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## PETROLOGY AND GEOCHEMISTRY OF ULTRAMAFIC XENOLITHS IN MAFIC ROCKS OF HUNGARY AND BURGENLAND (AUSTRIA)

(Figs. 9, Pl. 1, Tabs. 6)

**Abstract:** Petrological and geochemical data on ultramafic xenoliths in Cretaceous lamprophyres and Pliocene—Pleistocene alkaline basalts of the Carpathian—Pannonian region are compared. Chemical composition of xenolith components and calculated equilibrium data indicate similarity among a group of the xenoliths in lamprophyres from Alcsútdoboz-2 borehole and ultramafic nodules in kimberlites. Another group of xenoliths displays features similar to nodules in alkaline basalts. No differences have been recognized among xenoliths in Pliocene—Pleistocene alkaline basalts.

**Резюме:** В статье сравниваются петрологические и геохимические данные о ультрамафических ксенолитах в меловых лампрофрах и плиоцен-плейстоценовых щелочных базальтах Карпато-Паннонского региона. Химический состав ксенолитовых компонентов и вычисленные данные о равновесии намечают сходство между группой ксенолитов в лампрофрах из буровой скважины Алчутдобоз-2 и ультрамафическими включениями в кимберлитах. Следующая группа ксенолитов проявляет признаки похожие включениям в щелочных базальтах. Не наблюдались никакие различия между ксенолитами в плиоцен-плейстоценовых щелочных базальтах.

### *Introduction*

Peridotite xenoliths of mantle origin have been reported from several localities in the Carpathian—Pannonian region. The enclosing rocks form two groups on petrological and geochronological grounds (Fig. 1).

— Pliocene—Pleistocene alkaline basalts. Ultramafic nodules have been investigated from Burgenland (Richter, 1970; 1971), Balaton Highlands (Embey-Isztin, 1976; 1977), northern part of Nógrád—Gemer region in Southern Slovakia (Hovorka, 1981), Little Plain in Hungary (Szabó, 1978) and southern part of Nógrád—Gemer region (Molnár, 1980; János, 1984). The latter three studies have been carried out at Department of Petrology and Geochemistry, Eötvös University, Budapest.

— Cretaceous alkaline mafics—lamprophyre—carbonatite association, reported by Kubovics (1980; 1984), Horváth et al. (1983) and Horváth—Ódor (1984). Important petrogenetic problems of these rocks and their nodules have been cleared by Kubovics (1984). The Alcsútdoboz-2 borehole (Fig. 1) hit dyke rocks of this association, where large quantity of nodules of varied composition have been found (Szabó, 1985).

This paper is part of a comparative investigation to discuss origin and interrelationships of peridotite nodules in the above-mentioned mafic rocks of the Carpathian—Pannonian region.

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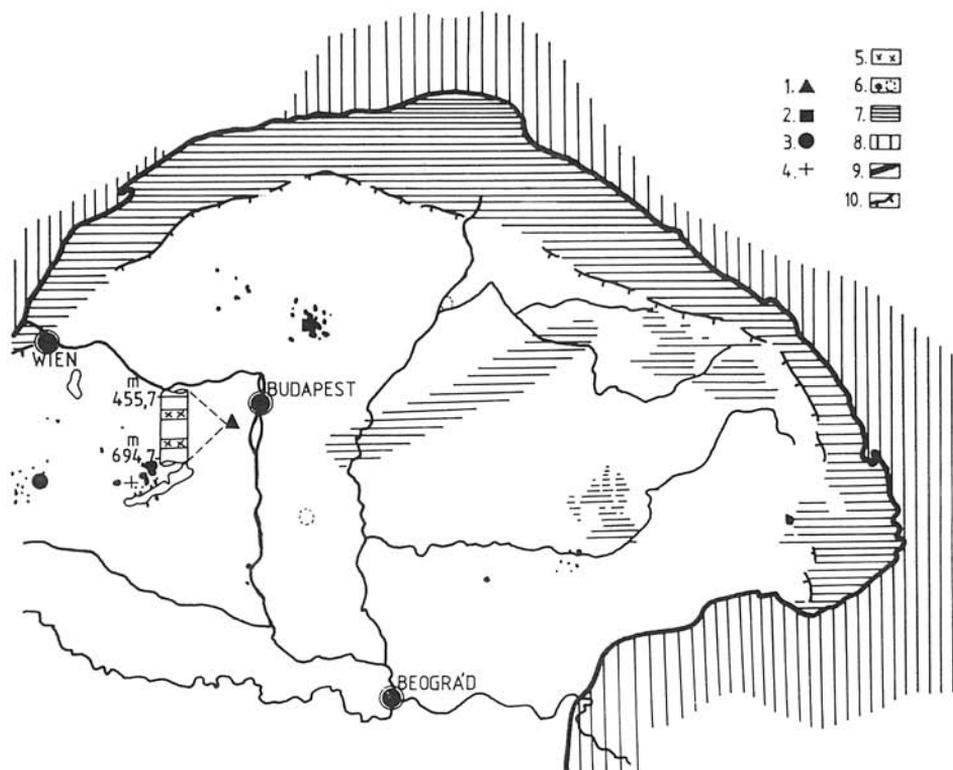


Fig. 1. Arrangement of alkaline basalts in the Carpathian region (after Balla, 1980).  
*Explanations:* 1 — AD-2 borehole; 2 — Nógrád—Gömör; 3 — Burgenland (Austria); 4 — Balaton Highlands; 5 — lamprophyre (Cretaceous); 6 — alkaline basalts (Pliocene—Pleistocene); 7 — flysch; 8 — Carpathian foredeep; 9 — contour of the Carpathian fold system; 10 — Klippen belt.

### *Petrography of xenoliths*

Mineral composition of the analysed nodules is shown in Tab. 1. One may note, that most of the ultramafic xenoliths in Cretaceous lamprophyres of Alcsútdoboz-2 borehole contain phlogopite. Projection points of the samples are summarized in an Ol—Opx—Cpx plot of Streckeisen (1974) (Fig. 2). Texture of the xenoliths shows deformation and recrystallization, indicating a complex metamorphic origin. These features are characteristic of xenoliths of upper mantle origin (Mercier—Carter, 1975; Green—Ringwood, 1976; Mercier—Nicolas, 1978).

Most ultramafic nodules show equigranoblastic (Harte, 1977) texture (Pl. 1, photo 1); others show mosaic-porphyroclastic, porphyroclastic and disrupted-laminated-mosaic-porphyroclastic texture (Pl. 1, photo 2).

Table 1  
Modes of xenoliths

| Locality                | Samples                         | OL   | OPX  | CPX  | SP  | PHL |
|-------------------------|---------------------------------|------|------|------|-----|-----|
| Burgenland<br>(Austria) | Lherzolite Tob-51               | 72.5 | 7.3  | 14.9 | 3.1 | 2.2 |
|                         | Lherzolite Tob-41               | 69.4 | 18.1 | 9.1  | 3.4 | —   |
|                         | Harzburgite Tob-43              | 92.6 | 7.4  | —    | —   | —   |
|                         | Harzburgite Tob-34              | 85.0 | 12.9 | —    | 2.1 | —   |
|                         | Wehrlite Tob-35                 | 81.6 | —    | 16.6 | 1.8 | —   |
| Balaton<br>Highland     | Lherzolite Szbk-1               | 75.8 | 15.9 | 8.3  | 0.1 | —   |
|                         | Lherzolite Szbk-2               | 76.8 | 7.2  | 15.3 | 0.7 | —   |
| Nógrád-<br>Gömör        | Lherzolite Bn-40                | 75.4 | 14.1 | 7.4  | 3.1 | —   |
|                         | Lherzolite Me-3b                | 78.2 | 12.7 | 5.8  | 3.3 | —   |
|                         | Harzburgite Ms-3a               | 87.4 | 10.2 | —    | 2.4 | —   |
|                         | Dunite Bn-3/4                   | 98.9 | —    | —    | 1.1 | —   |
| AD-2 bo-<br>rehole      | Lherzolite VIII/9               | 84.1 | 5.0  | 9.6  | 1.2 | 0.1 |
|                         | Lherzolite VIII/25              | 60.3 | 24.0 | 14.8 | 0.9 | —   |
|                         | Lherzolite VIII/27              | 80.6 | 5.0  | 12.3 | 1.2 | 0.9 |
|                         | Phlogopite-lherzolite VIII/22-A | 77.4 | 6.0  | 9.7  | 0.9 | 6.0 |
|                         | Dunite VIII/14                  | 96.5 | 1.3  | —    | 0.6 | 1.6 |
|                         | Harzburgite VIII/23             | 72.6 | 23.6 | —    | 3.8 | —   |
|                         | Wehrlite VIII/26                | 55.9 | —    | 40.9 | 0.8 | 2.4 |

*Electron microprobe investigations of xenoliths*

Analyses were made by an JXA—50 A microprobe (accelerating voltage: 15 kV, electron beam diameter: 1 micrometer).

Olivine

Chemical composition of olivines in xenoliths is shown in Tab. 2. One lherzolite from Burgenland, dunite from Nógrád—Gemer and wehrlite from Alcsút-

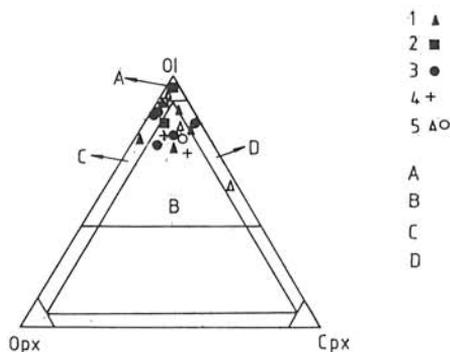


Fig. 2. Classification and nomenclature of ultramafic rocks (after Streckeis, 1974).

Explanations: 1 — AD-2 borehole; 2 — Nógrád—Gömör; 3 — Burgenland (Austria); 4 — Balaton Highlands; 5 — Phl content < 5 vol. %. A — dunite, B — lherzolite, C — harzburgite, D — wehrlite.

doboz-2 borehole show somewhat higher  $\text{FeO}_1$ -content in olivines, which causes some differences in Mg-values and Fo %/0, too. In spite of these differences, Mg-values of all samples are higher than 88, and Fo-content is  $90 \pm 2$  %/0: these values are characteristic of olivines of upper mantle origin (Carter, 1970; Wilkinson, 1975).

### Orthopyroxene

Chemical compositions are shown in Tab. 3.  $\text{FeO}_1$ - and MgO-values are almost the same, but one may note significant differences in  $\text{Al}_2\text{O}_3$ -content. Three lherzolite nodules from Alcsútdoboz-3 borehole show lower CaO- and  $\text{Cr}_2\text{O}_3$ -content than those in Pliocene—Pleistocene alkaline basalts.

One may note, that samples from Balaton Highlands have higher (ca. 1 %/0) CaO-content, also shown by Embey-Isztin (1977).

### Clinopyroxene

Chemical composition and calculated end-member ratios are shown in Tab. 4.  $\text{Cr}_2\text{O}_3$ -content of all samples is about 1 %/0, consequently we may apply the name Cr-diopside. Projection points of most clinopyroxene can be found in the endio- side field of the Ca—Mg—Fe plot (Fig. 3). It is important to mention, that clinopyroxenes of the wehrlite nodule are not separated from those of lherzolites. Besides these similarities significant differences in clinopyroxene composition can be recognized, especially in  $\text{SiO}_2$ - and  $\text{Al}_2\text{O}_3$ - values (Fig. 4). The samples from Burgenland have higher  $\text{Al}_2\text{O}_3$ - and tschermakite- and lower Mg-values. Conversely, the high ureyite-content (ca. 4 %/0) Cr-diopside has low  $\text{Al}_2\text{O}_3$ - and high  $\text{SiO}_2$ - concentrations.

Fig. 5 presents relationships of clinopyroxenes and coexistent orthopyroxenes in lherzolite nodules by their  $\text{Al}_2\text{O}_3$ - content. Our data have been supplemented by ones from Embey-Isztin (1977). Three lherzolites of Alcsútdoboz-2 borehole are clearly separated, which bears significant genetic consequences. Dawson (1980), Carswell (1980), Dawson—Smith (1977) and Delaney et al. (1980) have reported on similar, low- $\text{Al}_2\text{O}_3$  pyroxenes in nodules of kimberlites and carbonatites. According to Dawson (1980) and Boyd (1973) these pyroxenes originated from 100 to 200 km depth, where the upper mantle is relatively depleted in Al. Fig. 5 also shows that  $\text{Al}_2\text{O}_3$ -ratio of the pyroxene pairs show nearly constant values.

### Plate 1

Fig. 1. Photomicrograph showing equigranuloblastic texture in lherzolite from AD-2 borehole.

*Explanations:* Scale bar=1 mm, plane-polarized light.

Fig. 2. Photomicrograph showing laminated and disrupted mosaic porphyroclastic texture in wehrlite from AD-2 borehole.

*Explanations:* Scale bar=1 mm, plane-polarized light.

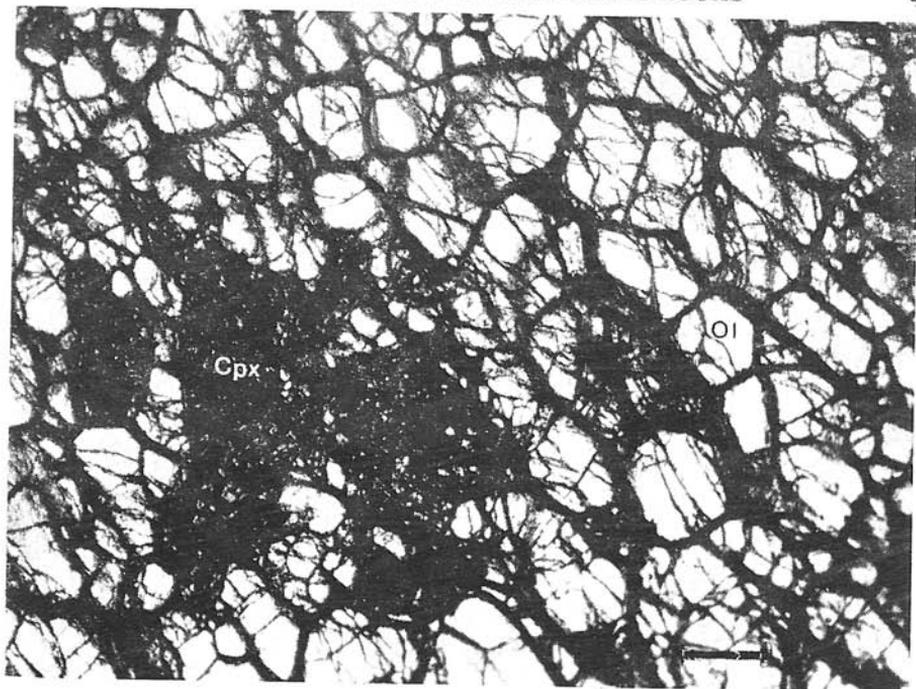


Table 2  
Electron microprobe analyses of olivines

Weight per cent oxides

|                                | 1      | 2     | 3      | 4      | 5      | 6     | 7      | 8      | 9     | 10    | 11     | 12     | 13     | 14    | 15    |
|--------------------------------|--------|-------|--------|--------|--------|-------|--------|--------|-------|-------|--------|--------|--------|-------|-------|
| SiO <sub>2</sub>               | 39.5   | 38.7  | 39.1   | 39.1   | 39.2   | 38.6  | 39.5   | 39.6   | 39.8  | 38.0  | 38.8   | 38.7   | 39.7   | 39.0  | 39.2  |
| Al <sub>2</sub> O <sub>3</sub> | n. d.  | 0.28  | 1.00   | 0.19   | n. d.  | n. d. | n. d.  | n. d.  | 0.07  | 0.15  | 0.16   | 0.74   | 0.43   | 0.42  | 0.10  |
| FeO <sub>t</sub>               | 11.2   | 9.70  | 9.30   | 8.60   | 9.20   | 8.25  | 7.80   | 8.60   | 8.05  | 9.15  | 11.0   | 9.20   | 8.45   | 9.30  | 11.1  |
| MnO                            | n. a.  | 0.15  | 0.15   | 0.18   | 0.15   | 0.10  | n. a.  | n. a.  | 0.12  | 0.20  | n. a.  | 0.09   | n. a.  | 0.10  | 0.20  |
| MgO                            | 49.9   | 50.6  | 51.0   | 52.3   | 52.0   | 52.0  | 53.2   | 51.8   | 50.2  | 51.7  | 50.5   | 51.8   | 52.1   | 50.8  | 48.3  |
| CaO                            | 0.09   | 0.06  | 0.08   | 0.04   | n. d.  | 0.08  | 0.11   | 0.06   | 0.07  | 0.06  | 0.20   | 0.01   | n. d.  | n. d. | n. d. |
| Total                          | 100.77 | 99.47 | 100.71 | 100.41 | 100.55 | 99.03 | 100.61 | 100.06 | 98.31 | 99.26 | 100.66 | 100.54 | 100.68 | 99.62 | 98.9  |
| 100 Mg<br>Fe + Mg              | 88.8   | 90.2  | 90.7   | 91.5   | 90.9   | 91.8  | 92.2   | 91.7   | 91.7  | 90.9  | 89.1   | 90.9   | 91.9   | 90.5  | 88.6  |
| Fe %                           | 88.7   | 90.1  | 90.5   | 91.3   | 90.8   | 91.7  | 92.1   | 91.6   | 91.6  | 90.7  | 88.8   | 90.9   | 91.9   | 90.5  | 88.6  |

Explanations: FeO<sub>t</sub> = total iron as FeO; n. d. — not detected; n. a. — not analysed.

- |                          |                           |                 |
|--------------------------|---------------------------|-----------------|
| 1. Lherzolite (Tob-51)   | } Burgenland<br>(Austria) | } Nógrád—Gömör  |
| 2. Lherzolite (Tob-41)   |                           |                 |
| 3. Harzburgite (Tob-43)  |                           |                 |
| 4. Harzburgite (Tob-34)  |                           |                 |
| 5. Wehrlite (Tob-33)     | } Balaton                 | } AD-2 borehole |
| 6. Lherzolite (Szbk-1)   |                           |                 |
| 7. Lherzolite (Szbk-2)   |                           |                 |
| 8. Lherzolite (Bn-40)    | } Highland                | }               |
| 9. Lherzolite (Me-3b)    |                           |                 |
| 10. Harzburgite (Ms-3a)  |                           |                 |
| 11. Dunite (Bn-3/4)      |                           |                 |
| 12. Lherzolite (VIII/9)  |                           |                 |
| 13. Lherzolite (VIII/25) | }                         | }               |
| 14. Lherzolite (VIII/27) |                           |                 |
| 15. Wehrlite (VIII/26)   |                           |                 |



Table 4  
Electron microprobe analyses of clinopyroxenes

Weight per cent oxides

|                                | 1     | 2     | 3     | 4     | 5      | 6     | 7     | 8     | 9     | 10     | 11     | 12    |
|--------------------------------|-------|-------|-------|-------|--------|-------|-------|-------|-------|--------|--------|-------|
| SiO <sub>2</sub>               | 50.5  | 51.1  | 52.2  | 52.2  | 52.8   | 50.8  | 52.2  | 54.1  | 54.5  | 54.5   | 54.0   | 53.2  |
| TiO <sub>2</sub>               | 0.75  | 0.89  | 0.71  | 0.07  | n. d.  | 0.32  | 0.15  | 0.12  | 0.13  | 0.07   | 0.15   | 0.17  |
| Al <sub>2</sub> O <sub>3</sub> | 5.45  | 5.65  | 6.05  | 3.25  | 2.26   | 4.93  | 3.15  | 1.82  | 1.86  | 1.27   | 2.37   | 2.36  |
| Cr <sub>2</sub> O <sub>3</sub> | 0.94  | 0.83  | 1.00  | 0.80  | 1.00   | 0.52  | 1.07  | 1.59  | 1.63  | 1.45   | 1.53   | 1.03  |
| FeO <sub>t</sub>               | 3.25  | 4.20  | 3.05  | 2.98  | 2.71   | 2.35  | 3.10  | 2.23  | 3.50  | 3.70   | 3.55   | 3.33  |
| MnO                            | 0.14  | 0.14  | 0.13  | 0.10  | 0.10   | 0.10  | 0.13  | n. d. | n. d. | 0.20   | n. d.  | 0.11  |
| MgO                            | 16.5  | 17.1  | 15.0  | 17.7  | 19.9   | 17.5  | 17.6  | 18.1  | 18.4  | 19.6   | 16.8   | 16.8  |
| CaO                            | 20.7  | 19.0  | 19.3  | 21.0  | 20.7   | 21.4  | 22.5  | 20.4  | 19.1  | 18.2   | 20.4   | 20.3  |
| Na <sub>2</sub> O              | 1.06  | 0.91  | 1.70  | 0.48  | 0.58   | 1.15  | 1.07  | 1.51  | 0.80  | 1.11   | 1.87   | 1.58  |
| Total                          | 99.39 | 99.82 | 99.14 | 98.58 | 100.03 | 99.03 | 99.97 | 99.87 | 99.92 | 100.10 | 100.67 | 98.88 |

Explanations: FeO<sub>t</sub> = total iron as FeO; n. d. — not detected.

End — member proportions and Mg — values

|                                      | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   |
|--------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|
| $\text{CaTiAl}_2\text{O}_6$          | 2.7  | 2.2  | 2.0  | 0.2  | —    | 0.9  | 0.4  | 0.3  | 0.4  | 0.2  | 0.4  | 0.5  |
| $\text{CaAl}_2\text{Si}_2\text{O}_7$ | 8.7  | 9.1  | 6.8  | 6.1  | 0.9  | 7.6  | 2.7  | 3.4  | 2.3  | 2.2  | 3.9  | 2.6  |
| $\text{CaFe}^{3+}\text{AlSiO}_6$     | 0.8  | —    | —    | 1.3  | 7.7  | 4.1  | 7.1  | —    | —    | 0.6  | —    | —    |
| $\text{NaAlSi}_3\text{O}_8$          | —    | —    | 8.7  | —    | —    | —    | —    | 0.3  | 0.9  | —    | 1.4  | 1.7  |
| $\text{NaFeSi}_2\text{O}_6$          | 4.2  | 3.1  | 0.5  | 1.1  | 0.4  | 3.0  | 2.2  | 5.7  | —    | 3.6  | 7.1  | 2.6  |
| $\text{NaCrSi}_2\text{O}_6$          | 2.7  | 2.3  | 2.9  | 2.3  | 2.9  | 1.5  | 3.0  | 4.5  | 4.7  | 4.1  | 4.3  | 2.5  |
| $\text{CaSiO}_3$                     | 33.2 | 31.5 | 33.5 | 37.3 | 35.1 | 35.5 | 37.8 | 37.2 | 36.2 | 33.4 | 36.7 | 38.5 |
| $\text{MgSiO}_3$                     | 45.2 | 45.8 | 41.0 | 48.2 | 52.9 | 47.4 | 47.8 | 48.1 | 50.2 | 52.2 | 44.5 | 47.2 |
| $(\text{Fe}+\text{Mn})\text{SiO}_3$  | 2.5  | 4.9  | 4.6  | 3.5  | 0.2  | —    | —    | 0.5  | 5.3  | 3.7  | 1.7  | 3.5  |
| 100 Mg                               | 87.7 | 87.9 | 89.8 | 91.4 | 92.9 | 92.9 | 90.9 | 93.6 | 90.4 | 90.1 | 89.4 | 90.0 |
| Fe + Mg                              |      |      |      |      |      |      |      |      |      |      |      |      |

- |   |                           |                 |
|---|---------------------------|-----------------|
| 1. Lherzolitite (Tob-51)                | } Burgenland<br>(Austria) | } Nógrád—Gömör  |
| 2. Lherzolitite (Tob-41)                |                           |                 |
| 3. Wehrilitite (Tob-35)                 |                           |                 |
| 4. Lherzolitite (Szbk-1)                | } Balaton<br>Highland     | } AD-2 borehole |
| 5. Lherzolitite (Szbk-2)                |                           |                 |
| 6. Lherzolitite (Bn-40)                 |                           |                 |
| 7. Lherzolitite (Me-3b)                 |                           |                 |
| 8. Lherzolitite (VIII/9)                |                           |                 |
| 9. Lherzolitite (VIII/25)               |                           |                 |
| 10. Lherzolitite (VIII/27)              |                           |                 |
| 11. Phlogopite-lherzolitite (VIII/22-A) |                           |                 |
| 12. Wehrilitite (VIII/26)               |                           |                 |

## Phlogopite

Several peridotite nodules, especially those in lamprophyres, contain phlogopite (Tab. 1). Chemical compositions (see Tab. 5), — especially  $\text{TiO}_2$ -,  $\text{Na}_2\text{O}$ - and  $\text{Cr}_2\text{O}_3$ - content —, show considerable differences; this indicates that the nodules bear micas of different origin (Delaney et al., 1980; Carswell, 1980, Dawson — Smith, 1977).

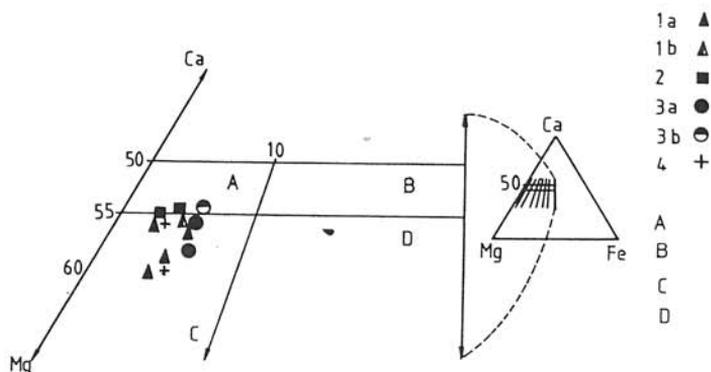


Fig. 3. Ca-Mg-Fe plots clinopyroxenes. (Nomenclature limits are taken from Deer et al., 1963).

*Explanations:* AD-2 borehole: 1a — lherzolite, 1b — wehrlite; Nógrád—Gömör: 2 — lherzolite; Burgenland (Austria): 3a — lherzolite, 3b — wehrlite; Balaton Highlands: 4 — lherzolite. A — diopside, B — salite, C — endiopside, D — augite.

Plotting the data in the  $\text{Cr}_2\text{O}_3$  —  $\text{FeO}_t$  plot of Dawson — Smith (1977) (Fig. 6) we may conclude, that phlogopites of lherzolite and dunite nodules from Alcsútdoboz-2 borehole lie in the peridotite field, hence these are of primary origin; while the micas of the phlogopite-lherzolite nodule lie in

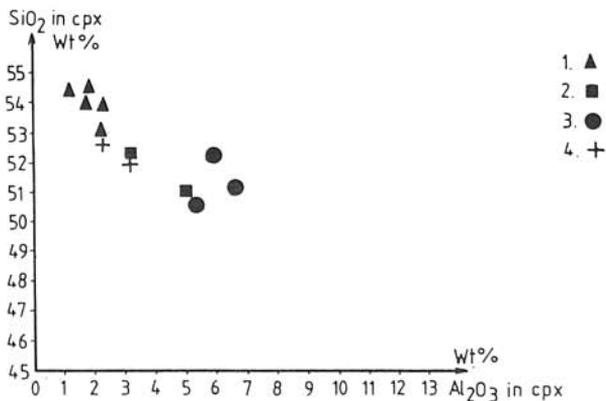


Fig. 4. Variation of wt. %  $\text{Al}_2\text{O}_3$  and  $\text{SiO}_2$  in clinopyroxene.

*Explanations:* 1 — AD-2 borehole; 2 — Nógrád—Gömör; 3 — Burgenland (Austria); 4 — Balaton Highlands.

the field of secondary phlogopite. Wehrnite nodule from Alcsútdoboz-2 borehole herzolite from Burgenland occupies a transitional position among fields of MARID, secondary and metasomatic micas. As Mg-values of both phlogopites are lower than Mg-values of coexisting clinopyroxene and olivine (see Tabs. 2, 4, and 5), these nodules do not form equilibrium systems, hence a MARID origin can be excluded.

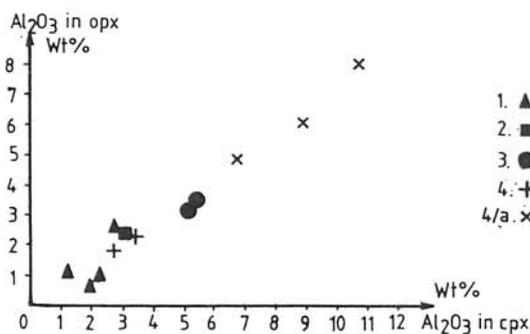


Fig. 5. Variation of wt. %  $\text{Al}_2\text{O}_3$  and  $\text{SiO}_2$  in orthopyroxenes and their coexisting clinopyroxenes in herzolites.

Explanations: 1 — AD-2 borehole; 2 — Nógrád—Gömör; 3 — Burgenland (Austria); 4 — Balaton Highlands, 4a — Balaton Highlands (Embeý-István, 1977).

Secondary origin is accepted for the sample from Burgenland, proved by higher  $\text{TiO}_2$ -,  $\text{Al}_2\text{O}_3$ - and  $\text{FeO}_t$ -, and lower  $\text{SiO}_2$ -values and the Mg-value (Carswell, 1975; Boyd, 1973). Richter (1971) has reported on a nodule containing phlogopite from Burgenland. He originated it from a  $\text{H}_2\text{O}$ - and  $\text{K}_2\text{O}$ -rich substance by decomposition of orthopyroxene and garnet.

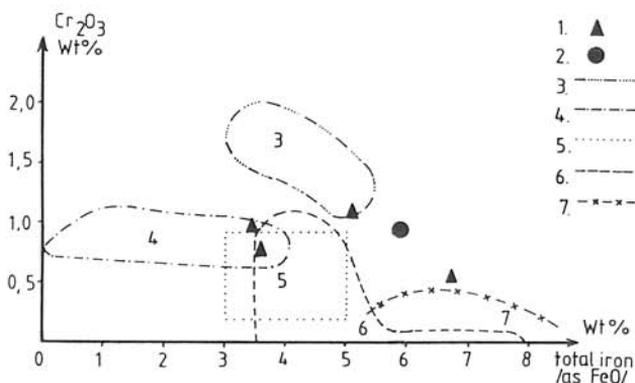


Fig. 6. Correlation of wt. %  $\text{Cr}_2\text{O}_3$  and  $\text{FeO}_t$  for micas (after Dawson-Smith, 1977).

Explanations: 1 — AD-2 borehole; 2 — Burgenland (Austria); 3 — secondary; 4 — peridotite; 5 — metasomatic; 6 — megacryst; 7 — MARID.

Table 5

Electron microprobe analyses of phlogopites

Weight per cent oxides

|  | 1     | 2     | 3     | 4     | 5     |
|--|-------|-------|-------|-------|-------|
| SiO <sub>2</sub>                               | 36.8  | 40.1  | 39.0  | 40.1  | 38.4  |
| TiO <sub>2</sub>                               | 7.28  | 0.55  | 0.35  | 0.17  | 1.11  |
| Al <sub>2</sub> O <sub>3</sub>                 | 14.6  | 12.0  | 14.5  | 9.83  | 11.6  |
| Cr <sub>2</sub> O <sub>3</sub>                 | 0.95  | 0.96  | 1.09  | 0.77  | 0.53  |
| FeO <sub>t</sub>                               | 5.91  | 3.48  | 5.13  | 3.65  | 6.70  |
| MnO  | n. d. | n. d. | n. a. | n. a. | n. a. |
| MgO  | 20.2  | 27.6  | 23.7  | 27.6  | 24.2  |
| CaO  | 0.06  | n. d. | n. d. | 0.15  | n. d. |
| Na <sub>2</sub> O                              | 0.54  | 2.43  | 1.03  | 1.07  | 1.20  |
| K <sub>2</sub> O                               | 10.8  | 7.75  | 10.2  | 9.70  | 9.90  |
| Total  | 97.14 | 94.87 | 95.0  | 93.04 | 93.64 |
| $\frac{100 \text{ Mg}}{\text{Fe} + \text{Mg}}$ | 85.9  | 96.5  | 89.1  | 93.1  | 86.6  |

*Explanations:* FeO<sub>t</sub> = total iron as FeO; n. d. — not detected; n. a. — not analysed.

- |                                      |                           |
|--------------------------------------|---------------------------|
| 1. Lherzolite (Tob-51)               | } Burgenland<br>(Austria) |
| 2. Lherzolite (VIII/27)              |                           |
| 3. Phlogopite-lherzolite (VIII/22-A) | } AD-2 borehole           |
| 4. Dunite (VIII/14)                  |                           |
| 5. Wehrlite (VIII/26)                |                           |

We propose the following scheme for the wehrlite from Alcsútdoboz-2 borehole. The wehrlite shows porphyroclastic texture of metamorphic character, and its clinopyroxene is of Cr-diopside composition. These features undoubtedly indicate a lherzolite of upper mantle origin. It is possible, that upper mantle metamorphism made orthopyroxene disappear and phlogopite appear.

### Spinel

Chemical composition and ratio of calculated end-members are shown in Tab. 6. Al-rich (= Cr-depleted) and Al-depleted (= Cr-rich) groups can be formed. The two groups are shown in the fields of alkaline basalt and kimberlite inclusions, respectively (Fig. 7). (These fields were separated by Basu — MacGregor, 1975 on account of large quantities of analytical data.) All samples from Alcsútdoboz-2 borehole — except harzburgite — appear in the kimberlite field, while nodules from young volcanites — except a lherzolite from Balaton Highlands — lie in the field of alkaline basalt.

Carswell (1980) divided spinels in ultramafic nodules into three groups by their Cr-values ( $100 \text{ Cr/Cr} + \text{Al}$ ), naming them as Al-spinel, Cr-spinel and chromite. Grouping of our samples in Carswell's (1980) plot is shown in Fig. 8.

Spinel of nodules in Pliocene—Pleistocene alkaline basalts — except a sample from Nógrád—Gömör and another from Balaton Highlands — appear in the Al-spinel field. Among nodules from Cretaceous lamprophyres of Alcsútdoboz-2 borehole, harzburgite contains Al-spinel, phlogopite-lherzolite contains Cr-spinel and three lherzolite nodules contain chromite. This indicates significant differences in origin of nodules from the lamprophyre, since according to Carswell (1980) stability range of chromite coincides that of garnet in kimberlite inclusions, while Al-spinel is stable in much lower P—T ranges.

Fig. 7. Variation of wt. %  $\text{Al}_2\text{O}_3$  in orthopyroxenes and their coexisting spinels in xenoliths (after Basu—MacGregor, 1975).

Explanations: 1 — AD-2 borehole; 2 — Nógrád—Gömör; 3 — Burgenland (Austria); 4 — Balaton Highlands; 5 — alkali basalt xenoliths (Basu—MacGregor, 1974); 6 — kimberlite xenoliths (Basu—MacGregor, 1974).

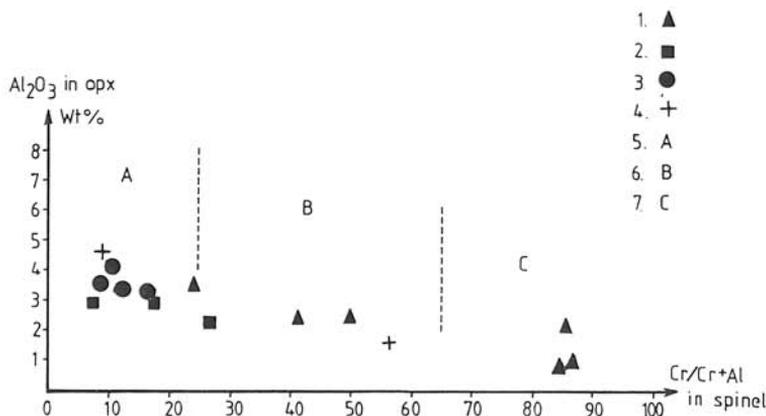
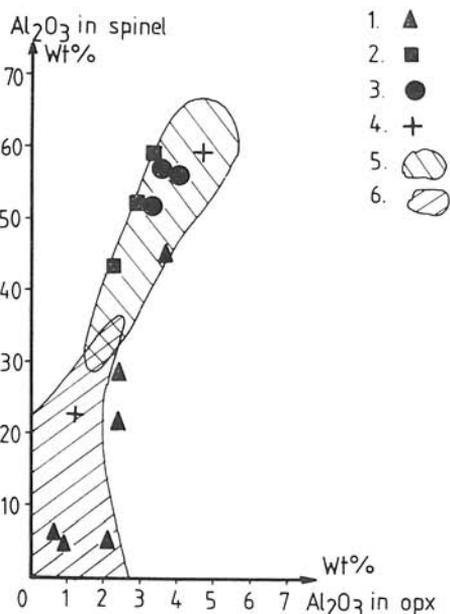


Fig. 8. Plot of  $100 \text{ Cr/Cr} + \text{Al}$  ratio in spinel against wt. %  $\text{Al}_2\text{O}_3$  in coexisting orthopyroxenes (after Carswell, 1980).

Explanations: 1 — AD-2 borehole; 2 — Nógrád—Gömör; 3 — Burgenland (Austria); 4 — Balaton Highlands; 5 — A — Al-spinel; 6 — B — Cr-spinel; 7 — C — chromite.

Table 6  
Electron microprobe analyses of spinels

Weight per cent oxides

|                                    | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10    | 11    | 12    | 13    | 14/a  | 14/b  | 15    | 16    |
|------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| MgO                                | 19.1  | 22.7  | 22.3  | 21.5  | 20.1  | 13.9  | 22.5  | 19.0  | 20.8  | 18.2  | 6.70  | 6.60  | 6.50  | 11.3  | 9.85  | 5.65  | 19.0  |
| MnO                                | 0.12  | 0.11  | 0.13  | 0.10  | 0.12  | n. d. | 0.10  | 0.14  | 0.10  | 0.16  | 0.40  | n. d. | 0.43  | 0.20  | 0.30  | 0.45  | n. d. |
| FeO <sub>t</sub>                   | 15.4  | 11.6  | 11.7  | 13.1  | 11.1  | 14.9  | 9.0   | 12.5  | 10.7  | 14.8  | 37.3  | 34.9  | 36.1  | 27.2  | 35.4  | 33.5  | 15.9  |
| Al <sub>2</sub> O <sub>3</sub>     | 51.5  | 56.4  | 55.7  | 48.4  | 58.7  | 22.7  | 59.2  | 43.2  | 51.9  | 46.0  | 5.00  | 6.10  | 4.80  | 28.6  | 21.3  | 3.20  | 44.9  |
| Cr <sub>2</sub> O <sub>3</sub>     | 11.8  | 8.70  | 10.1  | 14.8  | 9.10  | 45.6  | 8.64  | 23.3  | 16.2  | 18.9  | 45.9  | 51.6  | 48.7  | 30.4  | 31.8  | 53.6  | 19.1  |
| TiO <sub>2</sub>                   | 0.31  | 0.33  | n. d. | 0.15  | 0.10  | 0.10  | n. d. | n. d. | n. d. | 0.73  | 0.56  | 0.32  | 0.58  | 0.30  | 0.70  | 0.22  | n. d. |
| Total                              | 98.23 | 99.84 | 99.93 | 98.05 | 99.22 | 97.2  | 99.41 | 98.14 | 99.70 | 98.79 | 95.86 | 99.52 | 97.11 | 98.00 | 99.35 | 96.62 | 98.90 |
| (Fe <sub>2</sub> O <sub>3</sub> )* | 5.3   | 5.8   | 5.6   | 6.8   | 1.0   | 1.46  | 2.29  | 3.8   | 3.5   | 3.6   | 17.0  | 10.3  | 15.2  | 7.3   | 13.8  | 11.8  | 5.6   |

Explanations: FeO<sub>t</sub> = total iron as FeO; n. d. — not detected; (Fe<sub>2</sub>O<sub>3</sub>)\* — calculated values.

End — member proportions and Cr — values

|                                  | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   | 13   | 14/a | 14/b | 15   | 16   |  |
|----------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|--|
| MgAl <sub>2</sub> O <sub>4</sub> | 74.0 | 85.2 | 84.5 | 77.6 | 78.1 | 42.0 | 85.7 | 70.6 | 81.5 | 74.5 | 10.6 | 13.2 | 10.1 | 53.1 | 41.0 | 6.9  | 73.4 |  |
| FeAl <sub>2</sub> O <sub>4</sub> | 9.6  | —    | —    | —    | 12.3 | —    | 3.4  | —    | —    | —    | —    | —    | —    | —    | —    | —    | —    |  |
| MgFe <sub>2</sub> O <sub>4</sub> | —    | 1.4  | 0.9  | —    | —    | —    | —    | —    | —    | —    | —    | —    | —    | —    | 7.0  | —    | 5.1  |  |
| MgCr <sub>2</sub> O <sub>4</sub> | —    | —    | —    | 8.1  | —    | 23.0 | —    | 7.9  | 1.0  | —    | 25.1 | 22.4 | 24.1 | —    | —    | 28.0 | —    |  |
| MnFe <sub>2</sub> O <sub>4</sub> | 0.3  | 0.3  | 0.3  | 0.2  | 0.3  | —    | 0.2  | 0.3  | 0.2  | 0.4  | —    | —    | 1.3  | 0.5  | 0.6  | 1.4  | —    |  |
| Fe <sub>2</sub> TiO <sub>4</sub> | 0.6  | 0.6  | —    | 0.3  | 0.1  | 0.2  | —    | —    | —    | 1.5  | 1.5  | 0.9  | 1.5  | 0.7  | 1.7  | 0.6  | —    |  |
| FeFe <sub>2</sub> O <sub>4</sub> | 3.3  | 3.8  | 4.0  | 6.0  | 0.7  | 1.4  | 2.0  | 3.5  | 1.2  | 3.1  | 22.9 | 12.0 | 18.8 | 8.2  | 2.7  | 14.1 | 0.6  |  |
| FeCr <sub>2</sub> O <sub>4</sub> | 12.2 | 8.7  | 10.3 | 7.8  | 8.8  | 33.4 | 8.7  | 17.7 | 16.1 | 20.5 | 39.9 | 51.5 | 44.2 | 37.5 | 41.0 | 49.0 | 20.9 |  |
| 100 Cr                           | 12.1 | 8.8  | 10.3 | 15.8 | 8.8  | 56.3 | 8.7  | 25.5 | 16.7 | 20.7 | 66.0 | 73.4 | 69.3 | 37.9 | 41.4 | 77.0 | 20.9 |  |
| Cr+Al+Fe <sup>2+</sup>           |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |  |
| 100 Cr                           | 12.7 | 9.3  | 10.8 | 16.9 | 8.9  | 57.3 | 8.9  | 26.6 | 17.3 | 21.6 | 86.0 | 84.8 | 87.2 | 41.6 | 50.0 | 91.5 | 24.1 |  |
| Cr + Al                          |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |  |

1. Lherzolite (Tob-51)
2. Lherzolite (Tob-41)
3. Harzburgite (Tob-43)
4. Wehrlite (Tob-35)
5. Lherzolite (Szbk-1)
6. Lherzolite (Szbk-2)
7. Lherzolite (Bn-40)
8. Lherzolite (Me-3b)
9. Harzburgite (Ms-3a)
10. Dunite (Bn-3/4)

Burgenland  
(Austria)

Balaton  
Highland

Nógrád—Gömör

11. Lherzolite (VIII/9)
12. Lherzolite (VIII/25)
13. Lherzolite (VIII/27)
- 14/a. { Phlogopite- VIII/22-A core/  
rim/
- 14/b. { lherzolite
15. Dunite (VIII/14)
16. Harzburgite (VIII/23)

AD-2 borehole

*Geothermometric and geobarometric calculations and discussion*

Equilibrium temperatures and pressures have been calculated following the methods of Wood—Banno (1973), Wells (1977), Mercier—Carter (1975) and Mercier (1976), and figured on temperature—pressure plot of MacGregor (1974) (Fig. 9).

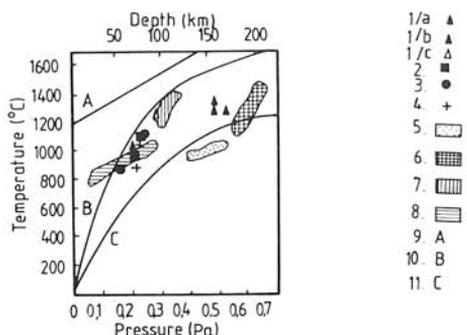


Fig. 9. Interpreted conditions for samples of different ultramafic xenoliths from Hungary and Burgenland (Austria) (after MacGregor, 1974).

*Explanations:* AD-2 borehole: 1a — lherzolite, 1b — harzburgite, 1c — phlogopite-lherzolite; Nógrád—Gömör: 2 — lherzolite; Burgenland (Austria): 3 — lherzolite; Balaton Highlands: 4 — lherzolite; lherzolite from kimberlite: 5 — granular, 6 — sheared; from alkali basalts: 7 — garnet pyroxenite, 8 — spinel lherzolite; 9 — A — dry peridotite solidus; 10 — B — oceanic geotherm; 11 — C — shield geotherm. Note: 5—11 C after MacGregor, 1974.

Our conclusions can be summarized as follows:

1. Xenoliths of Alcsútdoboz-2 borehole can be divided into three groups by temperature and pressure:

a) Lherzolites from extreme high P and T zones (about 150—170 km depth). Their points approach the continental geotherm rather. Equilibrium data resemble those of sheared texture inclusions in kimberlites.

b) High T, lower P phlogopite-lherzolite on the oceanic geotherm, in the field of garnet-pyroxenites of alkaline basalts (depth ca. 100 km).

c) Low P—T harzburgite on the oceanic geotherm in the field of spinel-lherzolites of alkaline basalts.

Thus we can postulate, that original melt of the lamprophyre came from at least 170 km depth, and its composition probably was similar to kimberlitic magma. This supposition is supported by textures of the three lherzolite nodules, chemical composition of their minerals and the calculated equilibrium pressure and temperature. The ascending magma brought along a xenolith association characteristic of alkaline basalts from a higher part of the upper mantle (ca. 60—100 km depth). Some of these xenoliths may have been metasomatized by the volatile-rich melt ascending from greater depths. This is a possible way to form phlogopite-containing wehrlite, which could have contained orthopyroxene at the beginning, as its texture and its Cr-diopside

clinopyroxene indicate (see the descriptions on clinopyroxene and phlogopite). Non-metasomatized xenoliths originating from higher zones does not contain phlogopite, as the harzburgite specimen proves it.

Also, it may be supposed after data not discussed here (Szabó, 1984), that magma mixing played some role in modifying the original composition of lamprophyre melt.

A tentative estimation can be made for the Cretaceous geotherm of the Transdanubian Midmountains after the xenoliths of Alcsútdoboz-2 borehole (Fig. 9). Up to 1000 °C the points lie on MacGregor's (1974) oceanic geotherm; on higher temperatures these draw near the continental geotherm. Present investigations may provide further data to interpret the dual character and to draw the geotherm. Also, these data may contribute to interpret tectonic processes initiating this kind of magmatism.

2. Xenoliths of Pliocene—Pleistocene alkaline basalts lie on the oceanic geotherm, between 800—1000 °C and between 1.2—1.5 Pa (Fig. 9), indicating an original depth of 60—80 km for rock fragments. Embey-Isztin (1977) assumed somewhat minor depth of origin for them. Areal differentiation cannot be shown as yet due to small number of samples, hence our data on alkaline basalts are considered as references only.

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