

Glasses in peridotite xenoliths from the western Pannonian Basin

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ABSTRACT. — Mantle peridotite xenoliths, hosted in alkali basalts of the Western Pannonian Basin, contain small amount of glass. These glasses are highly enriched in alumina and have lower Mg and Fe contents than host alkali basalts. Amphibole is present in some xenoliths, but its role in mantle glass formation was dismissed on the basis of petrographic and geochemical constraints. Mass balance calculation, in fact, require the involvement of metasomatic fluids, particularly for alkali elements. Metasomatism may also have triggered partial melting process at mantle depth.

Similar glass pockets occurring in lower crustal, granulite xenoliths may, on the other hand, be related to the combined effect of sudden decompression and heating in rapidly ascending host lavas.

RIASSUNTO. — In questo lavoro vengono studiati xenoliti di mantello, inclusi in lave alcaline provenienti dalla parte occidentale del Bacino Pannonico, che contengono discrete quantità di vetro. Questi vetri si presentano molto arricchiti in alumina e alcali e hanno contenuti in Mg e Fe più bassi dei basalti ospiti. Sulla base delle osservazioni petrografiche e dei dati geochemici, si ritiene che il ruolo dell'anfibolo, presente in alcuni xenoliti, nella

genesi di questi vetri sia minoritario. D'altro lato, usando dei bilanci di massa, viene invocato un processo metasomatico che aggiunga al sistema elementi alcalini e contemporaneamente inneschi un processo di fusione parziale.

Piccole tasche vetrose sono state osservate anche in xenoliti granulitici di bassa crosta, per le cui genesi, invece, si ipotizza un processo combinato di decompressione e riscaldamento da parte della lava ospite durante la risalita.

KEY WORDS: *Peridotite xenoliths, mantle glasses, metasomatism, Pannonian Basin.*

INTRODUCTION

Several workers reported sporadic small-scale melting phenomena in mantle xenoliths from alkali basalts involving the formation of glass films along grain boundaries as well as discrete melt pockets (e.g. Frey and Green, 1974; Irving, 1974; McRae, 1979; Stosch and Seck, 1980; Jones *et al.*, 1983). The melting has been widely ascribed to decompression effects and heating of the xenoliths during rapid ascent and eruption whereby the more

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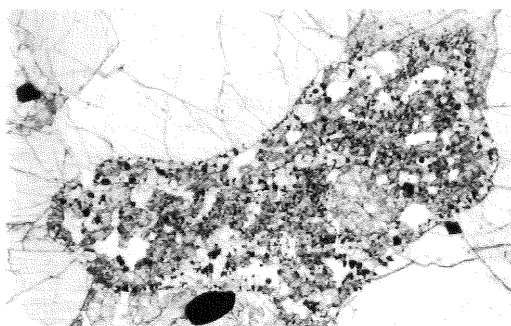
fusible phases (amphibole, mica, pyroxene, spinel or garnet) disintegrate and melt. Following this interpretation, the melting process is secondary in nature, i.e. it is unrelated to processes in the mantle source regions of the xenoliths. However, Jones *et al.* (1983), Schiano *et al.* (1992), Ionov *et al.* (1994), Sen *et al.* (1996) and Coltorti *et al.* (1999) have proposed that the small-scale melting of mantle xenoliths could take place at high pressure conditions. Most of these authors convincingly demonstrated that the melting process was initiated by metasomatic fluids enriched in incompatible trace elements.

PETROGRAPHY OF GLASS-BEARING MANTLE XENOLITHS

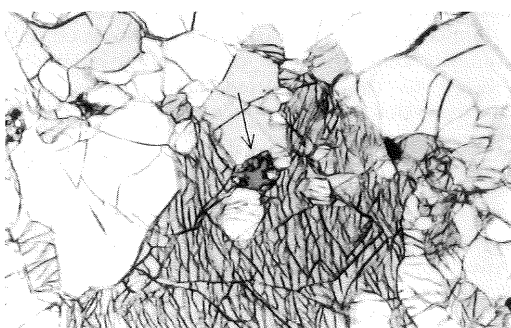
Texture, mineralogy and geochemistry of the peridotite xenoliths from the Western Pannonian Basin have been described elsewhere (Embey-Isztin, 1976; 1978; 1984; Embey-Isztin *et al.*, 1989; Kurat *et al.*, 1991; Downes *et al.*, 1992; Szabó *et al.*, 1995), therefore only a brief characterisation will follow here. The xenoliths occur in Pliocene alkali basalt flows as well as in basaltic tuffs. Localities include Szentbékállá (Szt), Bondoróhegy (Bo), Szigliget (Szg) and Gércé (G). All xenoliths contain spinel as an aluminous phase; garnet and plagioclase are typically absent. Textures are highly variable. However, protogranular and equigranular types prevail, porphyroclastic textures are restricted to one locality. In addition to these textural types that are very common in peridotite xenoliths of world-wide localities, Western Pannonian Basin peridotite xenoliths show a relatively high frequency of poikilitic texture types that are generally rare or absent from most spinel peridotite xenolith suites of alkali basalts. Xenoliths belonging to this group are either coarse- or fine-grained, the latter showing a typical mosaic equigranular texture. This term was originally introduced by Mercier and Nicolas (1975) to distinguish fine-grained, recrystallized textures with tiny spinel

inclusions from similar textures, but in which, the spinel is interstitial. Chemically the peridotites vary between fertile and highly depleted compositions. Some of the xenoliths contain clinopyroxenes exhibiting LREE-enriched patterns, whereas in other xenoliths the clinopyroxene is depleted in LREE. Undeformed (protogranular) xenoliths (mostly lherzolites but a few harzburgites) tend to show LREE-depleted, whereas deformed (equigranular) peridotites (lherzolites) have LREE-enriched patterns.

A few peridotite xenoliths, originally studied by Embey-Isztin *et al.* (1989), contain small amounts of glass that have not been described earlier. The glass-bearing peridotites we investigated are partly lherzolites (Szt-1006,



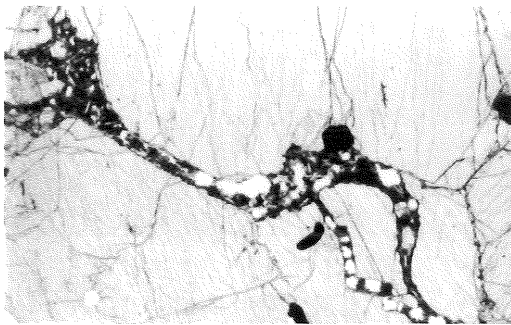
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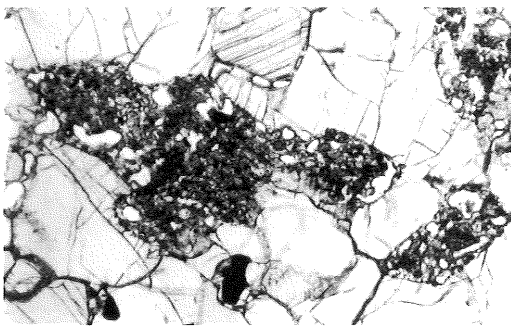
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Figs. 1-2 – 1) Disintegrated large primary clinopyroxene grain in sample Szt-1034, containing secondary small clinopyroxene and spinel crystals, vugs and glass. II N. M=20x. 2) Small patch of lilac brown interstitial glass, G-1055. II N. M=20x.

Szt-1069, Szt-1106, G-1005) and partly harzburgites (Szt-1033, Szt-1034, Szt-1116). The samples Szt-1069 and Szt-3007 are composite xenoliths, the latter being composed of both lherzolite and harzburgite portions. They do not contain amphibole except for the sample Szt-1106. The amphibole forms texturally well equilibrated grains, proving that the formation of amphibole - presumably by metasomatic replacement of clinopyroxene - preceded the recrystallisation process. The glasses are believed to be unrelated to the host alkali basalts or basanites. They range from small amounts associated with fine-grained clinopyroxenes that formed by disintegration of former larger primary clinopyroxene grains (samples Szt-1006, Szt-1033, Szt-1034, Szt-1069, Szt-1116; fig. 1) to distinct patches of



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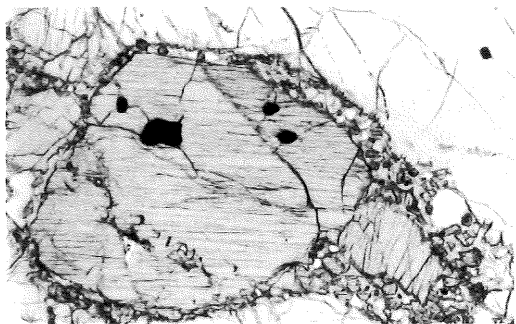


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Figs. 3-4 - 3) Narrow vein-system filled by glass, quench plagioclase and vugs. Szt-1034. + N. M=20x. 4) Disintegrated primary clinopyroxene grains in Szt-1033. II N. M=20x.

brown, lilac brown glass (G-1055; fig. 2) and widely developed interstitial veins of light-coloured glass containing tiny needles of quench plagioclase (Szt-1034; fig. 3).

In many xenoliths (including Szt-1006, Szt-1033 and Szt-1116, fig. 4) the small amount of light brown glass (50-75 μm) is found within blebs that are composed mainly of euhedral clinopyroxene crystals (40-320 μm) a few olivine, and abundant spinel microlites (10-40 μm) as well as in vugs. In Szt-1006, amorphous carbonates were also observed. Spinel grains are more densely concentrated at the border of blebs just as previously described by Maaløe and Printzlau (1979). The blebs may contain a few large relict spinel grains. They are texturally controlled; following the former places of clinopyroxene and spinel and are delineated by former grain boundaries. However, rarely they also form embayments into olivine and orthopyroxene. We found that glass associated with blebs is more frequent in poikilitic xenoliths than in xenoliths with other textural types and the majority of our glass-bearing samples belong to this special group (Szt-1006, Szt-1033, Szt-1034, Szt-1106 and Szt-1116). In general, clinopyroxenes in peridotites of this group were unstable and almost always show variable degrees of decomposition ranging from thin spongy rims around the crystals to complete disintegration of the original grains. Rarely, the glass occurs in interstitial areas forming narrow veins (Szt-1034, fig. 3, 5), whereas a few of these veins contain small needles of quench plagioclase and some carbonates, most of the glass veins are devoid of such crystals. In sample Szt 1106, glass is mainly associated with a thick reaction rim surrounding amphibole grains (fig. 6). One sample (G-1055) contained irregular shaped small patches of lilac brown glass (200-400 μm) at contacts between orthopyroxene, clinopyroxene and spinel (fig. 2). The glass is poor in quench crystals, with only scarce microliths of spinel embedded in it. All around the glassy areas clinopyroxene shows signs of disintegration and spherical vugs (250-500 μm).



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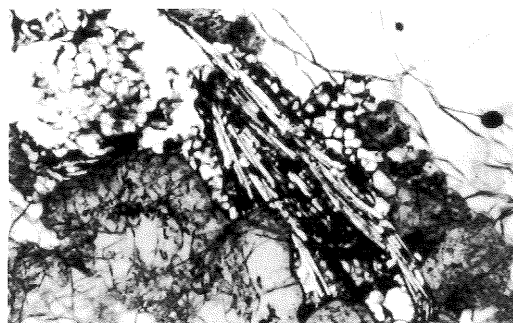
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Figs. 5-6 – 5) Narrow vein around a primary orthopyroxene with primary inclusion-spinels (poikilitic texture, Szt-1034). The vein is composed of fragments of primary orthopyroxene, secondary clinopyroxene, glass and vugs. II N. M=20x. 6) Texturally equilibrated amphibole grain in Szt-1106 showing signs of decomposition involving the formation of secondary clinopyroxene and glass. II N. M=40x.

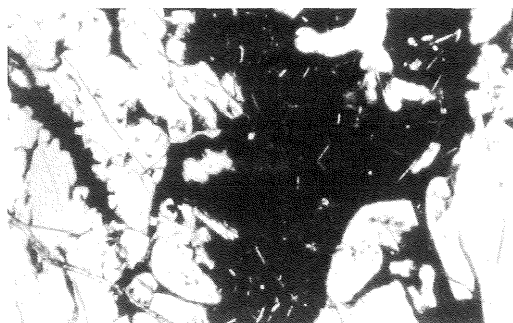
From the two composite xenoliths, Szt-1069 contains a thin vein of Type II clinopyroxenite crossing normal Type I protogranular peridotite (terminology after Frey and Prinz, 1978). Glass is confined to the border zone between Type II and Type I material. Small glass patches (2-133 μm) occupy interstitial spaces around Type II pyroxenes. In glassy areas, peculiar partly empty spherical structures can sometimes be seen, probably due to contraction caused by loss of a fluid component. Sample Szt-3007 is a rare type of composite xenolith that has numerous fragments of small coarse-grained and fine-grained Type I peridotite cemented by amphibole-bearing Type II pyroxenite (Embey-

Isztin, 1984). Here again, glass patches are associated with Type II material. The light-coloured and brownish glass around Type II clinopyroxenes and amphiboles may contain quench crystals of plagioclase. The glass may also show spherical structures associated with vugs (fig. 7).

In addition to mantle-derived peridotites, some of the Western Pannonian Basin volcanic vents contain lower crustal granulite xenoliths (Embey-Isztin and Scharbert, 1988; Embey-Isztin *et al.*, 1990, Kempton *et al.* 1997). These xenoliths are mafic granulites with a mineralogy of clinopyroxene + plagioclase \pm garnet \pm spinel \pm magnetite \pm ilmenite \pm



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Figs. 7-8 – 7) Dark glass with abundant elongated quench plagioclase needles and vugs with a spherical structure in the composite xenolith Szt-3007. The glassy area developed between Type II pyroxenite (lower left grey area) and Type I peridotite (upper right white area). II N. M=20x. 8) Widely developed glassy area containing tiny needles of quench plagioclase in the granulite xenolith. B-3007. +N. M=100x.

orthopyroxene. In general, granulite xenoliths are much more susceptible to melting than peridotites and indeed, many of the Western Pannonian Basin granulites show melting phenomena, especially those found at the locality of Bondoróhegy (Bo). However, we have analysed the composition of glass only in one of these xenoliths (Bo-3007). In this sample, disintegration of primary plagioclase and clinopyroxene grains is widely developed. Patches of dark-coloured glass contain quench crystals, especially abundant euhedral laths of plagioclase, but a few clinopyroxene and olivine crystals are also present (fig. 8).

GLASS COMPOSITIONS

Glass compositions from peridotites vary widely (Table 1). Although we did not analyse for P_2O_5 , it is likely that this oxide is also present since most workers reported P_2O_5 contents (up to ~ 2 wt%) including Jones *et al.* (1983), Ionov *et al.* (1994) and Brunet and Chazot (1999).

The glasses have less Mg and Fe, but more Al, Si and alkalis (especially K) than typical basaltic lavas of the volcanic region (cf. Embey-Isztin *et al.*, 1993a,b). Compared to glass compositions of the Olmani peridotites

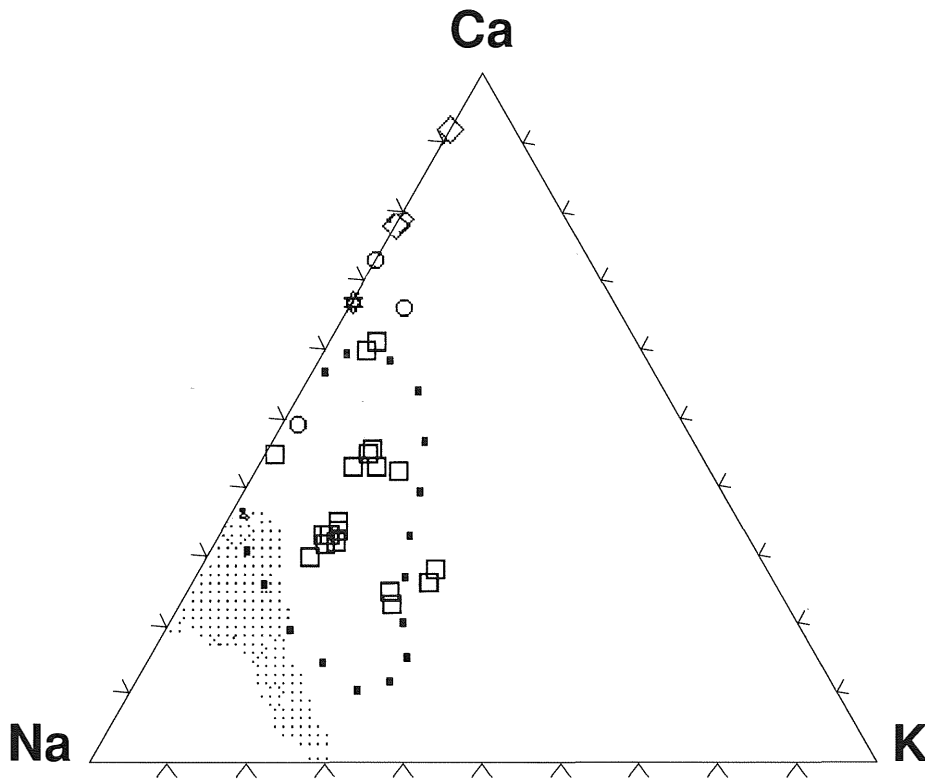


Fig. 9 – Glass compositions (Ca-Na-K) from mantle xenoliths of Western Pannonian Basin (open squares) and Bo-3007 granulite xenolith (diamonds). Circles represent synthetic partial melts of spinel peridotites produced under variable P , $X(H_2O)$, $X(CO_2)$ conditions of (Kushiro, 1971; Mysen and Boettcher, 1975). The star represents the composition of a 3:1 mixture of diopside/spinel. Encircled area: compositional field of natural glasses from mantle derived xenoliths from world-wide localities (Olmani, Tanzania, Jones *et al.*, 1983; Hoggar, Algeria, Girod *et al.*, 1981; Victoria, Australia, Frey and Green, 1974; Irving, 1974; Alaska, Francis, 1976; Canary Isles, Forbes and Starmer, 1974). Striped area: composition of glasses in melt pockets from Mongolian spinel peridotite xenoliths (Ionov *et al.*, 1994).

TABLE I
Electron microprobe analyses and CIPW norms of glasses in melt pockets.

	Szt-1034	Szt-1006			Szt-1033			Szt-1069			
SiO ₂	61.89	60.85	51.57	54.32	50.66	56.26	55.74	57.20	47.82	48.05	48.41
TiO ₂	1.24	1.23	1.22	1.02	1.25	0.90	0.90	0.89	2.43	2.38	2.99
Al ₂ O ₃	18.84	18.43	22.65	22.36	22.50	20.51	19.88	20.24	20.33	20.53	18.94
Cr ₂ O ₃	0.00	0.00	0.00	0.04	0.00	0.02	0.00	0.03	0.00	0.00	0.00
FeO	2.23	2.48	4.80	3.45	4.42	2.97	4.49	4.20	5.91	5.74	6.97
MnO	0.07	0.07	0.05	0.05	0.05	0.05	0.09	0.12	0.11	0.12	0.14
MgO	2.22	2.28	3.66	2.89	3.62	2.94	4.20	4.14	4.36	4.44	4.28
CaO	3.71	3.90	9.01	7.13	9.32	6.52	10.31	9.72	9.55	9.97	8.74
Na ₂ O	4.48	3.66	4.54	5.71	5.32	5.84	3.34	2.92	5.14	5.08	4.47
K ₂ O	3.69	3.72	2.25	2.38	2.17	2.58	0.69	0.76	2.69	2.41	3.16
Total	98.37	96.61	99.75	99.39	99.31	98.59	99.68	100.22	98.34	98.77	98.13
X _{Mg}	0.64	0.62	0.58	0.60	0.59	0.64	0.63	0.64	0.57	0.58	0.52
q	10.0	13.3	-	-	-	-	6.0	9.9	-	-	-
c	0.7	1.3	-	-	-	-	-	-	-	-	-
or	22.2	22.8	13.3	14.2	12.9	15.5	4.1	4.5	16.2	14.4	19.0
ab	38.5	32.1	26.4	36.7	22.0	42.8	28.4	24.7	11.7	12.8	15.1
ne	-	-	6.6	6.5	12.7	4.0	-	-	17.6	16.7	12.7
an	18.7	20.0	34.9	28.6	31.3	22.5	37.4	39.8	24.9	26.4	22.7
di	-	-	8.1	5.7	12.3	8.3	11.3	6.7	18.8	19.1	17.4
hy	6.9	7.6	-	-	-	-	10.2	11.8	-	-	-
ol	-	-	7.4	5.7	5.5	4.56	-	-	4.9	4.8	5.7
il	2.4	2.4	2.3	2.0	2.4	1.7	1.7	1.7	4.7	4.6	5.8
mt	0.5	0.6	1.1	0.8	1.0	0.7	1.0	0.9	1.3	1.3	1.6

Table 1: *continued*

	Szg-3007		Szt-1106		Szt-1116	G-1055	Bo-3007	BAD555*			
SiO ₂	52.43	52.58	51.48	53.44	58.95	59.12	57.98	56.50	43.35	41.07	45.99
TiO ₂	2.50	2.20	2.52	2.28	0.82	0.86	1.46	2.72	0.13	0.16	2.23
Al ₂ O ₃	21.30	21.26	21.08	18.70	21.31	21.46	19.96	21.46	31.54	22.40	15.71
Cr ₂ O ₃	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.02	nd
FeO	6.13	6.18	6.28	6.51	2.81	2.25	3.92	3.15	8.12	18.78	9.52
MnO	0.14	0.11	0.11	0.14	0.06	0.07	0.04	0.06	0.19	0.61	0.18
MgO	2.65	2.76	2.87	2.33	3.40	3.47	2.78	3.81	2.84	10.95	8.35
CaO	6.25	6.13	6.27	5.16	5.63	5.24	4.32	7.78	12.67	6.63	9.91
Na ₂ O	5.61	5.21	5.79	5.19	5.17	5.58	4.81	5.25	1.99	0.31	4.47
K ₂ O	2.25	2.26	2.24	4.08	1.85	1.93	3.79	0.13	0.02	0.00	2.54
Total	99.26	98.69	98.69	97.83	100.04	100.41	99.02	100.86	100.89	100.93	98.90
X _{Mg}	0.44	0.44	0.45	0.39	0.68	0.73	0.56	0.68	0.84	0.75	0.73
q	-	-	-	-	3.4	1.7	0.6	3.9	-	-	-
c	-	-	-	-	0.6	0.7	0.1	-	5.2	9.8	-
or	13.4	13.5	13.4	24.7	10.9	11.4	22.6	0.8	0.1	0.0	15.2
ab	37.3	39.1	34.6	32.8	43.8	47.0	41.1	44.0	16.1	2.6	3.2
ne	5.7	3.0	8.2	6.5	-	-	-	-	0.3	-	19.0
an	26.5	28.3	25.3	16.0	27.9	25.9	21.6	34.3	62.3	32.6	15.5
di	3.9	2.1	5.1	8.4	-	-	-	3.1	-	-	27.7
hy	-	-	-	-	11.3	1.11	10.3	8.1	-	39.8	-
ol	7.1	8.4	7.2	5.7	-	-	-	-	13.95	11.0	13.1
il	4.8	4.2	4.9	4.4	1.6	1.6	2.8	5.1	0.2	0.3	4.3
mt	1.3	1.4	1.4	1.5	0.6	0.6	0.9	0.7	1.8	4.1	2.1

*typical Balatonhighland basanite

TABLE 2
The range of major element compositions in glasses from different localities.

	Western Pannonian Basin	Olmani	Mongolia	Tahaa
SiO ₂	47.82 - 59.12	42.7 - 50.90	51.83 - 64.99	62.23 - 65.06
TiO ₂	0.82 - 2.99	0.60 - 3.72	0.02 - 0.74	0.60 - 0.99
Al ₂ O ₃	18.43 - 22.65	12.40 - 21.10	15.5 - 23.39	16.12 - 18.48
FeO _{tot}	2.20 - 6.87	0.70 - 10.90	1.66 - 4.49	0.90 - 4.25
MgO	2.22 - 4.44	0.71 - 12.30	0.48 - 4.25	1.15 - 3.23
CaO	3.71 - 10.31	2.30 - 12.80	0.21 - 8.05	0.81 - 1.65
Na ₂ O	2.92 - 5.84	0.40 - 7.30	6.80 - 10.55	3.82 - 6.10
K ₂ O	0.13 - 4.08	3.30 - 3.80	0.54 - 4.74	6.22 - 10.43

(Tanzania), Western Pannonian Basin glasses are more siliceous and aluminous. They are however, less silica-rich than glasses from Mongolian and Tahaa Island (Society archipelago) xenoliths (Table 2). This is compensated by smaller quantities of Fe, Mg and Ca both in Western Pannonian Basin and Mongolian glasses relative to the Olmani ones. The alkali content is high and variable, however the abundance of potassium is considerably greater in glasses from Tahaa xenoliths than in Western Pannonian Basin and other continental peridotite inclusions.

In our glasses a positive correlation between Mg and Ca and a negative one between Fe and Si exists. Jones *et al.* (1983) observed a positive correlation among P, Si, Ti and Na in the glasses of Olmani xenoliths. However, in Western Pannonian Basin glasses there is indication of a weak negative correlation between Si and Ti and no correlation between Na and Si. Na and Ti show a very weak positive correlation.

Some of the peridotite xenoliths contain glasses with quartz-normative compositions (Szt-1033, Szt-1034, Szt-1106, Szt-1116, G-1055). Because of the high alumina contents, some of these glasses are also corundum-normative (Table 1). In contrast, glasses in the other xenoliths are nepheline-normative. The abundance of normative nepheline is

particularly high in the glass composition of sample Szt-1069, owing to the low Si and high alkali content.

In the Ca-Na-K diagram (fig. 9) glasses from Western Pannonian Basin peridotites plot inside the area (encircled field) defined by compositional variability of similar glasses in Olmani, Tanzania (Jones *et al.*, 1983), Nunivak Island, Alaska (Francis, 1976), Algeria (Girod *et al.*, 1981), Victoria, Australia (Frey and Green, 1974; Irving, 1974), and Canary Isles (Forbes and Starmer, 1974). However, glasses from Mongolian peridotites are distinct by having considerably higher ratios of Na/K (striped area in fig. 9). Synthetic partial melts (Mysen and Boettcher, 1975; Kushiro, 1971) have much lower contents of potassium than mantle silicate glasses. Their composition is close to that of a 3:1 mixture of diopside/spinel, minerals that melt first in a peridotite assemblage (fig. 9)

Glass compositions in the lower crustal granulite xenolith (Bo-3007) are significantly different from those of the mantle peridotites (fig. 9) being extremely low in K but rich in Ca. They are also considerably richer in Al, Fe and Mg but lower in Si and Na relative to glasses in peridotites (Table 1). Their norm is dominated by anorthite and hypersthene and also contain significant amount of normative corundum (Table 1).

CHEMISTRY OF PHASES IN THE FINE-GRAINED
GLASS-BEARING ZONES

Secondary phases in fine-grained glass-bearing zones and blebs show differences in their chemistry compared to their respective primary phases in the host peridotite (Table 3). Generally, the Ca and Mg content of olivines in blebs and melt pockets is higher than in the Type I host lherzolite. In the latter, Ca in olivine and the Fo-content vary between 0.02-0.18 wt% and 88.2-91.5 respectively. (Embey-Isztin *et al.*, 2001). However, in samples Szg-3007 and Szt-1069 the small secondary olivines have lower Mg than the primary phase in the same sample. These samples are, however, composite xenoliths made up of Type I as well as Type II materials. Type II mantle rocks are considerably more iron-rich and less magnesian than Type I peridotites (e.g. Menzies, 1983; Embey-Isztin *et al.*, 1990). It may be that the lower forsterite contents of secondary olivines in the last two samples are due to the disturbing effect of the Type II component in these samples. Similarly, Francis (1976) and Maaløe and Printzslau (1979) found that in normal Type I lherzolites from Nunivak Island, Alaska and Dreiser Weiher, Germany the forsterite content of secondary olivines as well as the Ca content were consistently higher than in the olivines which compose the lherzolite. High levels of CaO in olivine are indicative of high temperatures (Adams and Bishop, 1982; Köhler and Brey, 1990) that must have prevailed in the xenoliths incorporated by the host magma.

There are significant differences in the composition of individual clinopyroxenes in the fine-grained zones of the same xenolith (Szt-1006, Szt-1003). In general, the Ca content of clinopyroxenes in blebs and melt pockets is consistently higher than that of the primary phase composing the matrix of the host lherzolites (Table 3). In contrast, the Mg content of clinopyroxene in the blebs is consistently less than that of the lherzolite. However, clinopyroxenes in blebs of the two composite xenoliths are the richest in Fe (FeO

4.00-5.19%) and therefore they show the lowest mg-values, which is a typical Type II feature.

The lower crustal granulite xenolith (Bo-3007) has quench olivine with Fo 64-65.5 and a very high content of CaO (0.59%) indicative of the high temperature that probably prevailed during transport and eruption.

GENESIS OF GLASSES IN WESTERN PANNONIAN
BASIN MANTLE XENOLITHS

Mantle xenoliths containing various proportions of glass genetically unrelated to their hosts were reported from a number of occurrences including Hawaii (White, 1966; Sen *et al.*, 1996); Victoria, Australia (Frey and Green, 1974; Irving, 1974; McRae, 1979); Canary Isles (Forbes and Starmer, 1974); Alaska (Francis, 1976); Eifel, Germany (Maaløe and Printzslau, 1979); Olmani, Tanzania (Jones *et al.*, 1983); Tahaa, Society archipelago (Schiano *et al.*, 1992); Mongolia (Ionov *et al.*, 1994) and Grande Comore, Indian Ocean (Coltorti *et al.*, 1999). These glasses are generally highly aluminous and rich in alkalis. They range from quartz to nepheline normative types and some of them have normative corundum due to the Al-rich nature. The glasses commonly contain quench crystals, mainly clinopyroxene, olivine, plagioclase and spinel (e.g. Frey and Green, 1974). Similar glasses have, however, also been described from peridotite xenoliths the origin of which was argued to be cognate with the host lava (Ellis, 1976; Irving, 1980). Most of the glass-bearing peridotites are spinel lherzolites or wherlites hosted in alkali basalt and basanite but more often emplaced in tuffs, diatremes or maars (Jones *et al.*, 1983). Breakdown of amphibole (White, 1966; Forbes and Starmer, 1974; Francis, 1976; Girod *et al.*, 1981), mica (Frey and Green, 1974) or even garnet (Hunter and Taylor, 1981) has been considered as a major factor in the genesis of some glasses. However, simple mass balance requirements suggests that additional factors, e.g.

TABLE 3

*Electrone microprobe analyses of secondary minerals in blebs.
Primary compositions are given for comparison.*

	Szg-3007					Szt-1006					Szt-1033		
	<i>ol</i> *	<i>ol</i>	<i>cpx</i> *	<i>cpx</i>	<i>pg</i>	<i>ol</i> *	<i>ol</i>	<i>cpx</i> *	<i>cpx</i>	<i>cpx</i>	<i>cpx</i>	<i>ol</i> *	<i>ol</i>
SiO ₂	40.33	39.84	52.19	50.16	52.74	40.35	40.90	52.94	48.72	50.09	47.61	40.38	40.79
TiO ₂	0.01	0.00	0.49	1.29	0.19	0.00	0.00	0.31	1.02	0.59	1.04	0.00	0.02
Al ₂ O ₃	0.03	0.05	6.83	4.35	29.05	0.00	0.04	2.37	11.54	5.73	8.60	0.01	0.06
Cr ₂ O ₃	0.01	0.00	0.72	0.66	Nd	0.00	0.11	2.54	1.75	2.60	2.98	0.00	0.09
FeO	1 1.25	14.93	2.88	5.19	0.66	10.15	7.91	3.64	2.97	2.69	2.82	9.90	9.22
MnO	0.14	0.24	0.10	0.13	nd	0.16	0.11	0.12	0.05	0.08	0.08	0.17	0.13
NiO	0.41	0.26	nd	nd	Nd	0.35	0.32	nd	nd	nd	nd	0.42	0.35
MgO	48.03	45.06	15.57	15.11	0.11	49.09	50.35	18.67	12.18	15.89	13.96	48.86	48.94
CaO	0.09	0.16	19.77	21.93	12.18	0.08	0.21	19.16	19.46	21.42	21.92	0.04	0.18
Na ₂ O	nd	nd	1.59	0.52	4.07	nd	nd	0.75	1.56	0.66	0.78	nd	nd
K ₂ O	nd	nd	0.00	0.00	0.43	nd	nd	0.00	0.52	0.02	0.02	nd	nd
Total	100.29	100.54	100.14	99.34	99.43	100.17	99.95	100.48	99.77	99.77	99.81	99.78	99.78
mg	88.40	84.32	90.60	83.84	-	89.60	91.90	90.14	87.96	91.32	89.82	89.79	90.44

	Szt-1033			Szt-1034			Szt-1069						
	<i>cpx</i> *	<i>cpx</i>	<i>cpx</i>	<i>ol</i> *	<i>ol</i>	<i>cpx</i> *	<i>cpx</i>	<i>pg</i>	<i>ol</i> *	<i>ol</i>	<i>cpx</i> *	<i>cpx</i>	<i>pg</i>
SiO ₂	52.67	48.32	51.12	40.26	40.72	53.02	52.44	58.64	40.56	40.31	51.83	49.27	50.71
TiO ₂	0.20	0.68	0.52	0.00	0.00	0.18	0.64	0.15	0.02	0.02	0.61	1.49	0.15
Al ₂ O ₃	2.82	8.57	5.74	0.01	0.03	2.85	3.76	25.58	0.03	0.05	6.18	8.67	31.07
Cr ₂ O ₃	0.43	3.05	1.15	0.04	0.07	1.00	1.17	nd	0.03	0.02	1.21	0.42	nd
FeO	2.74	2.96	3.08	9.02	9.28	3.02	3.42	0.44	10.07	11.31	3.65	4.00	0.50
MnO	0.07	0.05	0.06	0.14	0.14	0.05	0.10	nd	0.14	0.18	0.11	0.09	nd
NiO	nd	nd	Nd	0.40	0.41	nd	nd	nd	0.37	0.31	nd	nd	nd
MgO	17.02	15.21	16.16	49.55	49.40	17.95	17.90	0.14	48.52	47.64	15.90	14.84	0.17
CaO	23.81	20.68	21.72	0.08	0.16	20.66	19.72	8.09	0.10	0.23	18.79	20.27	14.31
Na ₂ O	0.18	0.53	0.41	nd	Nd	0.76	0.83	6.15	nd	nd	1.37	1.09	3.10
K ₂ O	0.00	0.00	0.00	nd	Nd	0.00	0.00	0.65	nd	nd	0.00	0.01	0.30
Total	99.94	100.05	99.96	99.48	100.21	99.49	99.98	99.84	99.83	100.1	99.65	100.14	100.31
mg	91.71	90.15	90.34	90.73	90.46	91.37	90.32	-	89.60	88.20	88.59	86.86	

ol = olivine. *cpx* = clinopyroxene. *pg* = plagioclase. * = primary phase

metasomatic enrichment or readjustment of alkalis, must play an important role in the process. The formation of glasses is commonly ascribed to decompression melting during rapid ascent of the xenoliths. Nonetheless, alternative proposals have also been put forward such as melting within the mantle adjacent to a magma body (Maaløe and Printzlau, 1979), different versions of cognate origin (Ellis, 1976; Irving, 1980) or accumulative origin (Irving, 1974).

We consider that, except for the xenolith Szt-1106, the breakdown of amphibole (or another potassium-rich phase such as mica) did not play a role in the genesis of glasses in Western Pannonian Basin mantle xenoliths. Firstly, even if pargasitic amphibole does occur in the lherzolites, its occurrence is scarce and it is

absent in all but one of the samples investigated. Secondly, the potassium content of the amphiboles is small, in some instances quite insignificant (Table 4), so the involvement of amphibole cannot account for the elevated potassium contents found in the glasses. Although there is compelling petrographic evidence for the role of breakdown of amphibole in the genesis of glass in the xenolith Szt-1106, the chemistry of this glass does not show any distinctive features compared with the other examples. In fact the chemical compositions and CIPW norms of pargasitic amphiboles (Table 4) are very different from those of the glasses. Therefore we conclude that the formation of glass must have involved the melting of additional phases

TABLE 4
Electron microprobe analyses and norms of pargasitic amphiboles from western Pannonian Basin mantle peridotites.

	Bo 1084	Szg 1072	Szg 1107	G 1063	Szt 1111	Ka	Ka 111	Ka 155
SiO ₂	42.18	43.40	42.28	42.44	42.91	43.10	44.10	43.70
TiO ₂	1.49	2.53	2.14	2.19	1.15	3.50	1.57	1.35
Al ₂ O ₃	14.85	15.30	15.00	14.80	14.33	15.40	13.50	14.60
Cr ₂ O ₃	0.86	1.24	0.89	1.27	1.15	0.59	1.21	1.27
FeO	4.41	3.70	4.36	4.24	4.11	4.90	4.20	4.00
MnO	0.07	0.03	0.07	0.07	0.05	0.10	0.07	0.05
MgO	17.63	17.00	17.26	17.09	17.81	16.70	18.40	18.40
CaO	11.07	10.70	10.32	10.87	11.55	10.30	10.40	10.80
Na ₂ O	3.57	2.98	3.84	3.59	2.95	3.40	3.60	3.30
K ₂ O	0.06	1.33	0.05	0.44	0.37	0.43	0.03	0.20
Total	96.19	98.21	96.22	96.99	96.37	98.42	97.08	97.67
or	0.37	6.41	0.31	2.68	2.27	2.58	0.18	1.21
lc	-	1.25	-	-	-	-	-	-
ab	0.74	-	4.03	0.85	0.41	5.43	7.64	4.22
ne	16.61	13.91	16.11	16.50	13.81	12.89	12.86	13.20
an	25.28	24.89	24.47	23.68	25.70	25.90	21.21	25.02
di	25.05	22.79	22.58	25.04	26.56	20.40	25.10	23.44
ol	27.69	24.00	26.91	25.03	27.23	25.16	28.11	28.37
il	2.94	4.89	4.22	4.29	2.27	6.75	3.07	2.63
cr	1.32	1.86	1.36	1.93	1.76	0.88	1.84	1.92
X _{Mg}	0.92	0.97	0.94	0.95	0.92	0.95	0.93	0.94

as well as materials introduced by metasomatic agents. In more general terms, our experience supports the view that the involvement of amphibole and/or mica in the partial melting cannot be safely demonstrated by chemical means because of the large variations of Ca/Na/K that exist for glasses reportedly derived from amphibole or mica (Frey and Green, 1974; Francis, 1976; Yaxley and Kamenesky, 1999). Frey and Green (1974) also reported glasses associated with phlogopite mica with Na>K despite low Na and high K in the mica. Finally, the high contents of K, Na and P in the glasses would require simultaneous melting of dispersed aggregates of mica, amphibole and apatite, which are extremely rare in peridotites (Ionov *et al.*, 1994). Although melting of amphibole as in xenolith Szt-1106, as in those of Nunivak Island (Francis, 1976), is demonstrable, the concept of its decompressional melting can hardly be of universal significance. This is also supported by the fact that most hydrous peridotites described in the literature show no trace of melting of mica, amphibole or apatite, even in small xenoliths.

The composition of the glasses is to some extent similar to that of synthetic glasses produced in natural peridotites. This indicates that diopside and spinel must be major components in the melting process. However, there are major deviations between the two types of glasses, especially in the content of K and Ti that are much higher in natural glasses. This makes the simple melting model based on the combined effect of heating by the host magma and pressure release during eruption of the xenoliths highly improbable. Partial melting during ascent is also unlikely since melting phenomena in peridotite xenoliths are rarely reported. If the partial melting occurred during ascent, all the xenoliths should have been partially molten, as they are all heated approximately to the same temperature and their sizes are also similar (Maaløe and Printzlau, 1979).

If we rule out the possibility of near surface decompression melting then we have to assume

that the process took place in the mantle. The high, oceanic-type geotherm observed in the Pannonian Basin (Dövényi and Horváth, 1988) is not inconsistent with partial melting within the spinel peridotite stability field especially if the effect of Cr is taken into account that enlarges the stability field of spinel towards higher depth. Partial melting may have been facilitated by the influx of volatiles such as H₂O and CO₂. Bali (1999) who also found carbonates in association with melt pockets in Western Pannonian Basin mantle xenoliths, suggested that these carbonates were formed by carbonatitic metasomatism in the mantle. Whereas mantle peridotites contain restricted amounts of alkalis, migrating metasomatic fluids can carry and add many elements and they are most probably responsible for the enrichment of the glasses in Si, Al, K and Na. Indeed, the highly variable enrichment of glasses in these elements is best explained by erratic contributions from fluids infiltrating the upper mantle. It has been shown that alkali silicate and carbonatite melts are the most likely candidates as metasomatic agents, rather than H₂O/CO₂-rich fluids (Hunter and McKenzie, 1989; Watson *et al.*, 1990). On the other hand, the SiO₂, TiO₂, Al₂O₃, Na₂O and K₂O content of the glasses cannot be derived from the existing minerals, which are characterised by low concentrations of these oxides. Therefore, it seems that the metasomatically induced *in situ* mantle melting model is the best explanation for the formation of glass patches in the xenoliths of the Western Pannonian Basin. The viability of this model was established by the study of Ionov *et al.* (1994) who used trace element as well as Sr, Nd isotope evidence to show that the formation of glass in Mongolian peridotite xenoliths had been initiated by a metasomatic enrichment in incompatible elements due to reactions with a migrating fluid phase in the upper mantle.

In recent years the possible metasomatizing agents have further been specified as being either (I) carbonatite, or (II) Na-alkali and (III) K-alkali silicate (e.g. Yaxley *et al.*, 1991; Sen *et al.*, 1996; Vannucci *et al.*, 1998; Coltorti *et*

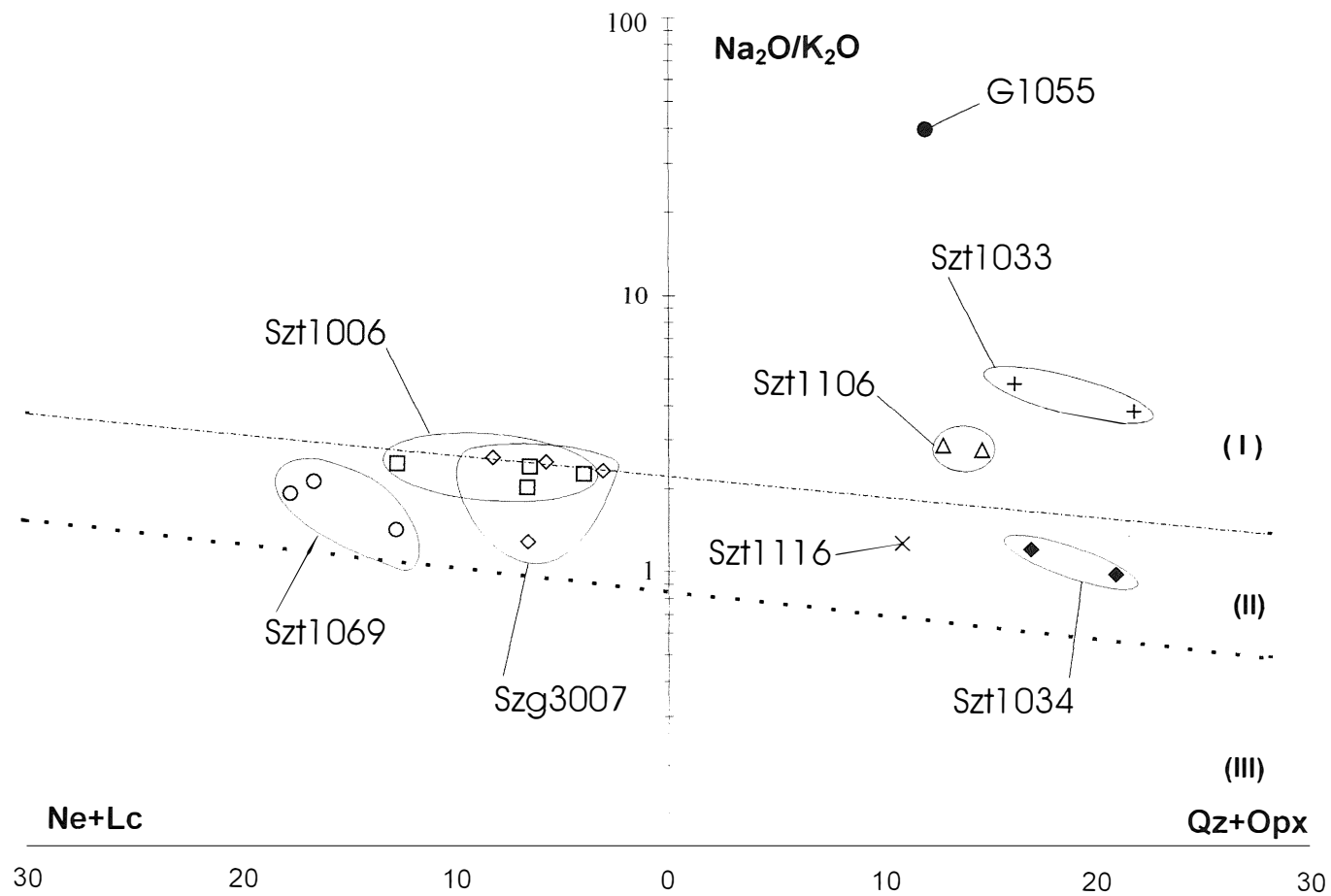


Fig. 10 – $\text{Na}_2\text{O}/\text{K}_2\text{O}$ vs normative minerals (Ne, nepheline; Lc = leucite; Qz = quartz; Opx = orthopyroxene) for western Pannonian Basin mantle glasses. Fields (I) glasses related to carbonatite; (II) Na-alkali silicate and (III) K-alkali silicate metasomatism (after Coltorti *et al.*, 2000).

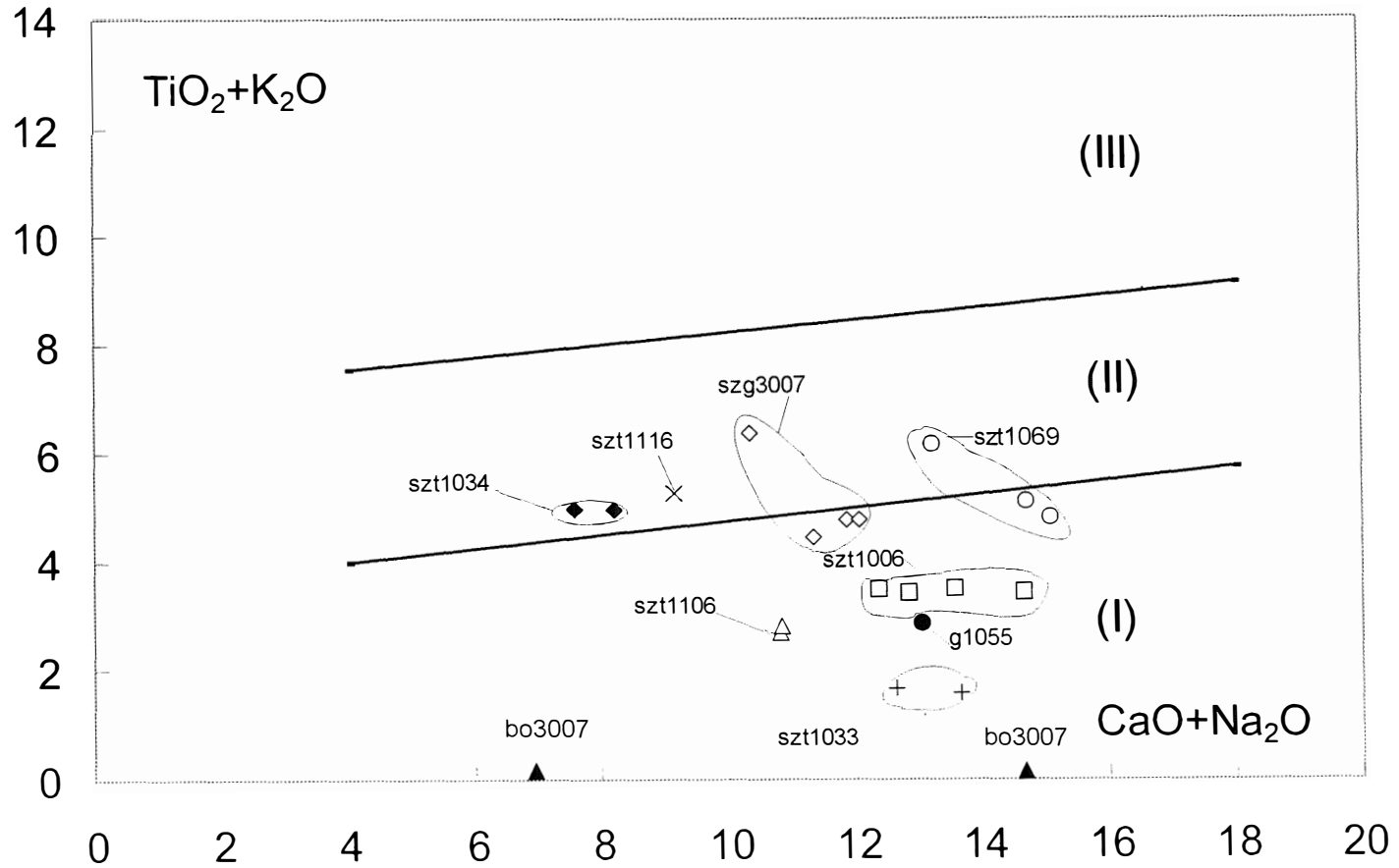


Fig. 11 – $\text{TiO}_2 + \text{K}_2\text{O}$ vs $\text{CaO} + \text{Na}_2\text{O}$ diagram for western Pannonian Basin mantle glasses. Fields (I) glasses related to carbonatite; (II) Na-alkali silicate and (III) K-alkali silicate metasomatism (after Coltorti *et al.*, 2000).

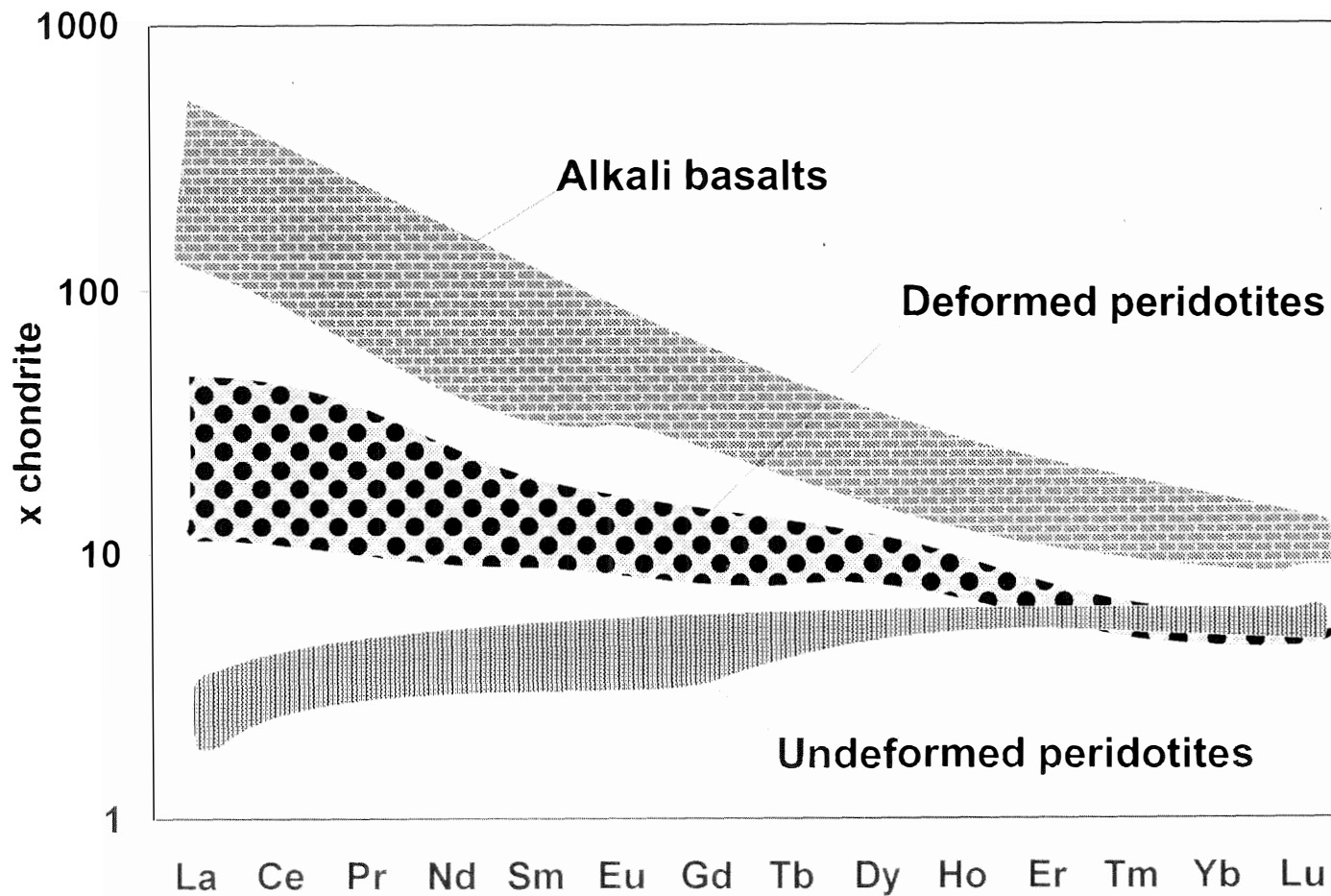


Fig. 12 – REE-patterns for western Pannonian Basin mantle peridotites (Embey-Isztin *et al.*, 1989; Downes *et al.*, 1992) and alkali basalts (Embey-Isztin *et al.*, 1993a).

al., 1999). Using $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratios vs normative Ne+Lc or Qz+Opx; $\text{TiO}_2 + \text{K}_2\text{O}$ vs $\text{CaO} + \text{Na}_2\text{O}$ as well as chondrite-normalized incompatible element diagrams for mantle glasses of world-wide occurrences Coltorti *et al.* (2000) demonstrated that these diagrams are suitable for distinguishing among glasses related to the three different types of metasomatizing agents mentioned above. Although we do not have trace element data for the Western Pannonian Basin mantle glasses, the use of the two major element diagrams gave consistent results. None of the Western Pannonian Basin glasses can be related to potassic metasomatism. Compositions of glasses from samples Szt-1033, Szt-1106 and G-1055 fall into the «carbonatite» field in both diagrams (fig. 10 and 11), whereas those from Szt-1034 and Szt-1116 show «Na-silicate» affinity. Less clear is the classification of the xenoliths Szt-1069 and Szt-3007 which plot in the «Na-silicate» field in fig. 10 but straddle the boundary between the «Na-silicate» and «carbonatite» fields in fig. 11. The less obvious is the status of Szt-1006 which lies well within the «carbonatite» area of fig. 11 but it is situated in the «Na-silicate» field of fig. 10. It is worth mentioning that the glass in the amphibole-bearing xenolith Szt-1106 is qz-normative (fig. 10) indicating that amphibole could not have played an essential role in the glass formation process. Amphibole did not contribute to the LREE-enrichment of deformed peridotite xenoliths (fig. 12); these rocks were enriched by cryptic metasomatism.

In contrast to peridotite xenoliths in which the formation of glass was exceptional, melting phenomena and glass are commonly observed in lower crustal granulite xenoliths. Especially in the Bondoróhegy granulite xenoliths, total decomposition of garnet and partial resorption of clinopyroxene and plagioclase are invariably associated with melting and quench phenomena. This difference in the melting behaviour is strange, since the size of granulite xenoliths is comparable to that of the peridotites and they were heated to the same temperature in the enclosing basaltic melt. One

possible explanation can be that granulites have mafic compositions that melt at considerably lower temperatures than do ultramafic peridotites. Another conspicuous difference between the peridotite and granulite xenoliths is that in the latter, the glass has retained the very low potassium content of the granulite host. The lack of enrichment in potassium and possibly in other highly incompatible elements in these particular glasses indicates that a fluid-driven metasomatic event, comparable to the one that affected mantle peridotites, is unlikely to be responsible for the melting in the lower crustal granulite xenoliths. All these suggest that in the case of granulite xenoliths, we are possibly dealing with decompressional melting in rapidly ascending xenoliths. The high abundance of small quench crystals, especially plagioclase in the vitreous matrix of xenolith Bo-3007 and elsewhere also support this view.

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