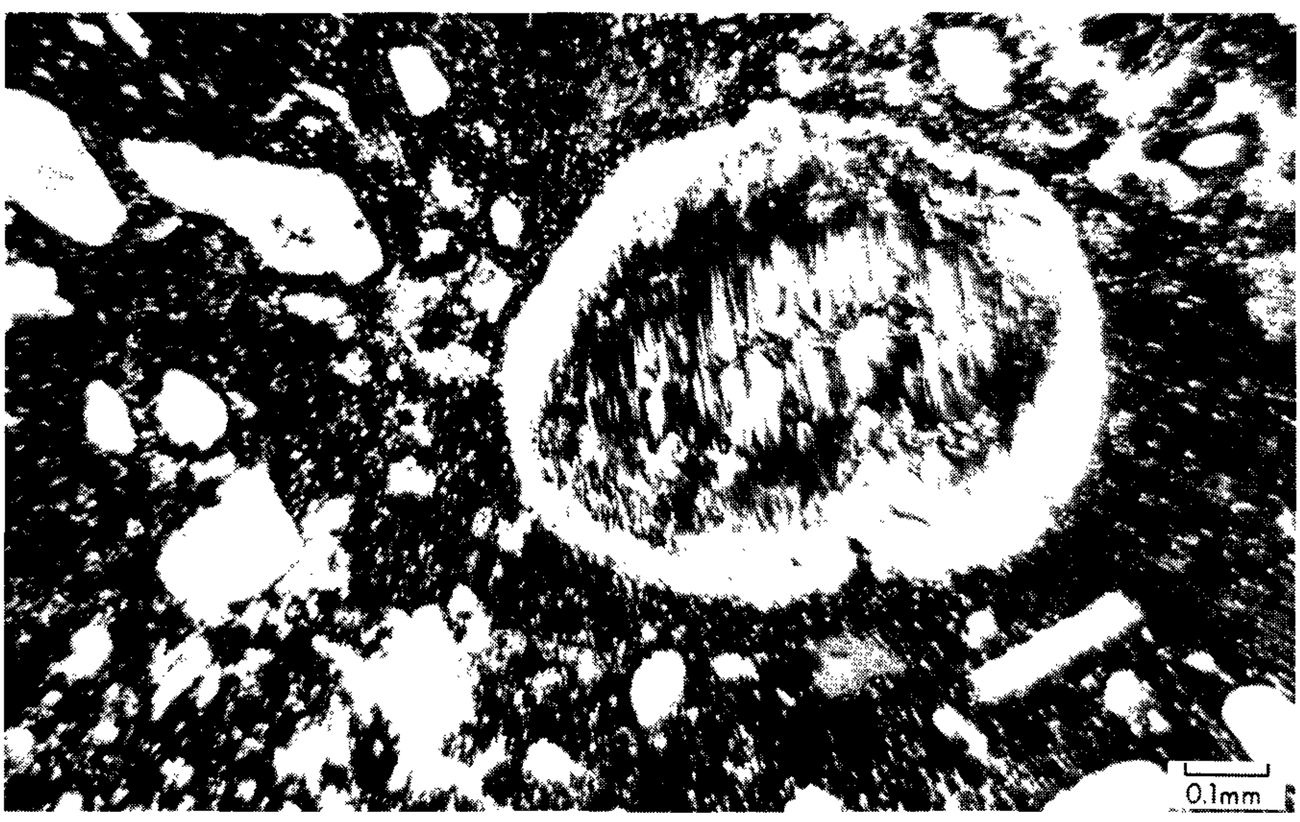


Plate 4-4-2. Cross diatreme serpentinized olivine macrocryst with phenocrystic serpentinized olivine, calcite (lower left) and phlogopite (lower right); field of view = 1.80 millimetres. XPL

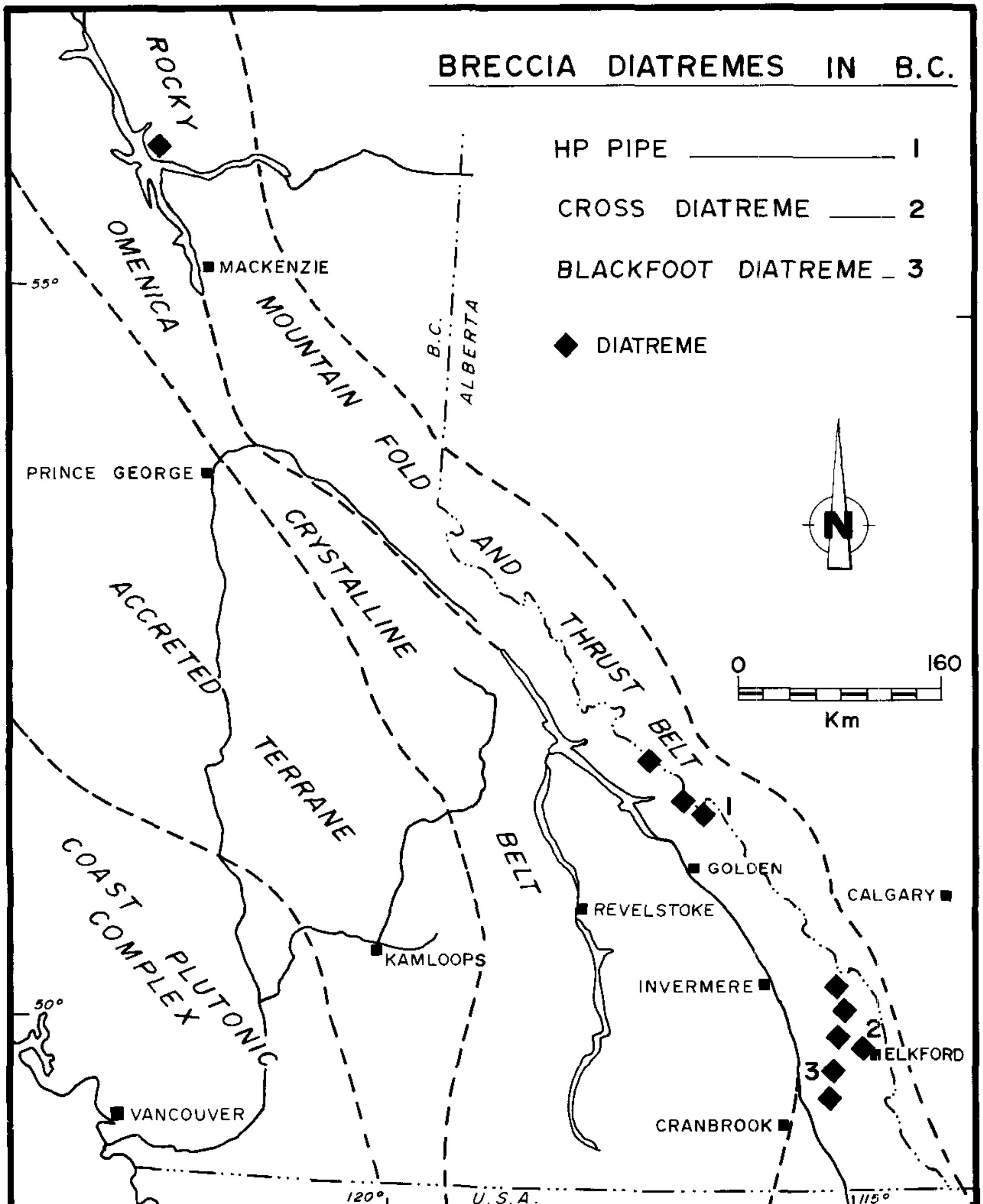


Figure 4-4-1. Locations of breccia diatremes in British Columbia (after J. Pell).


Plate 4-4-3. Cross diatreme macrocrystal garnet with kelyphitic alteration rim; field of view = 1.80 millimetres. PPL

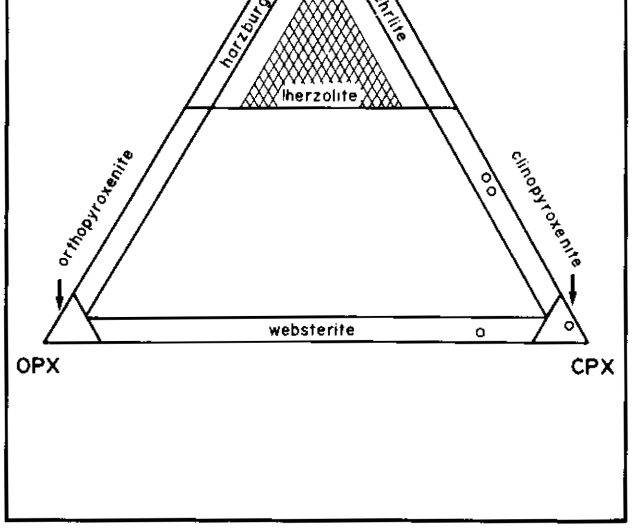


Figure 4-4-2. Peridotite ternary diagram for Cross and Blackfoot xenoliths.

The fine-grained groundmass is composed of serpentine and calcite with minor dissemminated talc, pyrite and magnetite. Calcite is also present as medium-grained, irregular-shaped masses suggesting late stage crystallization. X-ray spectra show the calcite to be pure calcium-calcite. Opaque, disseminated microlites are concentrated in the larger calcite centres.

Secondary pyrite forms massive rims around calcite. Bright red hematite often forms envelopes around the pyrite and dendrites penetrating calcite aggregates.

## THE BLACKFOOT DIATREME (82G/14)

### INTRODUCTION

The Blackfoot diatreme outcrops east of Blackfoot Creek, 60 kilometres northeast of Cranbrook at latitude 49°58′30″N and longitude 115°17′00″W. Access is by helicopter or on foot from a logging road in the Blackfoot-Quinn Creek valley. The diatreme is elongate in shape, approximately 1000 metres in length with a maximum width of 400 metres (Pell, 1986). It is recessive and surrounded by steeply dipping limestone beds of the Ordovician-Silurian Beaverfoot-Brisco Formation (Pell, 1986).

The diatreme intruded the miogeoclinal succession prior to the Jurassic-Cretaceous Columbian Orogeny (Pell, 1986). Its age has not yet been established but its character is very similar to other diatremes which, on the basis of stratigraphic evidence, are thought to be pre-middle Devonian in age (Roberts *et al.*, 1980).

### DESCRIPTION

The outcrop surface is very foliated and friable, light grey-green in colour and contains about 50 per cent inclusions consisting of angular limestone clasts and ultramafic xenoliths. Inclusions vary in size up to 10 centimetres in diameter. Xenoliths are predominantly hornblende clinopyroxenite, dunite and hornblendite. In contrast with the Cross diatreme, alteration is minimal, commonly affecting 4 to 15 per cent of the rock, although two samples exhibited entirely serpentinized olivine.

## DETAILED PETROGRAPHY

In the clinopyroxenite xenoliths, the clinopyroxene is in the diopside range and the orthopyroxene tends toward enstatite. Pyroxenes show incipient alteration on the grain boundaries and penetration by fine-grained veinlets of acicular serpentine and talc. Some embayments and small pockets of serpentinization are present as alteration along cleavage planes. Sieving and disintegration are also observed in the centre of some pyroxenes. Brown pleochroic interstitial hornblende is also present.

Spinels are red to brown in colour and angular. They are fractured and embayed with talc and serpentine. X-ray spectra indicate a predominantly chromite composition with minor magnesium, aluminum substitution. Phenocrystic calcite is present in some samples both as a primary phase and replacing other minerals. Cleavage shows strain undulation. Olivine, present in both the clinopyroxenite and dunite, may be completely replaced by platy serpentine and calcite or remain unaltered. Olivine composition, measured optically, is $Fo_{85}$.

In the hornblendite xenoliths, large (0.5-1.0 centimetre), euhedral hornblende grains with tan pleochoism are in contact with smaller (0.1-1.4 millimetres size) interstitial, brown pleochroic hornblende. Ilmenite with pitted texture occurs predominantly in the hornblendite but is also interstitial to hornblende and clinopyroxene in other xenoliths. Trace amounts of disseminated pyrite, often rimmed by magnetite, are also present.

Rounded and anhedral xenocrystic quartz grains, with serrated edges, are seen in only two samples. Rare orthoclase grains show no reaction rims.

Glass lapilli, with opaque microlites clustered around the edges, are yellow in plane polarized light. Many contain impurities or are devitrified and can be very dark in plane light. Compaction in the form of elongation with fiamme structures is common. Vesiculation is still apparent (Plate 4-4-4). Devitrification and/or alteration takes the form of serpentine and calcite. Lapilli consitute about 25 to 30 per cent of the rock volume.

Clinopyroxene phenocrysts are in the diopside range and orthopyroxenes are almost pure enstatite. Pyroxene crystals tend to be rounded or anhedral with narrow rims of serpentine and calcite. Minor alteration is present along cleavage planes. Grains of pure calcium-calcite are usually square and show weak alteration with serpentine veinlets crosscutting and rimming some grains. Pyrite is euhedral and occasionally rimmed with magnetite. Spinel is anhedral, sometimes fractured and embayed and shows a range of colour from golden-orange to reddish-brown. X-ray spectra reveal a slightly more chrome-rich spinel than the xenolithic spinel.

The matrix, which makes up the majority of the sample volume, is a tuffaceous mixture of impure carbonate and serpentine with a fibrous, matted texture.

# THE HP PIPE (82N/10)

## INTRODUCTION

The *HP* diatreme is exposed near the nose of the Campbell Icefield, 50 kilometres northeast of Golden at latitude 51°41'30"N and longitude 116°57'00"W. It is accessible by helicopter. The outcrop, at an elevation of 2400 metres, measures about 45 by 35

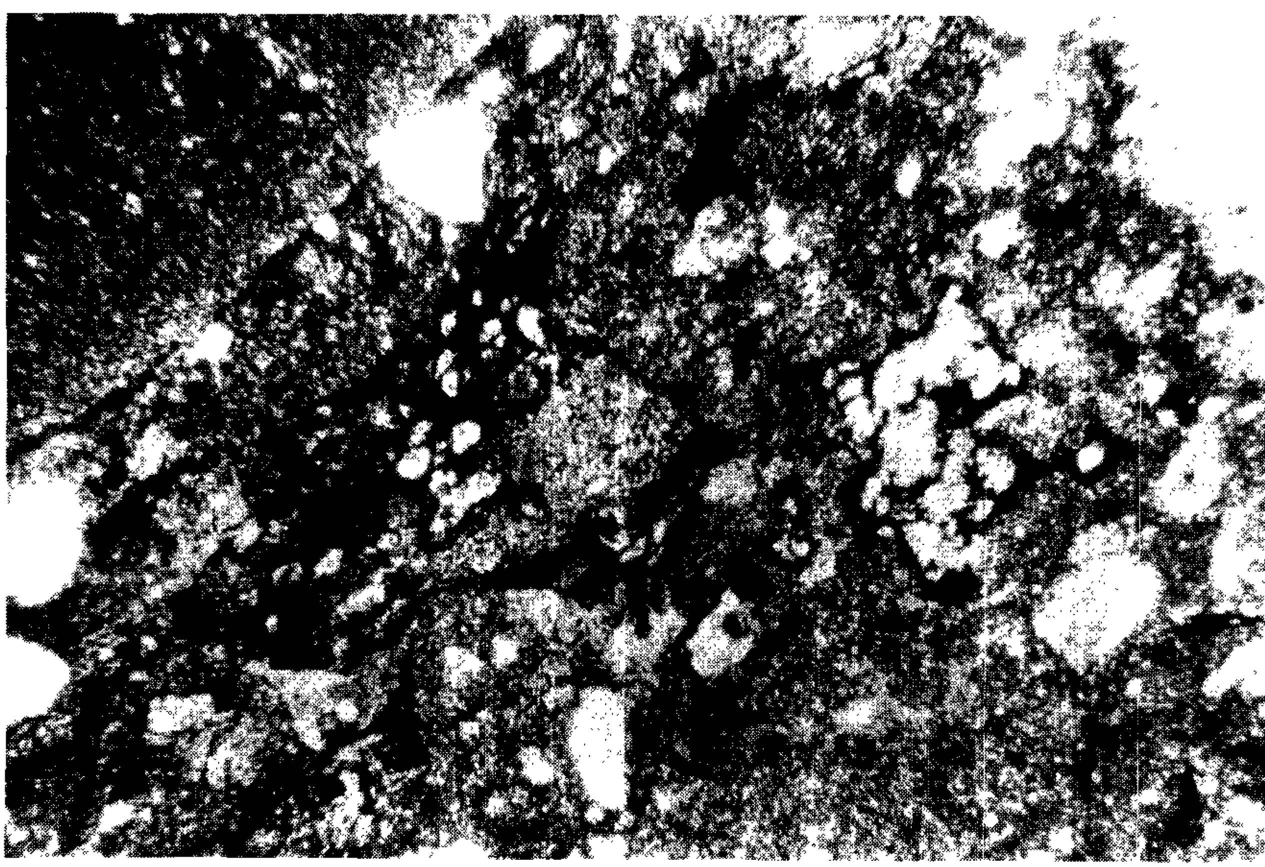

Plate 4-4-4. Blackfoot diatreme lapilli with opaque microlites and remnant vesicles; field of view = 1.10 millimetres. PPL

metres with topographic relief of less than 10 metres. The area was recently deglaciated, and the diatreme is almost completely exposed.

## DESCRIPTION

The diatreme is slightly elongated north-south and associated with crosscutting dykes (Pell, 1986). The breccia phase is a foliated, pale green, coarse-grained rock with 40 per cent inclusions. They consist of angular and rounded, white, marmorized limestone clasts 1 to 3 centimetres long; round, black pyroxene xenocrysts up to 5 centimetres diameter; green diopside xenocrysts up to 2 centimetres diameter; biotite books up to 3 centimetres diameter; and some autoliths ranging in size from 5 to 20 centimetres. The dyke phase is fine grained, darker green and contains far fewer inclusions, but has more abundant and finer grained biotite.

## DETAILED PETROGRAPHY

"Xenoliths" were sampled based on their field appearance of being dark, rounded, protruding features, though when examined more closely, they resembled more compact examples of the fine-grained phase and will therefore be referred to as nodules.

The nodules contain less than 25 per cent phenocrysts of biotite, garnet, pyroxene, calcite and spinel. The biotite is partially chloritized and moderately altered to serpentine and calcite. Acicular opaques are exsolved along cleavage planes in the biotite. Biotite X-ray spectra show high iron:magnesium ratios and occasionally zoning to iron-rich rims. Garnets are light green or brown in colour. They show a partly euhedral outline in contact with calcite (Plates 4-4-5 and 4-4-6) and an irregular contact with biotite (Plate 4-4-6). Optical characteristics and X-ray spectra indicate that the brown garnet is melanite, a titanium-bearing andradite, and the green garnet is titanium-free andradite. The pyroxenes are diopside and enstatite. They show textures ranging from good euhedral outlines to edge resorption and cleavage plane alteration. Calcite exhibits good crystal form and X-ray spectra indicate a pure calcium-calcite. Spinels are either a titanium-bearing magnetite or a red-brown chromite with minor amounts of aluminum, magnesium and titanium.

The nodule groundmass constituents are fine-grained serpentine, calcite, talc, chlorite and biotite.

The coarse-grained breccia phase contains macrocrysts of pyroxene, biotite, devitrified lapilli and altered phenocrysts of pyroxene, garnet, biotite and integral spinels. Clinopyroxenes are in the diopside-augite and titanaugite range and show margin alteration, alteration blebs and cleavage plane alteration to serpentine and calcite. The more iron-rich augite contains disseminated pyrite grains. Rims of opaques in a chlorite matrix are also found to envelope the grains. The orthopyroxene is enstatite and shows less alteration than the diopside and augite. Garnets form small euhedral crystals with interstitial calcite (Plate 4-4-7). X-ray spectra show the garnets to be titanium-bearing melanite similar to the nodular garnets. Biotite with tan pleochroism exhibits moderate corrosion. Spinels are angular and reddish-brown in colour.

The groundmass of the coarse breccia phase is comprised of biotite, melanite, pyrite, calcite and mangnesium-iron alteration minerals, serpentine and chlorite. Randomly oriented, acicular tan biotite makes up 30 to 40 per cent of the groundmass in some specimens and is not limited to those containing phenocrystic biotite. Melanite occurs as small aggregates (0.15 millimetre) of tiny euhedral crystals (0.02 millimetre) and constitutes 20 per cent of the rock volume. Melanites also outline devitrified lapilli (Plate 4-4-8).

The fine-grained dyke phase contains no orthopyroxene or relict lapilli. The macrocryst population consists of clinopyroxene and biotite while the phenocrysts comprise both these minerals together with garnet and spinel. Clinopyroxene is of the diopside and augite varieties and is highly altered and largely replaced by talc and calcite. Garnet, a titanium-free andradite, forms small, euhedral, pale green crystals and may be surrounded by a ring of relatively large, randomly oriented biotites. Partially altered biotite with serrated ends also shows compositional zoning at the ends, termed "battlemented" iron-rich ends (Williams *et al.*, 1982). Spinel, angular and red-brown in colour, is present in trace amounts. The groundmass is comprised of andradite clumps, biotite, serpentine, talc and chlorite.

## DIATREME COMPARISONS

The age of emplacement of the diatremes spans a wide time range in the Paleozoic. The Cross diatreme, intruding Pennsylvanian sedimentary rocks, has been dated using rubidium/strontium ratios at 240 million years (Smith, 1983) and 244 million years (Grieve, 1981) placing it near the Permo-Triassic boundary. Rubidium/strontium ratios in the HP pipe, which intrudes Cambro-Ordovician sedimentary rocks, date its intrusion at 347 million years (R.L. Armstrong, personal communication, 1986) placing it near the Devonian-Mississippian boundary. The Blackfoot diatreme intrudes Ordovician-Silurian rocks and closely resembles other southern British Columbian pipes which exhibit synsedimentary phases with Ordovician-Silurian strata (J. Pell, personal communication, 1986). Radiometric dating has not yet been completed.

Where ultramafic xenoliths occur, they vary in composition from one diatreme to another. Only the Cross and Blackfoot diatremes have ultramafic xenoliths which can be compared on a peridotite ternary diagram (Figure 4-4-2). The HP pipe has compacted nodules of diatreme material. The amount of ortho versus clinopyroxene in Cross xenoliths cannot be determined precisely due to pervasive serpentinization; a general field of spinel lherzolite is indicated. The majority of Blackfoot xenoliths are classified as hornblende clinopyroxenite.

Macrocrysts, where they occur, show no overlap among the diatremes except for the biotite mineral group. Cross diatreme macrocrysts consist of completely serpentinized olivine, disintegrating garnet of the pyrope-almandine-grossular variety and titanium-bearing phlogopite. Macrocrysts from HP are diopside, augite, titanaugite, enstatite and biotite. The Blackfoot diatreme has no macrocrysts.

The phenocryst populations in the three diatremes show many differences (Table 4-4-1). The HP phenocrysts are combined from all three phases (nodular, coarse-grained breccia and fine-grained dyke phases) as they are assumed to be consanguineous. Spinel is common to all three diatremes. Unambiguous clinopyroxene is present in Blackfoot and HP. The pyroxene phenocrysts at Cross are

**TABLE 4-4-1.**
**COMPARATIVE PHENOCRYST ASSEMBLAGES**

| Mineral | Cross | Diatreme Blackfoot | HP |
|---|---|---|---|
| Olivine | x | o | o |
| Phlogopite | x | o | o |
| Biotite | o | o | x |
| Spinel (chromite) | x | x | x |
| Magnetite | o | o | x |
| Calcite | o | o | x |
| Clinopyroxene | o | x | x |
| Orthopyroxene | o | o | x |
| Hornblende | o | x | o |
| Garnet (melanite) | o | o | x |

Note: x = present, o = absent.


Plate 4-4-5. HP diatreme nodular brown melanite garnet with calcite (right); field of view = 1.4 millimetres. PPL

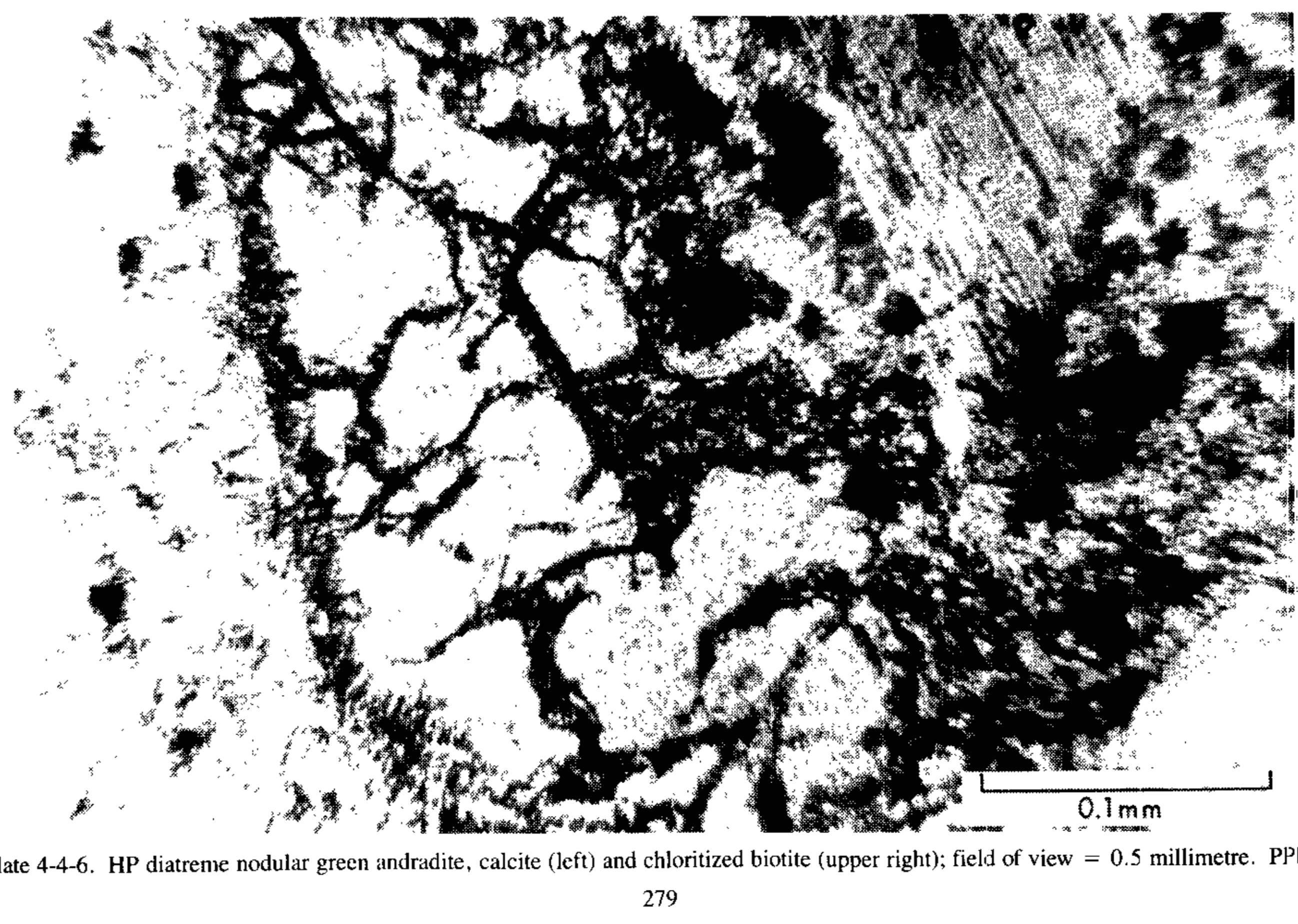


Plate 4-4-6. HP diatreme nodular green andradite, calcite (left) and chloritized biotite (upper right); field of view = 0.5 millimetre. PPL

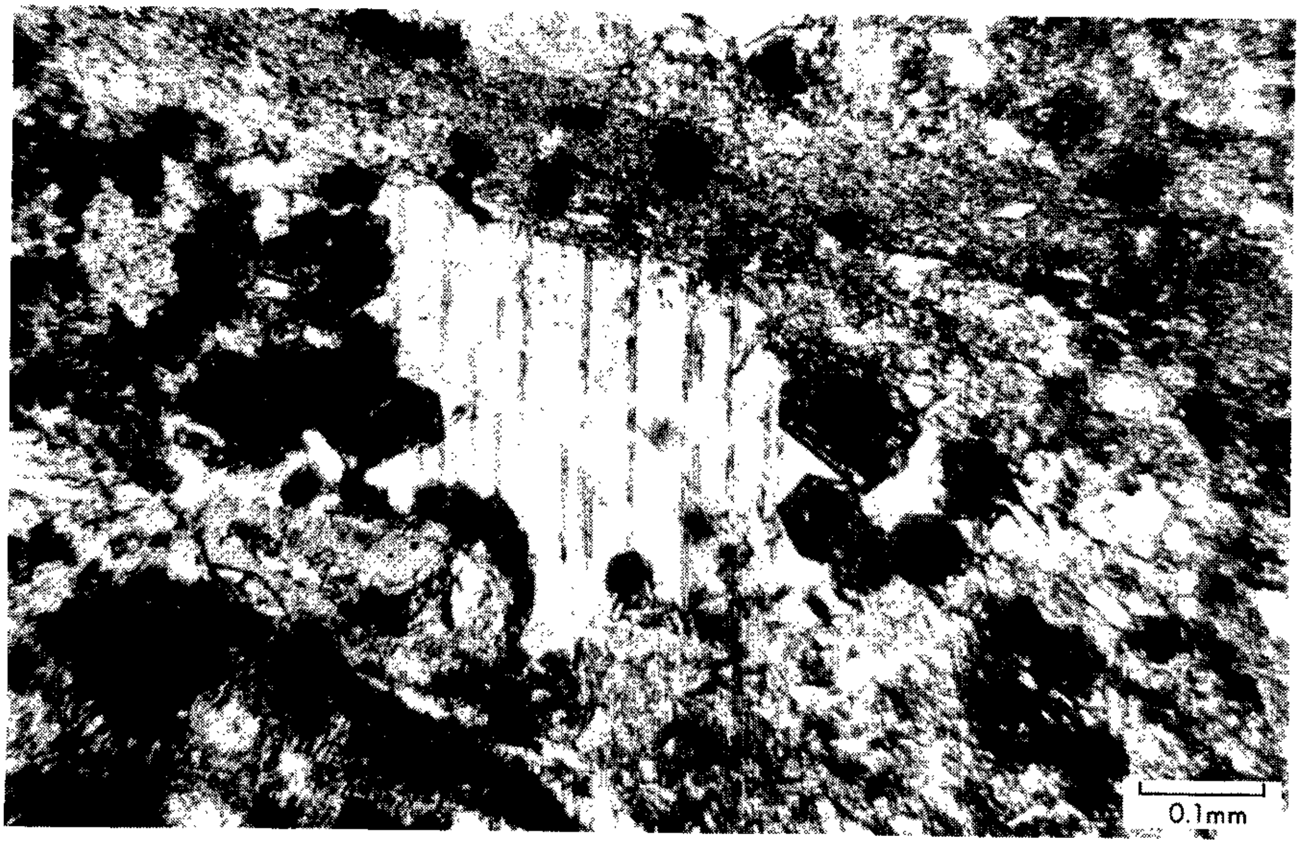


Plate 4-4-7. HP diatreme coarse-grained breccia phase, small euhedral melanite microgarnets with interstitial calcite, all in chloritized groundmass; field of view = 1.10 millimetres. PPL

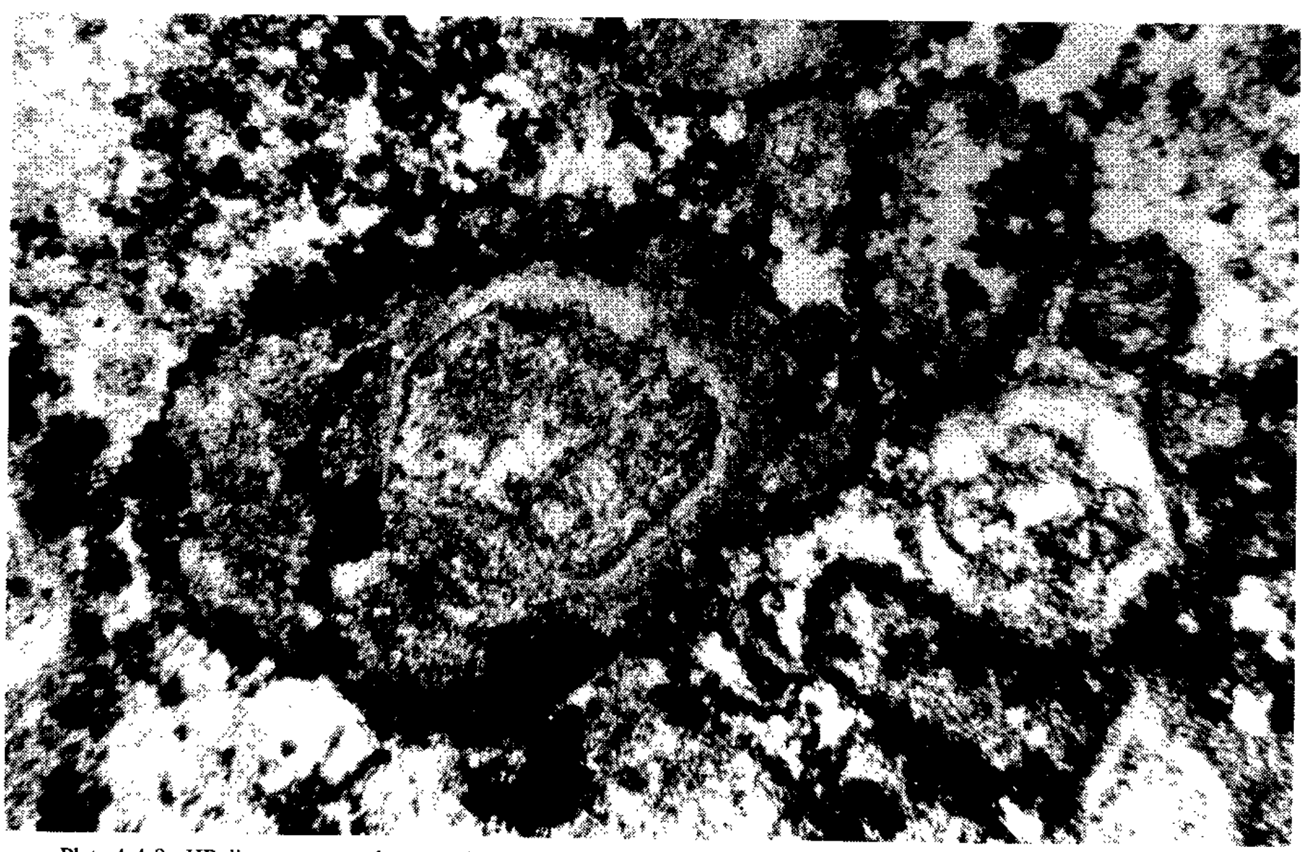

Plate 4-4-8. HP diatreme groundmass melanite garnets outlining devitrified lapilli; field of view = 1.40 millimetres. PPL

TABLE 4-4-2.
COMPARATIVE GROUNDMASS MINERALOGY

| Mineral | Diatreme Cross | HP |
|---|---|---|
| Serpentine | x | x |
| Calcite | x | x |
| Talc | x | x |
| Pyrite | x | x |
| Magnetite | x | o |
| Biotite | o | x |
| Chlorite | o | x |
| Garnet (melanite) | o | x |

Note: x = present, o = absent.

too serpentinized to allow distinctions to be made between orthopyroxene and clinopyroxene.

The Cross and HP diatremes are considered to have true igneous groundmasses of different compositions (Table 4-4-2). Some samples from HP also contain relict glass lapilli. Blackfoot is a tuffaceous diatreme with a fine-grained impure carbonate matrix of uncertain origin. Rare juvenile glass lapilli, some devitrified, together with rare phenocrysts make up the igneous component.

The three diatremes fall into distinct petrologic provinces. Only Cross conforms to the kimberlite definition outlined by Clement *et al.* (1984), and falls into the serpentine kimberlite classification of Skinner and Clement (1979). Blackfoot, with glass, pyroxene, hornblende and calcite, shows affinity to a limburgite as defined by Williams, Turner and Gilbert (1982). The HP diatreme and related dykes represent a unique assemblage; they contain melanite which is commonly associated with alkaline igneous rocks (Williams *et al.*, 1982; Deer *et al.*, 1962) but a classification for the complete assemblage remains elusive.

Varying degrees of serpentine and calcite alteration are common to all three diatremes. Cross is characterized by pervasive deuteric alteration of the iron-magnesium minerals, olivine, pyroxene and, to a lesser extent, garnet. Serpentinization and carbonatization occurred during the late stages of magmatic crystallization. Secondary alteration is manifest as pyrite rims, red hematite envelopes and dendritic hematite. Blackfoot shows minimal serpentinization and carbonatization of olivine. Talc replaces olivine, but pyroxene remains largely unaffected. Secondary alteration effects are not present at Blackfoot. The HP diatreme exhibits moderate deuteric alteration of pyroxene and to a lesser extent biotite, to serpentine, talc and calcite. The melanite garnets remain essentially unaltered. Secondary alteration takes the form of chloritization of biotite.

The mineral chemistry of biotites, spinels and garnets from the three diatremes has been compared. Biotite and phlogopite appear only in Cross and HP diatremes and fall into distinct chemical regions (Figure 4-4-3). To compare their mineral chemistries semi-quantitatively, the heights of the iron and mangnesium peaks of the printed X-ray spectra were measured. Ratios of (magnesium x 100)/(iron + magnesium) were calculated and compared to measurements of magnesium.

Chrome spinels are present in all three diatremes and in all xenoliths and nodules. A comparison of the xenolith and nodular spinel aluminum content was made using the ratio (aluminum x 100)/(aluminum + chromium) plotted against aluminum (Figure 4-4-4). Spinel chemistry shows varying aluminum ratios suggesting either that the Cross diatreme occupies the highest pressure-temperature space of the three diatremes, or merely a variation in the bulk chemistry.

Garnets are not present at Blackfoot. Pyrope-almandine-grossular garnets are seen at Cross whereas andradites characterize

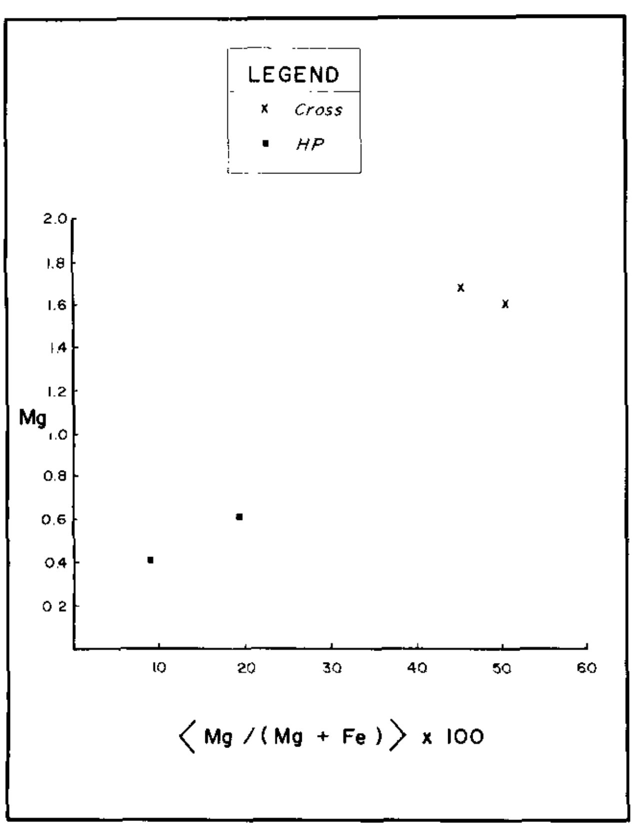


Figure 4-4-3. Magnesium component in biotite for Cross and HP diatremes.

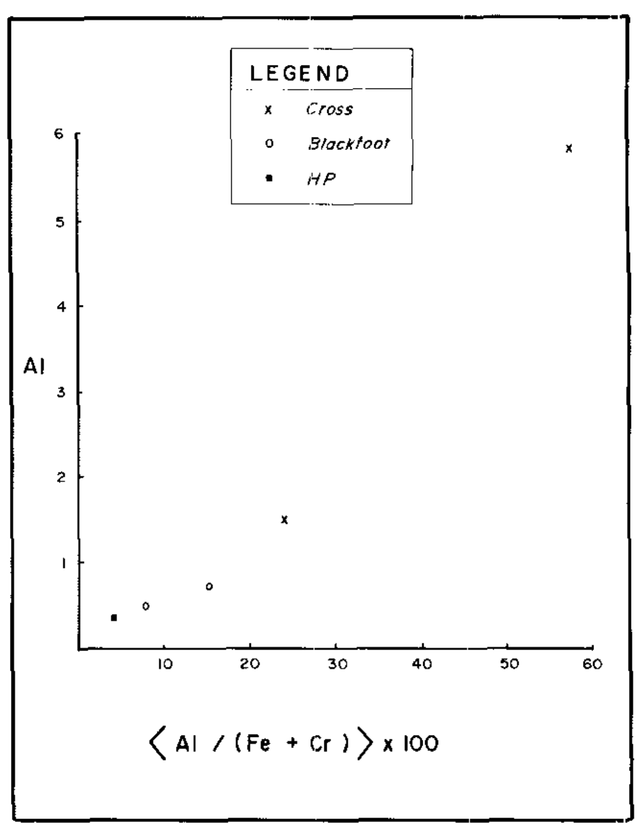


Figure 4-4-4. Aluminum component in chrome spinels both in the groundmass and in the xenoliths.

HP. Garnet stability field diagrams (for example, Meagher, 1980) suggest that the Cross garnets may occupy a higher pressure region than the HP andradite, though there is some possibility of overlap.

It is concluded from petrographic and SEM analysis that these three ultramafic breccia diatremes, which appear similar in the field, occupy quite distinct petrologic provinces.

## ACKNOWLEDGMENTS

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