Upper-mantle xenoliths in melilitic rocks of the Osečná Complex, North Bohemia

Svrchnoplášťové xenolity v melilitických horninách osečenského komplexu v severních Čechách (Czech summary)

(9 text-figs, 7 tabs)

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The melilitic Osečná Complex (79–49 Ma), located at the intersection of the Ohře Rift with the Lužice Fault in N Bohemia, originated from an upper mantle source. Associated diatremes (and maars?) filled with pelletal lapilli-ash tuff of olivine melilitite composition predate the formation of the Osečná Complex (olivine melilitolite – polzenite – melilite-bearing olivine nephelinite). Xenoliths of upper-mantle origin occur in both the massive rocks and pelletal lapilli-ash tuff of diatreme filling. Dunite to harzburgite in melilite-bearing olivine nephelinites represent depleted mantle. Glimmerite to mica clinopyroxenite in polzenites are possibly representatives of metasomatised upper mantle products. Garnet serpentinite, eclogite?, norite and ferro-dunite xenoliths are entrained from the local crystalline basement and occur in the diatreme filling only. They come from rocks of primary upper-mantle origin. The upper-mantle-xenolith suite indicates the presence of both depleted and enriched (metasomatised) upper mantle beneath the northern part of the Bohemian Massif. The associated ultramafic xenoliths of upper-mantle-derived rocks that intrude the local crystalline basement are indicative for lithospheric plate boundary.

Key words: mantle xenoliths, melilitic volcanics, Osečná Complex, Ohře Rift

Introduction

The young intraplate volcanism (Upper Cretaceous to Quaternary) of the Bohemian Massif (BM) forms an integral part of the Central European Volcanic Province (CEVP). The origin and distribution of the volcanism are controlled by the WSW–ENE-striking Ohře (Eger) Rift (OR) and the WNW–ESE-striking Labe (Elbe) Tectono-Volcanic Zone (LTVZ) as defined by Kopecký (1978). On the basis of radiometric dating (all data presented in this publication based on K/Ar method), Ulrych – Pivec (1997) and Ulrych et al. (1999) recognised two continental intraplate magmatic series in the BM:

1 – pre-rift series formed by unimodal ultramafic ultra-alkaline (melilitic/nephelinitic) volcanism representing a precursor of continental rifting and located exclusively in external wing blocks of the OR in N Bohemia and N Saxony (79–49 Ma, Ulrych – Pivec 1997 and Pfeiffer 1990), E Bohemia (69 Ma, Ulrych et al. 1996) and W Bohemia and Saxony in the Krušné hory Mts. – Erzgebirge (52 Ma, Pfeiffer et al. 1990).

2 – rift-related series of alkaline volcanism

2a – coexisting bimodal basanite – trachyte and olivine poor nephelinite – phonolite together with independent unimodal olivine nephelinite – tephrite/basanite series of the main volcanic episode (42–16 Ma) dominating in internal blocks of the rift, but also found in wing blocks,

2b – unimodal picrobasalt – tephrite/basanite (often strongly analcimised) in N Bohemia and coexisting bimodal strongly alkaline (basanite/tephrite – phonolite?) and weakly alkaline (trachybasalt/trachyandesite – trachyte/rhyolite) series of the late volcanic episode (13–4 Ma) present inside and outside the rift, respectively,

2c – unimodal olivine melilitite – olivine nephelinite series (2.0?–0.26 Ma) at the intersection of the OR with the Cheb–Domažlice Graben (NNW–SSE) near the western limitation of the Cheb Basin.

In accordance with the concept of Le Bas (1987), the characteristics of the pre-rift and rift-related series of young volcanism in the BM commonly require a strict discrimination between ultra-alkaline and alkaline volcanism. Ultra-alkaline volcanism, represented by olivine nephelinites and olivine melilitites, ijolites and carbonatites, appears to be associated with active domal uplift and not controlled by the extension and rifting in either space or time. Its products hence often lie outside the rift valleys (cf. Gregory Rift of East Africa) and pre-date the formation of rifts by several millions years, or they are located even in regions where no rifting is present (e. g., Cape Verde Islands Volcanic Province). Examples of the former type of volcanism are known from the Massif Central and the Rhine Graben in the Western and Central European Volcanic Provinces. The rare ultra-alkaline volcanism, e. g., in the Eifel Mts. (Lippolt 1983) is of Late Cretaceous age (110–105 Ma), however, the prevailing alkaline volcanism is Oligocene to Miocene in age.

Even though mantle xenoliths (dunite – harzburgite – lherzolite) are abundant in young volcanics of the BM (more than 100 known occurrences), they have not been studied systematically. Accounts of xenoliths were published by Fiala – Shrbený (1968) and by Frýda – Vokurka (1995) from the České středohoří Mts. (CS) and by Fediuk – Fediuková (1989) from N Moravia. Lherzolites from the Kozákov volcano, N Bohemia have been studied by Fediuk (1971), Vokurka – Povondra (1983) and Medaris et al. (1997, 1999). The most detailed recent reports of lherzolite xenoliths in nepheline basanitic lavas (6–4 Ma) from the Kozákov volcano documented two textural types of xenoliths: (i) medium-grained equigranular and (ii) coarse-grained protogranular, crystallised at a wide range of temperatures (680–1100 °C) and pressures (1.2–2.5 Gpa), which implies their extraction from a wide range of depths (Medaris et al. 1999).

Differences in the upper mantle composition beneath the BM can be suggested from scarce geochemical data for the BM upper mantle xenoliths. These correspond to the enrichment and impoverishment of lherzolite in incompatible elements quoted by Wedepohl (1987) and Wedepohl et al. (1994) from the Hessian Depression, Germany. The upper mantle beneath the CEVP reveals signs of (i) lateral heterogeneity (cf. Babuška – Plomerová 1988) and (ii) metasomatic influence (Lloyd 1987, Wilson – Downes 1991, Wedepohl et al. 1994, Wilson et al. 1995). In the BM, clinopyroxenite forms rare layers in lherzolite xenoliths and rare independent nodules in lava of the Kozákov volcano (Medaris et al. 1997) and Dobkovičky flow, CS (Mihaljevič 1993).

Based on textural and geochemical evidence, Lloyd – Bailey (1975) postulated a metasomatic transition between spinel lherzolite and alkali clinopyroxenite (clinopyroxene + titaniferous phlogopite + titanomagnetite, apatite, titanite and rare corroded olivine) for the xenolith suites from the rift-valley volcanics of the West Eifel, Germany and southwestern Uganda. Alkali clinopyroxenite xenoliths have not been described from young volcanic rocks of the BM yet. It has been suggested that metasomatism is either a necessary precursor to magmatism (Lloyd – Bailey 1975, Wass – Rogers 1980) or a consequence of alkali-basaltic magmatism (Wilshire et al. 1980, Menzies et al. 1985). The likely connection between the origin of alkali-clinopyroxenite xenoliths and intrusive alkali complexes was emphasised by Upton (1967), Lloyd – Bailey (1975), (1994), and Erickson et al. (1985). These authors considered all of them manifestations of the same igneous processes. Compared with the original lherzolite mantle, alkali-pyroxenite xenoliths indicate enrichment in incompatible and large-ion-lithophile elements, and the host lavas are thought to be indicative of the rheomorphic metasomatised mantle (Lloyd – Bailey 1975).

Lower crustal xenoliths are also poorly known in the BM. Anorthosite, granulite and charnockite xenoliths from basanite-diatreme breccias in the CS (Opletal – Vrána 1989) and basanitic lavas of the Kozákov volcano (Záhrubský 1998) are supposed to be the evidence of hidden deep-crustal complexes beneath N Bohemia. Based on geochemical characteristics, Kramer (1988) proposed an affinity of gabbroic xenoliths in Cenozoic volcanics of the Labe (Elbe) Valley Zone in Saxony to the older (Variscan?) mid-ocean ridge gabbros. However, gabbro xenoliths with similar geochemical signatures (Bořecký 1986, Mihaljevič 1993) are of the same Tertiary age as their host basanite lava from the CS and could represent cumulates (Ulrych et al. in press).

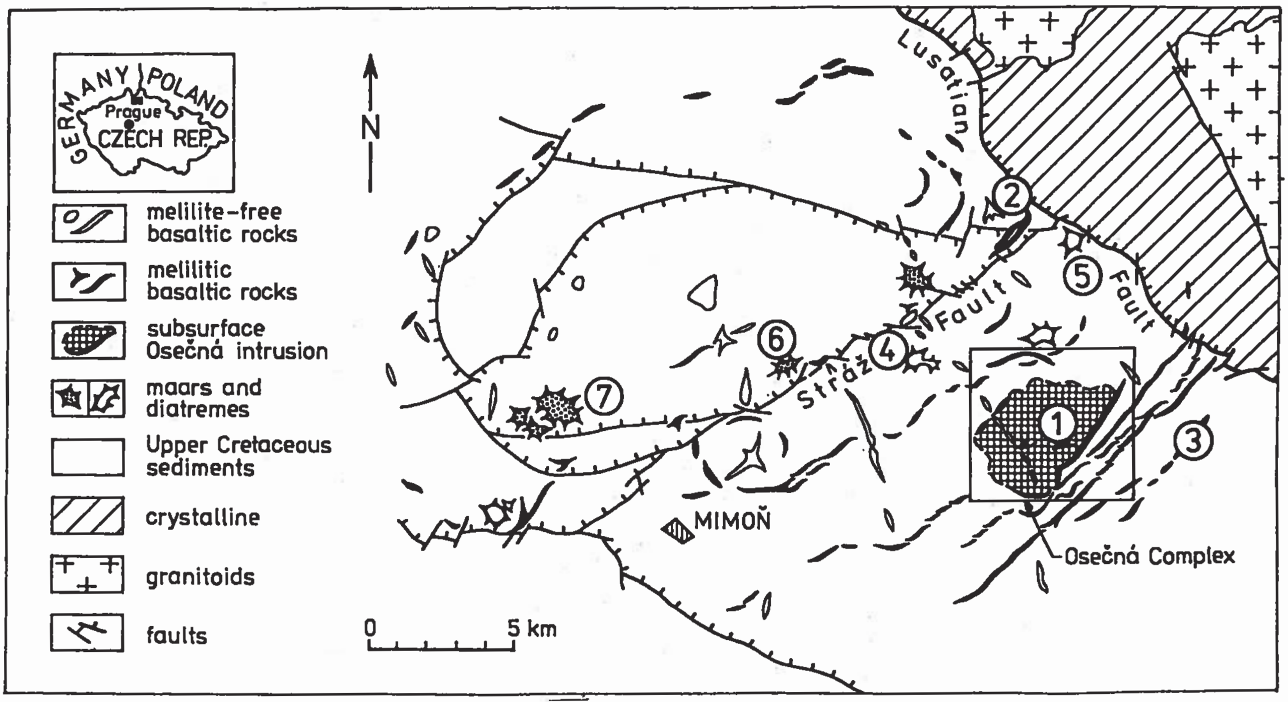

Fig. 1. Geological sketch of the north Bohemian Region with special reference to the presence of the pre-rift volcanic series of the Upper Cretaceous age (Osečná Complex) and riftogenic volcanic series of the Cenozoic age. Sampled localities: 1 – Osečná, borehole; 2 – Krkavčí návrší Hill near Zdislava, borehole; 3 – Small Devil's Wall near Český Dub, abandoned quarry; 4 – Kalvárie Hill near Hamr na Jezeře, borehole; 5 – Křížany, borehole; 6 – Na vinici near Stráž pod Ralskem, borehole; 7 – three maar structures near Zákupy (not sampled).

Ulrych (1986) and Mihaljevič (1993) interpreted hornblendite (diopside + kaersutite ± olivine, phlogopite) nodules in felsic (trachyte, sodalite syenite), lamprophyric (camptonite, gauteite) and mafic (basanitic) rocks of the CS, Doupovské hory Mts. composite volcano and W Bohemia as cumulates.

Geological setting of the Osečná Complex

Late Cretaceous to Tertiary volcanism of the northeastern part of the OR in N Bohemia (Fig. 1) is a type area for both of the two intraplate volcanic series (Ulrych – Pivec, 1997, Pivec et al. 1998) of the BM (see Introduction). However, the most typical representative of the pre-rift series volcanic activity is the Osečná Complex (OC), recognised by Pivec et al. (1986, 1998) and Ulrych et al. (1988). The OC (see Fig. 1, No. 1), with features of ring arrangement, consists of a central sill (lopolith-like intrusion) with an apparent thickness of 20–60 m, occupying an area of 12.5 km^2, and a system of conesheets and dykes (10 cm to 5 m thick). Its subsurface central olivine-melilitolite intrusion (79 Ma) contains metasomatic derivatives such as phlogopitites (70 Ma), pegmatoids (73 Ma) and ijolites as veins and small lensoid bodies. The olivine-melilitolite mineral assemlage (olivine + melilite + nepheline ± carbonate, /Zr,Ti/-bearing andradite, Mn-bearing ilmenite) exhibits a paragenetic relationship to carbonated ultra-alkaline ultramafic complexes (Flohr – Ross 1989). The associated dyke systems are developed as a marginal facies of the central body with numerous flat cone-sheets (35°) of polzenite composition (77 to 62 Ma) and a more steeply inclined cone-sheet system (60–75°) showing typical clinopyroxene-polzenite composition. Subvertical dip angles (90–80°) are characteristic for dykes of the NNE–SSW-striking Devil's Wall system (51–49 Ma). The Devil's Wall magmatism (Fig. 1, No. 3) comprises rocks ranging from olivine nephelinite to prevailing melilite-bearing olivine nephelinite to rare olivine melilitite. Their genetic association with the central olivine melilitite intrusion and associated conesheet system is questionable. Intrusions of the Devil's Wall system concluded the pre-rift history of.young volcanism of the BM.

The older generation of diatremes of the OC filled with pelletal lapilli-ash tuff (the so-called intrusive breccia) of olivine-melilitite composition is associated with regional faults, such as the Lužice (Lusatian) and Stráž faults. The absence of xenoliths of melilitic rocks of the OC in older diatreme fillings and their penetration by a polzenite dyke (77 Ma) indicate their formation prior to the OC formation. Dykes of tephrite/basanite composition, locally connected with younger generation of diatremes (filled with intrusive breccia of non-melilitic basaltic rock), pertain to the rift series (34 Ma). The youngest intrusions of picrobasalt (9 Ma) and flows of nepheline basanites (6.6–4.0 Ma) represent the youngest volcanics in N Bohemia; they also are associated with the above-mentioned regional faults.

Diatremes of this older system were first described from Křižany (850 by 210–240 m, Fig. 1, No. 5) by Rutšek (1973) and from Kalvárie Hill in Hamr na Jezeře (Fig. 1, No. 4 and Fig. 2) and Lesní Domky (500 by 50–250 m, Fig. 1, No. 8) near Osečná by Ulrych et al. (1988). The diatremes filled with pelletal lapilli-ash tuff of olivine melilitite composition (Fig. 3) containing mantle xenoliths are related to the Stráž Fault, which belongs to the Litoměřice Fault system that limits the OR to the SE and utilises the boundary between the Teplá–Barrandian and Saxothuringian terranes. The Stráž Fault forms the SE limit of the northeastern part of the OR near the intersection with the Lužice Fault. The diatremes occur exclusively outside the OR in external wing blocks, whereas maars (?) with upper crustal xenoliths, such as at localities Na vinici (750 by 70–100 m, Fig. 1, No. 6) or Zákupy (one larger, 1200 by 800 m in size and two smaller 500 m in diameter, Fig. 1, No. 7) are characteristic for internal blocks of the OR (Ulrych et al. 1988). Both volcanic forms are most probably manifestations of the same volcanic activity, now located in two blocks eroded to different levels due to the ~600 m vertical displacement magnitude along the Stráž Fault. Maars (?) with chaotic volcanic breccia containing exclusively crustal xenoliths are comparable with those known from the SE margin of the CS (Brus – Hurník 1984, Kopecký 1987–1988, Krutský 1994), Krušné hory Mts. (Malásek et al. 1980, Suhr – Goth 1996) or Lusatian region (Suhr 1999).

Other volcanic centres with subvolcanic melilitic rocks and upper mantle xenoliths in the northern part of the BM are Krkavčí návrší Hill (Fig. 1, No. 2) at the foot of Ještěd Hill, in the Zeughausgangzug near Hinterhermsdorf in Saxony and Bad Oybin area in Lusatia.

Analytical procedures

Representative rock samples come from cores drilled by the Czechoslovak Uranium Industry at four localities in the neighbourhood of Mimoň in N Bohemia (Fig. 1). Very rare samples of mantle xenoliths from both massive rocks and pelletal lapilli-ash tuffs of diatreme fillings were collected during drilling activity in the period of 1970–1990.

Major-element contents were determined using wet-analysis techniques in the Analytical Laboratory of the Department of Mineralogy, Geochemistry and Crystallography, Faculty of Science, Charles University, Prague.

The rock-forming minerals were studied in transmitted light in thin sections, in reflected light in polished sections and by electron microprobe JXA–50A with EDX spectrometer (EDAX PV 9400), using common rock-forming mineral (olivine, kaersutite, diopside, nepheline, magnetite, ilmenite) standards and the ZAF correction method. Instrumental conditions included an accelerating voltage of 20 kV, beam current of 1.5 10^{-9} A, beam diameter of 2–3 μm and a counting time of 120 s per element (analyst A. Langrová, Institute of Geology, AS CR).

Table 1. Petrographic and mineral characteristics of xenoliths (X) and their host rocks (HR)

Rock, locality Shape, size (in cm)	No.	Petrography	Mineralogy
HR-olivine melilitolite, Osečná-borehole for details see Ulrych et al. (1988)	46	massive, hypautomorphic, medium-to coarse-grained, gabbro-ophitic texture	olivine + melilite + nepheline ± monticellite, phlogopite, perovskite, apatite, spinels, carbonate
dunite layers (0.3–1.6) passing to parental olivine-rich melilitolite (Ulrych et al. 1988)	104 A	massive, hypautomorphic, coarse-grained, gabbroic to gabbro-ophitic texture	olivine + melilite ± nepheline, spinels
X-ferro-dunite, rounded (4x3x2)	99	black, massive, fine- to medium-grained (0.4 – 0.8 mm), equigranular texture – mosaic equigranular subtype sensu Mercier – Nicolas (1975), equant grains with irregular boundaries and slight internal strain	olivine (about 95 vol. %) ± magnetite; younger phlogopite (2–3) penetrating along grain boundaries – associated with late crystallisation of the host olivine melilitolite
X-garnet biotite clinopyroxenite, lenticular (2x1)	119	hypautomorphic, ophitic with transitions to grano-lepidoblastic texture ?, medium-grained; larger cpx and bi form framework of interfering laths; smaller cpx, hbl, ga and ap occupy the spaces; magmatic (cummulate?) with some stress features – Group II (ii)? sensu Lloyd (1981) or eclogite Subgroup I. A ? low-temperature division (450–550 °C) of Miyashiro (1990) accompanied by rocks of blueschist-facies	clinopyroxene Na-hedenbergite (70 vol. %) is colour zoned (brown-green core, green envelope) and overgrown by darker green hornblende overgrowths (8) ± Fe-biotite (10) laths in ophitic? relationship with cpx, garnet (10) fills interstices, apatite (2), magnetite; garnet–clinopyroxene pairs equilibration: 420–450 °C (Mori–Green 1978) and 430–460 °C (Mysen–Heier 1972)
HR-polzenite, Krkavčí návrší Hill near Zdislava-borehole for details see Ulrych et al. (1988)	66	massive, fine-grained, porphyritic texture and trachytic texture of matrix	olivine (phenocrysts) with moticellite rims + melilite ± phlogopite, nepheline, spinel, perovskite, serpentine group minerals, carbonate
X-glimmerite to mica garnet clinopyroxenite, subangular (4x2x1)	100	closely textured, hypautomorphic, medium-grained; deformation: strain lamellae and recrystallisation essential, fabric metasomatic – mantle nodule Group II (i) sensu Lloyd (1985)	patchy pale brown (Ti,Mg)-biotite (55 vol. %) invading and replacing pale green clinopyroxene (45) ± titanian magnetite and titanite in clusters, apatite, carbonate
X-altered garnet serpentinite, rounded (max. 6x5x4)	102	massive, totally serpentinized, silicified and carbonatized rock, original texture cannot be recognized with exception of individually pseudomorphosed garnet	various minerals of the serpentine group, psedomorphs after garnet, newly formed opal, magnetite and carbonates
HR-melilite-bearing olivine nephelinite, Small Devil's Wall at Český Dub – abandoned quarry for details see Ulrych et al. (1988)	23	massive microporphyritic texture with fine-grained matrix	olivine (phenocrysts) + clinopyroxene + nepheline ± melilite, spinel, apatite, carbonate
X-dunite to harzburgite, angular (1x0.5x0.5)	23A	massive, fine-grained (aver. 0.9 mm); mosaic transitional equigranular texture sensu Mercier – Nicolas (1975) with olivine porphyroclasts (3 x 1 mm); mantle nodule Group I sensu Lloyd (1981) and Frey – Prinz (1978)	olivine ± orthopyroxene (5 vol.%) with straight-lined grain boundaries converging in 120° triple points; ol and opx fabrics are week
HR-peletal lapilli-ash tuff of olivine melililite composition, diatreme of Kalvárie Hill at Hamr	109	green-grey strongly altered pelletal lapilli-ash tuff formed by clasts (up to 5 cm) of (i) upper Cretaceous sediments (claystones or marlstones??), (ii) crystalline rocks (granitoids >> crystalline schists), (iii) lapilli (max. 5x4x4 cm, aver. 2 m m) and coarse ash (up to 0.2 mm); lapilli often xenolith cored or forming a jacket (1–3 up to 7 mm) around larger xenoliths	clay minerals and carbonates forming strongly altered groundmass; partly altered lapilli with pseudomorphs and anomalous preserved relicts of primary mineral phases (olivine ± melilite?, spinels) in larger lapilli

HR-altered lapilli of olivine melilitite composition (5x4x4) surrounding granitic xenolith (about 1 cm)	111	massive, microporphyritic with fine-grained hemicrystalline matrix	altered olivine (microphenocrysts) + melilite ± spinels, apatite, carbonates and clay minerals
X-altered and partly disaggregated eclogite–griquaite (5x4x3)	103 and 103A	massive, partly disaggregated fine (No. 103) to medium-grained (No. 103A); eclogite Subgroup III. B or C ? High-temperature category (above 900 °C) of Miyashiro (1990) occurring as inclusions in basaltic rocks (granulite facies, deeper parts of continental crust) or forming eclogite layers in garnet serpentinite?	zoned garnet + omphacite ± spinel, anthophyllite (secondary); garnet–clinopyroxene pairs equilibration: 1150–1210 °C (Mori–Green 1978) and 1320–1400 °C (Mysen–Heier 1972)
X-altered garnet serpentinite, rounded (4x3x3)	110	for characteristics see garnet serpentinite No. 102, Krkavčí návrší Hill	
HR-altered pelletal lapilli-ash tuff, diatreme north of Křižany for details see Rutšek (1973)	101	for characteristics see diatreme filling No. 109, Kalvárie Hill at Hamr, and Rutšek (1973)	lapilli/xenoliths (up to 5 cm): aleurolites > sandstones > phyllites > marbles >> gabbroids; xenocrysts/crystal lapilli (up to 1–2 cm) kaersutite, clinopyroxene, phlogopite, pleonaste, olivine?, xenocrysts – almandine, fluorite
X-olivine norite angular for details see Rutšek (1973)	69	massive, hypautomorphic, coarse-grained (0.4–1.7 mm), gabbroic texture	labradorite An_{52-58} (63 vol. %) + orthopyroxene (27) ± olivine (7), spinel (2), apatite (1)
HR-altered basaltic breccia, maar ?, Na vinici at Stráž pod Ralskem	66	green-grey totally altered chaotic volcanic breccia with prevailing fragments of surrounding Upper Cretaceous sediments and underlying crystalline rocks (up to 10 cm in size); presence of upper mantle xenoliths not documented yet	clay minerals and carbonates

Petrological characteristics of the xenoliths

Brief petrographic (classification after Le Maitre ed. 1989) and mineral characteristics of the xenoliths and their host rocks are presented in Table 1. For chemical composition of xenoliths and their host rocks see Table 2.

Detailed petrological characteristics including modal and chemical compositions of host rocks of the xenoliths from the OC and their rock-forming minerals were published by Ulrych et al. (1988, 1991) and Pivec et al. (1998); the first descriptions of xenoliths from the Křižany diatreme were presented by Rutšek (1973).

Rock-forming minerals of the xenoliths

Olivine

Chemical compositions of olivines are given in Table 3. The Mg/(Mg + Fe) ratios of olivines from the xenoliths and host rocks are shown in Fig. 4.

Homogeneous olivine Fo_{83-84} (Table 3, No. 99) from the black ferro-dunite xenolith from olivine melilitolite (No. 46) is interpreted as being generally derived from differentiated plutonites (Brown Jr. 1980) or stratiform intrusions (Ilvitskii – Kolbantsev 1968). High contents of Ni and low contents of Ca are the main characteristic of this olivine.

Olivine forming a quasi-monomineral layer (No. 104) in the olivine melilitolite of the OC ranges to a slightly lower Fo content (Fo_{88}) than the olivine (Fo_{89-90}) of the host rock (No. 46). Concentric compositional zoning of olivines from the sample is perceptible in different contents of Ni and Ca and parallels the zoning of olivines from olivine melilitolites (cf. Ulrych et al. 1991).

Olivine Fo_{90} is characteristic of the dunite–harzburgite nodule (No. 23A) in melilite-bearing olivine nephelinite (No. 23) which has olivine of Fo_{87-88} composition.

Pyroxene

Chemical compositions of pyroxenes are listed in Table 4 and plotted in the classification diagram of Morimoto ed. (1988), Fig. 5.

Homogeneous clinopyroxene in the xenolith of garnet clinopyroxenite (Table 4, No. 119) is sodian hedenbergite impoverished in Al and Ti and enriched in Fe and Na. Clinopyroxene from glimmerite to phlogopite clinopyroxenite (No. 100) is of sodian-augite up to sodian- hedenbergite composition, with the same trends of crystal chemistry as in the garnet clinopyroxenite (No. 119).

Typical clinopyroxene in the xenolith of layered-mantle clinopyroxenite (Group I) from a basanite flow in the CS (Mihaljevič 1993) is also a sodian diopside but more Mg-rich and with significant jadeite and Cr content (cf. Table 4, analysis No. DL-1c and 1r).

Clinopyroxene of eclogite (No. 103) is typical omphacite with high Jd and low Ae component contents, and Jd/Ca-tsch > 0.5.

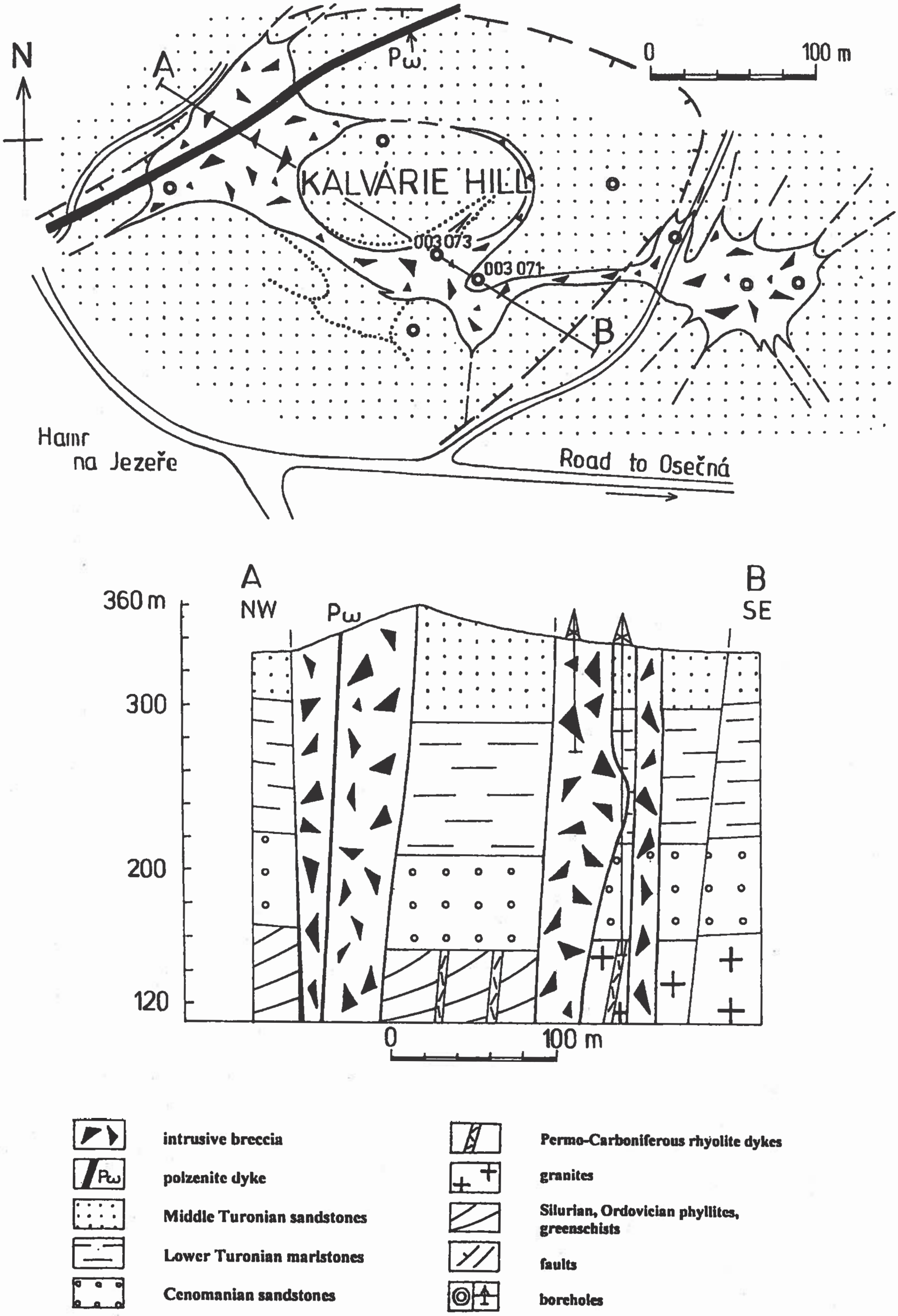

Fig. 2. Geological sketch (A) and profile (B) of the Kalvárie Hill diatreme near Hamr na Jezeře based on Pazdírek's (1992) data and new drilling results.

Table 2. Chemical analyses of the xenoliths and average composition of their host rocks

No.	104A	99	100	102	110	103	DL–1	DL–4	OM	PEG	IJ	PHL	MM	POL	MON	109	111
n	1	1	1	1	2	1	1	1	9	4	1	5	17	9	8	2	2
SiO_2	33.11	38.37	41.11	55.03	56.80	48.01	49.54	45.10	33.15	31.27	39.86	33.71	31.51	33.86	37.88	29.62	32.53
TiO_2	2.57	0.27	4.54	0.04	0.05	0.46	0.60	1.72	2.46	2.60	2.03	2.83	2.25	2.39	2.71	0.24	1.13
Al_2O_3	6.85	1.88	10.66	0.93	0.98	15.23	16.43	16.83	8.05	11.18	11.70	7.98	7.80	7.76	9.38	3.03	4.69
Cr_2O_3	0.07	0.09	0.11	0.40	0.44	0.10	0.06	0.05	0.01	0.01	0.01	0.07	0.02	0.15	0.19	0.11	0.13
Fe_2O_3	8.20	3.21	2.17	3.02	2.93	1.89	5.66	5.30	6.03	6.45	4.60	6.82	5.64	5.43	5.79	6.07	4.17
FeO	9.45	11.30	5.07	0.85	1.78	5.47	2.81	6.21	5.15	3.32	2.47	3.64	5.53	5.91	6.25	3.32	3.47
MnO	0.31	0.22	0.07	0.13	0.14	0.13	0.12	0.17	0.20	0.17	0.09	0.20	0.19	0.19	0.19	0.23	0.17
MgO	24.37	38.60	17.18	10.38	12.38	9.07	6.71	7.63	14.66	8.26	5.56	13.41	16.41	16.29	14.35	15.04	16.28
CaO	5.72	1.69	8.03	11.72	8.38	11.61	11.71	11.38	18.10	23.07	14.63	17.05	18.59	15.58	14.01	18.47	12.84
Na_2O	0.31	0.17	0.73	0.14	0.08	2.02	3.18	2.62	2.49	2.19	7.49	1.22	2.16	1.87	3.11	0.15	0.10
K_2O	1.87	0.41	5.70	0.30	0.12	0.72	0.54	0.45	2.17	1.87	1.28	3.06	1.55	1.98	1.45	0.14	0.42
P_2O_5	0.46	0.14	0.20	0.10	0.03	0.18	0.20	0.22	1.38	3.40	0.79	1.15	1.31	0.94	0.95	0.15	0.65
H_2O^+	5.88	3.28	3.32	3.49	4.65	1.70	2.95	2.82	3.96	4.84	4.31	3.72	3.77	3.55	1.62	5.45	5.56
H_2O^-	0.25	0.14	0.18	3.61	3.95	1.27	–	–	0.31	0.26	0.60	1.06	0.63	0.92	0.72	2.88	8.08
CO_2	0.18	0.12	0.46	9.23	6.81	1.81	–	0.17	1.11	0.94	4.02	3.17	2.30	1.93	2.13	14.10	8.65
F2	0.13	0.04	0.11	0.04	0.02	0.05	–	–	0.17	0.31	0.12	0.23	0.15	0.19	0.14	0.03	0.09
S	–	–	–	–	0.14	–	–	–	0.16	0.15	–	0.45	0.19	0.19	0.06	0.02	0.04
Σ	99.73	99.93	99.64	99.41	99.68	99.72	100.51	100.67	99.56	100.29	99.56	99.77	100.00	99.13	100.93	99.05	99.00
O=2F	-0.05	-0.02	-0.05	-0.02	-0.01	-0.02	–	–	-0.07	-0.13	-0.05	-0.10	-0.06	-0.08	-0.06	-0.01	-0.04
O=2S	–	–	–	–	-0.04	0.00	–	–	-0.04	-0.04	0.00	-0.11	-0.05	-0.05	-0.01	-0.01	-0.01
Σ	99.68	99.91	99.59	99.39	99.64	99.70	100.51	100.67	99.45	100.12	99.51	99.56	99.89	99.00	100.86	99.03	98.95

X – xenolith; 104A – dunite layer, Osečná; 99 – ferro-dunite X, Osečná; 100 – glimmerite to phlogopite clinopyroxenite X, Zdislava; 102 – garnet serpentinite X, Zdislava; 110 – garnet serpentinite X, Kalvárie Hill;
103 – eclogite X, Kalvárie Hill. DL-1 and DL-4 orthopyroxene gabbro X, Dolánky quarry, České středohoří Mts. (Mihaljevič 1993).
Osečná Complex: OM – olivine melilitolite, PEG – pegmatite in olivine melilitolite, IJ – ijolite in olivine melilitolite, PHL – phlogopitite in olivine melilitolite MM – micromelilitolite, POL – polzenite,
MON – melilite-bearing olivine nephelinite, 109 – diatreme breccia/pelletal lapilly tuff of olivine melilitite composition, 111 – peletal lapilli of olivine melilitite composition

Orthopyroxene in the harzburgite (No. 23A) from melilite-bearing olivine nephelinite (No. 23) is enstatite En_{88} with 0.4 wt. % Cr_2O_3 and is compatible with mantle derivation.

Amphiboles

Ferroedenitic common hornblende poor in Ti is characteristic of garnet clinopyroxenite (Table 4, No. 119) form-

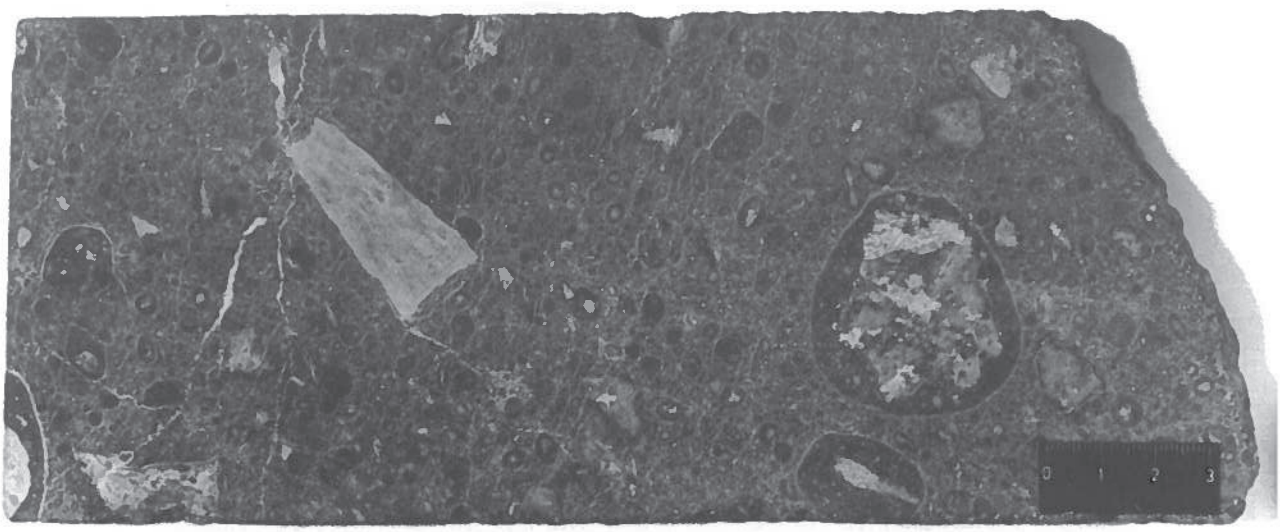

Fig. 3. Olivine melilitite pelletal lapilli-ash tuff of the Kalvárie Hill diatreme near Hamr na Jezeře (borehole No. 003 071, depth 119.88 m, see Fig. 2). Angular (light) xenoliths in lower part of photo is formed by Cretaceous marlstone; large lapillus is formed by coarse-grained granite (central part) with jacket (black) of olivine melilitite; pelletal lapilli (black) of olivine melilitite composition are dispersed in the fine-grained ashy groundmass.

Table 3. Chemical analyses of olivines and number of ions p. f. u.

No.	99c	99r	46c	46r	104c	104r	23A	23
SiO_2	39.73	40.32	40.41	40.15	40.37	40.56	40.69	39.98
FeO_{tot}	14.78	15.21	10.11	9.60	10.87	10.19	9.27	11.86
MnO	0.18	0.16	0.17	0.14	0.14	0.24	0.12	0.18
NiO	0.30	0.34	0.13	0.03	0.22	0.09	0.39	0.12
MgO	45.19	43.40	49.13	49.22	47.94	47.80	49.83	47.09
CaO	0.04	0.03	0.10	0.17	0.10	0.51	0.08	0.22
Total	100.22	99.46	100.05	99.31	99.64	99.39	100.38	99.45
Si	1.991	1.989	1.985	1.982	1.997	2.006	1.986	1.992
Fe	0.619	0.656	0.415	0.396	0.450	0.421	0.378	0.494
Mn	0.008	0.007	0.007	0.006	0.006	0.010	0.005	0.008
Ni	0.012	0.014	0.005	0.001	0.009	0.004	0.015	0.005
Mg	3.376	3.344	3.597	3.623	3.535	3.524	3.625	3.498
Ca	0.002	0.002	0.005	0.009	0.005	0.027	0.004	0.012
O	8	8	8	8	8	8	8	8
Fo	84.51	83.60	89.66	90.15	88.71	89.33	90.56	87.63

c – core, r – rim

ing rims and overgrowths on sodian hedenbergite, and rarely independent columns. Both minerals probably represent products of metasomatism mantle material (xenolith Group II), cf. Wass – Rogers (1980) or Lloyd (1987). Compositionally zoned anthophyllite in eclogite (No. 103) belongs to retrogression products (kelyphite rims and pseudomorphs after garnet).

Garnet

Optically and compositionally homogeneous almandine (Alm_{62-59} Grs_{16-21} Uvr_{10-13}) with very low Pyr contents is characteristic of garnet clinopyroxenite (Table 5, No. 119). This garnet plots in field I. A (low-temperature eclogite, Sifnos and Franciscan blueshists-facies; see Fig. 7) of Miyashiro's (1990) Ca–Fe^{2+}–Mg discrimination diagram. Homogeneous pyrope garnet (Pyr_{57-56} Alm_{16} Grs_{18-19} Uvr_7) occurs in fine-grained eclogite (No. 103). Compositionally zoned pyrope (Pyr_{80-61} Alm_{19-6} $Gros_{3-14}$ Uvr_5) grains, up to 2 mm in diameter, are present in medium-grained eclogite (No. 103 A) from the same locality. Garnet (Fig. 6) of the eclogite (Nos. 103 and 103A) plots in the field of high-temperature eclogites: (i) Subgroup III. B (inclusions in basaltic rocks) or (ii) Subgroup III. C (eclogite layers in peridotite rocks). In a similar diagram by Smulikowsky (1972) they plot in the griquaite field. Pyrope garnet (Pyr_{68-77} Alm_{9-17} Grs_{7-8} Uvr_5) is characteristic of garnet serpentinites (No. 110) from crystalline basement. Their chemical compositions correspond to pyrope from garnet serpentinite in the crystalline basement beneath the CS (Fiala 1965).

Micas

Chemical compositions of micas are shown in Table 6. Micas from the xenoliths and host rocks plotted in 100 Fe/Fe + Mg vs. Al^{iv} diagram are presented in Fig. 7.

Titanian magnesio-biotite forms the glimmerite – mica garnet clinopyroxenite xenolith (Table 6, No. 100). The magnesio-biotite (Table 6, No. 100) substantially differs from Ti-poor phlogopite II in olivine melilitolite of the OC

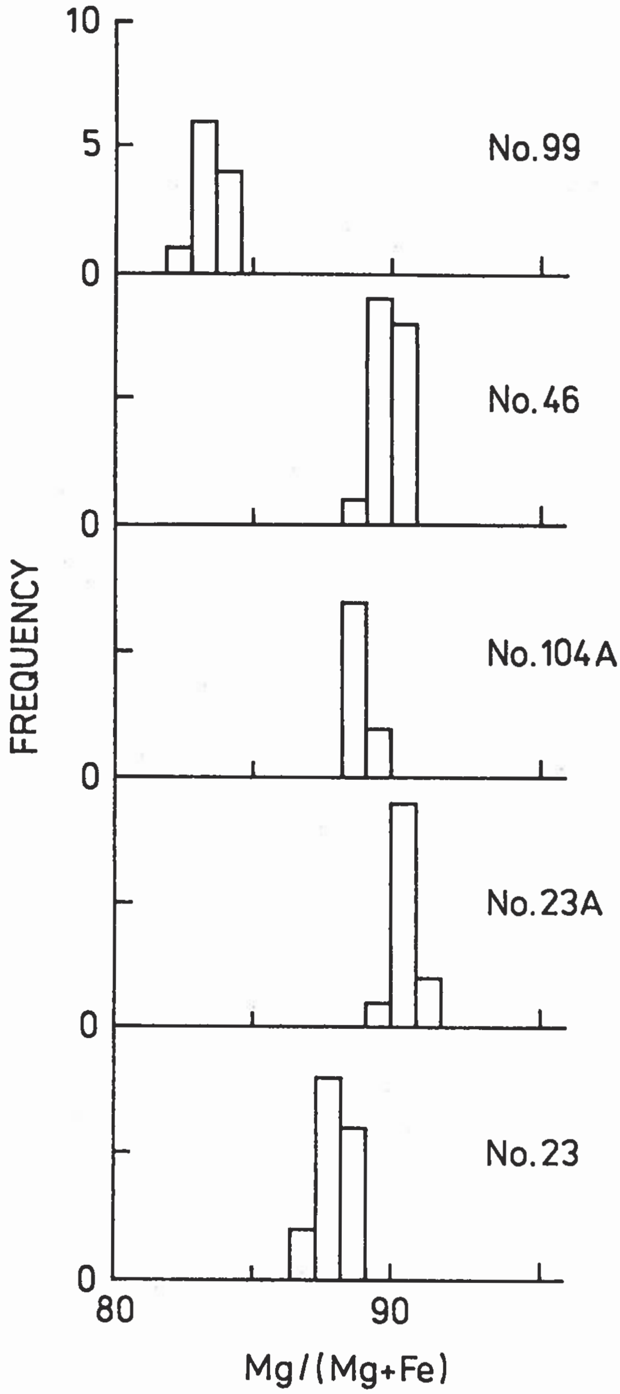

Fig. 4. Mg/(Mg + Fe) ratio of olivine from xenoliths and their host rocks. X – xenolith, HR – host rock. Sample Nos.: 99 – ferro-dunite X, Osečná; 46 – olivine melilitolite HR, Osečná; 104 A – dunite layer in olivine melilitolite HR, Osečná; 23 A – dunite to harzburgite X, Small Devil's Wall; 23 – melilite-bearing olivine nephelinite HR, Small Devil's Wall.

(cf. Table 6, No. 33). Phlogopite II formed metasomatically during the late stage of olivine-melilitolite crystallisation at the expense of phlogopite I, melilite and clinopyroxene (?) of primary crystallisation (cf. Ulrych et al. 1991). Foliated medium- to coarse-grained metasomatic garnet phlogopitites (phlogopite + garnet ± olivine, melilite, wollastonite, perovskite, apatite, spinels) represent the final

Table 4. Chemical analyses of pyroxenes and amphiboles and number of ions p. f. u.

No.	119c	119r	100	DL–1c	DL–1r	103	23A	119	103c	103r
SiO_2	51.07	51.97	51.02	50.64	50.61	55.95	55.11	42.19	55.01	55.13
TiO_2	0.08	0.10	0.33	0.24	0.35	0.31	0.04	0.05	–	–
Al_2O_3	0.40	0.40	2.28	5.95	6.19	13.02	4.10	9.73	4.05	5.47
Cr_2O_3	–	–	0.05	0.95	1.07	0.11	0.42	–	1.02	1.08
FeO_{tot}	17.78	18.41	12.25	3.57	3.25	2.40	6.09	24.89	11.25	8.35
MnO	0.32	0.35	0.20	0.07	0.16	–	0.12	0.54	–	–
MgO	7.22	6.82	11.38	15.19	14.73	8.49	33.70	5.21	24.36	26.32
CaO	21.03	20.76	20.31	21.76	21.88	12.37	0.71	11.54	2.11	1.52
Na_2O	1.51	1.42	1.91	1.08	0.63	6.98	0.08	1.84	–	–
K_2O	0.01	–	0.01	0.01	0.03	0.59	2.07	–	–	
Total	99.42	100.23	99.74	99.46	98.90	100.22	100.37	98.06	97.80	97.87
Si	1.984	2.011	1.910	1.846	1.865	1.966	1.890	6.639	7.605	7.500
Al^{IV}	0.016	–	0.090	0.154	0.135	0.034	0.110	1.361	0.395	0.500
Al^{VI}	0.002	0.018	0.011	0.102	0.134	0.505	0.055	0.443	0.265	0.377
Ti	0.002	0.003	0.009	0.007	0.010	0.008	0.001	0.006	–	–
Cr	–	–	0.001	0.027	0.031	0.003	0.011	–	0.111	0.116
Fe^{3+}	0.124	0.060	0.198	0.088	0.000	0.009	0.047	–	—	
Fe^{2+}	0.454	0.535	0.185	0.021	0.101	0.061	0.128	3.275	–	–
Mn	0.011	0.011	0.006	0.002	0.005	–	0.003	0.072	–	–
Mg	0.418	0.393	0.635	0.776	0.809	0.445	1.722	–	4.624	4.506
Ca	0.875	0.861	0.815	0.850	0.864	0.466	0.026	1.946	0.313	0.221
Na	0.114	0.107	0.139	0.076	0.045	0.476	0.005	0.452	–	–
K	–	–	–	0.000	0.001	0.026	–	0.416	–	–
O	6	6	6	6	6	6	6	23	23	23
Wo	46.28	45.40	41.39	39.67	40.43	29.99				
En	22.46	20.75	35.80	46.36	44.47	30.18				
Fs	24.38	28.23	10.44	1.19	5.50	4.16				
CaFeTsch	0.62	0	4.01	6.48	1.71	0.83				
CaTi Tsch	0.13	0	0.52	0.37	0.53	0.56				
CaAl Tsch	–	–	–	1.40	4.80	0.22				
Ae	6.03	4.67	7.25	–	–	–				
Jd	0.11	–	0.59	4.33	2.55	34.06				

DL–1 – mantle clinopyroxenite xenolith in basanite, Dobkovičky quarry; c – core, r – rim

products of metasomatic transformation. If compared with magnesio-biotite of the glimmerite xenolith, phlogopite II is enriched in Mg, and Si and depleted in Fe, Cr and Al. Significant Cr-content (0.17 wt. % Cr_2O_3), in magnesio-biotite (No. 100) can be indicative of its mantle origin. Nevertheless, such glimmerite to mica-clinopyroxenite xenoliths did not represent the source material of the host olivine-melilitite melt, but were only picked up by magma as it was rising (cf. Lloyd et al. 1991).

Ferro-biotite present in a garnet clinopyroxenite xenolith (No. 119) is poor in Ti and Mg. Phlogopite in ferro-dunite inclusion (No. 99) is similar to phlogopite II of the host olivine melilitolite (No. 46), but with higher Ti and slightly lower Mg contents. Both probably represent products of younger phlogopitisation of the host olivine melilitolite (Ulrych et al. 1988, Pivec et al. 1998).

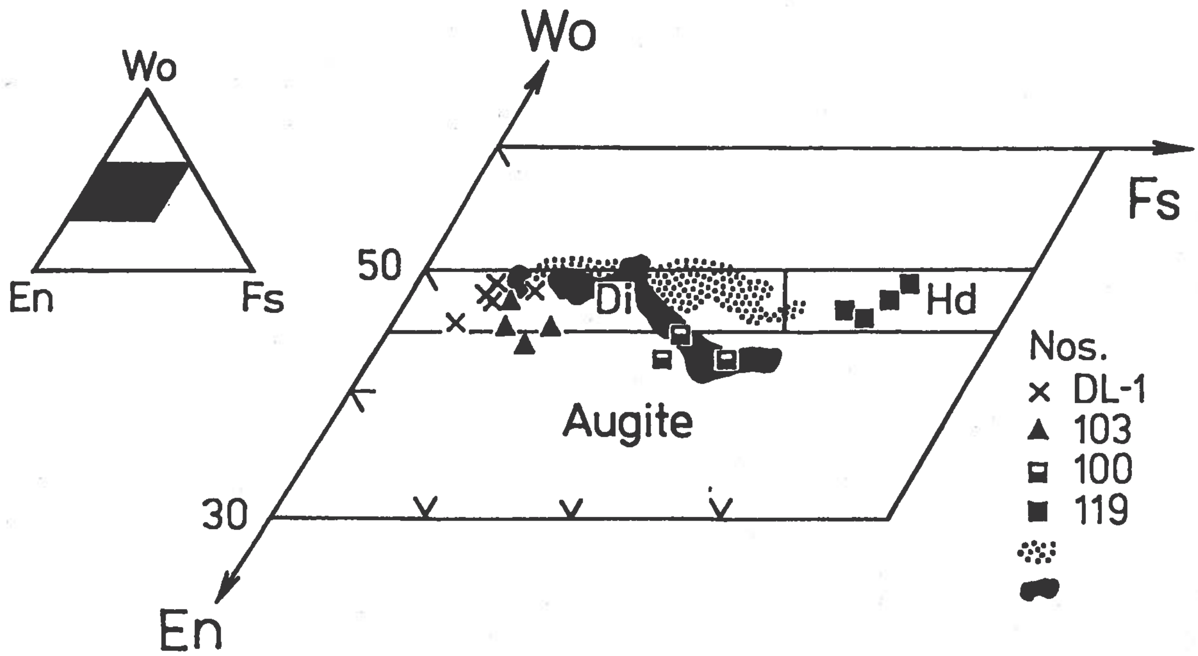

Fig. 5. Quad–pyroxenes from xenoliths and their host rocks plotted in a portion of the clinopyroxene quadrilateral (Morimoto ed. 1988). X – xenolith, HR – host rock. Sample Nos.: DL–1 – clinopyroxenite X, Dobkovičky (Mihaljevič 1989); 103 – eclogite X, Kalvárie Hill; 100 – glimmerite to phlogopite pyroxenite X, Krkavčí návrší Hill; 119 – garnet clinopyroxenite X, Osečná. Dotted area – field of magmatic pyroxenes, black area – field of metasomatic pyroxenes in mantle xenoliths from Uganda (Lloyd et al. 1991).

Table 5. Chemical analyses of garnets and number of ions p. f. u.

No.	119c	119r	103c	103r	103Ac	103Ar	110c	110r
SiO_2	37.08	37.16	41.13	41.03	42.13	41.21	41.37	41.49
TiO_2	–	–	0.19	0.24	0.28	–	0.21	0.29
Al_2O_3	18.32	18.80	22.27	22.33	21.90	23.34	22.10	21.94
Cr_2O_3	3.92	3.25	2.56	2.45	1.70	1.74	1.70	1.74
FeO_{tot}	27.26	27.40	8.11	8.55	5.78	9.68	8.98	9.68
MnO	0.24	0.27	–	–	–	–	–	–
MgO	0.84	0.76	15.70	15.36	22.08	16.79	20.60	19.11
CaO	11.47	12.38	10.26	10.39	5.39	7.89	5.01	5.68
Total	99.13	100.02	100.22	100.35	99.26	100.65	99.97	99.93
Si	5.985	5.981	5.945	5.934	5.965	5.906	5.885	5.949
Al^{IV}	0.015	0.019	0.055	0.066	0.035	0.094	0.115	0.051
Al^{VI}	3.467	3.545	3.735	3.738	3.617	3.845	3.587	3.654
Ti	–	–	0.021	0.026	0.030	–	0.022	0.031
Cr	0.500	0.413	0.292	0.280	0.190	0.197	0.191	0.197
Fe^{3+}	0.190	0.184	0.049	0.052	0.034	0.058	0.053	0.058
Fe^{2+}	3.624	3.504	0.931	0.982	0.650	1.102	1.015	1.103
Mn	0.033	0.037	–	–	–	–	–	–
Mg	0.202	0.182	3.383	3.312	4.661	3.587	4.368	4.085
Ca	1.984	2.135	1.589	1.610	0.818	1.211	0.764	0.873
cations	16	16	16	16	16	16	16	16
O	24	24	24	24	24	24	24	24
Alm	62.03	59.81	15.78	16.64	5.87	18.68	9.35	16.62
And	4.90	4.72	1.25	1.31	0.88	1.47	1.42	1.46
Sps	0.56	0.63	–	–	–	–	–	–
Pyr	3.46	3.11	57.31	56.09	80.08	60.79	77.17	68.70
Grs	16.22	21.14	18.24	18.84	8.26	14.05	7.01	8.24
Uvr	12.84	10.59	7.43	7.12	4.90	5.01	5.07	4.98

c – core, r – rim

Table 6. Chemical analyses of micas and number of ions p. f. u.

No.	100	33	119	99	46c	46r
SiO_2	37.07	40.15	35.74	37.76	37.01	37.17
TiO_2	5.61	0.88	1.10	4.28	3.68	2.89
Al_2O_3	13.50	12.85	12.82	15.22	15.64	15.29
Cr_2O_3	0.17	–	0.07	–	–	–
FeO_{tot}	15.16	5.87	27.24	6.20	5.25	6.64
MnO	0.19	0.03	0.59	0.04	0.03	0.03
MgO	14.60	24.81	7.70	20.68	22.29	21.04
CaO	0.10	–	0.18	–	–	–
BaO	0.12	0.31	0.48	1.71	1.99	2.12
Na_2O	0.50	0.12	0.08	0.18	0.34	0.37
K_2O	9.93	10.58	9.54	10.09	10.38	9.65
Total	96.95	95.60	95.54	96.16	96.61	95.20
Si	5.502	5.764	5.732	5.458	5.336	5.451
Al^{IV}	2.362	2.174	2.268	2.542	2.658	2.549
Fe^{IV}	0.136	–	–	–	–	–
TI^{IV}	–	0.062	–	–	0.006	–
Al^{IV}	–	–	0.155	0.051	0.024	0.094
Ti	0.626	0.033	0.133	0.465	0.393	0.319
Cr	0.020	–	0.009	–	–	–
Fe	1.746	0.705	3.653	0.750	0.633	0.814
Mn	0.024	0.004	0.080	0.005	0.004	0.004
Mg	3.231	5.310	1.841	4.456	4.791	4.600
Ca	0.016	–	0.031	–	–	–
Ba	0.007	0.017	0.030	0.097	0.112	0.122
Na	0.144	0.033	0.025	0.050	0.095	0.105
K	1.880	1.938	1.952	1.861	1.909	1.806
O	22	22	22	22	22	22

No 33 – phlogopitite in olivine melilitolite, Osečná borehole; c – core, r – rim

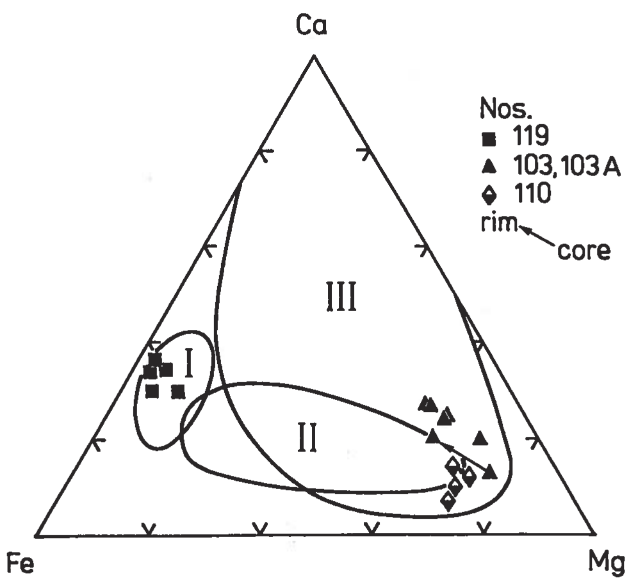

Fig. 6. Garnet from the xenoliths in the discrimination diagram of Miyashiro (1990). Xenoliths sample Nos.: 119 – garnet clinopyroxenite, Osečná; 103 and 103 A – eclogite, Kalvárie Hill; 110 – garnet serpentinite, Kalvárie Hill. Garnet fields: I – Sifnos and Franciscan eclogites (Subgroup I A), II – Western Norway (Subgroup II), III – Eclogites of Subgroup III occurring as inclusions in kimberlite, basaltic rocks, or as layers in periditites (after Miyashiro 1990).

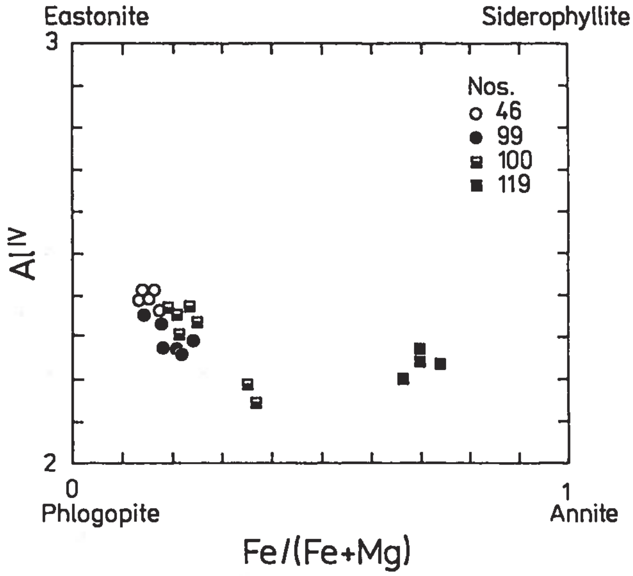

Fig. 7. Micas from xenoliths and their host rocks plotted in 100 Fe/Fe + Mg vs. Al^{IV} diagram; all Fe as Fe_{tot}. X – xenolith, HR – host rock. Sample Nos.: 46 – olivine melilitolite HR, Osečná; 99 – ferrodunite X, Osečná; 100 – glimmerite to phlogopite pyroxenite X, Krkavčí návrší Hill; 119 – garnet clinopyroxenite X, Osečná.

Spinels

Spinels from the xenoliths and host rocks are presented in Table 7 and plotted into the Johnson prism (Fig. 8).

Table 7. Chemical analyses of spinels and number of ions p. f. u.

No.	23c	23m	102c	110c	104c	99	100	66c	66i	66m	102r	110r	104r	46c	46r	119
SiO_2	0.00	0.12	0.11	0.12	0.09	0.00	0.16	0.07	0.08	0.11	0.19	0.16	0.20	–	–	0.08
TiO_2	1.07	23.33	0.28	0.15	1.18	13.97	21.05	0.77	1.11	9.48	0.41	0.19	11.36	1.27	9.66	0.28
Al_2O_3	15.18	2.80	22.62	19.03	40.98	5.73	4.26	47.93	53.59	13.47	25.12	20.50	9.33	40.17	8.93	0.12
Cr_2O_3	28.87	0.08	38.78	35.10	20.96	0.16	0.12	15.91	4.22	0.37	32.22	29.82	1.12	22.12	0.95	0.00
FeO_{tot}	38.51	68.47	20.97	26.63	17.02	66.32	67.10	16.16	20.19	53.61	22.13	28.19	66.73	14.93	68.10	93.11
MnO	0.19	0.37	0.21	0.41	0.12	1.60	0.18	0.12	0.08	0.27	0.27	0.44	0.81	0.05	0.11	0.11
MgO	13.61	3.29	15.62	15.73	18.62	6.73	3.89	17.08	19.37	14.23	17.11	16.64	6.30	20.00	6.39	0.00
CaO	0.02	0.22	0.12	0.29	0.10	0.00	0.19	0.05	0.03	0.21	0.16	0.38	0.10	0.00	0.00	0.05
Total	97.45	98.68	98.71	97.46	99.07	94.51	96.95	98.09	98.67	91.75	97.61	96.32	95.95	98.54	94.14	93.75
Si	0.000	0.004	0.003	0.004	0.002	0.000	0.006	0.002	0.002	0.004	0.006	0.005	0.007	0.000	0.000	0.003
Ti	0.026	0.633	0.010	0.007	0.027	0.374	0.575	0.018	0.024	0.242	0.015	0.009	0.303	0.026	0.256	0.011
Al	0.570	0.118	0.810	0.695	1.341	0.241	0.181	1.557	1.673	0.530	0.888	0.746	0.381	1.314	0.371	0.005
Cr	0.727	0.002	0.931	0.860	0.460	0.005	0.003	0.347	0.088	0.010	0.764	0.728	0.031	0.485	0.026	0.000
Fe^{3+}	0.684	1.368	0.355	0.460	0.263	1.238	1.175	0.248	0.298	0.000	0.370	0.485	1.204	0.231	1.270	1.982
Fe^{2+}	0.342	0.684	0.178	0.230	0.132	0.737	0.844	0.124	0.149	1.496	0.185	0.243	0.728	0.115	0.738	0.996
Mn	0.005	0.011	0.005	0.011	0.003	0.048	0.005	0.003	0.002	0.008	0.007	0.012	0.024	0.001	0.003	0.004
Mg	0.647	0.184	0.711	0.736	0.774	0.357	0.216	0.703	0.766	0.715	0.770	0.778	0.329	0.827	0.336	0.002
Ca	0.001	0.008	0.004	0.010	0.003	0.000	0.007	0.001	0.001	0.008	0.005	0.013	0.004	0.000	0.000	0.002
cation	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
O	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
$MgAl_2O_4$	28.49	5.91	40.49	34.76	67.05	13.47	9.03	77.85	83.64	25.61	44.41	41.41	19.04	65.68	18.55	0.27
Mg_2TiO_4	0.85	6.25	0.32	0.24	0.90	13.27	6.28	0.60	0.81	21.77	0.50	0.35	6.93	0.88	7.51	0.00
Mn_2TiO_4	0.00	0.56	0.00	0.00	0.00	2.70	0.27	0.00	0.00	0.37	0.00	0.00	1.19	0.00	0.16	0.18
Fe_2TiO_4	0.00	56.47	0.00	0.00	0.00	25.93	50.98	0.00	0.00	1.21	0.00	0.00	22.17	0.00	17.93	0.97
$MnCr_2O_4$	0.51	0.00	0.54	1.08	0.28	0.00	0.00	0.28	0.18	0.00	0.69	1.28	0.00	0.12	0.00	0.00
$MgCr_2O_4$	35.95	0.00	40.89	40.91	18.59	0.00	0.00	8.86	0.46	0.00	35.89	41.09	0.00	21.77	0.00	0.00
$FeCr_2O_4$	0.00	0.11	0.00	0.00	0.00	0.25	0.17	0.00	0.00	5.45	0.00	0.00	1.53	0.00	1.32	0.00
$FeFe_2O_4$	34.19	30.69	17.76	23.01	13.17	44.37	33.26	12.42	14.91	45.59	18.51	15.88	49.14	11.55	54.52	98.62

Numerous zoned isometric magnesiochromite grains are characteristic of both of the two occurrences of xenoliths of garnet serpentinite (Table 7, Nos. 102 and 110). Trends of zoning in spinel in both samples are similar. A bizonal trend of spinel crystallisation with (Mg,Fe)-Al-chromite (core) and Al-Ti-magnetite (rim) is present in spinels of dunite layers (No. 104c and r) and likewise in the spinels of the host olivine melilitolite of the Osečná intrusion (cf. No. 4c and r) (Ulrych et al. 1986).

Titanian magnetite with higher proportions of Al and Mg is present in ferro-dunite (No. 99). Rare titanian magnetite occurs in glimmerite to phlogopite clinopyroxenite (No. 100, see characteristic mineral association of metasomatic mantle clinopyroxenite of Group II). Nearly pure magnetite (with minor Ti) in garnet clinopyroxenite (No. 119) represents a younger generation of spinels associated with decomposition of primary mafic silicates. Rare spinels in eclogite No. 103 belong to complex (Al,Cr,Mg)-bearing varieties.

Xenolith associations

On the basis of the various mineral assemblages, mantle nodules in volcanic rocks have been usually classified (Lloyd – Bailey 1975; Frey – Prinz 1978, Lloyd 1981, 1987) into two groups:

– *Group I* nodules are spinel lherzolites, spinel harzburgites, wehrlites and dunites containing olivine, enstatite and clinopyroxene as major constituents with no (dunite to harzburgite No. 23) or only small amounts of amphibole and dark mica.

– *Group II* nodules are pyroxenites that contain mainly clinopyroxene with minor orthopyroxene and little or no olivine (glimmerite to mica garnet clinopyroxenite No. 100). In addition, they usually contain significant modal percentages of hydrous minerals (titaniferous phlogopite, amphibole) and may also be rich in titanite (or perovskite), titanomagnetite, apatite and rarely calcite and feldspar (Lloyd 1987). Some or all of the Group II nodules represent mantle rocks, some of which have been modified by metasomatism (Lloyd 1987). Group II nodules in Ugandan kamafugites have been subdivided into three groups on textural grounds (Lloyd 1981). Based on genetic aspects the BM group of nodules can be categorised as:

(a) mantle xenoliths unrelated to host magmas – stockwork of metasomatic or magmatic veins (based on xenolith textures), or magmatic + metasomatic, or deep-seated alkaline complex (e. g., Lloyd – Bailey 1975; Frey – Prinz 1978, Lloyd 1981, 1987);

(b) metasomatic or magmatic veining by melts related to host magmas (e. g., Irving 1980, Witt-Eickschen et al. 1998).

Melilitic rocks of the OC are characterised by presence of following xenolith associations:

(i) dunite to harzburgite from mantle (melilite-bearing olivine nephelinite – Little Devil's Wall),

(ii) glimmerite to mica clinopyroxenite from metasomatised mantle? (polzenite – Krkavčí návrší Hill),

(iii) ferro-dunite, garnet clinopyroxenite?, garnet serpentinite from local crystalline basement (olivine melilitolite – Osečná intrusion).

(iv) garnet serpentinite, eclogite, and norite from local crystalline basement (Kalvárie Hill and Křižany lapilli-ash tuffs of olivine melilitite composition in diatremes).

The xenolith suite from local crystalline basement partly resembles the high PT crystalline rocks (gneisses, granulites, garnet serpentinites, amphibolites) beneath the České středohoří region (Kopecký 1967, Kopecký et al. 1970) as known from the Třebenice area. Such a suite of xenoliths is characteristic for lithospheric plate boundaries.

However, the eclogite xenoliths found exclusively in the Kalvárie Hill diatreme occur in a low PT crustal rock xenolith suite of Lower Paleozoic phyllites, greenschists (± glaucophane) and albite granites. The rock association is similar to that in the nearby Železný Brod Volcanic Complex (Fajst et al. 1998).

Nevertheless, according to the chemistry of garnet these eclogite xenoliths can be classified (Miyashiro 1990) as *Subgroup III.B* (eclogites in basaltic rocks formed in deeper parts of continental crust) *or C* (eclogite layers in peridotitic rocks) corresponding to the *high-temperature division of eclogite facies* sensu Carswell ed. (1990). Equilibration temperatures of garnet–clinopyroxene pairs (core–rim) are 1150–1210 °C (Mori – Green 1978) and 1320–1400 °C (Mysen – Heier 1972). In Smulikowsky's (1972) jadeite–diopside–garnet diagram the eclogite xenoliths plot in the griquaite field, unlike common eclogites from W Sudetes.

A mica–garnet clinopyroxenite xenolith from the olivine melilitolite of the Osečná intrusion has a different chemical composition. According to the chemistry of its garnet, this solitary eclogite xenoliths can be classified as *Subgroup I. A* (eclogites accompanied by blueschist-facies regions, *sensu* Miyashiro 1990) corresponding to the *low-temperature division of eclogite facies sensu* Carswell ed. (1990). Equilibration temperatures of garnet–clinopyroxene pairs (core–rim) are 420–450 °C (Mori – Green 1978) and 430–460 °C (Mysen – Heier 1972).

Olivine, biotite (titaniferous phlogopite-biotite) and pyroxene (clinopyroxene) – the OBP series of Holmes (1942) – substantially occurring in xenoliths and also as xenocrysts and phenocrysts in volcanic rocks are of particular significance. These three minerals may provide clues to the PT crystallisation paths of the melt(s). Xenolith textures suggest that both magmatic and metasomatic processes may have been operating at depths; thus, xenocrysts may represent fragments of magmatic or metasomatic material (Lloyd et al. 1991). On the other

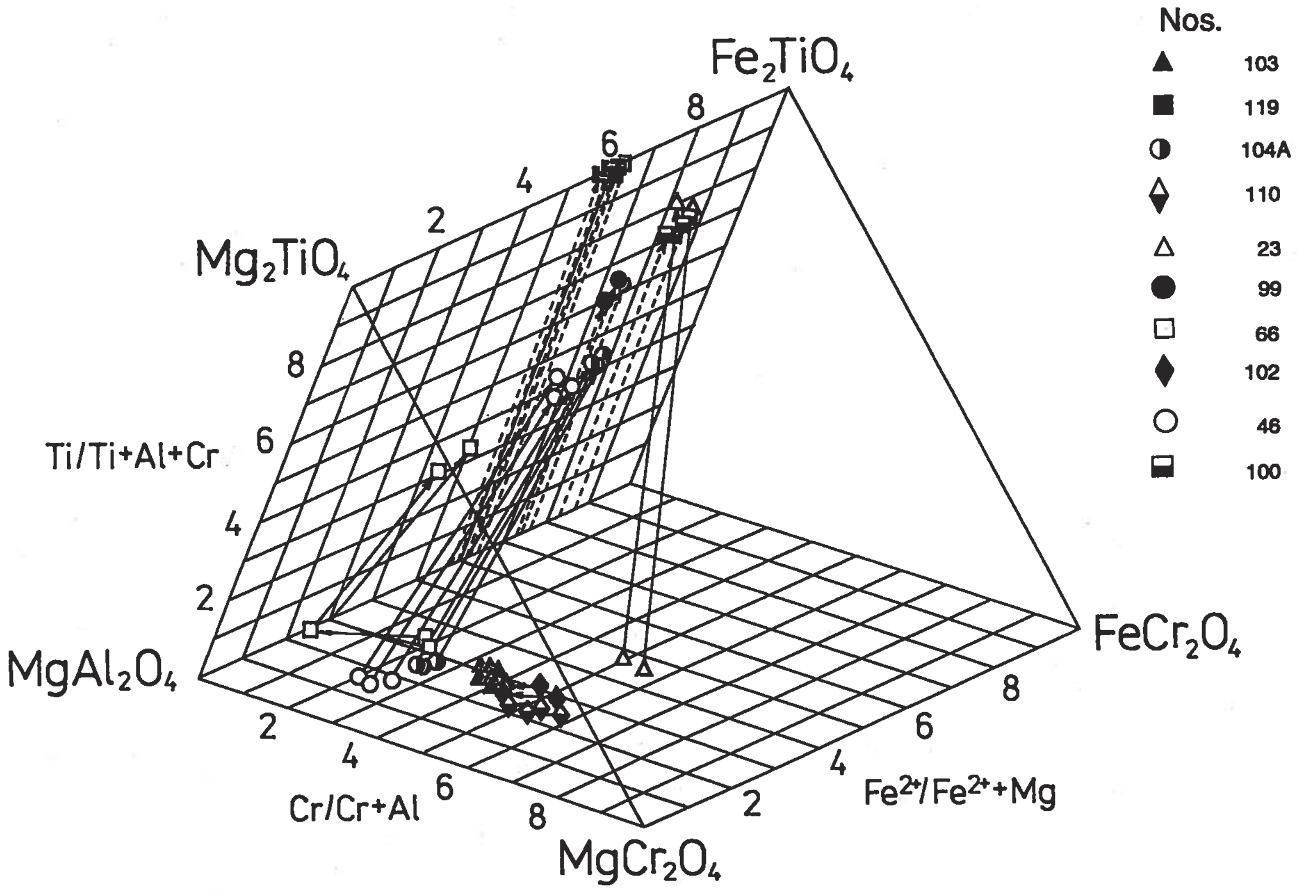

Fig. 8. Spinels from xenoliths and their host rocks plotted into the Johnson prism. X – xenolith, HR – host rock. Sample Nos.: 102 – garnet serpentinite, Krkavčí návrší Hill X; 110 – garnet serpentinite X, Kalvárie Hill; 104 A – dunite layer in olivine melilitolite HR, Osečná; 4 – olivine melilitolite HR, Osečná; 99 – ferro-dunite X, Osečná; 100 – glimmerite to phlogopite clinopyroxene X, Krkavčí návrší Hill; 119 – garnet clinopyroxenite X, Osečná; 103 – eclogite X, Kalvárie Hill; 110 – garnet serpentinite X, Kalvárie Hill.

hand, xenocrysts may represent high PT (cognate) phenocrysts. The compiled PT diagram in Fig. 9 (after Lloyd et al. 1991) shows that PT crystallisation conditions for glimmerite to mica clinopyroxenite xenolith (No. 100) could be analogous to the xenolith of average composition from the central fields of Uganda (<1200 °C and 30 kbar or <1000 °C and 17 kbar). Melting experiments on katungite (K-rich olivine melilitite) with 5 % H_2O added (Arima – Edgar 1983), showed olivine as the liquidus phase up to 20 kbar. Above this pressure, clinopyroxene replaced olivine on the liquidus (ca. 1200 °C) and phlogopite separated at 80–100 °C below this. Lower temperature/pressure of crystallisation can be supposed for the garnet clinopyroxenite (No. 119) and eclogite (No. 103) xenoliths.

Discussion and conclusions

The study of the upper-mantle xenolith association hosted in melilitic rocks of the OC has shown:

1. Upper-mantle xenoliths are common in Cenozoic massive rocks, breccias and tuffs of alkali basaltic composition of the BM. In particular they are concentrated along deep-seated faults. Mantle xenoliths are usually represented by lherzolites, dunites and harzburgites (Group I) as well as by pyroxenites (Group II), and xenocrystic olivine and pyroxene. The lack of lherzolite and the presence of dunite and harzburgite in the OC together with the high Mg# of their olivine may indicate magma extraction from depleted mantle. Xenoliths of glimmerite to mica clinopyroxenite are probably sourced in metasomatised upper mantle;

2. Lower crustal xenoliths (granulites, charnockites, gabbros) common in the same volcanic rocks of the BM, are generally interpreted as evidence of deep crustal complexes beneath the individual centres. Xenoliths of these rocks (norite) are very rare in the OC volcanics;

3. The most abundant xenoliths represent rocks of deeper crystalline basement (garnet serpentinite, eclogite, ferro-dunite, norite);

4. Upper-mantle xenoliths and xenoliths from the local crystalline basement are present in melilitic rocks of a single volcanic centre (OC); xenoliths of similar rock types (garnet serpentinite) are present in a dyke of polzenite (Krkavčí návrší Hill) and in pelletal lapilli-ash tuff of diatreme filling (Kalvárie Hill);

5. Evidence of the upper mantle as represented by very rare xenoliths of dunite to harzburgite (Group I sensu Lloyd – Bailey 1975; Frey – Prinz 1978) is confined to melilite-bearing olivine nephelinite of the Small Devil's Wall;

6. Group II xenoliths are K-rich glimmerite to mica clinopyroxenite, which may represent metasomatised upper mantle beneath the OC region – xenoliths of Group II (i) sensu Lloyd – Bailey (1975), Lloyd (1981), or veins related to the host magmas (Witt-Eickschen – Kramm 1998). They occur preferentially in polzenites;

7. Xenoliths of the local crystalline basement are represented by garnet serpentinite, documented in various rocks of the OC (olivine melilitolite and pelletal lapilli-ash tuff of diatreme filling); norite recognised in pelletal lapilli-ash tuff; and ferro-dunite in olivine melilitolite only. This association of ultramafic xenoliths is indicative for lithospheric plate boundaries; such boundary was probably active from pre-Variscan to Neoidic times in the N Bohemian region;

8. The xenolith of garnet biotite clinopyroxenite (Subgroup IIIB? sensu Miyashiro 1990) present in olivine melilitolite only may have formed in deeper parts of the continental crust. Equilibration temperatures of garnet–clinopyroxene pairs (core–rim) are 420–450 °C (Mori – Green 1978) and 430–460 °C (Mysen – Heier 1972).

Eclogite (griquaite) xenoliths present exclusively in the pelletal lapilli-ash tuff of Kalvárie Hill diatreme, may belong most probably to Subgroup IIIC? sensu Miyashiro (1990) representing eclogite layers ("internal eclogites") in peridotitic rocks. Equilibration temperatures of garnet–clinopyroxene pairs (core–rim) are 1150–1210 °C (Mori – Green 1978) and 1320–1400 °C (Mysen – Heier 1972);

9. Presence of mantle xenoliths in volcanic rocks associated with the Lužice (LTVZ) and the Stráž faults (OR) support the notion of their deep crustal range;

10. Diatremes and maars (?) are manifestations of the same volcanic activity, but at different erosional levels with about 600 m vertical displacement magnitude along the Stráž Fault;

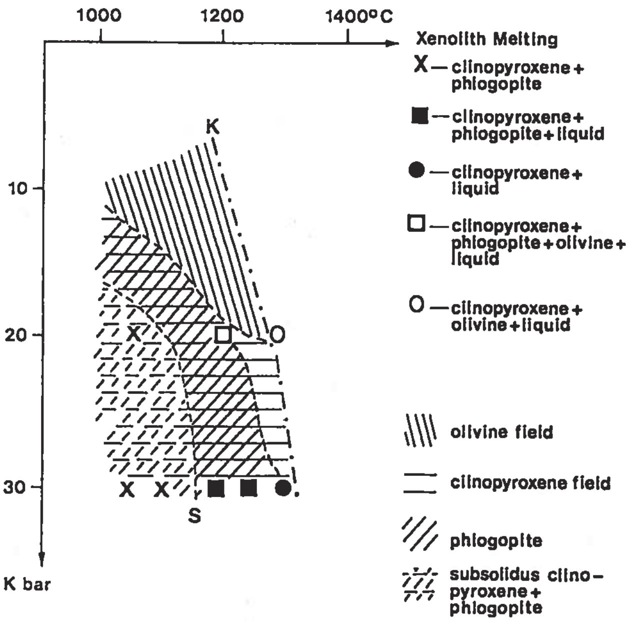

Fig. 9. PT fields for olivine, clinopyroxene and phlogopite in K-rich olivine melilitite (katungite) melt composition compiled by Lloyd et al. (1991). K – olivine-melilitite liquidus; liquidus phase between 10 and 20 kbar = olivine, between 20 and 30 kbar = clinopyroxene; S – approximate solidus for the average xenolith composition from the central fields of Bunyaruguru and Katwe–Kikorongo, Uganda.

11. The lack of xenoliths of melilitic rocks in the OC diatremes and maar (?) fillings and their penetration by polzenite dykes indicates that these centres of degassing probably represent products of the oldest phase of young volcanism within the BM (older than 79 Ma – olivine melilitolite and 77 Ma – polzenite of the OC, Pivec et al. 1998).

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Svrchnoplášťové xenolity v melilitických horninách osečenského komplexu v severních Čechách

Osečenský komplex (79–49 mil. let), tvořený diferenciační sérií melilitických hornin (olivinický melilitolit – polzenit – melilitický olivinický nefelinit), vystupující na křížení oháreckého riftu s lužickým zlomem vznikl ze svrchoplášťového zdroje. Geneticky spjaté diatrémy (a maary?) vyplněné lapillovým až popelovým tufem peletového typu složení olivinického melilititu předcházejí svým vznikem vývoj osečenského komplexu. Xenolity svrchoplášťového původu se vyskytují jak v masivních horninách, tak v tufech diatrem. Dunity až harzburgity v melilitickém olivinickém nefelinitu reprezentují ochuzený plášť. Glimerit až biotitický klinopyroxenit v polzenitech jsou patrně produkty metasomatizovaného svrchního pláště. Granátický serpentinit, eklogit, norit a ferro-dunit vynesené z místního krystalinického podloží se vyskytují pouze ve výplních diatrem. Pocházejí z hornin, které jsou primárně odvozeny ze svrchoplášťového zdroje. Skupina výše uvedených svrchoplášťových hornin indikuje přítomnost ochuzeného i obohaceného (metasomatizovaného) svrchního pláště pod severní částí Českého masívu. Výskyt xenolitů ultramafických hornin odvozených ze svrchního pláště, které intrudovaly do místního krystalinického podloží, jsou považovány za typické pro hranice lithosferické desky.