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SPINEL PERIDOTITE XENOLITHS FROM THE SHAVARYN-TSARAM VOLCANO, NORTHERN MONGOLIA: PETROGRAPHY, MAJOR ELEMENT CHEMISTRY AND MINERALOGY

(Figs. 7, Tabs. 3)

Abstract: Alkalic basaltic rocks within the Tariat depression in the northern Khangai highland, central Mongolia, contain mantle xenoliths which are particularly abundant and diverse in the Shavaryn-Tsaram cinder cone. The xenolith suite is dominated by primitive and slightly depleted spinel lherzolites with Na and Al-rich clinopyroxenes and low-Cr spinels, harzburgite nodules with low-Al high-Cr pyroxenes and spinel are very rare. Variations of major element contents in most peridotites show good mutual correlations and also correlate with Mg-number of silicates and Cr content in spinel in keeping with the concept of partial melting of primitive mantle. Mica and garnet-bearing rocks occur.

Резюме: Щелочные базальтоиды Тарятской впадины на севере Хангайского нагорья в МНР содержат мантийные ксенолиты. Они особенно обильны и разнообразны в пирокластике вулканического аппарата Шаварын-Царам. Здесь преобладают примитивные и слабо деплетированные лерцолиты с глиноземистыми клинопироксеном и шпинелью, но есть и гарцбургиты с хромистой шпинелью. Вариации содержаний главных окислов в большинстве перидотитов четко коррелируют друг с другом, а также с магнезиальностью силикатов и хромистостью шпинели в соответствии с моделью частичного плавления примитивной мантии. Имеются также слюдистые и гранатсодержащие перидотиты и сложные ксенолиты.

Ultramafic xenoliths in alkalic basalitic rocks are a major source of information on the structure and composition of the upper mantle beneath the continents. Volcanic fields associated with the Baikal rift system at the territory of the U.S.S.R. and Mongolia make up the largest areal of Cenozoic alkalic basaltic volcanism in Asia. Young volcanic rocks of the Khangai highland in the central Mongolia are located in the extreme south-eastern part of this areal. On the northern slope of the Khangai rise, at the junction of the Sumein and Choloot rivers, the Tariat depression is located — a graben-like structure filled with Pliocene to Recent alkalic basitic lavas (Fig. 1). A few volcanic centers have been recognized along its flanks, their deposits often containing mantle xenoliths and megacrysts (Кепежинскас, 1979).

The most abundant and diverse are mantle xenoliths in pyroclastic deposits of the Pleistocene eruptive center Shavaryn-Tsaram some 20 km southeast of township Tariat. Shavaryn-Tsaram is a low cinder cone with an outcrop of 600 × 350 m consisting of lava breccias, tuff breccias, cinder deposits with lapilli and volcanic bombs. The fragments of volcanic rocks are alkalic potassium-rich basaltoids: porous and streaky potassic basanites, limburgites, alkalic basaltic glasses. Peculiar chemical features of these rocks are high

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total alkali content (about 8—9 %) causing a high degree of silica undersaturation with normative feldspatoids reaching 20—30 %, rather low Mg-values (0.4—0.6), K_2O/Na_2O ratio is relatively high approaching unity (Кепежинскас, 1979).

Abundant xenoliths of crustal (granitoids, granulites) and mantle rocks occur in pyroclastic deposits of the volcano as well as megacrysts of clinopyroxene, garnet, mica and sanidine. Spinel peridotite nodules reach 50 cm in size and are sharply dominant among the mantle xenoliths. Some garnet-spinel lherzolites and pyroxenites, green and black spinel pyroxenites also occur. The general characteristic of xenoliths in the occurrence has been given by Кепежинскас (1979).

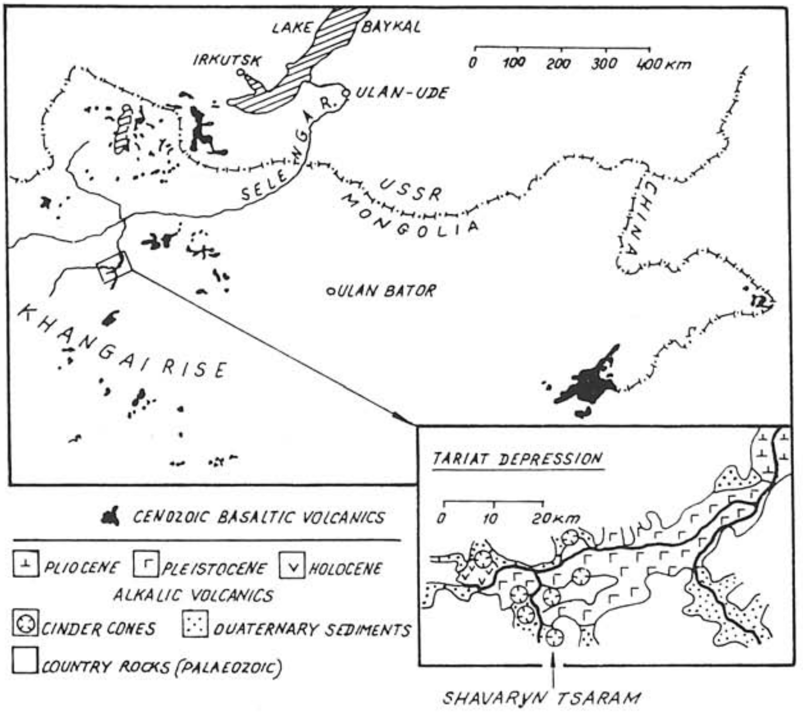

Fig. 1. Geographical location of the Tariat depression and the Shavaryn-Tsaram volcano. Compiled using data of Кепежинскас (1979) and Press et al. (1986).

The aim of this paper is to provide some data on the structure and composition of uppermost horizons of the upper mantle beneath the northern Mongolia on the basis of detailed petrological characteristics of spinel peridotite xenoliths of the Shavaryn-Tsaram volcano. The peridotites constitute a series from pyroxene-rich lherzolites to clinopyroxene-bearing harzburgites sharply dominated by lherzolites. The abundance of primitive or slightly depleted lherzolites is a distinctive feature of the Shavaryn-Tsaram peridotite series by contrast with nodule suites in most alkalic basaltic provinces of the world where more depleted peridotites (lherzolites-harzburgites) are more common.

Petrographic description

Lherzolites from the Shavaryn-Tsaram volcano are very fresh friable rocks, rare harzburgitic xenoliths are smaller and well cemented. The lherzolites contain as an average about 60 % olivine, 10—15 % clinopyroxene, orthopyroxene content is higher than that of clinopyroxene, spinel ranges from 1 to 3 %. However, in the whole peridotite series modal compositions are highly variable: olivine 40—80 %, clinopyroxene 1 — 15—20 %. The lherzolites typically have massive structure though clinopyroxene and spinel grains may show vague lineation patterns or concentrate in clots. Texture is allotriomorphic-granular, deformation features are very weak. Olivine and orthopyroxene range from 1 to 3 mm in size, rare orthopyroxene porphyroclasts about 5 cm across sometimes occur. Clinopyroxene and spinel have smaller grain-size, spinel occurs as very irregular grains or forms intricate intergrowths with orthopyroxene. Texturally the rocks belong to the common for mantle peridotites protogranular or coarse type.

The harzburgites may contain less than 2 % of clinopyroxene, spinel in them usually occurs as rare singular grains, grainsize of minerals varies greatly. Olivine not infrequently is represented by equidimentional and polygonal grains with stright or slightly curved grain boundaries with dominating 120° triple junctions, small grains of clinopyroxene and spinel are often confined to the latter. The textures are very similar to granuloblastic or mosaic and seem to be brought about by intensive metamorphic recrystallization. Some peridotites contain singular grains or small clots of accessory mica. Micaceous lherzolites (4230/16 and others) were also found which are fine-grained foliated rocks with equigranular-mosaic texture containing a few per cent of phlogopite. Few garnet-spinel lherzolite nodules have been found. They have higher pyroxene contents than most spinel lherzolites, garnet occurs either as rims around spinel or elongated blebs along grain boundaries.

Bulk rock chemistry

Bulk rock analyses show significant major and minor element variations (Tab. 1) which are at a first approximation due to the observed variations in modal composition. Fig. 2 demonstrates that all major oxides show good linear correlations with MgO. Similar trends are seen in Fig. 3 where FeO, CaO, Al_2O_3 and TiO_2 are plotted against the bulk rock Mg-values. The negative correlation between MgO and SiO_2, Al_2O_3, CaO, Na_2O and TiO_2 contents virtually reflects the decrease of modal pyroxenes (first of all clinopyroxene) in more magnesian (olivine-rich) peridotites. On the other hand, the decrease in total iron as MgO content and Mg-value go up demonstrates that in spite of the decrease in modal pyroxenes (which contain less iron than coexisting olivine) in harzburgites, simultaneous decrease in olivine fayalite content has a more significant overall effect.

Table 1

Chemical composition of spinel peridotite xenoliths from the Shavaryn-Tsaram volcano

	4230 /16	4399 /23	4399 /26	4500 /8	4500 /11	4500 /17	4500 /18	4500 /19d	4500 /21	4500 /33	4594 /2	4594 /6	STZ —1
SiO_2	44.60	42.44	43.33	44.44	44.44	43.33	45.77	42.59	44.81	44.54	46.14	44.55	44.60
TiO_2	0.20	0.01	0.07	0.20	0.17	0.07	0.05	0.08	0.16	0.12	0.19	0.18	0.18
Al_2O_3	3.60	1.40	1.40	3.70	2.70	1.00	1.10	1.37	3.60	3.20	4.30	4.00	4.00
Cr_2O_3	0.37	0.46	0.34	0.35	0.43	0.33	0.36	0.42	0.40	0.40	0.38	0.38	0.37
FeO*	8.70	7.47	8.91	8.46	8.48	8.60	7.15	7.09	8.10	8.03	8.10	8.03	8.09
MnO	0.15	0.15	0.17	0.18	0.17	0.16	0.16	0.14	0.17	0.16	0.19	0.17	0.12
NiO	0.23	n. d.	0.30	0.23	0.25	0.28	0.27	n. d.	0.24	0.26	0.20	0.23	0.22
MgO	38.80	46.18	44.11	38.12	38.48	44.80	43.28	45.93	37.80	39.53	35.70	37.73	37.13
CaO	2.47	0.76	0.64	2.94	4.00	0.59	0.66	0.96	2.84	2.20	3.40	2.93	4.01
Na_2O	0.23	0.10	0.11	0.35	0.35	0.10	0.11	0.10	0.32	0.24	0.38	0.34	0.41
K_2O	0.20	0.03	0.04	0.01	0.01	0.03	0.05	0.01	0.01	0.01	0.01	0.01	0.03
H_2O	0.11	n. d.	0.09	0.05	0.08	0.53	0.26	n. d.	0.08	0.08	0.08	0.21	0.07
Total	99.85	98.95	99.73	99.67	100.19	100.47	99.74	98.60	99.50	99.50	99.70	99.38	99.72

Note: FeO* — total Fe as FeO. Samples 4230/16, STZ-1 — wet chemical analysis, other — XRF analyses plus flame photometry for alkalies.

On the whole, the bulk rock major element variation patterns shown in Figs. 2 and 3 are consistent with the concept of partial melting of initial material (primitive lherzolite) rich in basaltic components whose composition projects close to the peridotite trend in these diagrams. The compositional variations may be caused either by different degrees of melting (Nickel — Green, 1984) or varying degrees of removal of the melt from the restite.

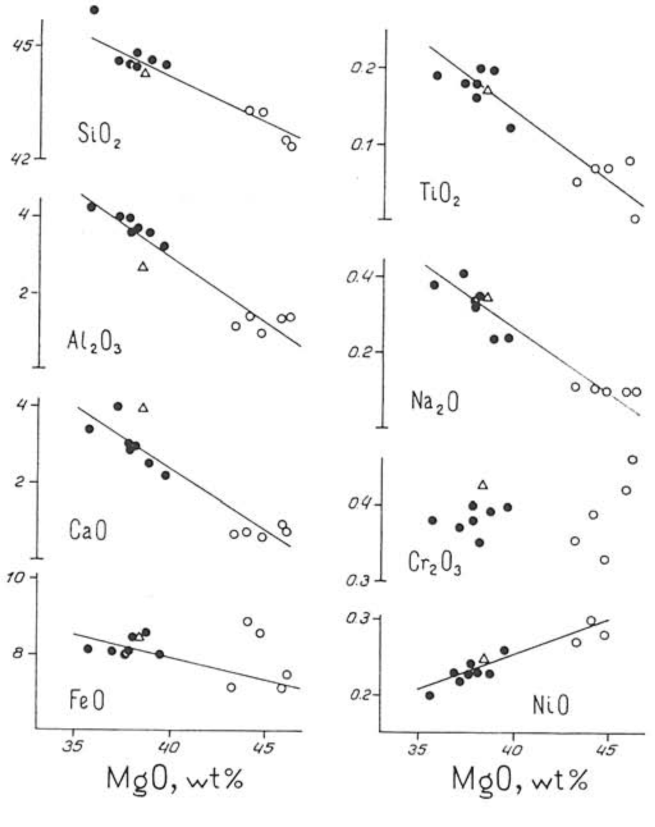

Fig. 2. A plot of MgO versus some major and minor oxides content in bulk rock peridotites.
Explanations: Filled circles — lherzolites; open circles — harzburgites; triangle — wherlite.

Deviations from the trends for some specific nodules can also be explained in the framework of this concept. The relative enrichment of CaO in the nodule 4500/11 is due to the presence of a band (vein) of a clinopyroxene-rich rock (wherlite). Such segregations in mantle peridotites, first of all, veins of green pyroxenites may have been formed as a result of crystal segregation from high-Mg primary mantle magmas of the type of picrites in cracks and pockets in peridotites. Subsequent mineral exsolution from the initial high--temperature pyroxene phase gave rise to polymineral websterites. Mineral compositions in the green websterite and lherzolite zones of a few composite nodules studied so far are almost the same suggesting a very primitive nature of the magmas parental for the websterites that were in chemical equilibrium with common mantle peridotites.

Note also that two harzburgitic nodules (4399/26, 4500/17) have higher total iron than is required by the trend determined by all the other samples (Figs. 2, 3). This indicates that the two rocks were enriched in iron as a result of a process other than that responsible for the general trend and probably superimposed on the latter. The presence of mica segregations in 4500/17 (see Tab. 3) and of fine-grained material along cracks and grain boundaries in 4399/26 suggests that this process may have been mantle metasomatism.

The absence of positive correlation between MgO and chromium might seem contradictory in view of the well-known geochemical behaviour of the latter as a „refractory" element. This „anomaly" may be due to the fact that in primitive mantle peridotites Cr is a minor isomorphous component of the phases (spinel and clinopyroxene) which are the first to be involved (and consumed) in partial melting.

The most outstanding feature of the major element chemistry of the Shavaryn-Tsaram peridotite xenolith suite is the predominance of primitive and slightly depleted nodules. Thus, the examination of Tab. 1 shows that the average contents of various oxides in lherzolite nodules typical for the occurrence (4230/16; 4500/8, 21, 33; 4594/2, 6; STZ-1): 3.8 % Al_2O_3, 3.0 % CaO, 0.32 % Na_2O, 37.8 % MgO etc. are very close to estimates of primary mantle compositions or pyrolite models. Similar conclusions have been arrived at by Press et al. (1986) who studied the petrology of another set of Shavaryn-Tsaram lherzolite nodules.

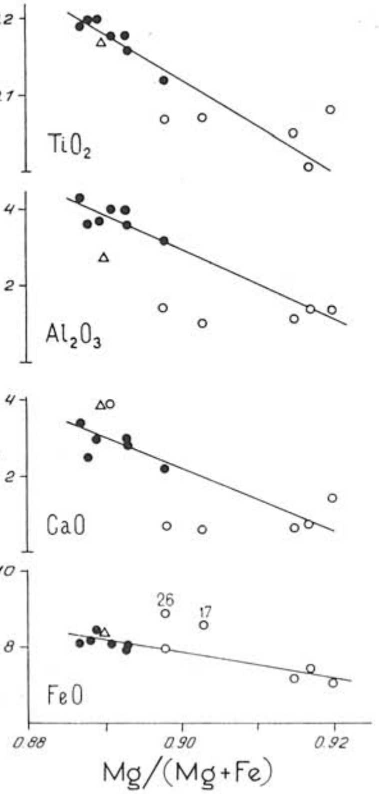

Fig. 3. FeO, CaO, Al_2O_3 and TiO_2 (wt. %) versus bulk rock Mg-value = Mg/$(Mg+Fe)_{at}$ ratio.

Mineralogy

Composition of minerals of the spinel peridotites (Tab. 2) changes systematically from lherzolites to harzburgites. A good positive correlation between the Mg-values of olivines and bulk rocks (Fig. 4) might seem quite obvious, but it demonstrates once more that the both parameters are the precise indicators of crystal-liquid fractionation processes (partial melting degree) and can be directly matched with petrochemical characteristics of the peridotites (Figs. 2, 3). High-Cr spinel as well as high-Cr (up to 1.5 % Cr_2O_3) and low-Al

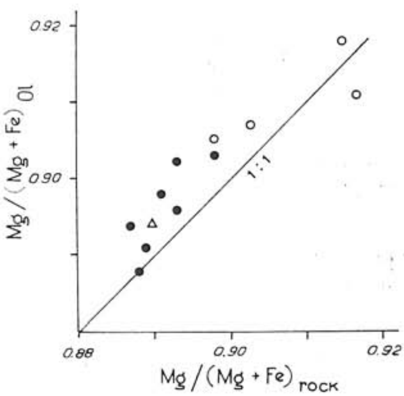

Fig. 4. A correlation diagram for olivine and bulk rock Mg-values.

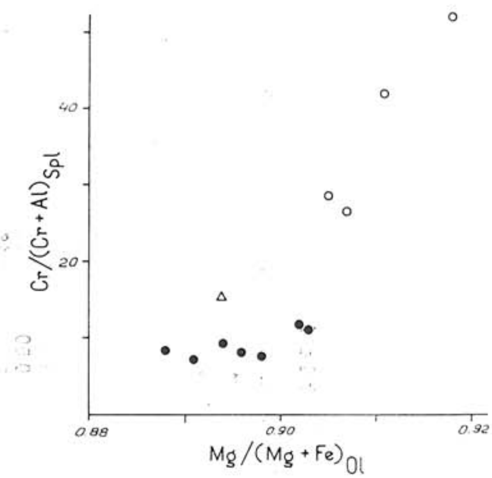

Fig. 5. Mg/(Mg+Fe) in olivine versus Cr/Cr+Al) in spinel.

(about 2 % Al_2O_3) clinopyroxenes have never been reported before for Shavaryn-Tsaram peridotite nodules. Their rareness once more stresses the relatively primitive nature of the volcano peridotite series, this time from the viewpoint of mineralogy. The $Cr/(Cr+Al)_{at}$ ratio reaches 0.4—0.5 for the most magnesian peridotites (harzburgites) (Fig. 5) whereas for peridotites with olivine Mg--values of 0.888—0.900 those ratios are almost identical and center around 0.1. If spinel chromium content is taken as a major indicator of partial melting degree of initial mantle peridotites, then all the nodules with Mg-values within this range should be attributed to primary or primitive peridotites. Fig. 6 drives one to a similar conclusion. It demonstrates that the alumina content of clinopyroxenes increases from 2 to more than 7 % as olivine Mg-values increase from 0.92 to 0.90, but then remains constant for the lherzolites with the same Mg-values range of 0.888—0.900. This may suggest that Mg/Fe ratios and probably some major oxide contents in primitive mantle peridotites vary within certain limits. This is indicated by the comparison of primitive peridotites from Shavaryn-Tsaram with those from other xenolith suites (Press et al., 1986).

Table 2

Microprobe analyses of minerals of the spinel peridotite xenoliths

	4399/23 — harzburgite				4399/26 — harzburgite				4500/8 — lherzolite			
	Ol	Opx	Cpx	Spl	Ol	Opx	Cpx	Spl	Ol	Opx	Cpx	Spl
SiO_2	40.99	56.24	54.01	0.11	41.24	56.43	53.07	0.21	41.25	55.10	52.21	—
TiO_2		0.05	0.15	0.15		0.12	0.52	0.33		0.17	0.95	0.15
Al_2O_3		2.02	3.42	33.19		3.27	4.90	42.82		4.28	7.37	59.52
Cr_2O_3		0.43	1.49	35.82		0.50	1.46	25.49		0.25	0.66	6.98
FeO*	8.58	5.53	2.20	14.40	9.32	5.82	2.46	12.39	10.40	6.51	2.68	10.59
MnO	0.09	0.10	0.05	0.23	0.10	0.10	0.06	0.19	0.12	0.12	0.06	0.09
NiO	0.37	0.10	0.05	0.20	0.33	0.06	0.00	0,24	0.36	0.09	0.03	0.45
MgO	49.27	34.13	15.87	17.03	49.86	34.02	15.37	19.04	47.53	32.37	13.94	21.24
CaO	0.03	0.43	20.83		0.04	0.50	20.69	0.03	0.04	0.45	19.57	
Na_2O		0.04	1.36			0.07	1.40			0.12	2.10	
Total	99.33	99.07	99.43	100.63	100.89	100.89	99.93	100.74	99.72	99.46	99.57	99.02
$\frac{Mg}{Mg+Fe}$, at	0.911	0.916	0.928	0.678	0.905	0.913	0.918	0.733	0.891	0.899	0.903	0.782

Note: FeO* total Fe as FeO; Ol — olivine; OPx — orthopyroxene; Cpx — clinopyroxene; Spl — spinel.

1st continuation of Tab. 2

	4500/17 — harzburgite				4500/18 — harzburgite				4500/21 — iherzolite			
	Ol	OPx	Cpx	Spl	Ol	OPx	Cpx	Spl	Ol	OPx	Cpx	Spl
SiO_2	40.18	55.51	53.05	0.52	42.04	57.19	55.50	0.08	40.90	54.93	52.88	0.06
TiO_2		0.07	0.28	0.11		0.02	0.05	0.08		0.12	0.55	0.10
Al_2O_3		3.25	5.33	45.17		1.46	2.22	26.32		4.10	6.41	56.06
Cr_2O_3	0.03	0.62	1.52	24.01		0.37	0.88	42.83		0.37	0.94	11.04
FeO*	8.99	5.72	2.02	11.11	7.99	5.00	2.07	14.25	9.69	6.16	2.60	10.98
MnO	0.09	0.10	0.05	0.15	0.10	0.10	0.08	0.16	0.15	0.13	0.09	0.12
NiO	0.36	0.09	0.03	0.23	0.36	0.08	0.05	0.13	0.38	0.09	0.03	0.37
MgO	49.31	33.61	14.94	19.48	50.30	35.05	16.81	16.32	50.07	32.81	14.47	20.40
CaO	0.06	0.48	20.92	0.03	0.07	0.54	20.93		0.03	0.53	20.27	
Na_2O		0.01	1.43			0.12	1.46			0.11	2.17	
Total	99.02	99.46	99.57	100.81	100.87	99.93	100.05	100.17	101.25	99.35	100.41	99.13
$\frac{Mg}{Mg+Fe}$, at	0.907	0.913	0.930	0.758	0.918	0.926	0.936	0.672	0.902	0.905	0.909	0.768

2nd continuation of Tab. 2

	4500/33 — lherzolite				4594/2 — lherzolite				4594/6 — lherzolite			
	Ol	Opx	Cpx	Spl	Ol	Opx	Cpx	Spl	Ol	Opx	Cpx	Spl
SiO_2	41.30	56.16	53.80	0.13	40.88	54.84	53.09	0.06	40.92	54.53	52.11	0.09
TiO_2		0.13	0.56	0.10		0.15	0.62	0.20		0.13	0.68	0.12
Al_2O_3		4.17	6.41	58.78		5.31	7.07	57.66		4.75	7.28	59.11
Cr_2O_3		0.33	0.80	10.76		0.45	0.80	8.80		0.32	0.73	7.82
FeO*	9.43	5.87	2.26	10.07	10.26	6.45	3.19	10.84	10.03	6.37	2.56	10.78
MnO	0.14	0.14	0.09	0.12	0.17	0.14	0.10	0.05	0.17	0.16	0.09	0.05
NiO	0.39	0.07	0.05	0.37	0.37	0.10	0.05	0.42	0.41	0.09	0.03	0.40
MgO	49.45	32.90	14.73	20.92	48.75	32.08	15.30	21.21	48.50	32.23	13.83	20.51
CaO	0.04	0.47	19.86		0.08	0.99	19.21		0.04	0.51	19.94	0.04
Na_2O		0.08	1.98			0.00	1.81			0.00	1.98	
Total	100.78	100.32	100.54	101.25	100.51	100.51	101.24	99.24	100.08	99.09	99.23	98.92
$\frac{Mg}{Mg+Fe}$, at	0.903	0.909	0.920	0.788	0.894	0.899	0.895	0.777	0.896	0.901	0.907	0.836

Pyroxene thermometry

Mineral equilibrium temperature estimates using Wells' (1977) thermometer give the range of 850—1100 °C (Ионов et al., 1984). The highest temperatures show garnet-spinel lherzolites, and the lowest — micaceous spinel peridotites (Fig. 7). In the former case this is due to the deeper origin of garnet-bearing rocks, in the latter the possible explanations may be either

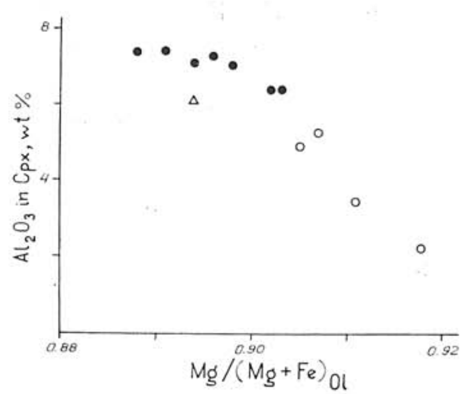

Fig. 6. Mg/(Mg+Fe) in olivine versus Al_2O_3 content of clinopyroxene.

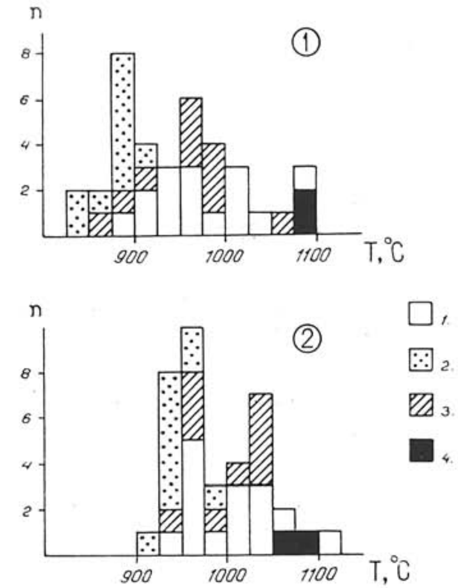

Fig. 7. A histogram of mineral equilibration temperatures distribution for various Shavaryn-Tsaram xenoliths.
Explanations: Geothermometers: 1 — Wells (1977), 2 — Sachtleben—Seck (1981). Additional data from (Ионов et al., 1984) have been used. 1 — common spinel peridotites; 2 — micaceous spinel peridotites; 3 — pyroxenites; 4 — garnet-spinel lherzolites.

the decrease of mineral equilibration temperatures during metasomatic transformation by fluids or the occurrence of the hydrous peridotites in the uppermost mantle horizons. The temperatures for common spinel peridotites range from 900 to 1050 °C, not showing any relationship with modal or chemical composition of the xenoliths and probably are defined by their different depths in the mantle section in accordance with the local geotherm. If the peridotites had suffered a partial melting event (T = 1300—1400 °C) they must have gone through a durable cooling stage afterwards accompanied by extensive diffusional redistribution of ions in mineral structures. Pyroxenes in some

Table 3

Microprobe analyses of phlogopites from peridotite xenoliths of the Shavaryn-Tsaram volcano

	4230/16	4500/17	4500/21	4500/33
SiO_2	38.22	38.18	38.60	39.68
TiO_2	6.16	3.78	4.34	4.11
Al_2O_3	14.52	16.62	15.88	17.38
Cr_2O_3	0.48	1.68	0.70	0.72
FeO*	3.95	3.44	3.75	3.59
NiO	0.15	0.20	0.18	0.19
MgO	21.50	21.94	21.39	21.50
BaO	1.64	n. d.	0.82	0.07
Na_2O	0.80	0.40	0.80	0.77
K_2O	8.72	9.58	8.66	9.33
Total	96.14	95.82	95.20	97.31

peridotites exhibit fine exsolution lamellae and slight zoning (higher Al and Cr in central parts of larger grains). The use of other geothermometers (Sachtleben—Seck, 1981) gives 40—80° higher estimates (Fig. 7) but does not change their distribution pattern.

Hydrous phases

Mica is the most common hydrous phase in the xenoliths and accessory amphibole occurs very rarely, unlike most other xenolith suites in alkaline basalts of the world. The micas are high-Mg phlogopites with rather variable (mostly high) contents of TiO_2 as well as BaO (Tab. 3) (Ионов et al., 1983). The presence of cross-cutting mica veinlets and petrographical evidence for the replacement of spinel and other minerals in some peridotites suggest that the introduction of mica is the result of mantle metasomatism.

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