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GLASS IN MANTLE-DERIVED PERIDOTITE XENOLITHS FROM THE McMURDO VOLCANIC GROUP, ANTARCTICA

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Abstract: Glass-bearing, mantle-derived peridotite xenoliths have been found in Late Cenozoic basanites at Turtle Rock and McMurdo Station, Ross Island, Antarctica. Glass in these xenoliths occurs as veinlets, interstitial pools, and thin films surrounding the primary xenolith minerals. The glass analyzed has three different compositions. Low-silica high-alkali glasses (42–48 wt% SiO_2, 4–6 wt% Na_2O+K_2O) are likely to represent volatile-rich melts which were incorporated from the host basanite magma. High-silica low alkali glasses (53.5–56 wt% SiO_2, 4–5 wt% Na_2O+K_2O) are non-alkaline and were possibly generated by decompressional breakdown of pargasitic amphibole. High-silica high-alkali glasses (55.5–57 wt% SiO_2, 14–15 wt% Na_2O+K_2O) are unique and resemble the chemical composition of the most evolved nepheline-trachyte.

1. Introduction

Occasionally, small amounts of glass can be observed in mantle-derived xenoliths and provide an insight into the nature of mantle metasomatism and magma generation (for example; FORBES and STARMER, 1974; FREY and GREEN, 1974; IRVING, 1974; FRANCIS, 1976; ELLIS, 1976; MACRAE, 1979; GIROD *et al.*, 1981; HUNTER and TAYLOR, 1982; JONES *et al.*, 1983; TAKAHASHI, 1986; KUO and ESSENE, 1986; FRANCIS, 1987; GAMBLE and KYLE, 1987; GARCIA and PRESTI, 1987; CHEN *et al.*, 1989; EDGAR *et al.*, 1989). Such a glass generally occurs as a vein-like material and an interstitial pool among the xenolith minerals. A minute amount of glass is also present as a glass-film coating the xenolith minerals. A wide range of chemical composition of the glass in mantle-derived xenoliths was reported from various localities. Consequently, a wide range of origins for the xenolith glasses has been discussed as follows;

1) Incipient melts partially fused in the upper mantle peridotites.
2) Decompressive melts of amphibole in the peridotite xenoliths.
3) Injection melts of the host magma into the peridotite xenoliths.
4) Mixtures of host magma (3) and interstitial melts (1 or 2) in the peridotite xenoliths.
5) Fractionated melts by crystallization of the trapped melts (1 to 4) in the peridotite xenoliths.
6) Modified melts by reaction of the trapped melts (1 to 4) with the solid wall of the peridotite xenoliths.

Late Cenozoic basanites of the McMurdo Volcanic Group (KYLE and COLE, 1974) on the western margin of the Ross Sea, Antarctica, carry a large number of xenoliths from the upper mantle (Prior, 1907; Thomson, 1916; Forbes, 1963; Forbes and Banno, 1966; Cole *et al.*, 1971; Stuckless and Ericksen, 1976; Kyle *et al.*, 1987; Gamble and Kyle, 1987; Niida, 1988). Some xenoliths from Foster Crater also contain a small amount of quenched glass (Gamble and Kyle, 1987). In some mantle-derived xenoliths from McMurdo and Turtle Rock, Ross Island, quenched glass is also observed as veins and interstitial pools. This paper presents the results of petrography and glass chemistry, and explains the plausible origins of the glasses.

2. Xenoliths Examined

The glass-bearing xenolith samples examined in this paper were collected at Turtle Rock (77°44′S, 166°48′E) and McMurdo Station (77°51′S, 166°40′E) on the Hut Point Peninsula in the McMurdo Sound region (Fig. 1). Spinel lherzolite xenoliths, associated with cumulate-type xenoliths, are common in the basanitoid scoria cone deposits at Turtle Rock (Niida, 1988). Basanite lava flows at McMurdo Station carry a large number of refractory dunite xenoliths from the upper mantle (Kyle *et al.*, 1987).

2.1. *Lherzolite* (*Sample No. 73–2*) *from Turtle Rock*

Xnolith sample 73–2 is typical of the spinel lherzolites from Turtle Rock, consist-

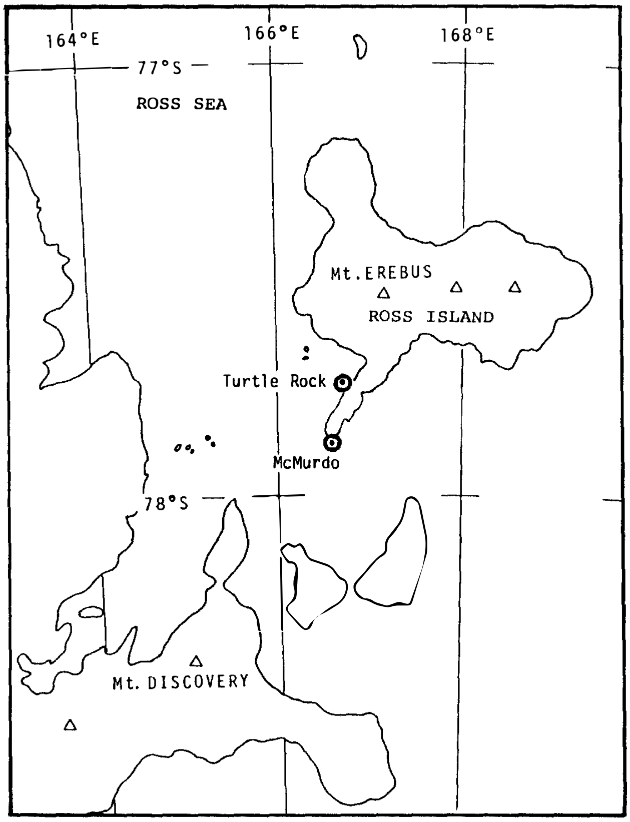
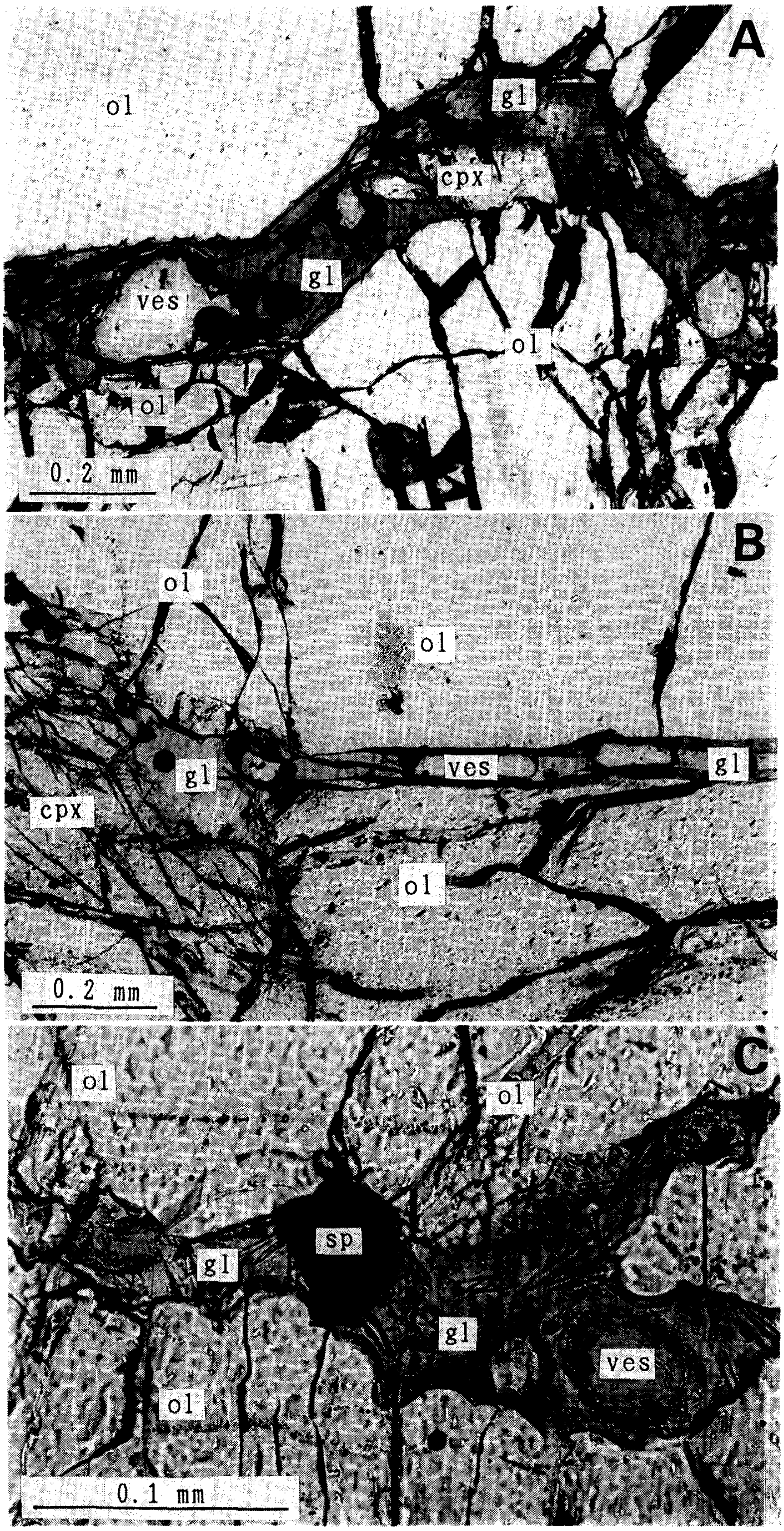


Fig. 1. Locations of sampling sites for the glass-bearing peridotite xenoliths derived from the upper mantle.



A: Brown glass-bearing veinlet in lherzolite xenolith (Sample No. 73-2). The glass contains a small amount of clinopyroxene and plagioclase microlites.

B: Pale brown glass-bearing veinlets in lherzolite xenolith (Sample No. 73-1E). The glass is almost free from crystallization.

C: Colorless glass-bearing veinlet in dunite xenolith (Sample No. RS3-1). The glass contains vesicles and microlites, in association with spinel (sp).

Fig. 2. Transmitted light photomicrographs showing the occurrence of glass in mantle-derived xenoliths from the Late Cenozoic basanites, Antarctica. The quenched glass (gl), in contact with primary olivine (ol) and clinopyroxene (cpx), contains vesicles (ves).

ing of 83 modal % olivine, 9% clinopyroxene, 7% orthopyroxene, and 1% spinel, as primary xenolith crystals from the upper mantle. The olivine grains are anhedral and granular, varying between 0.2 and 6.0 mm in diameter. The Mg^*-number ($Mg^* = 100\ Mg/(Mg+Fe)$) of the primary olivine ranges from 89.0 to 89.6. The clinopyroxene and orthopyroxene grains are also anhedral, varying between 0.1 and 3.5 mm. The spinel grains, frequently associated with pyroxene grains, are reddish brown.

Quenched glass is observed in veinlets, 0.01 to 0.7 mm wide, and are traceable for several cm in the lherzolite xenolith (Fig. 2A). Some veinlets continue to the host basanite lumps. Thin films of glass are also observed along grain boundaries, coating the primary xenolith crystals near the veinlets. The color of the glass in the veinlets is yellowish brown to brown and grades into that of the host basanite glass. The veinlet glass is in contact with xenolith crystals of olivine, clinopyroxene, orthopyroxene, and spinel. In most cases, the glass contains a small number of euhedral crystals of olivine and clinopyroxene, less than 0.1 mm long, and tiny needles of plagioclase.

2.2. *Lherzolite (Sample No. 73–5) from Turtle Rock*

Spinel lherzolite 73–5 is composed of primary upper mantle crystals of 72% olivine, 15% orthopyroxene, 11% clinopyroxene, and 2% spinel. The Mg^*-number of the primary olivines ranges from 89.7 to 90.3. The spinel has a reddish brown color, with an Mg^*-number in the range 64.8–65.0 and a Cr^*-number ($Cr^* = 100\ Cr/(Cr+Al)$) between 33.2–33.6.

Dark brown glass is observed as interstitial pools less than 1 mm in diameter among the primary upper mantle crystals. Very thin glass films are also observed along the grain boundaries of the primary crystals. The glass contains small vesicles. Although crystallization within the glass is generally absent a small amount of plagioclase microlites are observable under the microscope.

2.3. *Lherzolite (Sample No. 73–1E) from Turtle Rock*

Spinel lherzolite 73–1E consists mostly of 88% olivine, 7% orthopyroxene, 3% clinopyroxene, and 2% spinel. The cut surface of the lherzolite xenolith is characterized by a lustrous white color. Such an unusual surface color of the lherzolite xenolith can be explained by glass films coating the xenolith crystals. The Mg^* of the primary olivine from the lherzolite xenolith ranges from 89.3 to 89.7. The primary spinel, greenish brown in microscopic color, has an Mg^*-number ranging 71.7–72.7 and has a Cr^*-number ranging 19.7–22.9.

Quenched glass is observed in veinlets, approximately 0.05 mm in maximum width, with many branches and sometime fills the cracks invading the xenolith crystals (Fig. 2B). In addition, glass-films are observed along grain boundaries. In both occurrences the glass is microscopically colorless to very pale brown and is almost free of crystallization. Some primary olivines in contact with the glass show a convex surface shape. The surface of the primary pyroxenes and spinels in contact with the glass is partially fused, displaying a scale-like shape as the surface structure.

2.4. *Dunite (Sample No. RS3–1) from McMurdo*

The dunite RS3–1 sample examined in this paper is from a composite xenolith, in which large numbers of dunite fragments, up to about 3.5 cm in diameter, are included in kaersutite clinopyroxenite, collected from the basanite lava flow at McMurdo Station. The examined dunite fragment, 1.3×2.5 cm wide, consists moslty of primary mantle olivine with trace amounts of red brown spinel and interstitial orthopyroxene. The primary olivine shows an anhedral equigranular shape with conspicuous kink bands. The $Mg^{\#}$-number of the olivine ranges from 89.2 to 90.1. The spinel has a high $Cr^{\#}$-number ranging from 58.7 to 66.4 and an $Mg^{\#}$-number ranging from 52.0 to 54.7.

Quenched glass is observed in veinlets and can be traced for more than 1 cm in the dunite fragment (Fig. 2C). The width of the glass-bearing vein varies up to a maximum of 0.2 mm. Small amounts of secondary phlogopite and greenish brown spinel, less than 0.1 mm long, appear along the glass-bearing veinlets. Although the glass is almost free of crystallization, small amounts of microlitic needle-like crystals of plagioclase are observable in the glass. Vesiculation, which is considered to have taken place during quenching, is prominent in the veinlet glass. Primary olivines and spinels in contact with the glass exhibit a convex surface structure probably resulting from contact partial melting.

3. Glass Chemistry

The glasses in the mantle-derived xenoliths were analyzed with the JEOL JXA 733 electron microprobe at the National Institute of Polar Research using the standard method of the institute and the BENCE-ALBEE correction procedure. A wide diameter electron beam (10–20 microns) was used for the glass area. Average chemical compositions of the analyzed glasses are presented in Table 1.

All analyses were plotted on the alkali-silica diagram (Fig. 3). The plots show three separate clusters (Clusters A, B, and C).

Table 1. Average glass compositions from mantle-derived lherzolite (L) and dunite (D) xenoliths.

Xenolith type	L	L	L	L	D
Sample No.	73–2	73–2	73–5	73–1E	RS3–1
Glass	host	veinlet	pool	veinlet	veinlet
No. of analysis	5	5	4	4	8
SiO_2	42.19	46.31	43.38	54.28	55.70
TiO_2	5.21	5.04	5.50	2.69	1.41
Al_2O_3	14.36	14.13	14.95	18.00	24.42
Cr_2O_3	0.02	0.03	0.01	0.02	0.03
FeO*	12.58	11.20	11.15	4.11	0.93
MnO	0.21	0.17	0.25	0.09	0.02
MgO	5.32	5.23	5.18	4.16	0.20
CaO	12.26	10.87	11.29	7.77	1.56
Na_2O	3.40	3.25	3.49	3.40	6.27
K_2O	1.66	1.55	2.02	2.05	7.89
P_2O_5	1.27	1.18	1.63	2.13	n.d.
Total	98.48	98.96	98.84	98.69	98.45

* Total iron as FeO*.

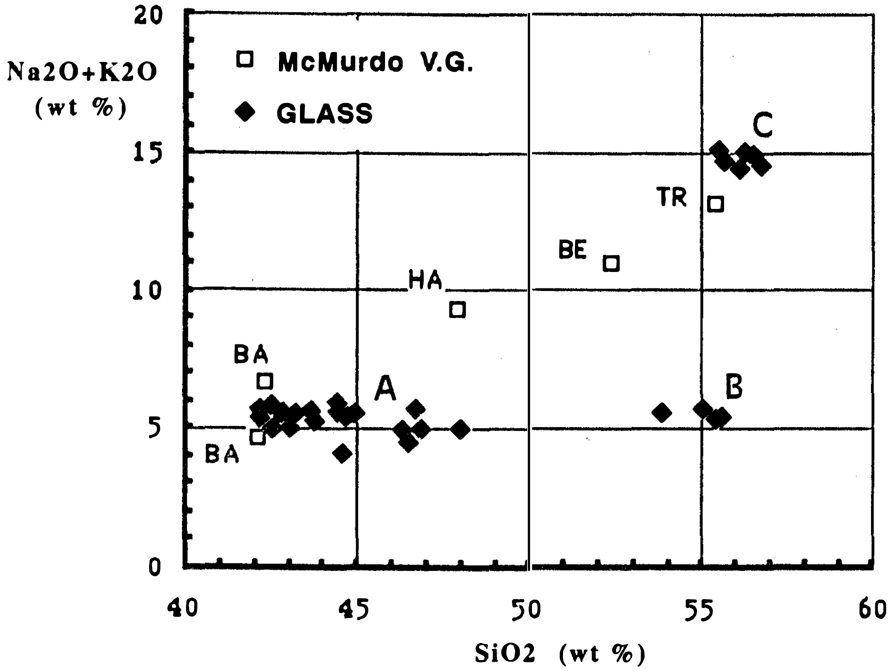


Fig. 3. *Na_2O+K_2O versus SiO_2 contents for the glass in mantle-derived xenoliths from the Late Cenozoic basanites, Antarctica. Three separate clusters are evident, A (glass in lherzolites 73–2 and 73–5), B (glass in lherzolite 73–1E), and C (glass in dunite RS3–1). Representative compositions of the McMurdo Volcanic Group (BA: basanite, HA: nepheline hawaiite, BE: nepheline benmoreite, TR: trachyte) after* KYLE *and* RANKIN *(1976).*

Cluster A (low-silica high-alkali glass): The spinel lherzolites, 73–2 and 73–5, from Turtle Rock contain the low-silica high-alkali glasses, of which compositions vary from basanitic toward that of cluster B as shown in Fig. 3. The SiO_2 contents range from 42 to 48 wt% (water-free basis), whereas the total alkali contents are relatively homogeneous (4 to 6 wt% Na_2O+K_2O).

Cluster B (high-silica low-alkali glass): The spinel lherzolite, 73–1E from Turtle Rock, contains the high-silica low-alkali glasses, of which compositions are characterized by a non-alkaline nature. The glass is basaltic andesite in composition and distinctly magnesian (4 to 5 wt% MgO). The SiO_2 contents range from 53.5 to 56 wt%, whereas the total alkali contents range from 5 to 6 wt%.

Cluster C (high-silica high-alkali glass): The dunite RS3–1 from McMurdo Station contains the high-silica high-alkali glass, of which compositions resemble that of an evolved nepheline-trachyte. The SiO_2 contents range from 55.5 to 57 wt%, whereas the total alkali contents are relatively homogeneous (14 to 15 wt% Na_2O+K_2O). The glasses is characterized by a very high abundance of K_2O.

4. Discussion

A simple explanation for the origin of the various types of glass in the upper mantle-derived xenoliths is that they represent incipient melts formed by partial melting of peridotitic xenoliths. As mentioned by many workers (*e.g.*, MAALOE and PRINTZLAU, 1979; JONES *et al.*, 1983), the chemical and petrographic nature of the various glass types exhibit a considerable modification from the primitive melts. Recently, KUO and ESSENE (1986) proposed a slight modification melt model where the xenolith glass from Saudi Arabia was generated by partial melting within the upper mantle at temperatures higher than 1000°C, followed by crystallization of 10 vol% diopside at lower temperatures. However, simple mass balance generally requires consumption of additional phases that are not present in the xenoliths or metasomatic adjustment of alkalis and other elements.

The other possible origin for the intra-xenolithic glass has been explained by volatile-rich melts incorporated from the host magma (*e.g.*, MERTES and SCHMINCKE, 1985). In the case of this study, the low-silica high-alkali glass (Cluster A in Fig. 3) has a basanitic composition similar to that of the host basanite and shows a heterogeneity with compositional deviations from the original composition of the host basanite. The occurrence of some glass veinlets being continuous from the host basanite also supports the explanation that the glass was incorporated from the host magma and then mixed with the high-silica low-alkali melt having the chemical composition Cluster B in Fig. 3.

It has also been discussed that the glasses in upper mantle-derived xenoliths result from the decompressional breakdown of kaersutitic or pargasitic amphiboles (*e.g.*, FORBES and STARMER, 1974; FREY and GREEN, 1974; FRANCIS, 1976; GIROD *et al.*, 1981). Some types of glass were explained as being melts related to decompressional breakdown of mica (FREY and GREEN, 1974) or garnet (HUNTER and TAYLOR, 1982) within peridotite xenoliths. The high-silica low-alkali glass in the lherzolite xenolith 73–1E is considered to have been formed by pargasite breakdown melting. According to the results of simple mass balance calculations for the various types of glass, olivine and other additional phases might be produced together with the melt. In this case, however, it is difficult to realize petrographically the pre-existence of pargasitic amphibole in the lherzolite xenolith.

The chemical composition of the high-silica high-alkali glass in the dunite xenolith RS3–1 tends to lie near the trachyte composition (KYLE and RANKIN, 1976) as shown in Fig. 3 and has an evolved magmatic nature characterized by low Mg*-numbers and high alkali contents. The high K_2O content indicates the potentiality to crystallize phlogopite. It is considered that a possible melt resulting a trachyte magma eruption exists in the upper mantle beneath the Hut Point Peninsula, Ross Island.

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