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Petrography of the Mountain Lake Pipe, Grande Prairie Area, Alberta, Canada

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Petrography of the Mountain Lake Pipe, Grande Prairie Area, Alberta, Canada

Special Report 15

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Abstract

Twelve samples rich in altered juvenile olivine from the Mountain Lake Pipe (holes ML95-1 and ML95-3) were studied for texture and mineralogy. Contrary to an earlier interpretation that Mountain Lake Pipe rocks are entirely extrusive crater-facies products, all of the samples studied show olivine pellets and evidence of pelletal nucleation, both of which are characteristic of diatreme-facies kimberlite. Rocks of the Mountain Lake Pipe show a mixed origin and have been tentatively classified as hybrid alkaline ultramafic rocks, with some petrological affinities to alnoitic magmas. Despite the occurrence of such diamond indicator minerals as garnet (G5, G9, G11), chrome diopside, chromite and picro-ilmenite, which indicate contribution of a kimberlitic component, the economic potential of the rocks as a diamond source is estimated as low.

1 Introduction

In 1995, two holes (ML95-1 and ML95-3) were drilled by the Alberta Geological Survey into the Mountain Lake Pipe (Figure 1). The Mountain Lake Pipe is intruded into the Wapiti Formation, which consists of sandstone, siltstone, mudstone and coal (Leckie et al., 1997).

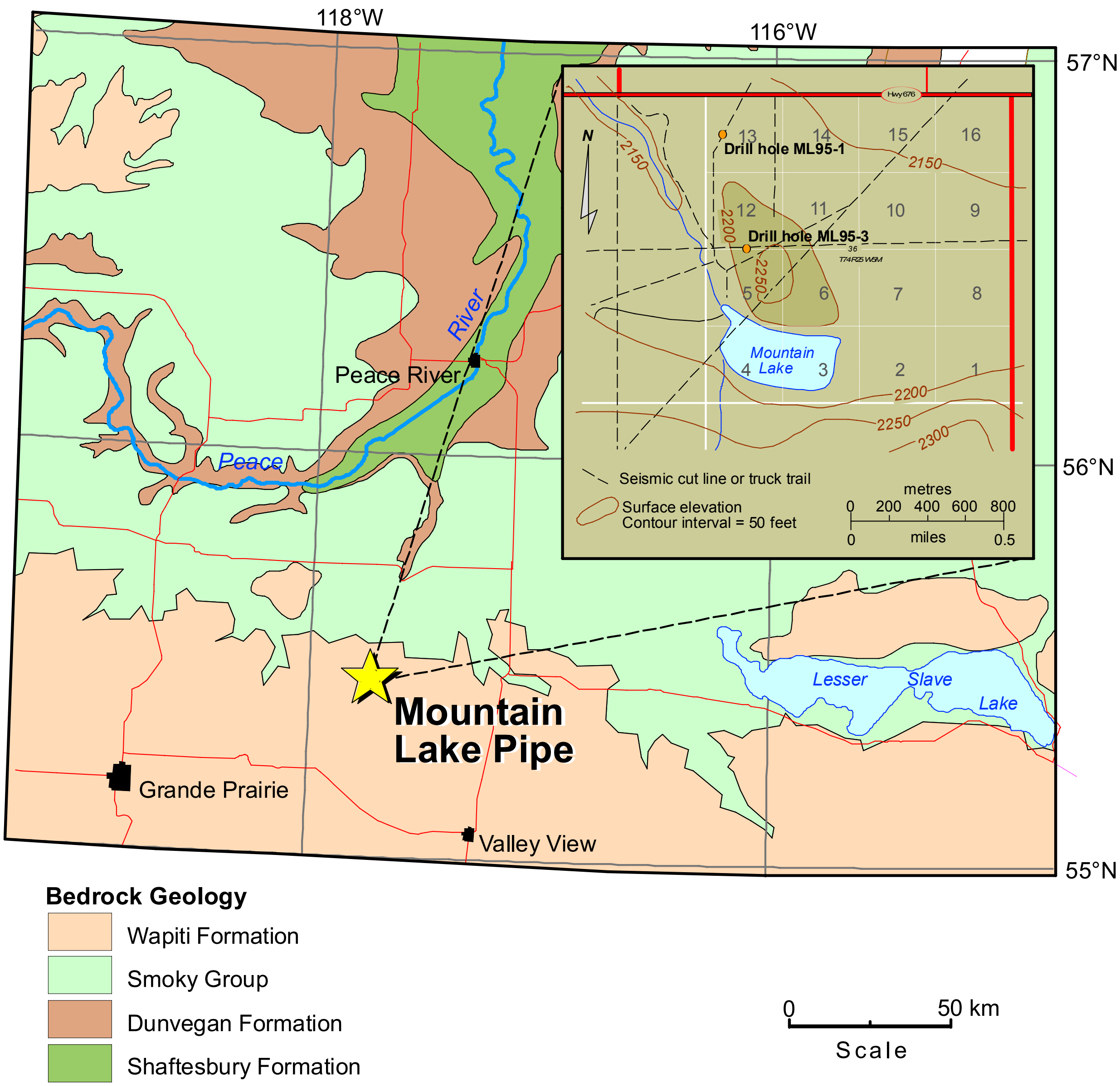

Figure 1. Locations of drillholes ML95-1 and ML95-3 in the Mountain Lake Pipe.

The purpose of this project was to obtain a petrological classification of the rocks of the Mountain Lake Pipe through study of the freshest samples of the collected core, in which the original mineralogy might be preserved. The samples were therefore chosen from intervals that are massive and rich in juvenile components. The following depths were sampled: 7.2 m, 35 m, 64 m and 161.9 m in hole ML95-1, and

20.1 m, 29.8 m, 88.8 m, 117.9 m, 128.2 m, 134 m, 165 m and 172.7 m in hole ML95-3. Due to the destructive effect of water on smectite-enriched rocks, thin sections were prepared without any liquid. Note that microscopic data and relevant conclusions refer to the sampled intervals only and might not be always consistent with data collected from other intervals.

The samples can be divided into two types: crystal tuff and olivine pellet tuff. Crystal tuff consists of various large grains in a fine-grained groundmass, and olivine pellet tuff consists of large, altered olivine grains in a fine-grained groundmass. These rocks are, for practical reasons, described as 'tuff', although no clear evidence is available for their effusive evolution. Poor sorting, shortage of structural porosity and undisturbed coatings and rims of euhedral olivine, all argue against their extrusive character. Genetically, the Mountain Lake Pipe 'tuff' is probably 'tuffisite' or intrusive tuff (*see* Mitchell, 1989; *after* descriptions by Cloos, 1941), sometimes also called 'injected tuffisite' (Kazak and Yakobson, 1999). Hole ML95-1 (total depth of about 160 m) contained mainly crystal tuff with possible contributions of superficial sedimentary materials. In the samples from hole ML95-3 (total depth of 175 m), olivine pellet tuff is most abundant.

The complex mineralogy of all components, crystal tuff, olivine pellet tuff and the lithic particles, suggest a possible mixed origin for the pipe rocks. The crystals and xenoliths derived from the country rock indicate different sources: sedimentary rocks, crystalline basement, trachytic/phonolitic volcanism and, most likely, rhyolitic volcanism. The source of the petrologically variable clasts is uncertain. For the reasons given in the 'Crystal Tuff' section, however, the disaggregated Wapiti Formation seems a highly unlikely source. The ultramafic autoliths and all varieties of altered olivine are almost certainly of mantle origin.

Rocks of the Mountain Lake Pipe were initially described as kimberlite (Wood and Williams, 1994). Later, according to Leckie et al. (1997), they were classified as alkaline ultrabasic volcanic rocks. Due to extensive secondary clay alteration that obliterated original mineralogy, it seems doubtful that the Mountain Lake Pipe rocks can ever be satisfactory classified. However, in this paper we hope to explain petrographic peculiarities and apply the Clement and Skinner (1985) approach to textural classification. The descriptions and determinations of minerals are based on thirty thin sections of drill core, which is stored at the core storage facility (Mineral Core Research Facility) of the Alberta Geological Survey in Edmonton, Alberta.

2 Petrography

The crystal tuff and olivine pellet tuff of the Mountain Lake Pipe differ in texture (Appendices 1 and 2, Plate 1). Olivine pellet tuff comprises broken or euhedral grains and coated, pellet-shaped grains of olivine (Appendix 2, Plate 2). Olivine pellet tuff and crystal tuff are usually mixed in variable proportions. As a result of secondary alteration, the original may be a glassy matrix and olivine grains were totally replaced by smectite. The crystal tuff grains, however, are mostly fresh and well preserved. In the samples from hole ML95-1, crystal tuff is more abundant than in those from hole ML95-3 (Appendix 1). A number of grains, but probably not all crystals, are believed to be from wallrock contamination, whereas the olivine pellets are of juvenile origin. In hole ML95-3, the juvenile olivine pellets (lapilli) are most abundant and the unaltered crystal grain contributions decrease to less than 1% at 134 m (Appendix 1, Table 1.1). Various xenoliths and autoliths are randomly included in the rock. No correlation was observed between type and amount of inclusions and the depth of the sample. Petrographic details for the relevant core intervals are described in Appendix 1. Appendix 2 contains photomicrographs of features, textures and structures noted in the core (Plates 1 to 10).

2.1 Crystal Tuff

The unaltered grains, mainly crystals and volcanic particles, constitute up to 35% of the rock volume (Appendix 1, Table 1.1). The crystals, ranging in size from 0.2 to 0.5 mm, are mostly incomplete, being frequently broken and angular (Appendix 1; Plates 1A and B). Their mineralogical composition, mainly quartz and feldspar, shows an important contribution of non-ultrabasic volcanic sources (Appendix 1, Table 1.2). The grains are fresh and generally not altered, indicating a very short transportation distance (Plates 1A and B). Their dimensions are more than 10 to 25 times the maximum size of the clastic grains included in any of the sedimentary Wapiti Formation fragments found in the thin sections of core. This textural relationship excludes the possibility that these grains resulted from disaggregation of Wapiti Formation rocks.

Olivine content is significantly lower in the crystal tuff than in the olivine pellet tuff (Appendix 1, Table 1.2), and the olivine grains are less perfect and smaller in size. Moreover, due to flow and internal friction, the coatings on the olivine grain tend to be thinner. The intergranular matrix is significantly more abundant in perovskite and chromite inclusions from destroyed olivine rims than the matrix of the olivine pellet tuff (Plates 3A to C).

The crystal tuff grains include strained and unstrained quartz, chert, clear plagioclase (usually andesite-labradorite), sanidine, green hornblende, oxy-hornblende, biotite and clinopyroxene (Appendix 1, Table 1.2). Microcline, sericitized plagioclase (usually oligoclase), epidote, actinolite, sphene and dravite-tourmaline occur less commonly. Most of the green hornblende and pyroxene grains are likely of volcanic, trachyte-phonolite origin, but some of them might also be from plutonic sources. The unstrained quartz grains and clear plagioclase may have come from rhyolitic volcanism. The strained quartz grains are probably derived from the crystalline basement.

The crystal tuff in hole ML95-1 is interlayered with cross-bedded sandstone (Leckie et al., 1997), which might indicate crater facies for this tuff. However, the mixing of crystal tuff with olivine pellet tuff indicates diatreme facies. The interlayering with sedimentary rocks may be the result of sill-like intrusions of the ‘intrusive tuff’ (tuffisite). This possibility needs further investigation.

2.1.1 Secondary Replacements

In addition to common olivine and matrix alteration to smectite in the crystal tuff, there is further replacement of clay by analcite, zeolites and quartz. The replacements are younger than the main clay alterations.

Alteration of olivine grains to analcite is common in the upper section of hole ML95-1 at 7.2 m, and it is almost ubiquitous at 35 m. Many clay pseudomorphs are partly or totally replaced by analcite. The inclusions of chromite and perovskite inherited from olivine are frequently found within the replacing analcite. Locally, analcite (Plates 4A and B) is accompanied by imprecisely determined zeolite, whose characteristics are closest to stilbite. Zeolite crystals are tabular in shape with well-defined cleavage and are frequently twinned. Partial alteration of plagioclase to analcite was also noted. Replacement of clay by analcite and zeolite is a low-temperature metasomatic process. Analcite and zeolite were analyzed by scanning electron microscope (SEM).

Silicification of altered olivine grains is less extensive then analcitization. Nevertheless, silicification is common locally in ML95-1 (at depth 64 m), occurring as authigenic quartz infillings within altered olivine. New authigenic quartz is usually amoeboid in shape (Plates 4C and D). Euhedral replacements are less common.

2.2 Olivine Pellet Tuff

Typical olivine pellet tuff occurs in hole ML95-3 (Plates 1C and D). It consists of olivine particles, totally altered to smectite, up to 4 mm in size. The olivine pseudomorphs are surrounded by a fine-grained matrix. Xenoliths of sedimentary rocks and unaltered tuff grains (such as quartz, feldspar, amphibole and pyroxene) are randomly included in olivine pellet tuff. Due to coating, included sedimentary fragments sometimes assume a pellet shape (Plate 2A). Two textural varieties of pellet can be distinguished in thin sections of olivine pellet tuff: irregular brecciated pellets and rounded pellets. They cannot be clearly discriminated, as both varieties of olivine particles might be mixed together. Olivine can grade in shape from broken grains to perfectly euhedral ones (Plates 5A to D). In the brecciated variety, which is dominant in hole ML95-3 (except at depth 134 m), individual grains of olivine are loosely 'floating' in the matrix. Many of them (at 117.9 m) are broken and angular. Transitional grain textures toward pelletal forms occur as well. The olivine pellet tuff is dominant at depth 134 m in hole ML95-3.

2.2.1 Pellet Texture

The rounded objects that occur ubiquitously in most of the Mountain Lake cores are likely similar, in origin and texture, to objects in diatreme kimberlites called 'pelletal lapilli' by Clement and Skinner (1979); see also Mitchell (1989, p. 47). They vary in shape from subrounded to perfectly spherical or elliptical. The sphericity of olivine grains is due mainly to external coating (Plates 2B and C). The pellets range in size from 0.5 to 1.5 mm and can take several forms. The larger ones, up to 4 mm, frequently show porphyritic textures (Plate 2D) and are probably autoliths. Smaller particles, up to 1 mm in size, commonly include only one olivine grain. Sometimes pellets show cores of feldspar or other fragments from the wallrock, which may have been nucleating centres (Plates 6A to C). At 134 m depth in hole ML95-3, concentric layers of apophyllite have grown over some 'pelletal lapilli'. Two zones typically occur across the pellet: an internal core and an outer shell. The internal core is usually outlined by original olivine, whose clay is commonly lighter than the smectite of the outer shell.

2.2.2 Inclusions in Pellets

Fibrous, opaque inclusions are common in the internal zone of the pellets (Plate 5B). The opaque fibres are up to 10 µm in width, and up to 0.3 mm in length. More detailed optical determination and microprobe analysis have not yet been done. Perovskite is abundant in the external clay zone of a pellet, but very uncommon in the internal zone outlined by original olivine. Perovskite grains, up to 30 µm in size, are clear, transparent and pale yellow in colour (Plates 5C and D). Due to an octahedral habit, which is more frequent than its normal cubic shape, and a very high refractive index, perovskite is deceptively similar to microdiamond in the Mountain Lake Pipe.

Chromite crystals, up to 60 µm in size, are common inclusions in the pellets. Chromite grains are mostly euhedral and their surfaces are frequently intergrown with very fine grained perovskite. An unusual myrmekite-textured chromite sometimes occurs within clay (Plate 3D). The myrmekitic chromite was formerly intergrown with olivine (depth 161.9 m in hole ML95-1). Occasionally, the inner zones of pellets are infilled with secondary zeolite (scolecite?) or calcite (Plate 2B).

It is emphasized that pellets or 'lapilli', especially in hole ML95-3, did not originate as effusive clasts, since precipitation of perovskite and chromite in their rims would not be possible in superficial conditions. Their origin could be explained by rapid crystallization of magma droplets onto the surfaces of grains acting as nucleating centres, as described by Clement and Skinner (1979) for the diatreme 'kimberlite pellets'. Presumably, all coated country-rock clasts that often occur in the Mountain Lake Pipe samples were formed in this way.

2.3 Matrix

The texture and mineralogy of the matrix of both crystal tuff and olivine pellet tuff are generally consistent in all of the samples studied. The primary minerals and volcanic glass in the interclastic matrix have been destroyed by secondary smectite alteration. Only inclusions of perovskite, chrome spinel and very fine grained opaque impurities of pyrite and iron oxide remain unaltered. Locally in the matrix clay, which is usually yellow-brown in colour, small clusters of lighter clay lacking impurities, can be found. These might be altered olivine debris.

The opaque inclusions are distributed in the matrix randomly without any evidence of sorting or segregation. Nevertheless, evidence of matrix flow (e.g., at 35 m in hole ML95-1) is sometimes noticeable due to a weak linear arrangement of elongated pyroclastic grains. The rate of flow was not very high. The matrix structures do not show any disruptions or fragmentation that might be the result of eruption onto the surface. In some intervals (e.g., 134 m in hole ML95-3), the matrix of pelletal lapilli tuff is undisturbed by flow.

At 134 m in hole ML95-3, phenocrystic apophyllite (mineralogically similar to zeolite) is commonly included in the matrix. Rarely, it also infills thin veinlets. Apophyllite phenocrysts, up to 0.03 mm in size, are subhedral to euhedral-quadratic in shape and sometimes form clusters of tabular crystals, about 0.3 mm in size (Plates 7A to D). In polarized light, apophyllite is typically uniaxial (negative), with very low birefringence and subnormal blue interference colours. Isotropic grains of apophyllite also occur. As optical and crystallographic properties of apophyllite are very close to those of melilite, the grains were analyzed on the University of Alberta's electron microprobe to avoid misidentification. Because F and OH^{-} were not analyzed, the member of the series fluoroapophyllite-hydroxyapophyllite is undetermined (Dunn et al., 1978). Results from the microprobe analysis of apophyllite are included in Appendix 3, Table 3.1.

At the same sample location, fine-grained calcite (up to 0.05 mm in size) is mixed with the matrix clay. The origin of the matrix calcite is not clear: it might be a juvenile product from carbonatite magmas or local precipitate due to fluid reaction with carbon dioxide.

2.4 Lithic Inclusions

Lithic particles are very common in the Mountain Lake Pipe samples. They range up to several centimetres in hand specimen, but in thin sections their size is noticeably up to a few millimetres. They can be roughly classified as xenoliths and autoliths. The xenoliths are mostly clastic sedimentary rocks (from the Wapiti Formation), volcanic trachyte/phonolite and plutonic-metamorphic fragments (Plates 8A to D).

For practical purposes, all lithic fragments that contain any altered olivine, which is certainly a juvenile component, are considered to be autoliths (Plates 9A to D). The distinction between porphyritic autoliths and single-grain or pellet-shaped olivine is artificial, as both have the same juvenile origin. The autoliths also show well-defined limits. Their matrix might differ in texture and/or mineralogy from the matrix of the host rock. Apart from the above lithic types, particles composed of fine-grained (approx. 0.01 mm), equigranular carbonate (calcite?) also occur. Among carbonate grains, clusters of brown-coloured clay, up to 0.05 mm in size, are evenly distributed. No other minerals have been found. These particles cannot be classified, as their origin is unknown. They might be sedimentary xenoliths or juvenile carbonatite fragments.

2.4.1 Xenoliths

Trachyte-phonolite fragments are quite common in the core sections rich in crystal tuff. Without any proof, they were arbitrary classified here as xenoliths. However, their accidental, wallrock origin is not certain. If the ultramafic pipe material was hybridized by shallow, alkaline trachyte-phonolite magmas, then all these volcanic inclusions may prove to be autoliths. The undivided trachyte-phonolite particles are the only volcanic rock type common in the Mountain Lake Pipe. They generally occur in crystal tuff. In olivine pellet tuff, volcanic particles are less common. Due to their fine-grained texture, detection of feldspathoids is very difficult. Nepheline was found in only one particle. Trachyte-phonolite pieces show subrounded shapes and are up to 0.7 mm in size. Their texture is porphyritic and shows development of K-feldspar grains of sanidine and anorthoclase composition (Plates 8A and B). Twinned anorthoclase crystals are up to 0.2 mm in length. The subhedral phenocrystic amphibole, biotite and apatite (at 7.22 m in hole ML95-1) occur in trachyte as well. Phenocrystic clinopyroxene is less frequent.

Volcanic glass particles are angular to subrounded in shape and up to 1 mm in size. They show vitroporphyritic texture and a glassy matrix. Tiny crystals of feldspar, amphibole or biotite, arranged in a fluidal pattern, occur in the matrix (Plate 8C). Many chert-textured particles included in the crystal tuff might be devitrified volcanic glass. Some of them contain feldspar phenocrysts. Uncommonly, glassy pieces show pellet coatings with inclusions of perovskite (88.8 m in hole ML95-3).

Plutonic-metamorphic grains consist of strained quartz, mosaic-textured quartz, quartz intergrown with mica or pyrophyllite, sericitized plagioclase (usually oligoclase), microcline, and some green hornblende. This group also includes minor epidote, actinolite, sphene and dravite-tourmaline.

Sedimentary particles of fine-grained clastic rocks and carbonaceous particles are very common xenoliths in all core levels (Plate 8D). In thin section, their size is up to 3 mm. Sedimentary rock fragments are commonly greywacke with fine-grained texture and good sorting. The clastic grains included in particles are frequently angular, with the grain size never higher than 0.02 mm. Some particles are shale with excellent stratification. In relation to their grain size, they might be classified from very fine grained sandstone to mudstone. They are frequently impregnated by smectite.

Fragments of carbonized wood with cellular structure, up to 2 mm in size, occur randomly in many thin sections (Plate 6D). Wood particles are impregnated mainly by nepheline, zeolite or ferrugineous carbonate. Irregularly shaped carbonaceous particles with no cellular wood structure are also common.

2.4.2 Autoliths

Three textural types of olivine-bearing autolith were observed. The most common type is porphyritic. Less frequent are porphyroclastic-textured and aphanitic-textured autoliths. In thin section, they are up to 10 mm in size and show diversified shapes, from round elliptical to angular or irregular.

Uncommonly, some porphyroclastic autoliths are comprised of other sedimentary xenoliths and older juvenile autoliths. An unusual inclusion, in which olivine grains are included in fine-grained, stubby prismatic clinopyroxene and phlogopite (Plate 9A), occurs in a large ultrabasic (autolithic) cluster included in crystal tuff (7.22 m in hole ML95-1).

Porphyritic autoliths are frequent in both crystal tuff and olivine pellet tuff. They show randomly oriented grains of subhedral to euhedral olivine (altered to clay), up to 0.5 mm in size, included in the fine-grained clay or calcite matrix (Plate 9B). The perovskite grains, up to 20 µm in size, are abundant and evenly distributed throughout the matrix. Apart from perovskite, euhedral crystals of chromite are also common in autoliths. Small grains of apophyllite occur in a few autoliths (161.9 m in hole ML95-1). Uncommonly, the clay matrix is enriched in fine-grained calcite (134 m in hole ML95-3; 165 m in hole ML95-3).

The porphyritic variety of autolith, where olivine is altered to calcite (Plate 9C) is less common. The matrix consists of a mixture of fine-grained calcite and smectite with abundant inclusions of perovskite and chromite. Uncommonly, very fine grained mica (phlogopite?) is also intergrown with the calcite. Calcite is not present as a secondary impregnation, and such autoliths might be carbonatite related (Plate 9D).

Porphyroclastic autoliths are scarce in the thin sections. Their texture and mineral content show crystal tuff. They occur in hole ML95-3, and are most common at 29.8 m. The particles are up to 8 mm in size, and include porphyroclasts and phenocrysts of olivine, sanidine and amphibole, up to 0.3 mm in size. Fine-grained biotite is uncommon. Olivine is frequently replaced by secondary zeolite. These autoliths sometimes have inclusions of mudstone, chalcedony chert and trachyte-phonolite grains.

Aphanitic autoliths are rare and genetically enigmatic. The particle found at 134 m in hole ML95-3 is about 3 mm in size, angular in shape and coated by a clay-perovskite-calcite rim. The particle matrix is composed of very fine grained clay, likely from altered olivine, which is mixed with calcite. Opaque fine-grained pigment and random perovskite occur in the matrix. A minor amount of mica flakes and K-feldspar grains, about 0.4 mm in size, are found in the groundmass.

3 Diamond Indicator Minerals

Possible diamond indicator minerals found in thin section were analyzed by electron microprobe at the University of Alberta (Appendix 3, Tables 3.1 to 3.6). In addition, a thin section with mineral grains was experimentally prepared. Using distilled water and alcohol, about 30 g of the crushed sample from 165 m in hole ML95-3 was washed out from smectite. The extracted grains were mounted in rows on the thin section. Apart from considerable feldspar and amphibole, several dozen clinopyroxene grains, many chromite grains, more than twenty ilmenite grains and four garnet grains were found (Plates 10A to D). Ilmenite was first analyzed qualitatively by scanning electron microscope (SEM). Because none of the grains contained any significant amount of magnesium, no further microprobe analysis of ilmenite was carried out.

3.1 Clinopyroxene

The microprobe results from seven clinopyroxene grains in thin sections (Appendix 3, Table 3.2), show regular low-chromium diopside, indicating that it is not a diamond indicator mineral (it is too rich in iron to be an indicator). The ternary plot of molar contributions of CaO, MgO and FeO in the clinopyroxene grains analyzed is shown in Figure 2. Leckie et al. (1997) reported on euhedral grains of clinopyroxene included in juvenile lapilli. Their discovery is sufficient proof of a juvenile origin for some clinopyroxene. However, examination of 30 thin sections during the present study detected no diamond indicator minerals inside the juvenile particles except for chromite (chrome spinel) and perovskite. This means that juvenile clinopyroxene is not common, and most of the pyroxene grains occurring in the core are exotic, mainly from lateral volcanic sources.

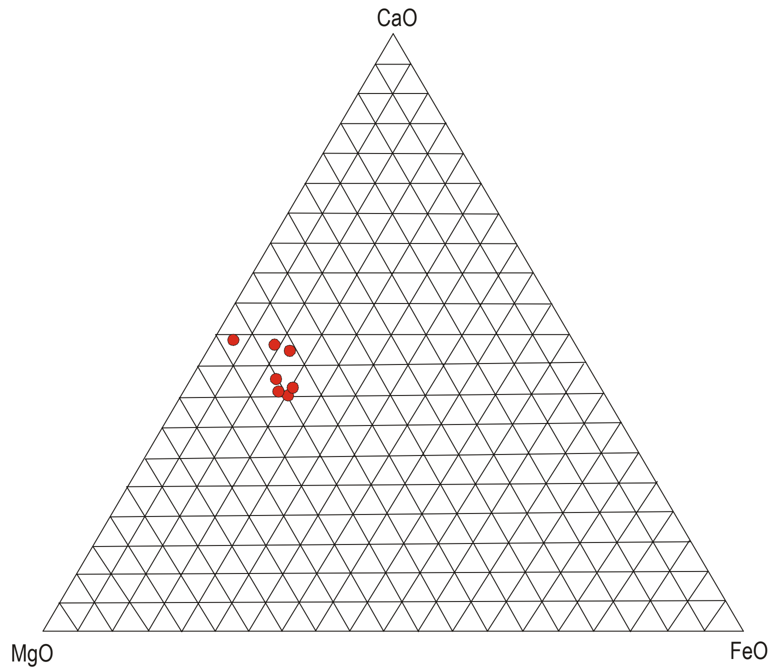

Figure 2. Ternary plot of the molar contributions of CaO, MgO and FeO in clinopyroxene from 35 m in hole ML95-1 and 165 m in hole ML95-3.

3.2 Chromite

Chromite and different chrome spinels are the only minerals of certain juvenile origin that can be considered as diamond indicator minerals in these samples. Their origin is related to precipitation from juvenile magma. The analytical results from fifteen chromite grains from 165 m in hole ML95-3 are included in Appendix 3, Tables 3.3 and 3.4. Their Cr_2O_3 versus MgO plot is in or close to the Argyle Chromites Field, although none of the analyses fit inside the Diamond Inclusions Field.

3.3 Garnet

Garnet is a rare mineral in these samples. Four grains, up to 0.2 mm in size, were found at 165 m in hole ML95-3. Three of them were washed out from the crushed rock, and one was found directly in thin section (Plate 10D). In addition, one grain was found (but not analyzed) at 134 m in hole ML95-3. The grains found in thin sections are included in the matrix and their origin is uncertain. The analytical data for these grains are presented in Appendix 3, Table 3.5. According to Dawson and Stephens (1975 and 1976) they can be classified as G5 (magnesian almandine, two grains), G11 (titanian uvarovite-pyrope, one grain) and spessartine (not a diamond indicator, one grain). It is important to note that no real G10 garnets were found. The G10 garnets reported by Leckie et al. (1997) are G9s according to the Dawson and Stephens (1975) classification.

3.4 Perovskite

Ten microprobe analyses of perovskite grains were carried out. The total for all analyses is around 90 weight percent (Appendix 3, Table 3.6). The missing 8 to 10 percent can probably be attributed to rare-earth elements (Ce, La or Y?) and possibly Th, which were not analyzed.

4 Conclusions

Abundant perovskite, chromite and olivine at all sampled levels, an amphibole (frequently oxy-hornblende), and common carbonate-bearing autoliths suggest that the rocks of the Mountain Lake Pipe show affinities to pseudokimberlitic (alnoitic or monchiquitic?) rocks rather than kimberlitic *sensu stricto* rocks. Also, low magnesium content in the majority of clinopyroxene (frequently augite), common amphibole (three varieties), spessartine and analcite are all atypical of kimberlite. Additional mineralogical characteristics, such as secondary analcite and apophyllite, are similar to some alnoitic ultramafic rocks from the Missouri River Breaks in Montana (Hearn, 1989). On the other hand, some xenocrystic minerals, such as garnets (G5, G9 and G11), picro-ilmenite and chrome diopside, analyzed by Leckie et al. (1997), indicate that a kimberlitic component was involved in the Mountain Lake Pipe. Although this last finding is encouraging for diamond exploration, on the basis of investigations to date, diamond potential is not high. Nevertheless, it is worth remembering that in Western Australia (near Wandagee) diatremes of picritic monchiquite, which have a mineralogical content close to the Mountain Lake rocks, do have rare diamonds (Jacques et al., 1988). According to the investigations of Dobrzhinetskaya et al. (1996), the occurrence of rod-like inclusions of the polymorph of ilmenite in olivine from the ultra-high pressure metamorphic peridotites in the Central Alps (Alpe Arami) requires pressures of 10 to 15 GPa (depth of 300 to 450 km). During the exhumation process, at pressures below 10 GPa, crystallographically oriented rods of β-ilmenite have been found to be exsolved from the ultra-high pressure Ti-bearing polymorph of olivine *wadsleyite*. In the Mountain Lake Pipe, the altered olivines contain abundant inclusions of chromite, perovskite, and ubiquitous rod-like inclusions having optical and textural characteristics that are similar to those described by Dobrzhinetskaya from Alpe Arami. The rods included in olivine of the Mountain Lake Pipe have not yet been chemically analyzed. However, as they appear to be β-ilmenite, their precipitation suggests that they may have formed in the pressure-temperature stability field of diamond.

Due to the ubiquitous occurrence of perovskite, the pipe might also have economic potential for rare-earth elements, a possibility that has not yet been investigated. In addition, the niobium (Nb_2O_5) content in perovskite is up to 1.488 wt.% (Appendix 3).

The complete original mineralogy of the Mountain Lake Pipe is presently unknown because of the ubiquitous clay alteration. For more accurate classification, the rocks must be studied at deeper levels below surface, where original minerals might be preserved. Also, a search for low-calcium chrome-pyrope (G10) garnet, preferably in thin-sectioned mineral concentrates, is recommended. The samples studied do not show textures typical for eruptive ejection of crater facies. In particular, fragmentation of the interclastic matrix and structural porosity, which should be ubiquitous in effusive rocks, is not observed. Moreover, the good segregation and stratification of clasts characteristic of airfalls, does not occur.

Consequently, the rock might be tentatively classified as *hybrid alkaline ultramafic*. The alkalinity is mainly due to analcite and sanidine. This classification is not much different from that proposed by Leckie et al. (1997), who described these rocks as alkaline ultrabasic volcanic. The classification by

Leckie is partly based on core logging notes, where contributions of the crater facies, especially airfalls, are depicted as predominant. In these logging notes, the airfall portions may be exaggerated. Nevertheless, it is possible that some diatreme-facies rocks might be accidentally squeezed toward the subcrater zones and consequently cut by fluvial channels or covered by airfalls or debris flows. It is also important to note that the above conclusions cannot be fully extended to unsampled core sections.

Although the rocks of the Mountain Lake Pipe are technically not kimberlites, they can still be categorized according to Clement and Skinner's (1979) kimberlite texture classification. All varieties of olivine pellet tuff, especially from hole ML95-3, fit well with *tuffisitic breccia* of the diatreme facies. Their pellet components, with all observed phenomena of crystal and lithic fragment nucleation, are diagnostic textural features of the diatreme facies (Mitchell, 1989). The crystal tuff, following Clement and Skinner's (1979) scheme, can be classified as *crystallinoclastic tuffisite* of the diatreme facies. Crystal tuff probably resulted from a lateral , 'close to pipe wall subfacies' of the main diatreme infill. Its plutonic and metamorphic crystal fragments are xenocrysts, whereas volcanic grains might be xenocrysts or phenocrysts from lateral, active volcanic sources. Two lateral volcanic sources might have been involved: trachytic-phonolitic and rhyolitic.

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Appendix 1: Petrographic Descriptions of Samples

Hole ML95-1

Depth 7.22 m: Crystal tuff (3 thin sections)

Texture: The rock is composed of crystals and lithic particles cemented by fine-grained smectite minerals. Clay particles, pseudomorphic after olivine, occur abundantly among the crystal grains. The crystals, lithic particles and olivine make up ~60 vol % of the rock. Sorting of grains is poor, but weak flow arrangement of elongated particles is noticeable.

Crystals: Grains and/or lithic grains (~25 vol %).The grains, up to 0.4 mm in size, commonly show subangular to angular shapes, but subhedral phenocrysts occur as well.

Common: Unaltered plagioclase (An35–44), sericitized plagioclase (oligoclase), sanidine, quartz.

Infrequent: Diopside-augite, hornblende, oxy-hornblende, microcline, biotite, epidote, chalcedony, serpentine, muscovite.

Lithic: Chert, volcanic glass, phonolite-trachyte (one grain with phenocrystic apatite), quartz, crystalline schist, mudstone.

Olivine: (30–35 vol %) Irregularly shaped smectite particles, pseudomorphic after olivine, are ubiquitous. Uncommonly, the olivine particles are pellet textured. They are up to 1 mm in size.

Secondary: The altered olivine particles are frequently replaced by analcite and zeolite of natrolite-group minerals.

Autoliths: Ultrabasic olivine, pellet-textured tuff particle, about 1 cm in size, is included in the crystal tuff. A few angular crystals of feldspar and plutonic quartz occur in the matrix of the particle, which is composed of a fine-grained smectite with very minor perovskite inclusions. The matrix texture does not show any evidence of flow displacement. Xenoliths of sedimentary origin and an autolithic fragment are included in the ultrabasic particle.

Matrix: (~45 vol %) The groundmass clay is fine grained and brown-yellow in colour. It is rich in impurities, fine-grained perovskite and chromite. Less commonly, grains of ilmenite and magnetite occur in the matrix.

Depth 35.0 m: Crystal tuff (3 thin sections)

Texture: The rock is composed of crystals and lithic particles welded by fine-grained matrix smectite. The crystal grains are frequently angular, broken shards. Lithic particles are subrounded to subangular in shape. Clay particles, pseudomorphic after olivine, are less common and are commonly replaced by analcite. The crystals and lithic grains make up ~35 vol % of the rock. Sorting is poor, but flow arrangement of elongated biotite and feldspar grains is distinctive.

Crystals: Grains and/or lithic grains (~35 vol %). The crystal grains, up to 0.5 mm in size, commonly show subangular to angular shapes, but subhedral phenocrysts occur as well. The lithic grains range in size up to 2 mm.

Common: Quartz, unaltered plagioclase (An35–44), sericitized plagioclase (oligoclase), sanidine.

Infrequent: Diopside-augite, hornblende, oxy-hornblende, biotite, epidote, serpentine, muscovite.

Lithic: Chert, volcanic glass, phonolite-trachyte, quartz schist. Silty shell, mudstone and wood fragments from the Wapiti Formation are also found.

Olivine: (<10 vol %) Clay particles, pseudomorphic after olivine, are uncommon.

Secondary: The altered olivine grains are commonly replaced by analcite.

Autoliths: Porphyritic fragments, up to 3 mm in size, containing altered olivine crystals included in the fine-grained clay matrix, are uncommonly found. One rounded particle of fine-grained calcite, about 5 mm in size, was observed. The carbonate cluster is coated by a fine-grained smectite with many perovskite and chromite grains included.

Matrix: (~55 vol %) The groundmass clay is fine grained and brown-yellow in colour. It is rich in impurities, fine-grained perovskite and, less frequently, chromite.

Depth 64.0 m: Olivine pellet and crystal silicified tuff (1 thin section)

Texture: The rock is mostly composed of olivine grains, altered to clay (35–45 vol %), crystal grains (~5 vol %) and rare lithic particles supported by the fine-grained smectite matrix (~50 vol %). Silicification occurs as the replacement of the interiors of some olivine grains by authigenic quartz. Sorting and arrangement of grains is very poor. Uncommon carbonaceous, silty particles of Wapiti Formation are noticeable.

Crystals: Grains and/or lithic grains (~5 vol %). The grains, up to 0.3 mm in size, commonly show angular shapes.

Common: Clear plagioclase (An28–35), sanidine, quartz. Some quartz grains, especially those showing euhedral shapes, might be authigenic crystals rather than clasts.

Infrequent: Sericitized (plutonic?) plagioclase, diopside/augite, hornblende, biotite, phlogopite, muscovite, epidote, magnetite.

Lithic: Rare phonolite-trachyte and devitrified volcanic glass.

Olivine: (35–45 vol %) Clay particles, up to 1.5 mm in size and pseudomorphic after olivine, are ubiquitous. They range in shape from broken pieces to perfectly euhedral grains. Pelletal or rounded olivine particles are very rare.

Secondary: The altered olivine grains are sometimes infilled by authigenic quartz that replaces clay.

Autoliths: Not found.

Matrix: (~50 vol %) The groundmass clay is fine grained, brown-yellow in colour and rich in impurities. The fine-grained perovskite and chromite are less common in the matrix.

Depth 161.9 m: Crystal tuff and/or olivine pellet tuff (3 thin sections)

Texture: The crystal tuff portion (~65 vol %) is mixed with olivine lapilli tuff (~35 vol %), olivine-bearing autoliths and, less common, Wapiti Formation(?) xenoliths. The crystal tuff consists of mostly angular grains, which are matrix supported. The crystal and lapilli particles are poorly sorted with no segregation observed. A very weak arrangement of elongated grains and elliptical lapilli is noticeable.

Crystals: Grains and/or lithic grains (~15 vol %). The grains, up to 0.3 mm in size, mostly show angular shapes, although euhedral grains of feldspar occur as well.

Common: Quartz, plagioclase (An17–45; frequently zoned), sanidine.

Infrequent: Diopside/augite, hornblende, oxy-hornblende, biotite, microcline, muscovite, epidote and dravite-tourmaline.

Lithic: Trachyte, devitrified volcanic glass.

Olivine: (~35 vol %) Altered olivine particles are very common. They range in shape from subhedral grains to perfectly rounded or elliptical pellets, up to 4 mm in size.

Secondary: Uncommonly, altered olivines are infilled by authigenic quartz.

Xenoliths: Sandstone, silty shells, carbonaceous mudstone and wood clusters, up to 2 mm in size, are common country-rock inclusions.

Autoliths: Porphyritic particle with carbonatized olivine crystals in the fine-grained matrix of clay-calcite-perovskite; the particle, 5 mm in size, is elliptical in shape. A few other, irregularly shaped particles with altered olivine occur as well. Grains of apophyllite occur in one particle matrix. Silty shell xenolith, 4 mm in size, is included in one of the autolithic particles.

Matrix: (~50 vol %) The groundmass clay is fine grained, brown-yellow in colour and rich in impurities. The fine-grained perovskite and chromite are less common in the matrix. A few grains of possible apophyllite were observed in the matrix (161.9 m in hole ML95-1).

Hole ML95-3

Depth 20.0 m: Olivine pellet tuff (2 thin sections)

Texture: The altered olivine, frequently pelletal, is the main component of the rock. Crystal grains and lithic grains are minor. Lithic particles of silty shell, wood particles and carbonaceous mudstone (Wapiti Formation?), up to 5 mm in size and matrix supported, are randomly distributed in the rock. Sorting of grains is very poor. A weak arrangement of elongated grains and elliptical pellets is noticeable.

Crystals: Grains and/or lithic grains (~2 vol %). The grains are angular to subrounded in shape and range in size from 0.1 to 0.4 mm.

Common: Plagioclase, sanidine.

Infrequent: Clinopyroxene, orthopyroxene, hornblende, oxy-hornblende, serpentine, chromite, ilmenite (7 grains with coordinate location), chalcedony, phlogopite, epidote, carbonate, sphene (1 grain).

Lithic: Volcanic glass (frequently devitrified), trachyte (rare).

Olivine: (~50 vol %) The altered olivine grains are up to 3 mm in size. The olivine particles are mostly rounded and transitional to pelletal in shape. The euhedral ones are less common. Fine-grained chromite, commonly euhedral and up to 0.05 mm in size, is a ubiquitous inclusion in altered olivine.

Pellets: (~60% of total olivine) The lapilli range in size from 0.5 to 5 mm and are spherical or elliptical in shape. The perovskite and/or chromite inclusions occur ubiquitously in rims of pellets.

Xenoliths: Xenoliths of devitrified volcanic glass, wood, carbonaceous mudstone and silty shale are up to 5 mm in size.

Autoliths: Crystal tuff autolithic clusters randomly occur in the rock.

Matrix: (~50 vol %) The fine-grained smectite contains abundant impurities, fine-grained chromite and perovskite grains. Fine-grained mica flakes occur in the matrix.

Depth 29.8 m: Olivine pellet tuff (1 thin section)

Texture: The rock consists mostly of altered olivine, frequently pelletal, lithic fragments and minor crystal grains. The matrix supports all particles. Sorting of grains is very poor. No arrangement of elongated grains is noticeable

Crystals: (~2 vol %) Crystal grains, angular to subrounded, are up to 0.3 mm in size.

Common: Sanidine.

Infrequent: Clinopyroxene, orthopyroxene, hornblende, serpentine, phlogopite and muscovite.

Olivine: (~60 vol %) Olivine is dominant. The altered grains range in size from 0.2 to 2 mm. The olivine particles are mostly rounded and transitional to lapilli in shape. The euhedral ones and broken fragments are less common.

Pellets: (~50% of total olivine) The pellets range in size from 0.3 to 4 mm and are spherical or elliptical in shape. Uncommonly, larger pellets are infilled by secondary zeolite (scolecite (?); (negative) with $2V\alpha \sim 5$. The perovskite/chromite inclusions occur ubiquitously in rims of the pellets. Locally, pellets are coated by black, dusty carbon (?).

Xenoliths: Angular wallrock xenoliths, up to 1.5 mm in size, consist of devitrified volcanic glass, clusters of organic matter (red-brown and up to 1 mm in size), mudstone and siltstone.

Autoliths: Porphyritic fragment up to 1 cm in size, consisting of carbonatized altered olivine in a fine-grained, clay-calcite-mica-perovskite matrix (one particle). Crystal tuff with porphyroclastic texture, 8 mm in size (one particle).

Matrix: (~30 vol %) Fine-grained smectite with abundant impurities.

Depth 88.8 m: Olivine pelletal and/or breccia tuff (1 thin section)

Texture: The altered grains of olivine, ranging in size from 0.2 to 2 mm, are subhedral, rounded and angular in shape. The roundness of grains is enhanced by common pelletal coating, which is also developed on some lithic clusters. The lapilli and grains are supported by the matrix. Sorting of grains and arrangement is very poor. The fine-grained 'wedge' of clay is included in the rock. The clay does not contain any altered olivine particles or lapilli, but fine-grained and well-sorted crystals. This might be an inclusion of the airfall sediment(?).

Crystals: (~2 vol %) Crystal grains, up to 0.4 mm, consist mostly of sanidine, clinopyroxene, hornblende, muscovite, epidote, chromite and rare ilmenite (1 grain).

Olivine: Olivine grains make up ~40 vol % of the rock. Euhedral grains are very rare. Transition to spherical lapilli is common.

Pellets: (30% of total olivine) The lapilli, spherical or elliptical in shape, range in size from 0.5 to 3 mm. Some pellets contain kernels of sedimentary lithic particles. The perovskite/chromite inclusions occur ubiquitously in rims of pellets.

Xenoliths: Angular mudstone, sandstone and shell particles, up to 5 mm in size.

Autoliths: Particles with porphyritic texture, consisting of altered olivine in a smectite matrix, occur randomly.

Matrix: (~50 vol %) The matrix is composed of smectite with impurities.

Depth 117.9 m: Olivine pelletal and/or breccia tuff (1 thin section)

Texture: The rock consists mainly of altered particles of olivine, uncommon lithic fragments and crystal grains. The clasts are poorly sorted with a weak arrangement of elongated particles. The clastic fragments are mostly supported by the matrix.

Crystals: (<5 vol %) The crystal grains, angular to subangular, vary in size from 0.02 to 0.1mm.

Common: Plagioclase, sanidine.

Infrequent: Hornblende, clinopyroxene, biotite, epidote, apatite.

Olivine: (~ 65 vol %) Olivine, up to 1.5 mm in size, varies in shape from broken fragments to perfectly euhedral grains that are sometimes infilled with serpentine. Secondary infillings of zeolite (scolecite?) occur randomly in olivine as well. The perovskite and/or chromite inclusions occur abundantly in pelletal shells and rims of olivine.

Pellets: (10–15% of total olivine) The pellets are up to 1.5 mm in size.

Xenoliths: Occasional angular sedimentary particles consist of fine-grained greywacke (~1.5 cm in size; Wapiti Formation?), carbonaceous particles and carbonatized shell.

Autoliths: Occasional autoliths consist of porphyritic, irregularly shaped pieces with altered olivine in the clay matrix.

Matrix: Fine-grained smectite with frequent inclusions of chromite, up to 0.03 mm in size. Tiny grains of perovskite and chromite are common in the matrix. One grain of euhedral prismatic apatite, 0.05 mm in length, was found. Thin flakes of muscovite, arranged by flow, occur in the matrix.

Depth 128.2 m: Olivine breccia tuff (1 thin section)

Texture: The rock consists mainly of altered particles of olivine, uncommon lithic fragments and subordinate amounts of crystal grains. The clasts are not sorted and are supported by the matrix.

Crystals: (<5 vol %) The crystal grains, up to 0.2 mm in size, are angular to subangular in shape.

Common: Feldspar (common plagioclase and minor sanidine)

Infrequent: Hornblende, clinopyroxene, biotite, orthopyroxene, serpentine and rare muscovite.

Olivine: (~30 vol %) The altered olivine is ubiquitous. It is irregularly shaped, subhedral or pelletal. Broken particles are common. The perovskite and chromite inclusions occur ubiquitously in olivine. Grains of apophyllite are included in one clay cluster after olivine.

Pellets: (~5% of total olivine) The pellets, up to 1 mm in size, are mostly spherical.

Xenoliths: (<5 vol %) Mudstone, devitrified volcanic glass, carbonaceous particles and very rare trachyte.

Autoliths: Not found.

Matrix: Impure, fine-grained smectite clay with frequent grains of chromite, up to 0.03 mm in size. Tiny grains of perovskite are common in the matrix.

Depth 134.0 m: Olivine pellet tuff (8 thin sections)

Texture: The rock consists mostly of particles of olivine altered to clay. Lithic fragments and minor crystal grains are less common. Particles are mostly clast supported. Crystal grains occur only in the matrix. All these components are randomly oriented and not sorted. Stratification was not observed.

Crystals: (<1 vol %) Crystal grains, ranging in size from 0.1 to 0.2 mm, include feldspar, clinopyroxene, orthopyroxene, hornblende, oxy-hornblende, epidote, garnet (1 grain), ilmenite (1 grain), chromite, biotite-phlogopite.

Olivine: (75–80 vol %) Olivine is dominant. The altered grains, up to 1.5 mm in size, vary from irregularly shaped to euhedral. Many of them are pellets coated by spherical shells.

Pellets: (40–50% of total olivine) The lapilli, which vary in size from 0.5 to 2 mm, are spherical or elliptical. The perovskite-chromite inclusions occur ubiquitously in olivine and lapilli. Locally, lapilli are coated by black, dusty carbon. Uncommon apophyllite segregations occur on pelletal rims.

Xenoliths: Angular mudstone xenoliths, up to 5 mm in size.

Autoliths: Particles with porphyritic texture, consisting of altered olivine in a smectite and carbonate matrix, occur randomly.

Matrix: (15–20 vol %) The matrix is composed of fine-grained smectite. A fine-grained, phenocrystic(?) apophyllite was frequently observed in the matrix. The crystals of apophyllite, up to 0.05 mm in size, are frequently euhedral and grouped in clusters. Apophyllite grains are mostly isotropic. Some grains show a weak birefringence and are uniaxial (negative) with subnormal blue interference colours. Apophyllite was determined by optical characteristics and analyzed by microprobe (Appendix 3, Table 6). Tiny crystals of calcite, up to 0.05 mm in size, are loosely distributed in the matrix.

Depth 165.0 m: Olivine breccia tuff (3 thin sections)

Texture: The rock consists mostly of altered clay particles of olivine and minor amounts of crystal grains and lithic fragments. The olivine grains vary from broken fragments to subhedral, with sizes ranging from 0.1 to 3 mm. The spherical lapilli are minor. The clasts are very poorly sorted and supported by the matrix. The clastic grains do not show any segregation or stratification. Organic matter impregnated with siderite and pieces of carbonized wood are noticeable.

Crystals: (~5 vol %) The crystal grains, angular to subrounded, range in size from 0.01 to 0.3 mm.

Common: Quartz and feldspar.

Infrequent: Clinopyroxene (diopside or augite diopside with Z/γ = 48°), hornblende, oxy-hornblende, phlogopite, orthopyroxene, garnet (G5 and G11), chromite, ilmenite, magnetite, serpentine clusters.

Olivine: (~ 60 vol %) Olivine is ubiquitous and totally altered to smectite. Olivine that is altered to serpentine occurs rarely. The grains are irregularly shaped (broken), subhedral or pelletal. The perovskite and chromite inclusions are common on rims of olivine and pellets.

Pellets: (~5% of the total olivine) The pellets, up to 0.7 mm in size, are subrounded to spherical in shape. Broken fragments of pellets are infrequent.

Xenoliths: Angular, glassy, devitrified shards and pieces of mudstone and wood, up to 1 mm in size, occur rarely.

Autoliths: One porphyritic particle, consisting of altered phenocrystic olivine in a carbonate-smectite matrix.

Matrix: (~35 vol %) Fine-grained, yellowish smectite dominates in the matrix. Fine-grained chromite, perovskite, ilmenite and magnetite are randomly distributed in the matrix.

Depth 172.7 m: Crystal tuff and/or olivine pellet tuff (2 thin sections)

Texture: The rock consists of crystal grains, particles of olivine altered to clay, and lithic fragments (less common). All of these clasts are poorly sorted and supported by the matrix. The clastic components do not show any segregation or stratification, although a very weak arrangement of elongated grains and elliptical lapilli is noticeable.

Crystals: (~15 vol %) The crystal grains are angular to subangular, and range in size from 0.02 to 0.5 mm.

Common: Quartz and feldspar, with dominating andesite plagioclase. Some grains of quartz are subhedral. K-feldspar is mostly sanidine with 2Vγ = 0–5γ. Perthite K-feldspar grains occur randomly. Plagioclase (~An35) is mostly very fresh and rarely zoned. Sericitized plagioclase, probably from plutonic and metamorphic sources, occurs infrequently as well.

Infrequent: Amphibole, biotite, clinopyroxene and serpentine, up to 0.2 mm in size, are less common than quartz and feldspar. Amphibole comprises regular green hornblende (Z/γ = ~12γ), which is most common, and oxy-hornblende (Z/γ = 0γ). The oxy-hornblende is distinctly brown-red in colour for N

Olivine: (~40 vol %) The altered olivine is ubiquitous and is irregularly shaped, subhedral or pelletal. The perovskite and chromite inclusions occur ubiquitously in altered olivine rims and on pellet rims.

Pellets: (~10% of total olivine particles). The pellets, up to 1 mm in size, are spherical or elliptical in shape. Broken pellets are rare A few pellets contain nucleating kernels of quartz and feldspar.

Xenoliths: Among lithic particles, the most frequent are epiclasts(?) of siltstone and sandstone, and carbonaceous wood particles, up to 2 mm in size. The carbonized particles are sometimes impregnated by nepheline. Less common are trachyte-phonolite fragments and fibrous metamorphic particles.

Autoliths: One porphyritic particle, 3 mm in size, consisting of altered olivine in a mica-carbonate matrix, was noted.

Matrix: (~40 vol %) Very fine grained, yellow-brown smectite is dominant. It is rich in opaque impurities and tiny flakes of mica. Magnetite, chromite and perovskite occur in the matrix. Fine-grained alteration products (leucoxene) after ilmenite are randomly included in the matrix.

Table 1.1. Major rock components.

Sample	Grains[1] (vol %)	Olivine[2] (vol %)	Matrix (vol %)
ML95-1 (7.2 m)	~25%	~30%	~45%
ML95-1 (35.0 m)	~35%	<10%	~55%
ML95-1 (64.0 m)	~5%	~45%	~50%
ML95-1 (161.9 m)	~15%	~35%	~50%
ML95-3 (20.1 m)	~2%	~50%	~50%
ML95-3 (29.8 m)	~2%	~65%	~30%
ML95-3 (88.8 m)	~2%	~50%	~50%
ML95-3 (117.9 m)	<5%	~65%	~35%
ML95-3 (128.2 m)	<5%	~45%	~50%
ML95-3 (134.0 m)	<1%	~80%	~20%
ML95-3 (165.0 m)	~5%	~60%	~35%
ML95-3 (172.7 m)	~15%	~40%	~45%

[1]crystals and volcanic particles

[2]olivine particles replaced by clay and olivine pellets

Table 1.2 Description of more common cristal tuff unaltered minerals. Possible origin: (v) volcanic, (p) plutonic, (m) metamorphic, (u) uncertain.

Mineral	Description
Biotite (v)	Very elongated flakes with extremely strong pleochroism: γ - black-brown, α - yellow.
Clinopyroxene (v) or (u)	Usually anhedral, broken grains. Common diopside. Z/γ = 38° - 48°; (+ve); Some grains (probably augite) show very weak pale grey pleochroism. One grain (possibly Cr diopside?, not analysed) show distinct pleochroism in green colour.
Hornblende (v), (p) and (u)	Three varieties occur: I. Pleochroism: γ - pale green, α - pale yellow; Z/γ = 18° (-ve). II. Pleochroism: γ - dark olive-green, α - light olive-green; Z/γ = 8-10° (-ve). III. Pleochroism: γ - brown-green, α - yellow; z/γ = 18 -22° (-ve).
Microcline (m)	Common rounded, corroded rims. Typical "tartan"- textured twinnings.
Orthopyroxene (u)	Enstatite. Colourless; Straight extinction; (+ve); Low birefringence. On rims, grains are commonly corroded or replaced by serpentine.
Oxy-horblende (v)	Commonly broken, anhedral grains occur. Pleochroism: γ - dark red-brown, α - yellow; z/γ = 0°. (-ve)
Plagioclase (p)	Commonly sericitized grains, with 15-25% An content.
Plagioclase (v)	Very clear and unaltered grains. Anorthite content (35-45%). Polysynthetic twinnings and zonal textures are frequent. Grain shapes ranging from broken shards to subhedral. Common broken shards. Subhedral grains are less common.
Quartz (p/m)	Common undulatory extinction. Mosaic-textured grains. Some grains are intergrown with pyrophyllite or mica. Uncommonly, needle-like rutile inclusions occur.
Quartz (v)	Entirely strain-free grains with unitary extinction. Broken shards are common. Subhedral and euhedral grains scaecely occur.
Sanidine (v)	Unaltered clear grains, unheadral to euhedral in shape. Very low $2V\alpha$ = 0° - 10°

Appendix 2: Photomicrographs

Plate 1. General textures

A) crystal tuff with included wood fragment, crossed polars (ML95-1, 35.0 m); B) Crystal tuff texture, polars partly uncrossed (ML95-1, 161.9m); C) olivine pellet tuff, plane-polarized light (ML95-3, 134.0 m); D) olivine pellet tuff (brecciated), crossed polars (ML95-3, 117.9 m).

Plate 2. Pellets

A) pellet with sedimentary lithic particle forming the nucleus, plane-polarized light (ML95-1, 88.8 m); B) pelletal olivine infilled with zeolite, crossed polars (ML95-3, 134.0 m); C) pellet overgrowing olivine, crossed polars (ML95-3, 134.0 m); D) pellet-shaped autolithic particle, crossed polars (ML95-3, 134.0 m).

Plate 3. Chromite and perovskite inclusions

A) chromite overgrown by perovskite crystals included in clay (ML95-1, 7.22 m); B) chromite grains included in clay, plane-polarized light (ML95-1, 7.22 m); C) perovskite grains included in clay, plane-polarized light (ML95-1, 7.22 m); D) myrmekite-textured chromite included in clay pseudomorphing olivine, plane-polarized light (ML95-3, 134.0 m).

Plate 4. Secondary replacements

A) analcite (black, euhedral crystals) and zeolite (grey) replacing smectite in crystal tuff, crossed polars (ML95-1, 7.22 m); B) analcite replacing smectite, crossed polars (ML95-1, 35.0 m); C) authigenic quartz replacing pseudomorphic clay after olivine, crossed polars (ML95-1, 64.0 m); D) authigenic quartz replacing pseudomorphic clay after olivine, crossed polars (ML95-1, 64.0 m).

Plate 5. Olivine rim textures (ML95-3)

A) euhedral olivine pseudomorphed by clay and serpentine (117.9 m); B) unidentified fibrous inclusions in olivine (bottom left corner) and pelletal rim with perovskite and chromite inclusions, plane-polarized light (134 m); C) olivine coated by rim enriched in perovskite, plane-polarized light (134 m); D) pellet rim with perovskite-chromite inclusions, plane-polarized light (134 m).

Plate 6. Nucleated pellets and carbonized wood

A) quartz grain nucleus, crossed polars (ML95-3, 172.9 m); B) quartz grain nucleus (ML95-3, 172.9 m); C) carbonized wood particle impregnated by nepheline (ML95-3, 172.9 m); D) K-feldspar grain nucleus, crossed polars (ML95-1, 7.22 m).

Plate 7. Apophyllite in the matrix and pellets (ML95-3, 134.0 m)

A) microphenocrystic apophyllite plane-polarized light; B) apophyllite infilling phlogopite grain, plane-polarized light; C) phenocrystic apophyllite, plane-polarized light; D) apophyllite in the pellet, plane-polarized light.

Plate 8. Xenoliths

A) trachyte-phonolite particle with lath-shaped anorthoclase phenocrysts, crossed polars (ML95-1, 7.22 m); B) Trachyte-phonolite with phenocrysts of apatite and corroded anorthoclase, plane-polarized light (ML95-1, 7.22 m); C) volcanic glass with phenocrysts of amphibole and biotite, plane-polarized light (ML95-3, 165.0 m); D) xenolith of sedimentary Wapiti Formation, crossed polars (ML95-1, 161.9 m).

Plate 9. Autoliths

A) Matrix of stubby clinopyroxene intergrown with phlogopite in the autolith (ML95-1, 7.22 m); B) porphyritic particle with olivine in the fine-grained calcite-clay-chromite matrix (ML95-3, 134.0 m); C) rounded autolith with carbonatized porphyrocrystic olivine in the clay-calcite-perovskite (carbonatite?) matrix (ML95-3, 134.0 m); D) calcite-clay particle (carbonatite?) coated by clay with abundant fine-grained inclusions of perovskite and chromite, crossed polars (ML95-1, 35.0 m).

Plate 10. Grains in the matrix

A) partly serpentinized clinopyroxene, crossed polars (ML95-3, 165.0 m) B) orthopyroxene (enstatite) surrounded by replacing analcite, partly uncrossed polars (ML95-3, 29.8 m); C) grains of oxyhornblende (red), hornblende (green and yellow-green) and wood particle in crystal tuff, plane-polarized light (ML95-1, 35.0 m); D) xenocrystic garnet, plane-polarized light (ML95-3, 165.0 m).

Plate 1. General textures

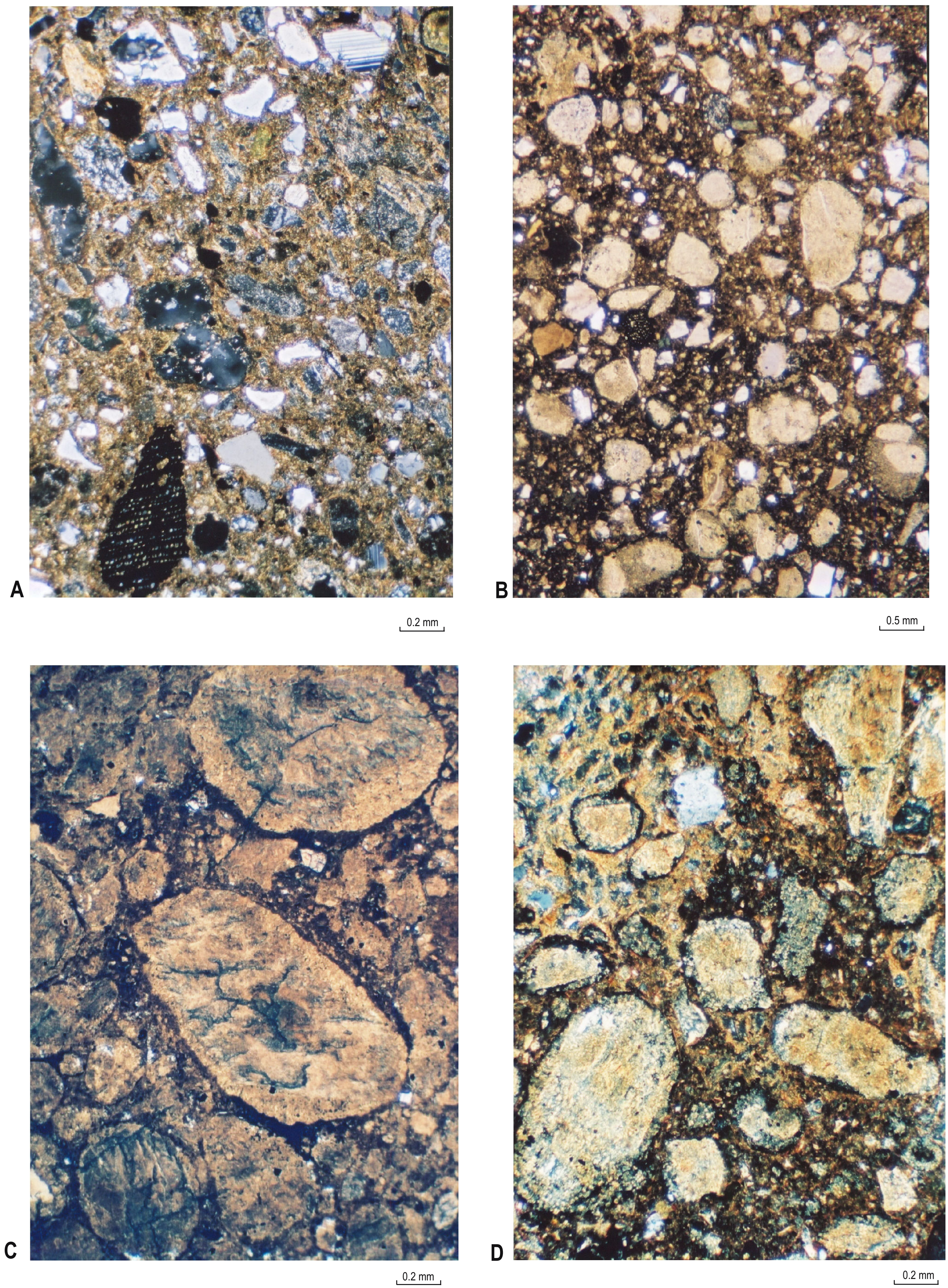
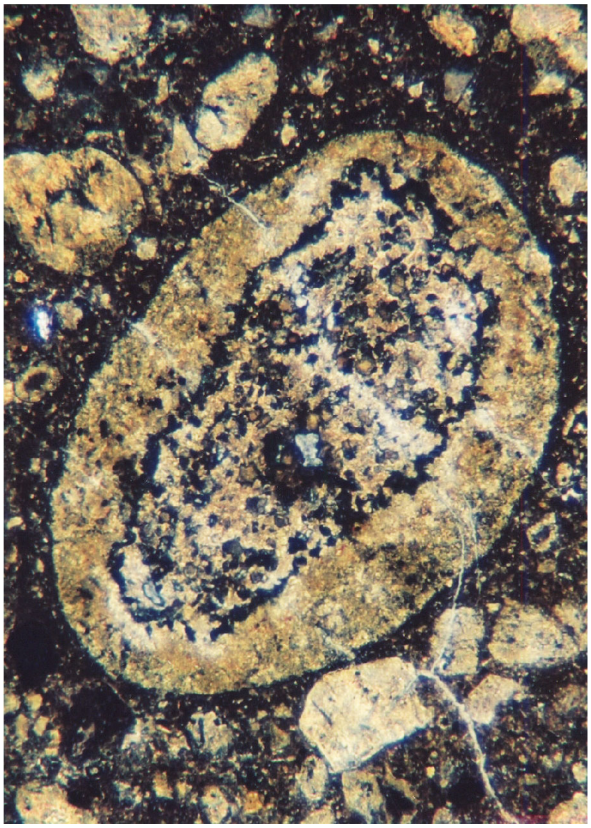
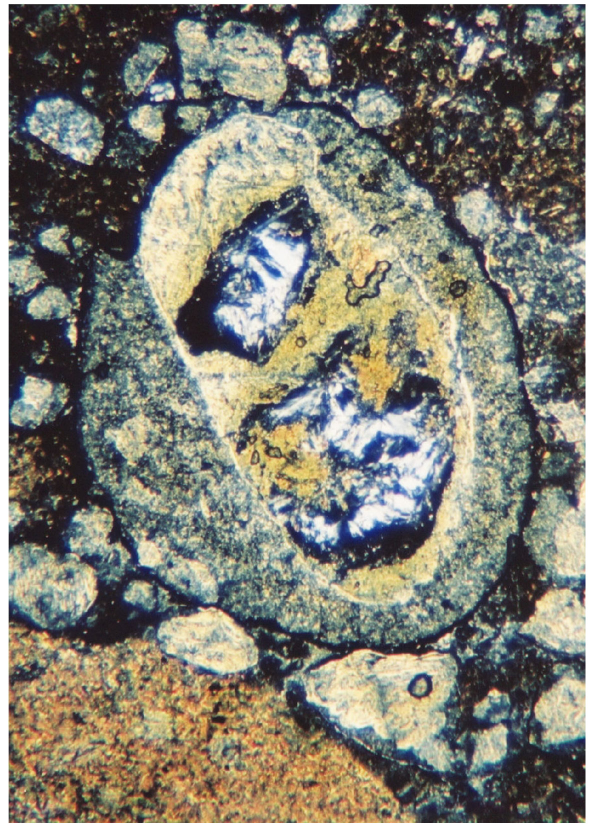


Plate 2. Pellets



A

0.5 mm



B

0.5 mm

C

0.2 mm

D

0.4 mm

Plate 3. Chromite and perovskite inclusions

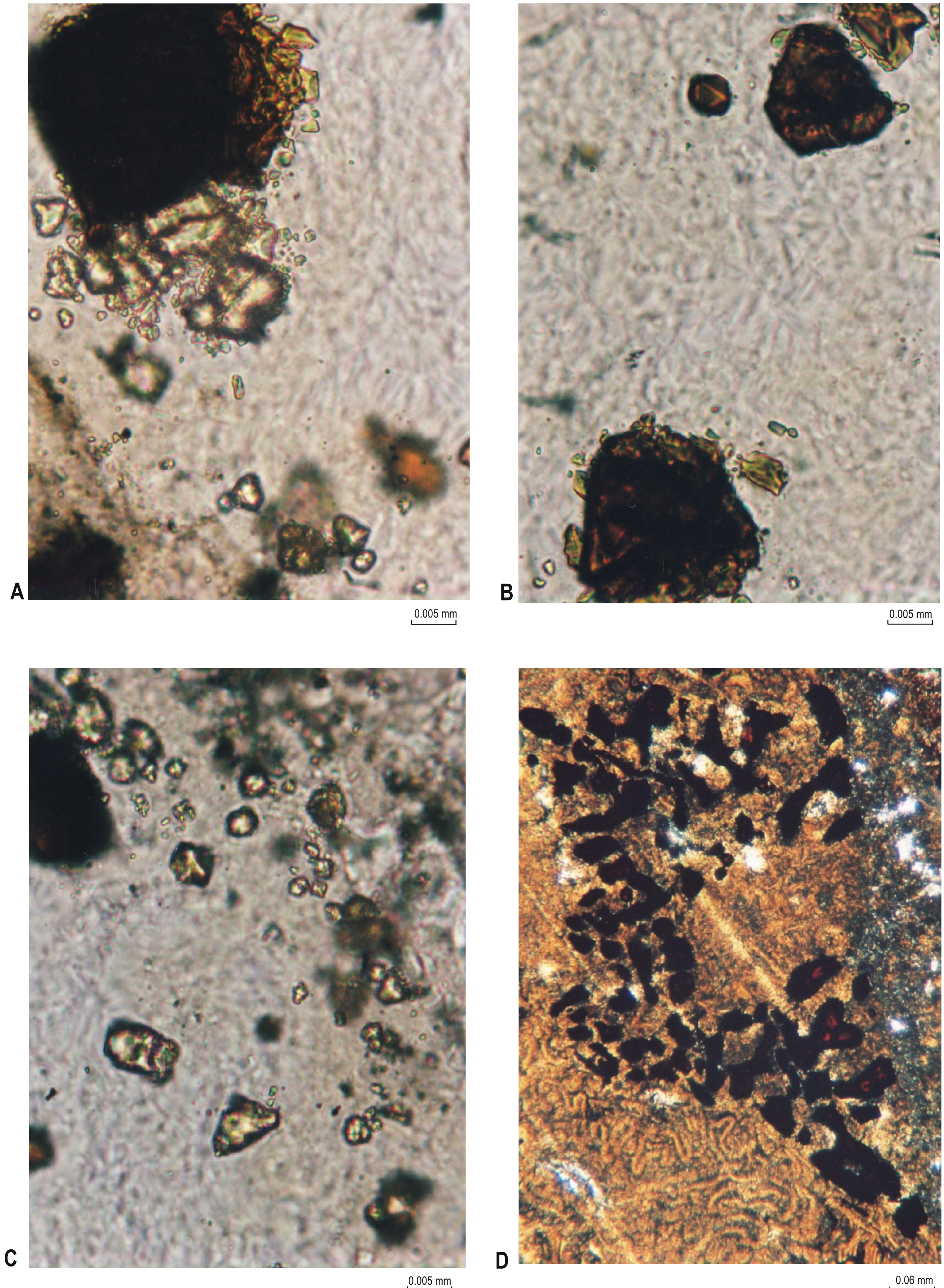


Plate 4. Secondary replacements

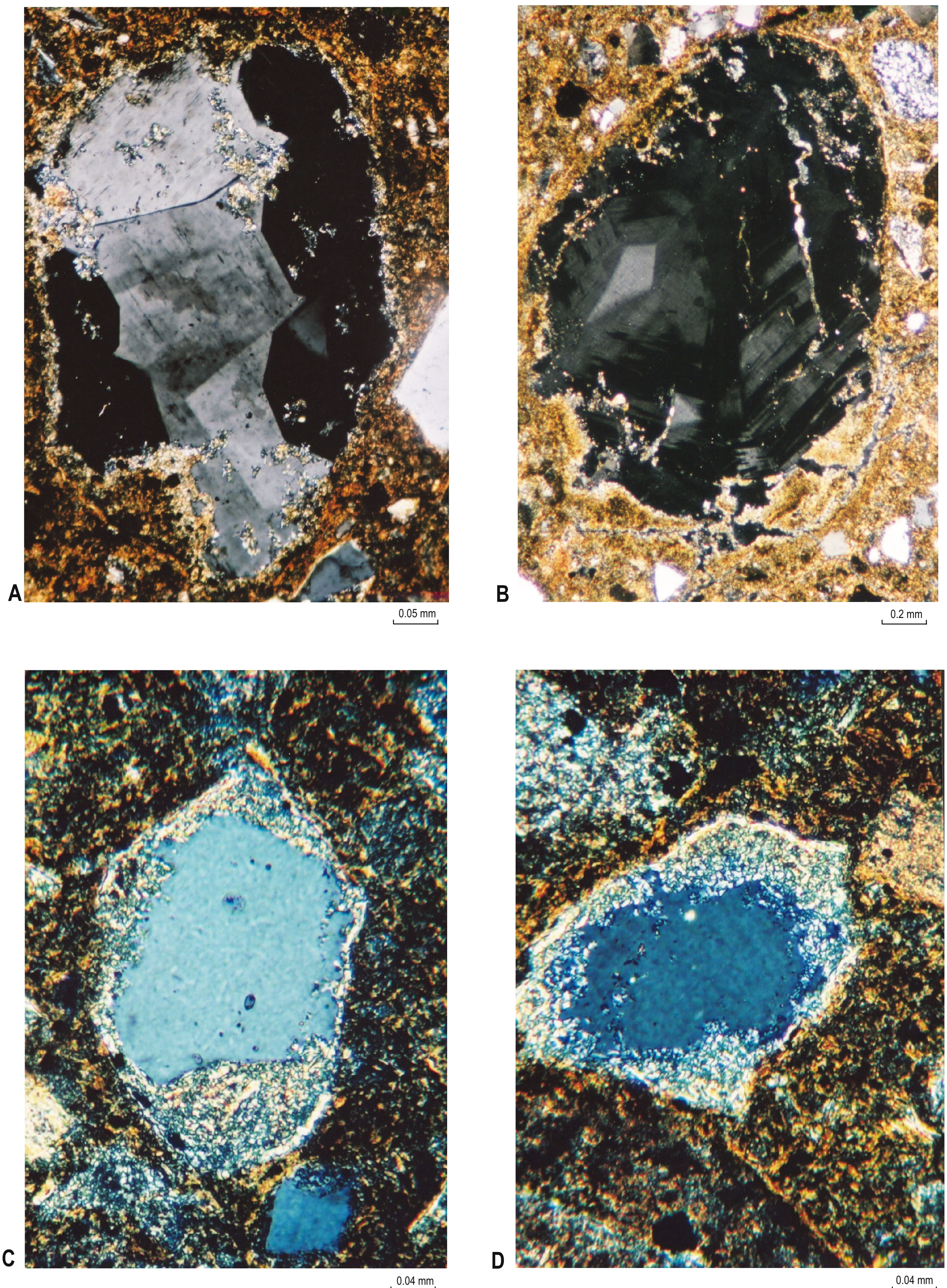


Plate 5. Olivine rim textures (ML95-3)

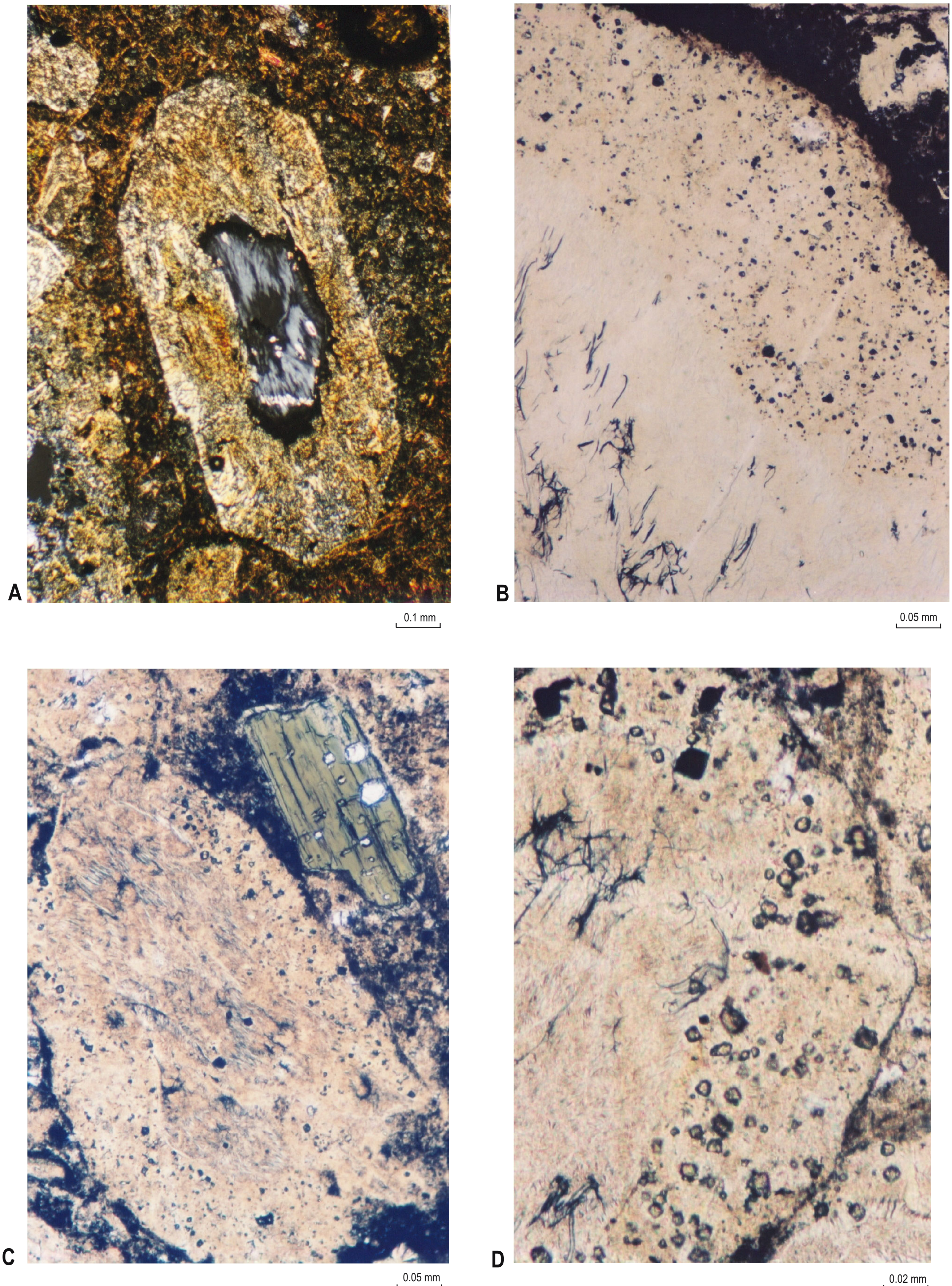


Plate 6. Nucleated pellets and carbonized wood

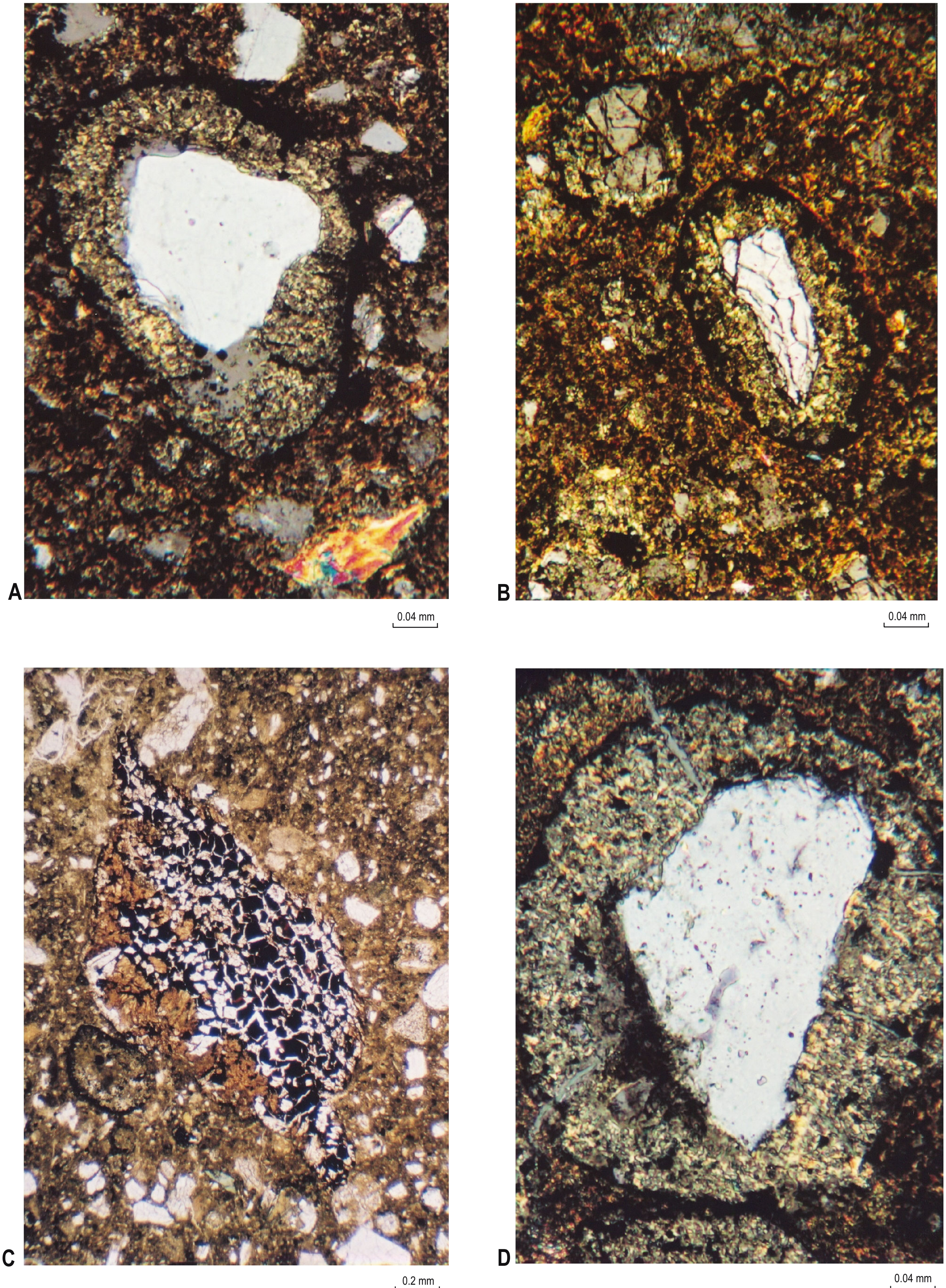


Plate 7. Apophyllite in the matrix and pellets (ML95-3, 134.0 m)

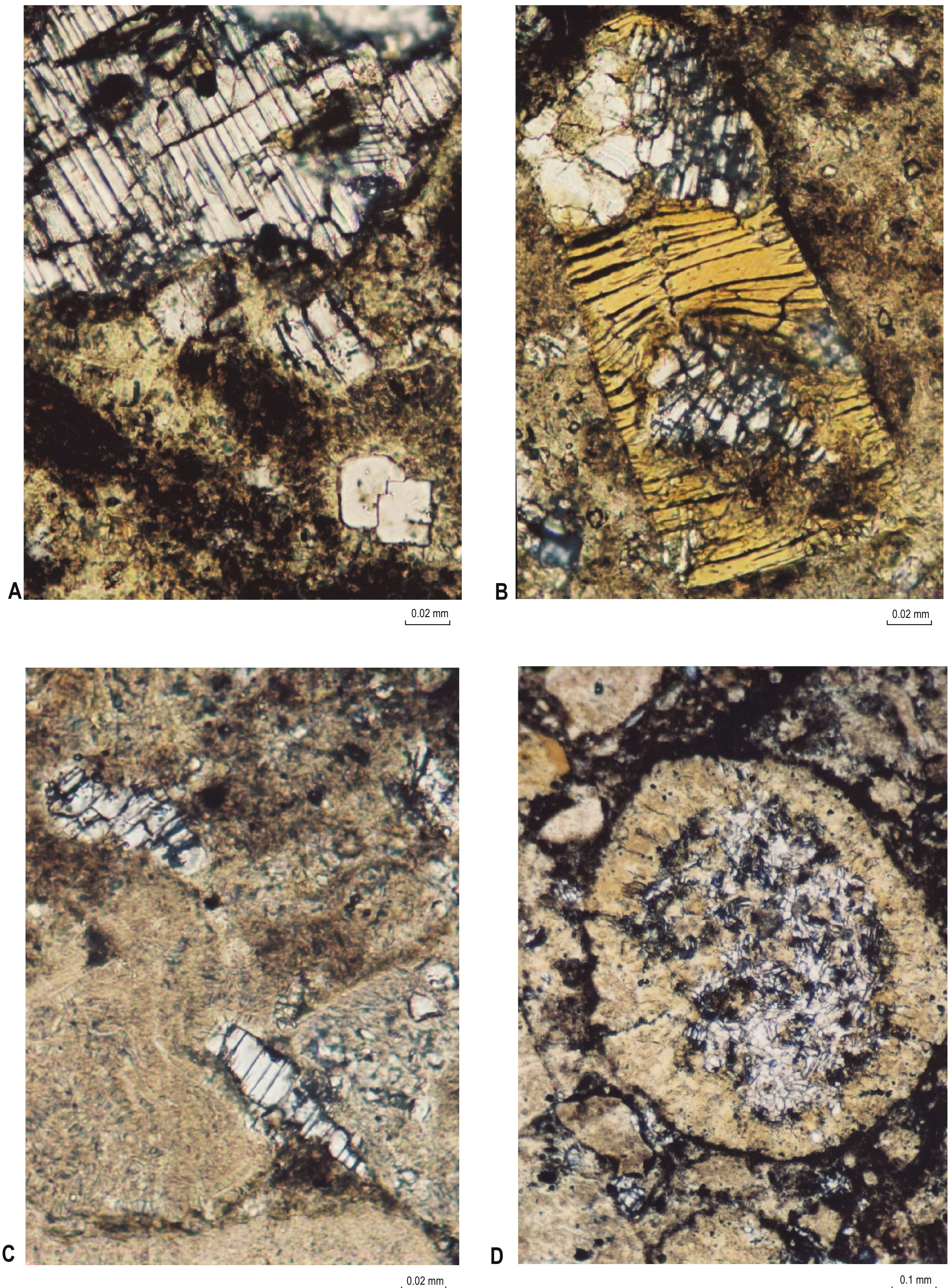


Plate 8. Xenoliths

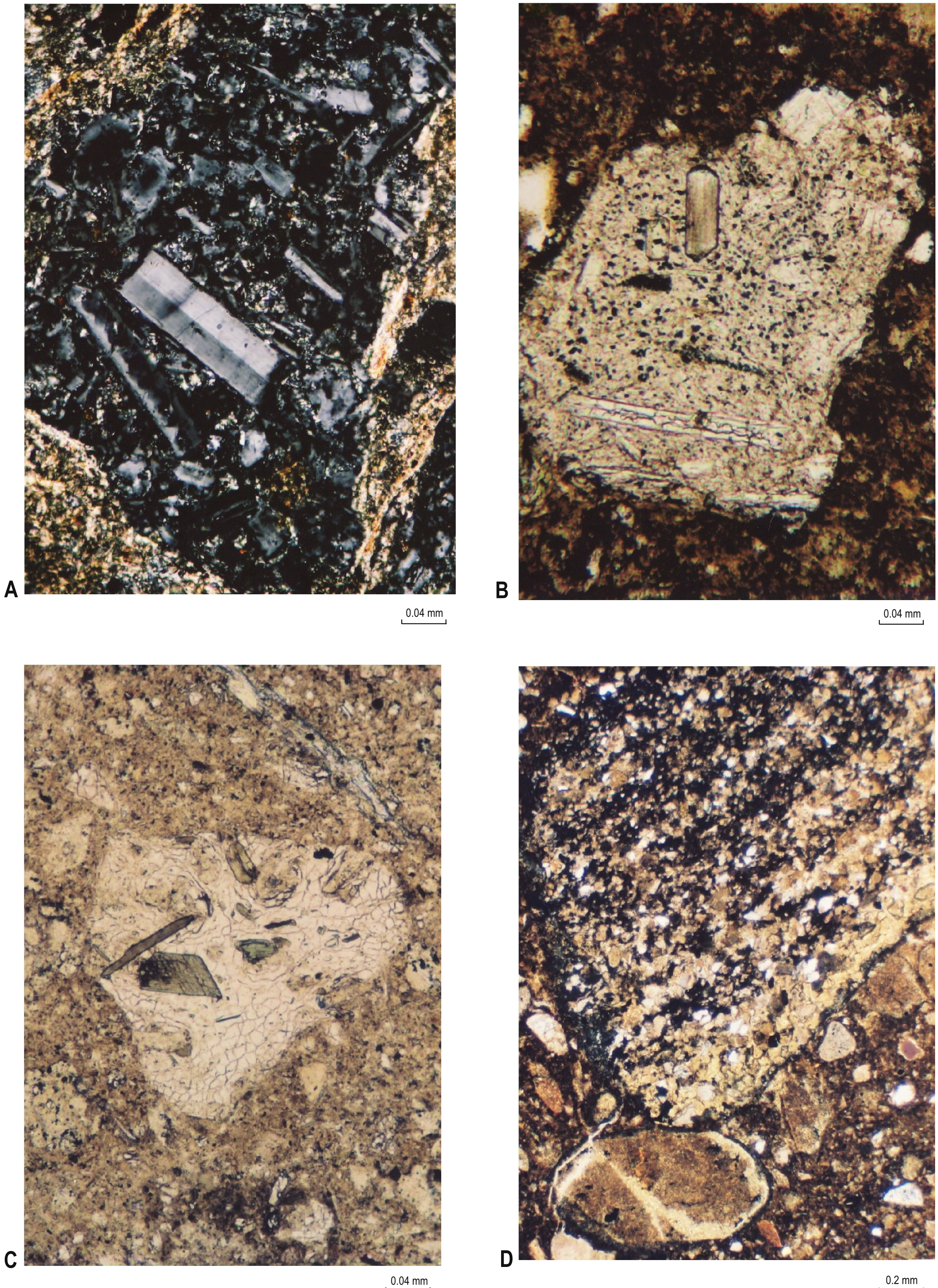
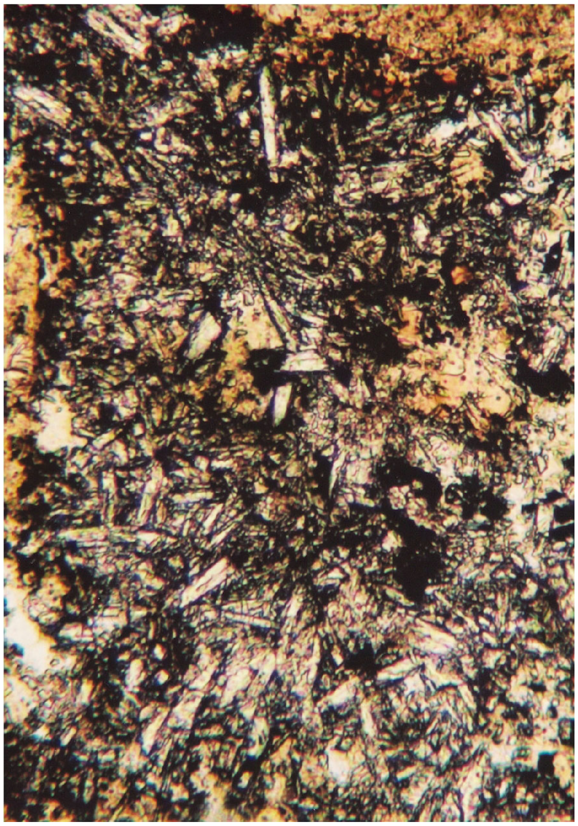
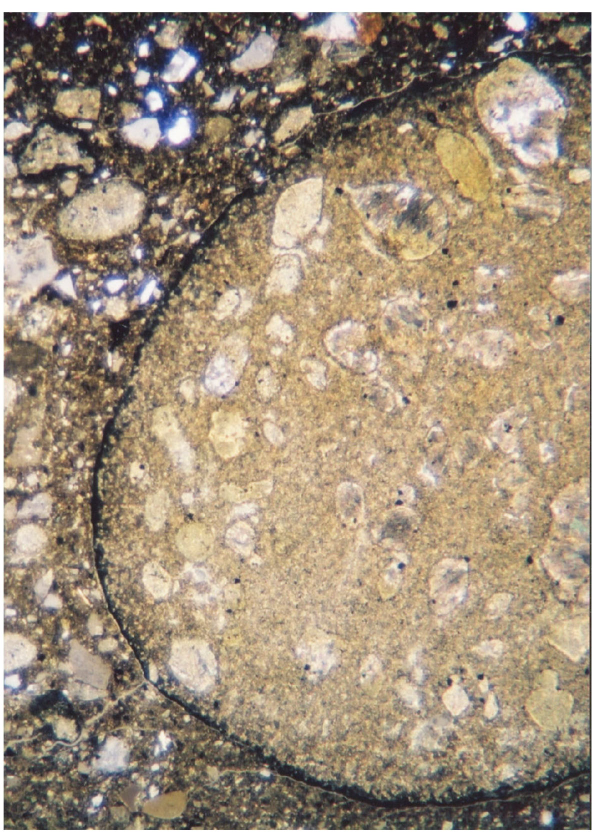


Plate 9. Autoliths



A

B



C

D

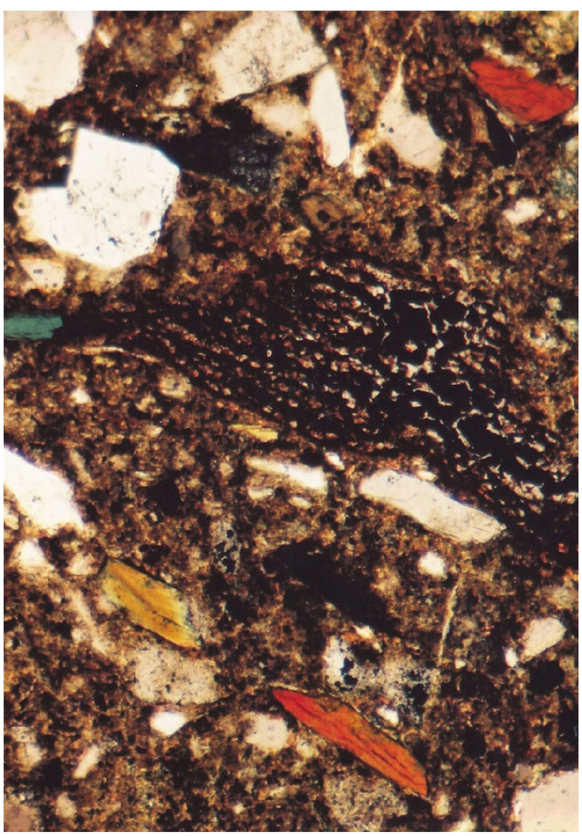
Plate 10. Grains in the matrix

A

0.02 mm

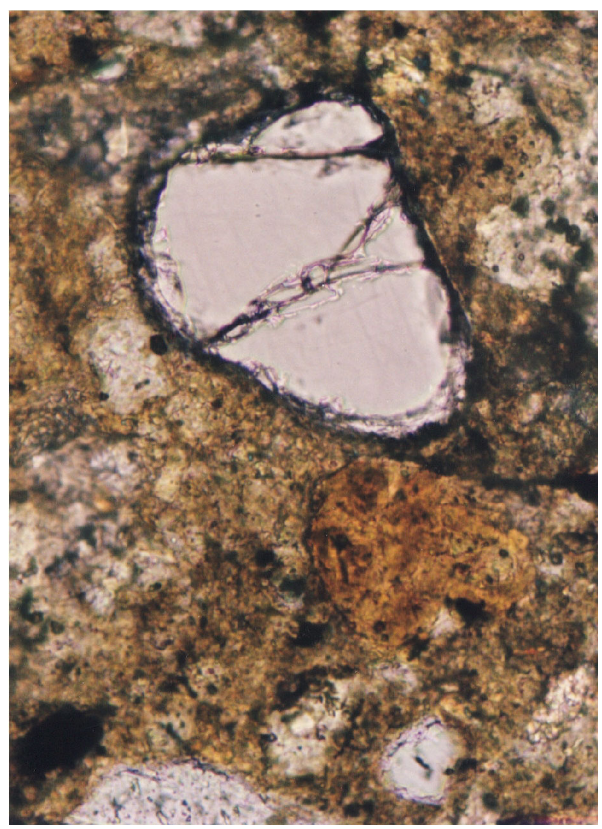
B

0.04 mm



C

0.1 mm



D

0.02 mm

Appendix 3. Analytical Results

Table 3.1. Electron microprobe analysis from apophyllite from the Mountain Lake Pipe. All results are in weight percent.

Sample No.	Na_2O	Al_2O_3	K_2O	MgO	SiO_2	CaO	Total
ML95-3-134C-1a	0.048	0.025	3.144	0.012	52.106	25.521	80.856
ML95-3-134C-5a	0.166	0.477	4.018	0.069	49.457	24.511	78.698
ML95-3-134C-1b	0.073	0.2	4.13	0.063	51.173	24.637	80.276
ML95-3-134C-5b	0.079	0.399	4.484	0.031	50.273	24.506	79.772
Minimum	0.048	0.025	3.144	0.012	49.457	24.506	78.698
Maximum	0.166	0.477	4.484	0.069	52.106	25.521	80.856
Average	0.091	0.275	3.944	0.044	50.752	24.794	79.901
Sigma	0.051	0.204	0.569	0.027	1.143	0.489	0.916
No. of samples: 4							
Cation Total O = 8.0							
Sample	**Na**	**Al**	**K**	**Mg**	**Si**	**Ca**	**Total**
ML95-3-134C-1a	0.0056	0.0018	0.2401	0.0011	3.1184	1.6366	5.0037
ML95-3-134C-5a	0.0199	0.0349	0.3183	0.0064	3.0707	1.6307	5.0809
ML95-3-134C-1b	0.0085	0.0143	0.3196	0.0057	3.1038	1.6012	5.0532
ML95-3-134C-5b	0.0094	0.0288	0.3507	0.0029	3.082	1.6098	5.0837
Minimum	0.0056	0.0018	0.2401	0.0011	3.0707	1.6012	5.0036
Maximum	0.0199	0.0349	0.3507	0.0064	3.1184	1.6366	5.0836
Average	0.0109	0.0199	0.3072	0.004	3.0937	1.6196	5.0553
Sigma	0.0062	0.0149	0.0472	0.0025	0.0214	0.0168	0.0371
No. of samples: 4							

Table 3.2. Electron microprobe analysis of clinopyroxene from the Mountain Lake Pipe.

SAMPLE No.	Na_2O	Al_2O_3	CaO	Cr_2O_3	MgO	SiO_2	TiO_2	MnO	FeO	Total
ML95-1-35.0-6-1	0.043	0.615	24.664	0.166	17.245	54.178	0.05	0.076	2.412	99.449
ML95-1-35.0-8-1	0.241	2.806	23.421	0.002	15.132	51.202	0.295	0.093	5.996	99.188
ML95-3-165-1-2	0.309	2.458	19.32	0.102	15.749	52.585	0.386	0.236	9.083	100.228
ML95-3-165B-65	0.384	5.07	22.645	0.036	14.145	49.602	0.453	0.131	7.107	99.573
ML95-3-165B-51	0.312	1.525	20.475	0	15.202	52.653	0.286	0.397	9.024	99.874
ML95-3-165B-45B	0.314	3.551	22.09	0.122	14.868	50.819	0.296	0.162	7.201	99.423
ML95-3-165B-28A	0.328	1.87	20.146	0.019	15.984	52.99	0.38	0.437	8.439	100.593
Minimum	0.043	0.615	19.32	0	14.145	49.602	0.05	0.076	2.412	99.188
Maximum	0.384	5.07	24.664	0.166	17.245	54.178	0.453	0.437	9.083	100.593
Average	0.276	2.556	21.823	0.064	15.475	52.004	0.307	0.219	7.037	99.761
Sigma	0.111	1.454	1.926	0.066	0.983	1.542	0.129	0.145	2.331	0.5
No. of samples: 7										

Table 3.3 Electron microprobe analysis of chromite from the Mountain Lake Pipe.

SAMPLE No.	MgO	V_2O_3	CaO	MnO	Al_2O_3	ZnO	TiO_2	FeO	SiO_2	Cr_2O_3	NiO	ZrO_2	Nb_2O_5	Total
ML95-3-165-3-1	15.452	0.164	0.064	0.351	17.817	0.123	1.523	17.496	0.2	44.271	0.189	0.033	0	97.683
ML95-3-165-3-2	15.397	0.124	0.091	0.382	17.069	0	3.44	30.26	1.07	29.849	0.071	0	0.023	97.776
ML95-3-165-3-3	14.174	0.128	0.331	0.379	13.601	0	2.454	25.58	0.319	40.613	0.104	0	0.028	97.711
ML95-3-165-7-1	13.259	0.114	0.033	0.274	26.118	0.219	0.035	18.811	0.034	38.665	0.07	0.015	0	97.647
ML95-3-165B-63	15.454	0.114	0.053	0.303	17.968	0.043	1.432	17.881	0.177	43.93	0.106	0.022	0	97.483
ML95-3-165B-64C	14.908	0.088	0.156	0.325	14.571	0.106	1.38	18.078	0.238	47.088	0.101	0	0	97.039
ML95-3-165B-61-1	14.649	0.135	0.068	0.307	11.532	0	1.736	18.627	0.118	50.666	0.149	0.021	0.027	98.035
ML95-3-165B-60-1	15.009	0.268	0.298	0.358	16.86	0.149	1.415	19.161	0.381	42.921	0.101	0	0	96.921
ML95-3-165B-56-1	0.088	0.16	37.03	0	0.49	0	50.777	2.374	0.258	0.202	0	0.061	0.925	92.368
ML95-3-165B-55A	10.196	0.165	0.023	0.367	10.052	0.3	0.087	20.664	0.051	57.893	0.051	0.035	0	99.884
ML95-3-165B-49	13.86	0.185	0.059	0.364	10.808	0.195	1.704	19.26	0.111	50.908	0.09	0.004	0	97.548
ML95-3-165B-45A	14.25	0.135	0.127	0.342	11.004	0.076	1.511	19	0.133	50.781	0.116	0	0.044	97.519
ML95-3-165B-43	13.758	0.066	0.107	0.396	10.379	0.02	1.609	19.878	0.126	51.505	0.105	0.032	0	97.981
ML95-3-165B-46	14.197	0.078	0.021	0.381	10.528	0	2.089	20.488	0.091	50.59	0.105	0.078	0.003	98.649
ML95-3-165B-31A	15.684	0.155	0.06	0.289	17.647	0.156	1.557	17.059	0.178	44.225	0.175	0.047	0	97.232
Minimum	0.088	0.066	0.021	0	0.49	0	0.035	2.374	0.034	0.202	0	0	0	92.368
Maximum	15.684	0.268	37.03	0.396	26.118	0.3	50.777	30.26	1.07	57.893	0.189	0.078	0.925	99.884
Average	13.356	0.139	2.568	0.321	13.763	0.092	4.85	18.974	0.232	42.94	0.102	0.023	0.07	97.432
Sigma	3.908	0.049	9.535	0.096	5.709	0.096	12.731	5.736	0.251	13.584	0.047	0.025	0.237	1.572
No. of samples: 15														

All results in weight percent.

Table 3.4 Cr_20_3 versus MgO in chromite from the Mountain Lake Pipe.

SAMPLE No.	MgO	Cr_2O_3
ML95-3-165-3-1	15.452	44.271
ML95-3-165-3-2	15.397	29.849
ML95-3-165-3-3	14.174	40.613
ML95-3-165-7-1	13.259	38.665
ML95-3-165B-63	15.454	43.930
ML95-3-165B-64C	14.908	47.088
ML95-3-165B-61-1	14.649	50.666
ML95-3-165B-60-1	15.009	42.921
ML95-3-165B-55A	10.196	57.893
ML95-3-165B-49	13.860	50.908
ML95-3-165B-45A	14.250	50.781
ML95-3-165B-43	13.758	51.505
ML95-3-165B-46	14.197	50.590
ML95-3-165B-31A	15.684	44.225
No. of samples: 14		

All results in weight percent.

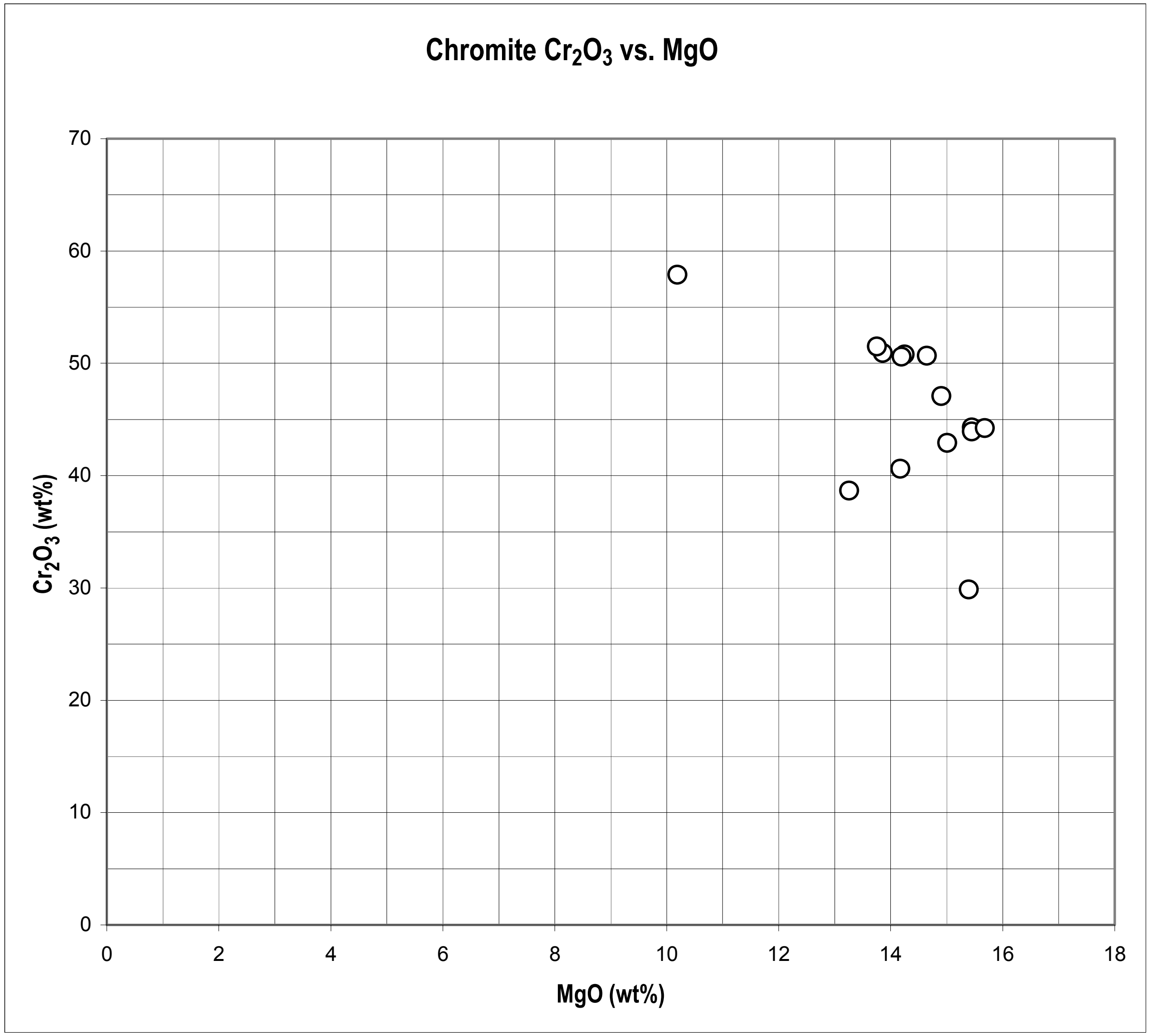


Table 3.5 Electron microprobe analysis of garnet from the Mountain Lake Pipe.

SAMPLE No.	Na_2O	Al_2O_3	CaO	Cr_2O_3	MgO	SiO_2	TiO_2	MnO	FeO	Total	Garnet Type
ML95-3-165B-62	0.024	21.534	2.272	0.209	8.335	38.131	0.258	0.647	27.822	99.232	(G5) Magnesian almandine
ML95-3-165B-47	0.043	13.591	6.09	8.197	17.803	37.14	0.839	0.218	5.502	89.423	(G11) Uvarovite pyrope
ML95-3-165B-33	0.037	20.658	0.724	0	3.02	36.551	0.097	19.969	18.822	99.878	Spessartine
ML95-3-165-1-1	0.006	21.761	2.562	0.006	7.101	38.225	0.016	0.355	30.106	100.138	(G5) Magnesian almandine
Minimum	0.006	13.591	0.724	0	3.02	36.551	0.016	0.218	5.502	89.423	
Maximum	0.043	21.761	6.09	8.197	17.803	38.225	0.839	19.969	30.106	100.138	
Average	0.027	19.386	2.912	2.103	9.065	37.512	0.302	5.297	20.563	97.168	
Sigma	0.016	3.892	2.267	4.064	6.253	0.807	0.372	9.783	11.16	5.177	
No. of samples: 4											

All results in weight percent.

Table 3.6 Electron microprobe analysis of perovskite from the Mountain Lake Pipe.

SAMPLE No.	Na_2O	Al_2O_3	CaO	FeO	MgO	SiO_2	TiO_2	Cr_2O_3	SrO	Nb_2O_5	MnO	Total
ML95-3-165B-61-2	0.23	0.493	36.902	2.272	0.061	0.075	51.663	0.251	0.234	0.936	0	93.117
ML95-3-165B-61-3	0.304	0.903	35.273	3.269	0.692	1.503	48.612	0.075	0.382	1.315	0.001	92.329
ML95-3-165B-61-4	0.401	1.277	30.922	2.642	1.576	7.61	44.292	0	0.528	1.081	0.009	90.338
ML95-3-165B-60-2	0.322	0.712	36.13	2.687	0.173	0.551	50.525	0.033	0.456	1.298	0	92.887
ML95-3-165B-60-3	0.339	0.874	35.32	3.49	0.39	1.036	47.881	0	0.589	1.443	0	91.362
ML95-3-165B-58-1	0.219	0.499	36.56	2.331	0.061	0.124	51.27	0.194	0.208	0.897	0	92.363
ML95-3-165B-58-2	0.211	0.543	37.047	2.481	0.058	0.188	51.898	0.187	0.301	1.038	0.006	93.958
ML95-3-165B-58-3	0.272	0.658	36.147	2.449	0.114	0.209	50.526	0	0.355	1.009	0	91.739
ML95-3-165B-56-2	0.213	0.478	36.962	2.431	0.084	0.128	51.56	0.21	0.237	0.927	0	93.23
ML95-3-165B-56-3	0.379	0.659	35.806	2.476	0.124	0.23	50.876	0.056	0.638	1.488	0.015	92.747
Minimum	0.211	0.478	30.922	2.272	0.058	0.075	44.292	0	0.208	0.897	0	90.338
Maximum	0.401	1.277	37.047	3.49	1.576	7.61	51.898	0.251	0.638	1.488	0.015	93.958
Average	0.289	0.71	35.707	2.653	0.333	1.165	49.91	0.101	0.393	1.143	0.003	92.407
Sigma	0.071	0.25	1.799	0.406	0.481	2.313	2.372	0.099	0.154	0.222	0.005	1.041
No. of samples: 10												

All results in weight percent.