

1 Metasomatic effects in the lithospheric mantle beneath the NE Bohemian Massif: a  
2 case study of Lutynia (SW Poland) peridotite xenoliths.

3

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15 *Abstract:*

16 Spinel lherzolite and spinel harzburgite mantle xenoliths occur in the 4.56 ±  
17 0.2 Ma Lutynia basanite (SW Poland). Only one contains minor pargasitic amphibole.  
18 Minerals forming the xenoliths are unzoned. Olivine (Fo<sub>89.8-92.4</sub>) contains 0.34 – 0.45  
19 wt.% NiO and <780 ppm Ca, orthopyroxene is Al enstatite (#mg 0.90 – 0.92, Al 0.06  
20 – 0.17 a.pfu), clinopyroxene is Al, Cr diopside (#mg 0.91 – 0.93, Al 0.104 – 0.197  
21 a.pfu). Exsolved orthopyroxene occurs in the clinopyroxene and vice versa. Al/Mg  
22 spinel occurs in symplectites with clinopyroxene. Second generation crystals of  
23 olivine (Fo<sub>88.0-91.7</sub>, Ca up to 1800 ppm), clinopyroxene and spinel occur in small  
24 interstitial patches containing feldspar. Clinopyroxene II is Al-poor (0.018 – 0.070  
25 a.pfu, #mg 0.921 – 0.932) when coexisting with alkali feldspar (An<sub>4-14</sub>, Ab<sub>49-71</sub>), or  
26 with plagioclase (An<sub>37-46</sub>, Ab<sub>51-58</sub>) it is Al – rich (0.046 – 0.261 a.pfu; #mg 0.907 –  
27 0.925). Four types of REE patterns are found in the clinopyroxene: (group A) flat  
28 HREE with LREE content increasing smoothly; (group B) flat HREE with an abrupt  
29 increase of MREE and LREE; (group C) LREE- enriched, flat HREE with negative  
30 inflection at MREE; (group D) smoothly LREE enriched and with no flat HREE  
31 pattern. The exception is clinopyroxene from xenolith MM30 which is extremely  
32 depleted in LREE. Cpx I from all the xenoliths (excluding MM30) contain high  
33 amounts of Th and U.

34 Cpx trace element compositions record a degree of partial melting event from  
35 8 to 15% (in MM30 >27%). Major- and trace-element compositions of minerals record  
36 further cryptic metasomatism induced by a CO<sub>2</sub>-bearing alkaline melt. Variable REE  
37 patterns for Cpx I from groups A, B and C are due to chromatographic enrichment,  
38 with group A peridotites located closest to the metasomatic source and group C  
39 being the furthest. The pargasite-bearing MM04 was probably the closest to the  
40 metasomatic source and thus recorded incipient modal metasomatism.

41 Clinopyroxene – spinel symplectites and ortho –/clinopyroxene exsolutions  
42 suggest that the peridotites were transported from the garnet- lherzolite regime  
43 mantle facies into the spinel one where they cooled and equilibrated at 960 – 1000  
44 °C. The patches formed by the second generation of minerals are an effect of pre –  
45 eruption infiltration by the basanitic melt.

46

47 Key words: lherzolite – harzburgite xenoliths, upper mantle, chromatographic  
48 metasomatism, SW Poland, Cenozoic basanite.

49

## 50 1. INTRODUCTION

51 Late Cretaceous to Pleistocene basaltic rocks are widespread in Europe  
52 (Lustrino and Wilson, 2007). Their origin is associated with collision between the  
53 African and Euroasian plates which led to development of a lithospheric rift system in  
54 the northern foreland of the Alps and uplift of Variscan basement blocks (Massif  
55 Central, Rhenish Massif, Bohemian Massif; Wilson and Downes, 2006).

56 Cenozoic lavas are common in the Bohemian Massif. The Eger Graben is the  
57 largest occurrence but numerous smaller ones are located in the NE part of the  
58 Massif (Sudetes and the Fore – Sudetic Block in SW Poland and N Czech Republic).  
59 More than three hundred outcrops of volcanic rocks, mostly basanites, nephelinites  
60 and basalts, are known from SW Poland (Ladenberger et al., 2006). They are  
61 concentrated in two large (Lubań – Frydlant, Złotoryja – Jawor) and three smaller  
62 (Niemcza – Strzelin, Niemodlin, Łądek Zdrój) volcanic fields in the Sudetes and in the  
63 Fore Sudetic Block (Fig.1a). Blusztajn and Hart (1989) and Ladenberger et al. (2006)  
64 showed that the lavas are derived from an inhomogeneous mantle source including  
65 DMM, EM and HIMU components. Volcanic activity in SW Poland mainly occurred in  
66 two main episodes: Late Oligocene (33.7 – 31.3 Ma) and Early Miocene (24.5 – 21  
67 Ma; Birkenmajer, 2004). The third, the youngest episode is recorded only in Łądek

68 Zdrój ( $5.46 \pm 0.2 - 3.83 \pm 0.17$  Ma; Birkenmajer, 2002). Young volcanic activity  
69 occurs also in the Czech (i.e. southern) part of Sudetes (Bruntal area,  $3.69 \pm 0.56$  Ma  
70 to  $0.8 \pm 0.11$  Ma; Foltýnová, 2003; Kozákov volcano, 4 - 6 Ma; Šibrava and Havlíček,  
71 1980).

72 Mantle xenoliths occur in some of the lavas in SW Poland and were described  
73 from Łądek Zdrój (Blusztajn and Shimizu, 1994; Kozłowska-Koch, 1976), Złotoryja –  
74 Jawor vicinity (Białowolska, 1980) and Lubań (Bakun–Czubarow and Białowolska,  
75 2003; Puziewicz, 2005). They are mostly anhydrous peridotites. Amphibole – bearing  
76 peridotites have been only described at Wołek Hill (Napieralska and Muszyński,  
77 2006) and Wilcza Góra, where amphibole is associated with phlogopite (Matusiak–  
78 Małek et al; unpublished data).

79 In the present paper we describe mantle xenoliths in Cenozoic volcanic rocks  
80 from Łądek Zdrój area located in the Sudetes Mts.

81

## 82 2. REGIONAL GEOLOGY

83 Outcrops of Variscan basement may be followed through Western and Central  
84 Europe from Portugal and Spain through France and Germany and then to the Czech  
85 Republic and Poland. The eastern part of the Variscan orogen in Europe, i.e. the  
86 Bohemian Massif, is limited to the Sudetes Mts. in the north – east. Basanitic lavas,  
87 carrying mantle xenoliths described in this paper, occur in the Orlica–Śnieżnik dome  
88 (Western Sudetes). The dome consists of supracrustal formation (micaschists with  
89 intercalations of marble, quartzite and amphibolite) occurring in synforms and  
90 orthogneisses in the antiforms. Rocks forming the dome record medium to high grade  
91 metamorphism. Ultrahigh pressure ( $>2.7$  GPa) conditions are recorded in eclogitic  
92 rocks occurring in the eastern part of the dome (Bröcker and Klemd, 1996). The  
93 supracrustal series is assumed to be Neoproterozoic (Mazur et al., 2006). U – Pb and  
94 Pb – Pb zircon datings indicates that the age of intrusion of the magmatic protolith of  
95 orthogneisses is 500 Ma (Oliver et al., 1993; Turniak et al., 2000; Kröner et al., 2001).

96

97 FIGURE 1. ABOUT HERE

98

99 The Tertiary basanites of the Śnieżnik dome, belong to the Central European  
100 Volcanic Province (CEVP). In this paper we describe mantle xenoliths from Lutynia  
101 village (“Szwedzkie Szańce” quarry; Fig.1b) near Łądek Zdrój. They occur in a

102 basanitic volcanic plug (Wierzchołowski, 1993) dated at  $4.56 \pm 0.2$  Ma (K–Ar age;  
103 Birkenmajer et al., 2002). The basanite also carries clinopyroxene megacrysts and  
104 xenoliths of the crustal basement (gneisses, granites, quartzites; Kozłowska-Koch,  
105 1976). Other xenolith occurrences in the Łądek Zdrój area comprise Zalési (Czech  
106 Republic; Fediuk and Fediuková, 1985), Lutynia II and Łądek Zdrój (Kozłowska-Koch,  
107 1976). The Lutynia (Szwedzkie Szańce and Lutynia II), Łądek Zdrój and Zalési are  
108 located 3 – 4 km from each other and probably form a single volcanic structure (Fig.  
109 1a).

110

### 111 3. ANALYTICAL METHODS

112 Our study is based on major and trace element analyses of minerals in  
113 fourteen xenoliths. The modal compositions were established by an image analysis  
114 method (Higgins, 2000). The major element composition of minerals was performed  
115 on  $>120$   $\mu\text{m}$  thick polished sections by using EMP Cameca SX–50 (Observatoire Midi  
116 Pyrénées, University Toulouse III) and Cameca SX–100 (University of Vienna,  
117 Department of Lithospheric Research). Operating conditions in both the used  
118 microprobes were identical. The accelerating voltage and beam current were 15 kV  
119 and 20 nA, respectively; PAP correction procedure was applied and natural and  
120 synthetic phases were used as standards. The counting times were extended to  
121 detection limits of 200 ppm for Ca, 320 ppm for Cr and 400 ppm for Ni.

122 Concentrations of REE and other trace elements in clinopyroxene were  
123 determined in situ on a Cetac LSX-266 laser ablation module coupled with an Agilent  
124 7500 ICP – MS instrument (Observatoire Midi Pyrénées, University Toulouse III). The  
125 NIST 610 and NIST 612 glass standards were used to calibrate relative element  
126 sensitivities. Each analysis was normalized using CaO values first determined by  
127 electron microprobe. A beam diameter of 50 – 100  $\mu\text{m}$  and a scanning rate of 20  $\mu\text{m}/\text{s}$   
128 were used. The theoretical detection limits range from 10 – 20 ppb for REE, Ba, Th,  
129 U, Zr to 2 ppm for Ti. The accuracy on a typical laser analysis is between 1 and 10%.  
130 The clinopyroxene trace element data set also includes new analyses of  
131 clinopyroxene separates from Lutynia investigated by Blusztajn and Shimizu (1994).  
132 They were mounted in epoxy resin and analyzed using a New Wave Research  
133 UP213 LASER coupled to an Agilent 7500a quadrupole ICP – MS system at the  
134 Research School of Earth Sciences Birkbeck/UCL. A laser diameter of 55  $\mu\text{m}$  and a  
135 pulse frequency of 20 Hz were used, with a laser dwell time of 20 s.

136 Whole – rock analyses of the peridotites were not performed as the size of the  
137 xenoliths was too small to separate a sufficient amount of bulk rock without host  
138 basanite – related veinlets.

139 The Morimoto (1989) classification scheme is used for pyroxenes, while for  
140 spinel we use Haggerty (1991). Mineral abbreviations are: Ol (olivine), Cpx  
141 (clinopyroxene), Opx (orthopyroxene), Sp (spinel), Af/Pl/Fsp (alkali  
142 feldspar/plagioclase/feldspar), Amp (amphibole). Fo stands for  $(Mg/(Mg+Fe))*100$ ,  
143 #mg for  $Mg/(Mg+Fe^{2+})$ , while #cr for  $Cr/(Cr+Al)$ ; cation ratios are given per formula  
144 unit. The An content is  $(Ca/(Ca+K+Na))*100\%$  and the Or content is  
145  $(K/(Ca+K+Na))*100\%$ , which are the cation ratios per formula unit of feldspar. The Sp  
146 chemical composition was recalculated for three cations;  $Fe^{2+}$  and  $Fe^{3+}$  contents  
147 were calculated by charge balance according to Deer et al. (1993).

148 Temperatures were calculated using the Opx – Cpx geothermometers of Wells  
149 (1977) and Brey and Köhler (1990a) assuming a pressure of 1.5 GPa. Temperatures  
150 were calculated for at least 3 (mostly 5 or more) pairs of Opx/Cpx of the same  
151 generation.

#### 152 4. PETROGRAPHY OF XENOLITHS

153 The mantle xenoliths are angular to oval and vary in size from 1 to 10 cm, but  
154 one sample (MM30) is a 5x20 cm wide, apple–green elongated (10 cm long) xenolith.  
155 Most have protogranular textures (Mercier and Nicolas, 1975) and only two of the  
156 fourteen investigated grade into the porphyroclastic type (MM15, MM30; Fig.2a, 2b).  
157 The grain size varies from 200  $\mu m$  to >1 cm (see below). Kink bands occur in some  
158 olivine grains. Xenolith MM04 displays a weak foliation defined by elongation of Ol  
159 and Opx grains.

160

161 FIGURE 2. ABOUT HERE

162

163 Most of the xenoliths are Sp harzburgites (7 samples) and Sp lherzolites (6  
164 samples). One plots on the lherzolite/harzburgite boundary in the classification  
165 diagram (Fig.3; Tab.1). Subscripts I, II and III are used to indicate generation of a  
166 mineral: I = rock–forming minerals, II = second generation, minerals occurring in  
167 patches, III = exsolution in generation I mineral.

168

169 TABLE 1. FIGURE 3 ABOUT HERE

170

171 OI I and Opx I occur as large crystals (200  $\mu\text{m}$  – 1.5 cm), while OI II (15 – 50  
172  $\mu\text{m}$ ) corresponds to small crystals within patches. Cpx I occurs as large (100 – 600  
173  $\mu\text{m}$ ), isolated grains but also forms symplectites (up to 1 cm long) with Sp I (100  $\mu\text{m}$  –  
174 1 cm) in most xenoliths (Fig. 2c). Patches (from 150 to 600  $\mu\text{m}$  long) formed by  
175 subhedral to vermicular crystals of Cpx II (1 – 50  $\mu\text{m}$ )  $\pm$  OI II (15 – 50  $\mu\text{m}$ )  $\pm$  rounded  
176 relicts of Opx I (1 – 50  $\mu\text{m}$ )  $\pm$  Sp II (single  $\mu\text{m}$ )  $\pm$  Pl/alkali Fsp occur between grains of  
177 Opx I  $\pm$  OI I  $\pm$  Cpx I  $\pm$  Sp I in all the xenoliths (Fig. 2d). In some xenoliths the patches  
178 occur not only at the grain boundaries but also inside Opx I crystals (Fig.2e). Fringes  
179 of small (ca. 5  $\mu\text{m}$ ) brown crystals of Sp II embedded in an alkali feldspar matrix often  
180 surround Sp I crystals in contact with these patches. Scarce vermicular grains of Cpx  
181 II, OI II and Af or Pl occur at the margins of Opx I in some xenoliths (Fig. 2f).

182 Elongated exsolution lamellae (10 – 100  $\mu\text{m}$ , in extreme cases up to 1 cm  
183 long) of Sp III occur in Opx I and Cpx I crystal cores. The Sp III lamellae are  
184 accompanied by Opx III lamellae in Cpx I and by Cpx III lamellae in Opx I grains. In  
185 scarce grains of Opx I, Cpx I and OI I rounded inclusions of Sp III (50 – 200  $\mu\text{m}$  in  
186 diameter) occur. In xenolith MM04 the Opx III/Cpx III and Sp III lamellae are  
187 accompanied by 20  $\mu\text{m}$  – long, oval exsolutions of amphibole. Rims of crystals which  
188 show exsolved cores are always clear (Fig.2g).

189 Reaction zones between the xenoliths and host basanite occur in 5 of the  
190 xenoliths. They are formed either by 20 – 100  $\mu\text{m}$  in diameter/length rounded or  
191 elongated crystals of olivine or only slightly underlined by lighter (in BSE image) rims  
192 of minerals (mainly Opx I and OI I) reacting with the basanitic melt (Fig.2h). Some  
193 xenoliths contain veins of infiltrated host lava which can be traced from the contact  
194 with the surrounding basanite. These veins are up to 100  $\mu\text{m}$  wide, and are filled with  
195 anhedral to subhedral crystals of feldspar as well as minute crystals of opaque oxides  
196 and apatite (Fig. 2h).

197

## 198 5. MINERAL CHEMICAL AND GEOCHEMICAL COMPOSITION

### 199 5.1. MINERAL MAJOR ELEMENT COMPOSITION

200 The Fo content in OI I varies from 89.8 to 92.4% (Fig. 4) and the NiO content  
201 varies from 0.34 to 0.45 wt.% (Tab. 2). The Ca content ranges from microprobe

202 detection limit (200 ppm) to 780 ppm. Marginal parts of Ol I grains in contact with  
203 patches are characterized by low NiO content (ca. 0.28 wt.%) and high Ca content  
204 (ca. 1000 ppm).

205

206 FIGURE 4. ABOUT HERE

207

208 Ol II occurring in patches is characterized by Fo and NiO contents slightly  
209 lower than those in Ol I (Fo<sub>88.0</sub> versus Fo<sub>91.7</sub> and 0.18 versus 0.42 wt.%, respectively;  
210 Tab. 2). The Ca content is generally higher than in Ol I and reaches 1800 ppm.

211 Opx I as well as Opx III have the same composition of Al-enstatite (and  
212 enstatite in xenoliths MM25 and MM30; Fig.5 a – c). Their #mgs are 0.90 - 0.92,  
213 while the Al content varies from 0.06 to 0.17 a.pfu (Tab. 3).

214

215 FIGURE 5. ABOUT HERE

216

217 Cpx I (Ca 0.842 – 0.902 a.pfu) from all the xenoliths, except MM30 has  
218 composition of Al, Cr–diopside, (#mg 0.91 – 0.93, Al=0.104 – 0.197a.pfu, Cr=0.016 –  
219 0.34 a.pfu; Tabs. 4 and 5, Fig.5a). The Na content varies from 0.035 to 0.074,  
220 whereas the Ti content is negligible (<0.005 a.pfu). The relationships between #mg  
221 and Al and between Ca and Na, which allow good discrimination between the  
222 clinopyroxenes, are shown in Fig. 5 d and e.

223 Cpx I in xenolith MM30 is exceptional for its extremely high #mg (0.943 –  
224 0.948) and Ca content (0.901 – 0.924 a.pfu) and low Al content (0.079 – 0.097 a.pfu;  
225 Tabs. 4 and 5, Fig. 5a).

226 Cpx II has a variable composition depending on the type of feldspar occurring  
227 in a given patch (Fig. 5b). Cpx II coexisting with plagioclase is Cr, Al ± Ti-augite or  
228 rarely Cr, Al, Ti-diopside, Cpx II associated with alkali Fsp is mostly Cr–augite, rarely  
229 Cr diopside (Fig. 5b). The basic chemical features of both types of Cpx II are shown  
230 in Tables 4 and 5.

231 Cpx III forming lamellae is a Al, Cr–diopside/augite; the chemical composition  
232 of Cpx III is similar to that of Cpx I from the same xenolith, except for lower #mg (Fig.  
233 5d) and Ca content (Fig. 5e) as well as slightly higher Ti content (Tabs.4 and 5).

234

235 TABLES 2,3,4,5 ABOUT HERE

236

237 The Sp I is Al- and Mg- rich (Fig. 6); the Cr content is commonly 0.330 – 0.523  
238 a.pfu (#cr 0.168 – 0.271). However, in xenoliths MM04 and MM30 Cr is 0.612 – 0.669  
239 a.pfu (#cr 0.314 – 0.347) and in MM15 it is 0.880 – 0.896 (#cr 0.459 – 0.472; Tab.6;  
240 Fig.4). The #mg in Sp I varies from 0.722 to 0.837, only in xenolith MM15 it is 0.678 –  
241 0.690. The Ti content is low, up to 0.015 a.pfu. Sp II has variable chemical  
242 composition, i.e. Cr content 0.427 – 0.936 a.pfu (#cr 0.23 – 0.488), #mg 0.647 –  
243 0.786. The Ti content in some Sp II grains is elevated to 0.020 a.pfu (Tab.6). Sp III  
244 forming lamellae in Cpx I, Opx I and inclusions in Ol I has a variable Cr content from  
245 0.300 to 0.521 a.pfu (#cr 0.157 – 0.269; Tab.6), only Sp III in MM04 and MM30  
246 contains 0.307 - 0.619 a.pfu of Cr (#cr 0.161 – 0.337; Tab.6). The #mg of Sp III in all  
247 the xenoliths is similar (0.716 – 0.868) and the Ti content is low (<0.006 a.pfu).

248

249 FIGURE 6. ABOUT HERE

250

251 The composition of feldspar occurring in patches is extremely variable and  
252 ranges from plagioclase to alkali feldspar (Tab.7). The An content in plagioclase  
253 reaches 48%, while the Or content in alkali Fsp reaches 52% (Tab.7, Fig.7).  
254 Plagioclase (An 37 – 46; Ab 51 – 58) and alkali Fsp (An 4 – 14, Ab 49 – 71, Or 14 -  
255 45) also occur in veins of host lava crosscutting the xenoliths. Their closely resemble  
256 those of their equivalents in the host basanite (alkali Fsp An 3 – 13, Ab 48 – 74, Or  
257 13 – 48; Pl An 41 – 50, An 41 – 50; Tab. 8, Fig.7).

258

259 FIGURE 7. ABOUT HERE

260

261 Amphibole in xenolith MM04 is pargasite (Tab.8). Its #mg is 0.88 – 0.89, Na  
262 content is variable ranging from 0.84 to 0.93 a.pfu, while the Cr and K contents are  
263 rather constant (0.20 – 0.21 a.pfu and 0.15 – 0.16 a.pfu, respectively).

264

265 TABLES 6,7,8 ABOUT HERE



266

## 267 5.2. CLINOPYROXENE TRACE ELEMENTS

268 Four main types of REE patterns, all characterized by light REE (LREE)  
269 enrichment and a flat pattern for heavy REE (HREE) but displaying slight differences,  
270 occur in Cpx I grains.

271 The first group (group A) is characterized by smooth “spoon-shaped” REE  
272 pattern ( $La_N/Lu_N = 4.91 - 20.90$ ;  $La_N/Sm_N = 2.76 - 4.21$ ) with flat HREE pattern ( $Dy_N$   
273  $/Lu_N = 1.04 - 1.38$ ; Fig. 8a). The second group (group B) is LREE-enriched  
274 ( $La_N/Lu_N = 8.50 - 55.29$ ,  $La_N/Sm_N = 4.63 - 17.53$ , Fig. 8c), with a strong increase in  
275 concentration from Eu (Dy in xenoliths MM15) to La. The third group (group C) is  
276 characterized by steep La – Pr (Nd – Sm – Dy) negative inflection ( $La_N/Lu_N = 3.06 -$   
277  $11.92$ ;  $La_N/Sm_N = 10.05 - 16.39$ ; Fig. 8e). The REE pattern of the group D shows a  
278 constant increase of LREE content ( $La_N/Lu_N = 7.30 - 8.34$ ; Tab.9; Fig.8a). The pattern  
279 becomes flat from Nd to La ( $Nd_N/La_N = 0.88 - 1.12$ ).

280

281 FIGURE 8. ABOUT HERE

282

283 Cpx I in xenoliths from all the groups contains relatively high amounts of Th  
284 and U and low amounts of Ba (Figs.8a – f). Ta content is always low and varies  
285 between groups ( $Ta_N_{groupA} = 1.50 - 3.11$ ,  $Ta_N_{groupB} = 0.61 - 1.55$ ,  $Ta_N_{groupC} = 0.35 - 1.62$ ,  
286  $Ta_N_{groupD, xen. MM04} = 5.86$ ). Xenoliths MM15 and MM29 which, according to their REE  
287 patterns, belong to group B have  $Ta_N = 0.10$  and  $Ta_N = 0.15$ , respectively. Almost all the  
288 xenoliths display a negative Zr and Ti anomaly (group A:  $La_N/Zr_N = 4.47 - 18.65$ ,  
289  $La_N/Ti_N = 15.65 - 67.52$ ; group B:  $La_N/Zr_N = 82.10 - 182.44$  (302 and 203 in xenoliths  
290 MM15 and MM29, respectively),  $La_N/Ti_N = 44.92 - 142.55$  (591.75 in xenolith MM15);  
291 group C:  $La_N/Zr_N = 77.26 - 168.50$   $La_N/Ti_N = 10.16 - 51.16$ ; group D:  $La_N/Zr_N = 1.20 -$   
292  $1.57$ ,  $La_N/Ti_N_{xen.MM04} = 12473.11$ ).

293 The REE content in Cpx I from xenolith MM30 differs from those of all the  
294 groups described above in that its REE abundances are all strongly depleted ( $La_N/Lu_N$   
295  $= 0.07$  and  $Lu_N = 0.37$ , Fig. 5e, 5f).

296

297 TABLE 9. ABOUT HERE

298

299                   6. *TEMPERATURE AND PRESSURE ESTIMATIONS*

300           Temperatures obtained on clear rims of Opx I and Cpx I by different methods  
301 are in good agreement with each other, which suggests that the minerals were in  
302 chemical equilibrium (Tab.10). The temperatures of equilibration of Cpx I and Opx I  
303 range from 960°C to 1000°C (Tab. 10). Those calculated using Cpx III lamellae in  
304 Opx I and Opx III lamellae in Cpx I fall in the same range.

305           Since all the xenoliths are spinel facies peridotites, calculation of their  
306 pressure of equilibration is difficult due to the lack of reliable geobarometers. The  
307 spinel is stable between 0.9 (Presnall et al., 2002 and references therein) and 1.55  
308 GPa (Klemme and O'Neill, 2000 and references therein) at 1000 °C. The spinel-  
309 pyroxene symplectites originated by garnet decomposition due to pressure decrease  
310 and cooling. We speculate that the uplift of garnet facies peridotites into the spinel  
311 facies is more likely on short distance and thus the post-garnet symplectites  
312 originated close to the garnet – spinel boundary in the mantle, which was close to ca  
313 1.55 GPa at 1000 °C.

314  
315           TABLE 10. ABOUT HERE  
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317                   7. *DISCUSSION*

318           The history of mantle peridotites from Lutynia is recorded in the three  
319 generations of minerals. Opx I and Cpx I grains contain abundant exsolution of Cpx  
320 III, Opx III and Sp III. Clear rims and exsolved cores of host pyroxene grains have the  
321 same chemical composition (ex. Fig. 5 d – e) which indicates re-equilibration under  
322 spinel-facies conditions and temperatures between 960 °C and 1000°C. Pyroxene  
323 exsolutions indicate the cooling of the peridotites as the miscibility of clino- and  
324 orthopyroxene decreases at decreasing temperature.

325           Clinopyroxene – spinel symplectites, like those from Lutynia, are often  
326 attributed to decomposition of garnet during re-equilibration of garnet peridotites in  
327 the spinel stability field (e.g. Downes et al., 2003; Falus et al., 2007). The low degree  
328 of MREE/HREE fractionation in clinopyroxenes that form symplectites ((Sm/Yb)<sub>N</sub>  
329 =0.29 – 3.17, but in xenolith MM15: 5.76) indicates that it was formed at the expense  
330 of garnet in the Sp – stability field; indeed if clinopyroxene has crystallized in

331 equilibrium with garnet, the HREE would be preferentially incorporated in garnet  
332 resulting in  $(\text{Sm}/\text{Yb})_N > 5$  (Bonadiman et al., 2008 and references therein).

333 The decomposition of garnet may be due to heating or decompression events.  
334 The studied peridotites are chemically well equilibrated and pyroxene exsolution  
335 suggests equilibration after cooling. Therefore, we conclude that the garnet  
336 decomposition is related to decompression and possibly cooling.

337

### 338 7.1. PARTIAL MELTING

339 Variation in mineral composition in the Lutynia peridotites suggests that they  
340 are residues after melt extraction. This process is expressed by the variable and high  
341 #mg and low Al in pyroxenes, high Fo content in Ol I, the negative correlations of  
342 #mg vs. Al and Ti vs. Yb contents in Cpx I, and the negative #mg vs. #cr correlation  
343 in Sp I. Negative correlations between #cr and Yb and Lu also suggest that  
344 distribution of these elements in Cpx I was controlled by partial melting rather than  
345 metasomatism (Ackerman et al., 2007).

346

347 FIGURE 9. ABOUT HERE

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349 As rare amphibole grains occur in only one of the xenoliths and no phlogopite  
350 is present, Cpx I is the main host for REE. The partial melting degree may be  
351 therefore estimated based on the assumption that Cpx I controls the distribution  
352 coefficient for Lu and Yb in the residuum (Norman, 1998). We have calculated the  
353 amount of extracted melt using both batch and fractional melting models. For the  
354 starting bulk composition of the mantle ( $C_0$ ) and fraction of diopside in the source  
355 ( $X_{\text{Cpx}}$ ) we have assumed the same values as Norman (1998; see Fig.9). The  
356 modeling suggests that batch melting would require an unrealistically high degree of  
357 partial melting (Norman, 1998), whereas  $\text{Yb}_N/\text{Lu}_N$  ratios in Cpx I fit the fractional  
358 melting very well, giving results ranging between 7 and 15% (Fig. 9). Calculated  
359 partial melting degree in xenolith MM30 is about 27%. This result is problematic as so  
360 high degree of melt extraction would extinguish entire clinopyroxene I from the rock.  
361 Thus we assume, that this result is an artefact.

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## 7.2. METASOMATISM

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FIGURE 10. ABOUT HERE

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Trace element composition (e.g. elevated REE content, Sr/Ce ratios lower and La/(La/Yb) ratios higher than in undepleted primitive mantle) of Cpx I reveals that the Lutynia peridotites were metasomatically enriched. Most of the xenoliths from Lutynia have been affected by cryptic metasomatism which is recorded only in trace element composition of Cpx I.

Xenolith MM04 is foliated and contains Cpx I with pargasite exsolution. Cpx I in this xenolith is depleted in Al (0.15 a.pfu) and contains more Ca (0.86 – 0.87 a.pfu) compared to Cpx I from groups A, B and C (Fig. 5 d).

The REE pattern of group D clinopyroxenes displays a continuous increase from HREE to LREE. The LREE enrichment, as well as the occurrence of amphibole, suggests a modal metasomatism related to the circulation of a hydrous agent within the upper mantle, whereas the other xenoliths only record cryptic metasomatism (Fig.10). These features could be interpreted as evidence of a chromatographic effect, with group D located closest to the metasomatic source. Alternatively, the group D xenoliths may come from a different mantle region than the other.

Blusztajn and Shimizu (1994) suggested (on the base of Ti/Zr ratio and U-shaped clinopyroxene REE patterns) that peridotites from Lutynia have been enriched by a carbonatitic melt. Carbonatite metasomatism is supported by the strong LREE-enrichment and high Th and U contents (eg. Touron et al., 2008 and references therein) and moderate to strong negative anomalies in Ti and Zr in groups B and C. In the (Ti/Eu)/(Yb/Lu)<sub>N</sub> diagram by Coltorti et al. (1999) the Cpx I from Lutynia group A and B xenoliths plot in carbonatite fields. On the other hand, the trace element composition of Cpx I does not display the other basic features assigned to carbonatite metasomatism, i.e. positive Sr anomaly and Ta – Ba content above primitive mantle level (e.g. Coltorti et al., 1999; Ionov et al., 2002). Thus, a typical carbonatite metasomatic agent seems to be excluded for the Lutynia mantle peridotites.

The incompatible trace element compositions of Cpx I from Lutynia are similar to those from the Ray Pic mantle xenoliths (French Massif Central; Zangana et al.,

396 1997; 1999). Xenoliths from both occurrences (i.e. groups A, B and C from Lutynia  
397 and LREE-enriched protogranular, protogranular/porphyroclastic and porphyroclastic  
398 peridotites from Ray Pic) display similar REE patterns characterized by strong Th-, U-  
399 and LREE-enrichment. Zangana et al. (1997 and 1999) proposed an alkaline  
400 fluid/melt as the metasomatic agent for peridotites from Ray Pic. By analogy, an  
401 alkaline fluid/melt is a possible metasomatic agent for Lutynia xenoliths.

402 To test this hypothesis we have calculated a melt in equilibrium with the  
403 clinopyroxene of xenolith MM04. We have used only this clinopyroxene, as its REE  
404 pattern displays a continuous enrichment in REE, which is a typical pattern for Cpx in  
405 equilibrium with an alkaline melt. It also does not record any significant melting  
406 processes. The REE patterns of other samples (groups A, B and C and xenolith  
407 MM30) show both melting (HREE) and enrichment (LREE) processes, thus they  
408 cannot be totally in equilibrium with a melt.

409

410 TABLE 10. ABOUT HERE

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412 For computing the composition of fluid in equilibrium with xenolith MM04, we  
413 have used Cpx/alkali basalt partition coefficients dataset given in Tab.11. The  
414 theoretical melt in equilibrium with xenolith MM04 is strongly LREE- and MREE-  
415 enriched, while HREE are flat (Fig. 11). Such a REE pattern is typical for an alkaline  
416 melt. The high Th and U contents in Cpx I from MM04, as well as in other Lutynia  
417 xenoliths, suggest that this parental alkaline melt probably contained small amounts  
418 of CO<sub>2</sub>.

419

420 FIGURE 11. ABOUT HERE

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423 The REE patterns of Cpx I in groups A, B and C are similar to those of Cpx of  
424 mantle xenoliths from Spitsbergen (Ionov et al., 2002), Oman (Grégoire et al., 2009)  
425 and Cameroon (Teitchou, personal communication). These authors propose a two-  
426 stage evolution model to explain the geochemical features of mantle samples they  
427 investigated. First, an upper mantle domain experienced partial melting, which  
428 caused depletion in incompatible elements – especially LREE. Later, a metasomatic  
429 melt of alkaline affinity, more or less CO<sub>2</sub>-enriched, circulated within the previously

430 depleted mantle resulting in its enrichment in incompatible elements. A similar two-  
431 stage model may be applied to the Lutynia mantle xenoliths investigated in our study.

432 Trace element composition of group D xenoliths, despite REE patterns  
433 differing significantly from the patterns of other groups, is in general similar to trace  
434 element composition of groups A, B and C. Thus, we assume that all the  
435 investigated mantle xenoliths were metasomatised by a similar alkaline and probably  
436 CO<sub>2</sub>-bearing agent. According to the chromatographic metasomatism model of Ionov  
437 et al. (2002) the depleted mantle which is located close to the magmatic source (vein,  
438 dyke) of the metasomatic agent is percolated by a relatively large volume of melt  
439 which enriches it in the whole set of incompatible trace elements including the whole  
440 suite of REE. This may explain also the crystallization of purely metasomatic mineral  
441 phases such as amphibole. Such a strongly enriched mantle is represented in the  
442 present study by group D xenoliths (Fig.8a). As the metasomatising agent percolates  
443 through the mantle further from the source, its REE composition is continuously  
444 fractionated from the less incompatible (HREE) to the most incompatible (LREE)  
445 ones. Finally this mechanism of metasomatism superimposed on LREE-depleted  
446 patterns inherited from partial melting, may explain the variable shapes of REE  
447 patterns observed in metasomatised mantle peridotites from Lutynia: those relatively  
448 close to the “metasomatic source” are enriched either in the less incompatible and  
449 the most incompatible REEs (group A xenoliths), while in those located furthest from  
450 the source, only the most incompatible REE (LREE and MREE) are enriched (group  
451 B and C xenoliths, Fig. 8c and 8e).

452

### 453 *7.3. ORIGIN OF VARIATION IN CLINOPYROXENE CHEMICAL* 454 *COMPOSITION*

455 Clinopyroxenes I from groups A, B (except for MM15 and MM29; see below)  
456 and C, display homogeneous chemical compositions within a given group. The  
457 relationship between major element composition and REE patterns of Cpx I suggests  
458 that major element composition of clinopyroxene I might have been affected by the  
459 cryptic metasomatism. Alternatively, the slightly higher Na/Ca ratio in group C  
460 clinopyroxenes (fig.5e) suggests that this group might have equilibrated at slightly  
461 higher pressures than group A and B xenoliths (Brey and Köhler, 1990b).

462 Clinopyroxenes I and III from xenolith MM15 are highly magnesian (#mg=0.93)  
463 and define a well separated group, enriched in Na (>0.07 a.pfu) and of slightly lower

464 Ca content. This xenolith displays porphyroclastic texture which, according to Mercier  
465 and Nicolas (1974), results from deformation of primarily protogranular rock. The  
466 major element chemical composition of clinopyroxene I in this xenolith may be a  
467 result of adaptation to conditions in which the deformation took place. Location of the  
468 deformation event in the mantle column is problematic, as clino- and orthopyroxene  
469 in xenolith MM15 are not in equilibrium and thus determination of their equilibration  
470 temperature is impossible and the temperatures calculated for the clino- and  
471 orthopyroxene exsolutions give contrary results (Tab.10). The  $Sm_N/Yb_N$  ratio in Cpx I  
472 is 5.76 which suggest that this sample may represent deeper part of mantle, where  
473 Cpx I would crystallize in equilibrium with garnet. Textures in almost all of the  
474 investigated xenoliths record its provenance from garnet – stability field  
475 (clinopyroxene – spinel symplectites), but only in MM15 the origin is frozen in trace  
476 element composition of Cpx I. On the other hand, the REE pattern as well extended  
477 trace element diagram for Cpx I from this xenolith mimics the main trends  
478 characteristic for group B xenoliths, thus we assume, that it was also enriched by  
479  $CO_2$ -bearing alkaline melt suggested above.

480 The major element composition of Cpx I from xenolith MM29 exhibits a  
481 depleted nature (# mg = 0.93, Al = 0.12 a. pfu, Ca = 0.90 a. pfu, Na = 0.04 a. pfu).  
482 However, the REE pattern classifies the xenolith as LREE-enriched B group (Fig.8c).  
483 This xenolith may represent rocks furthest from the source of metasomatism, which  
484 preserved the chemical composition of pre-metasomatic clinopyroxene, and where  
485 only the TE/REE characteristics has been changed.

486 The major and trace element composition of minerals in xenolith MM30 makes  
487 exceptional due to its extremely depleted nature (Fig. 5d,e; Fig.8e, f, Fig.9, Fig.10).  
488 The Al contents in Opx and Cpx differ significantly from bordering grains (e.g. 0.008  
489 vs. 0.01 a.pfu) but do not differ among the two groups (0.06 – 0.10 and 0.08 – 0.10  
490 a.pfu, respectively). Thus we suggest that Opx I and Cpx I in xenolith MM30 are not  
491 in equilibrium and that Cpx represents a crystallized melt. This xenolith may  
492 constitute a part of strongly depleted mantle which was further affected by a  
493 metasomatic melt. The intruding agent was depleted (Cpx I records an extremely  
494 high degree of partial melting) and carried only selected elements such as Sr, Ti and  
495 Th (Fig.8e, f).

496

#### 7.4. LATE ENRICHMENT PROCESSES

Patches occurring between grains of rock-forming minerals are known in many mantle xenolith worldwide; however their origin is still unclear (Shaw, 1999). The most striking feature of minerals occurring in patches, mostly Ol II and Cpx II, is the change in their Ca contents in respect to Ol I (780 ppm in Ol I, 1800 in Ol II) and Cpx I (0.84 – 0.92 a.pfu in Cpx I, 0.69 – 0.91 in Cpx II). An important feature of patches is the diversity of feldspar composition: it varies continuously from Pl to alkali Fsp. The chemical composition of the feldspars in patches is, however, similar to those of the host basanite feldspars (Fig. 7). Thus we suggest that the patches are a manifestation of an infiltration of a melt whose chemical composition was similar or even identical to that of the host basanite. The continuous chemical variation of feldspars in patches suggests it crystallized at supersolvus conditions, thus at depths where high temperatures persisted during crystallization. Infiltration must have taken place before the eruption since the melt had time to react with primary minerals, resulting in crystallization of the second generation of minerals (i.e. Ol II, Cpx II, Sp II).

The infiltration of melt to form 100 µm wide veins in some of the xenoliths must have been a very late event (probably the last one before eruption), as the composition of feldspars in the veins is identical to that of host basanite plagioclase and alkali feldspar (Fig.7). The vermicular forms of clinopyroxene and olivine occurring in the zones around Opx I and forming the patches are similar to those produced experimentally by Shaw and Dingwell (2008) at 1 atm by incongruent dissolution of orthopyroxene at the contact with silica-undersaturated melt. Thus it may be a result of reaction between infiltrating basanitic melt and Opx I.

#### 7.5. THE UPPER MANTLE BENEATH THE NORTH-EASTERN PART OF THE BOHEMIAN MASSIF.

Lutynia is one of the easternmost Cenozoic volcanic occurrences in the CEVP. Its xenoliths offer an opportunity to get information about the lithospheric mantle beneath the NE part of the Bohemian Massif at a relatively recent time (ca. 5 Ma). Xenolith-bearing Cenozoic lava occurrences of similar age also occur at Kozákov in the Sudetes (Ackerman et al. 2007), located ca 150 km WNW from Lutynia, and from the Eger Graben in western part of the Bohemian Massif.



530 Christensen et al. (2001) compared data from xenolith fabrics and  
531 geothermometry with SKS shear wave splitting and *Pn* anisotropy and proposed a  
532 three layered model for the mantle beneath Kozákov. According to this, the upper (32  
533 – 43 km) and lower (<67 km) layers are formed of equigranular peridotites, whereas  
534 the middle layer (43 – 67 km) is formed of protogranular peridotites. Formation of the  
535 layers was probably linked to Variscan convergence of the mantle.

536

537 FIGURE 12. ABOUT HERE

538

539 The majority of the Lutynia xenoliths display protogranular textures, and the  
540 Cpx I major element composition (Fig. 12), estimated fractional melting degree, and  
541 Cpx trace element contents are similar to those of some xenoliths from Kozákov. The  
542 less-depleted equigranular peridotites from Kozákov (subjected to 4.2 – 9% partial  
543 melting) and groups A and B from Lutynia display similar REE shapes in Cpx, despite  
544 some differences in absolute content of trace elements, especially HREEs (Fig. 13a).  
545 The same is true for patterns of the Kozákov protogranular (6.7 – 13.2% of partial  
546 melting) and group C xenoliths (Fig. 13b). Xenoliths containing clinopyroxene  
547 displaying REE characteristics similar to those of the upper equigranular xenoliths  
548 from Kozákov were not found in Lutynia.

549

550 FIGURE 13. ABOUT HERE

551

552 Clinopyroxenes in peridotites from Lutynia and Kozákov have similar major  
553 and trace element compositions. The ranges of temperatures (Brey and Köhler,  
554 1990a) recorded in peridotites from both occurrences differ significantly: the lower  
555 equigranular and protogranular xenoliths from Kozákov record temperatures from  
556 875 to 1116°C while in the Lutynia xenoliths the temperatures vary in the narrow  
557 range 960 – 1000°C. On one hand clinopyroxene composition in both the  
558 occurrences is similar, but the equilibration temperatures vary significantly – this  
559 results from different compositions of orthopyroxene, especially Ca contents, which  
560 strongly affects the equilibration temperatures (Fig.14). Thus the Kozákov peridotites  
561 are petrographically different from those from Lutynia. However, the lava occurrence  
562 in Kozákov is much larger than that in Lutynia, and the discrepancies may result from  
563 different scales of mantle sampling.

564

565 FIGURE 14. ABOUT HERE

566

## 567 8. CONCLUSIONS

568 The peridotite xenoliths at Lutynia represent the mantle beneath the NE part of  
569 the Bohemian Massif at ca. 5 My. They equilibrated in a narrow temperature range of  
570 960 – 1000 °C. The spinel-clinopyroxene symplectites and unmixing of ortho- and  
571 clinopyroxene suggest that their protoliths were garnet peridotites, that converted to  
572 spinel-peridotites as temperatures and pressures decreased.

573 The Lutynia mantle underwent partial melting with melt extraction degrees  
574 mostly from 8 to 15%. The depleted peridotitic mantle was afterwards  
575 metasomatically refertilized. The peridotite supposedly closest to the metasomatic  
576 source contains minor amounts of pargasitic amphibole and its clinopyroxene REE  
577 content displays continuous enrichment from HREE to LREE. However, the  
578 metasomatism was almost entirely cryptic and is recorded only in the clinopyroxene  
579 trace elements. The REE contents in the clinopyroxenes vary among the xenoliths.  
580 However, there are three main REE patterns, differing in LREE and MREE content.  
581 We suggest that the different REE patterns are related to chromatographic  
582 enrichment by the same metasomatic agent. A carbonatitic metasomatism in Lutynia  
583 was proposed by Blusztajn and Shimizu (1994). Our study indicates that some  
584 features are in agreement with a carbonatitic imprint in peridotites from Lutynia,  
585 nevertheless their trace element contents suggest that CO<sub>2</sub>-bearing alkaline silicate  
586 melt is the most likely metasomatic agent.

587

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598

599

600 FIGURE CAPTIONS:

601

602 Fig.1. (a) Cenozoic volcanic fields in SW Poland. Based on a map of Badura and Przybylski  
603 (2000); (b) Basaltic rocks in the vicinity of Łądek Zdrój. Based on 1:100 000 geological map  
604 of Sawicki (1995).

605

606 Fig.2. Phase relationships and structure of xenoliths from Lutynia. (a) Protogranular structure  
607 (xenolith MM09) sensu Mercier and Nicolas (1975) occurring in most xenoliths. Optical  
608 image, crossed polarizers; (b) Porphyroclastic structure in xenolith MM15. Optical image,  
609 crossed polarizers; (c) Vermicular crystals of Spl I and Cpx I forming a symplectite. Xenolith  
610 MM08, optical image, crossed polarizers; (d) Feldspar and opaques vein rooted in basanite  
611 intruding into the xenolith. Xenolith MM04, BSE image (e) BSE image of Opx I crystals: the  
612 core contains lamellae of Cpx I II and Spl III, while the rim is exsolution-free. Xenolith MM08,  
613 BSE image; (f) "Patch" filled with small crystals of Cpx II, Ol II and anhedral alkali Fsp. Pl  
614 may occur instead of alkali Fsp. Xenolith MM29, BSE image; (f) "Patch" filled with minerals  
615 as in (g) inside an exsolved core of Opx I. Xenolith MM31, BSE image ; (h) Crystals of Cpx II  
616 forming a vermicular rim around Opx I. Xenolith MM04, BSE image.

617

618 Fig.3. Modal composition of xenoliths. The groups are defined basing on the Cpx I REE  
619 composition, see paragraph "3.3 Clinopyroxene trace elements".

620

621 Fig.4. Relationship between Fo content in Ol and #cr in Sp. All the xenoliths from Lutynia  
622 plot on the olivine – spinel mantle array (OSMA) of Arai (1994).

623

624 Fig. 5. Major elements composition of clinopyroxene and orthopyroxene. (a) Points  
625 representing Cpx I and Opx I on the Fs – Wo – En classification diagram. (b) Points  
626 representing Cpx II and Opx II on the Fs – Wo – En classification diagram (c) Points

627 representing Cpx III and Opx III on the Fs – Wo – En classification diagram; (d) Relationships  
628 between #mg and Al contents in Cpx I, Cpx II and Cpx III (e) Relationships between Ca and  
629 Na contents in Cpx I, Cpx II and Cpx III; field symbols as in (d).

630 Fig.6. Points representing spinel in the diagram  $\text{FeAl}_2\text{O}_4 - \text{MgAl}_2\text{O}_4 - \text{MgCr}_2\text{O}_4 - \text{Fe Cr}_2\text{O}_4$ .

631 Fig.7. Points representing Fsp from patches and host basanite in the An – Or – Ab diagram.

632 Fig. 8 Trace element composition of Cpx I. (a) Primitive mantle-normalized (McDonough and  
633 Sun, 1995) REE pattern for groups A and D Cpx I. (b) Primitive mantle-normalized  
634 incompatible elements pattern for groupa A and D Cpx I. (c) Primitive mantle-normalized  
635 REE pattern for group B Cpx I. (d) Primitive mantle-normalized incompatible elements  
636 pattern for group B Cpx I. (e) Primitive mantle-normalized REE pattern for group C and  
637 xenolith MM30 Cpx I.(f) Primitive mantle-normalized incompatible elements pattern for group  
638 C and xenolith MM30 Cpx I.

639 Fig.9. Batch and fractional melting models based on Yb and Lu contents in Cpx (Norman,  
640 1998) compared with data from the Cpx I from xenolith from Lutynia. (a) fractional melting  
641 model; (b) batch melting model. Formulae for the two models are given. The abbreviation  
642 and values used in the formulas:  $C_{\text{Cpx}}$  – concentration of trace element in diopside;  $C_0$  –  
643 starting bulk composition in the source (see the text);  $X_{\text{Cpx}}$  – the fraction of diopside in the  
644 source (see the text);  $D_{\text{Cpx}}$  – crystal/liquid distribution coefficient: 0.40 for Yb and 0.35 for Lu;  
645  $f$  – the degree of partial melting. Symbol n stands for “normalized to primitive mantle values”  
646 (McDonough and Sun, 1995)

647

648 Fig.11. Primitive mantle-normalized (McDonough and Sun, 1995) REE pattern for liquid in  
649 equilibrium with Cpx I from xenolith MM04. The REE content for liquid in equilibrium with  
650 MM04 was computed with partition coefficients given in Tab.11.

651

652 Fig.12.  $\text{Al}_2\text{O}_3/\text{CaO}$  ratio in Cpx I from Lutynia compared to composition of clinopyroxene from  
653 xenoliths from Kozákov (Czech Republic; Ackerman et al., 2007).

654

655 Fig. 13. Primitive mantle-normalized (McDonough and Sun, 1995) REE patterns in Cpx from  
656 Lutynia and Kozákov (Ackerman et al., 2007) (a) REE patterns of Lutynia groups A and B

657 clinopyroxenes (grey field) and Kozákov lower equigranular xenoliths; (b) REE patterns of  
658 Lutynia group C Cpx (grey field) and Kozákov protogranular xenoliths.

659

660 Fig. 14. Al<sub>2</sub>O<sub>3</sub> vs. CaO content in orthopyroxene from Lutynia and Kozákov (Ackerman et al.,  
661 2007). Colored circles – orthopyroxene from Kozákov.

662

#### 663 REFERENCES:

- 664 Ackerman, L., Mahlen, N., Jellnek, E., Medaris, G. Jr., Ulrych, J., Strnad, L., Mihaljevič, M.,  
665 2007. Geochemistry and evolution of subcontinental lithospheric mantle in Central  
666 Europe: Evidence from peridotite xenoliths of the Kozákov volcano, Czech Republic.  
667 *Journal of Petrology* 48 (12), 2235-2260.
- 668 Arai, S., 1994. Characterization of spinel peridotites by olivine - spinel compositional  
669 relationship: Review and interpretation. *Chemical Geology* 113, 191-204.
- 670 Badura, J., Przybylski, B., 2000. Neotectonic map of Lower Silesia. Central Geological  
671 Archive, Polish Geological Institute.
- 672 Bakun-Czubarow, N., Białowolska, A., 2003. Gabbroic enclaves from basaltoids of the  
673 Lubań and Złotoryja regions, Lower Silesia. Xth meeting of the Petrology Group of the  
674 Mineralogical Society of Poland. Mineralogical Society of Poland, Głuchołazy, 32-34.
- 675 Białowolska, A., 1980. Geochemiczna charakterystyka niektórych bazaltoidów Dolnego  
676 Śląska i ich ultramafitowych enklaw. *Archiwum Mineralogiczne* XXXVI (2).
- 677 Birkenmajer, K., Lorenc, M. W., Pécskay, Z., Zagożdżon, P.P., 2004. Wiek, cykle i kierunek  
678 migracji trzeciorzędowego bazaltowego wulkanizmu Dolnego Śląska w świetle  
679 datowań K–Ar. In: K.J.-Ś. M. Michalik, Skiba, M., Michalik, J., (Ed.), VIII Ogólnopolska  
680 Konferencja Naukowa „Datowanie minerałów i skał”. Wydział Geologii, Geofizyki i  
681 Ochrony Środowiska AGH, Instytut Nauk Geologicznych UJ, Komitet Badań  
682 Czwartorzędu PAN, Kraków.
- 683 Birkenmajer, K., Pécskay, Z., Grabowski, J., Lorenc, M. W., Zagożdżon, P.P., 2002.  
684 Radiometric dating of the Tertiary volcanics in Lower Silesia, Poland. II. K – Ar and  
685 paleomagnetic data from Neogene basanites near Łądek Zdrój, Sudetes MTS.  
686 *Annales Societatis Geologorum Poloniae* 72, 119-121.
- 687 Blusztajn, J., Hart, R.S., 1989. Sr, Nd and Pb isotopic character of Tertiary basalts from  
688 southwest Poland. *Geochimica et Cosmochimica Acta* 53, 2689-2696.
- 689 Blusztajn, J., Shimizu, N., 1994. The trace-element variations in clinopyroxenes from spinel  
690 peridotite xenoliths from southwest Poland. *Chemical Geology* 111 (1-4), 227-243.
- 691 Bonadiman, C., Coltorti, M., Duggen, S., Paludetti, L., Siena, F., Thirwall, M.F., Upton, B.J.,  
692 2008. Palaeozoic subduction-related and kimberlite or carbonatite metasomatism in  
693 the Scottish lithospheric mantle. Geological Society, London, Special Publication 293  
694 (1), 303-333.
- 695 Brey, G.P., Köhler, T., 1990a. Geothermobarometry in four-phase lherzolites II. New  
696 thermobarometers and practical assessment of existing thermobarometers. *Journal of*  
697 *Petrology* 31 (6), 1353-1378.
- 698 Brey, G.P., Köhler, T.P., 1990b. Calcium exchange between olivine and clinopyroxene  
699 calibrated as a geothermobarometer for natural peridotites from 2 to 60 kb with  
700 applications. *Geochimica et Cosmochimica Acta* 54, 2375 - 2388.
- 701 Bröcker, M., Klemm, R., 1996. Ultrahigh-pressure metamorphism in the Śnieżnik Mountains  
702 (Sudetes, Poland): P-T constraints and geological implications. *Journal of Geology*  
703 104 (4): 417-433.
- 704 Christensen, N.I., Medaris, L.G., Wang, H.F., Jelinek, E., 2001. Depth variation of seismic  
705 anisotropy and petrology in central European lithosphere: A tectonothermal synthesis

706 from spinel lherzolite. *Journal of Geophysical Research-Solid Earth* 106 (B1), 645-  
707 664.

708 Coltorti, M., Bonadiman, C., Hinton, R.W., Siena, F., Upton, B.G.J., 1999. Carbonatite  
709 metasomatism of the oceanic upper mantle: Evidence from clinopyroxenes and  
710 glasses in ultramafic xenoliths of Grande Comore, Indian Ocean. *Journal of Petrology*  
711 40 (1), 133-165.

712 Deer, W.A., Howie, R.A., Zussman, J., 1993. An introduction to the rock-forming minerals.  
713 Longman Scientific & Technical, New York.

714 Downes, H., Reichow, M.K., Mason, P.R.D., Beard, A.D., Thirlwall, M.F., 2003. Mantle  
715 domains in the lithosphere beneath the French Massif Central: trace element and  
716 isotopic evidence from mantle clinopyroxenes. *Chemical Geology* 200 (1-2), 71-87.

717 Falus, G., Szabó, C., Kovács, I., Zajacz, Z. and Halter, W., 2007. Symplectite in spinel  
718 lherzolite xenoliths from the Little Hungarian Plain, Western Hungary: A key for  
719 understanding the complex history of the upper mantle of the Pannonian Basin.  
720 *Lithos* 94 (1-4), 230-247.

721 Fan, Q.C., Liu, R.X., Xie, H.S., Zhang, Y.M., Xu, P., Lin, Z.R., 1997. Experimental study of  
722 spinel-garnet phase transition in upper mantle and its significance. *Science in China*  
723 *Series D-Earth Sciences* 40 (4), 383-389.

724 Fediuk, F., Fediuková, E., 1985. Postmezozoické alkalické vulkanity severní Moravy. *Acta*  
725 *Universitatis Carolinae – Geologica*, Neužil 4, 355 – 382.

726 Foltýnová, R., 2003. Geochemicko – petrografická charakteristika neovulkanitů severní  
727 Moravy a Slezska. Master thesis, Masaryk University, Brno.

728 Grégoire, M., Langlade, J.A., Delpech, G., Dantas, C., Ceuleneer, G., 2009. Nature and  
729 evolution of the lithospheric mantle beneath the passive margin of East Oman:  
730 Evidence from mantle xenoliths sampled by Cenozoic alkaline lavas. *Lithos*, 112,  
731 203–216. Griffin, W.L., O'Reilly, S.Y., 1987. The lower crust in eastern Australia:  
732 xenolith evidence. In: J.B. Dawson, D.A. Carswell, J. Hall and K.H. Wedepohl (Eds.),  
733 *The nature of the Lower Continental Crust*. Geological Society Special Publications  
734 25, 363-374.

735 Haggerty, S.E., 1991. Oxide mineralogy of the upper mantle. In: D.H. Lindsley (Ed.), *Oxide*  
736 *Minerals: Petrologic and Magnetic Significance*. Mineralogical Society of America,  
737 355–416.

738 Higgins, M.D., 2000. Measurement of crystal size distributions. *American Mineralogist* 85 (9),  
739 1105-1116.

740 Ionov, D.A., Bodinier, J.L., Mukasa, S.B., Zanetti, A., 2002. Mechanisms and sources of  
741 mantle metasomatism: Major and trace element compositions of peridotite xenoliths  
742 from Spitsbergen in the context of numerical modeling. *Journal of Petrology* 43 (12),  
743 2219-2259.

744 Klemme, S., O'Neill, H. StC., 2000. The near-solidus transition from garnet lherzolite to  
745 spinel lherzolite. *Contributions to Mineralogy and Petrology* 138, 237-248.

746 Kozłowska-Koch, M., 1976. Petrography of ultramafic nodules in basaltoids from the environs  
747 of Łądek (Sudetes). *Bulletin de l'academie Polonaise des Sciences* XXIV (2), 67-76.

748 Kröner, A., Jaekel, P., Hegner, E., Opletal, M., 2001. Single zircon ages and whole - rock  
749 Nd isotopic systematic of early Paleozoic granitoid gneisses from the Czech and  
750 Polish Sudetes (Jizerske hory, Karkonosze Mountains and Orlica-Śnieżnik Complex).  
751 *International Journal of Earth Sciences* 90, 304-324.

752 Ladenberger, A., Michalik, M., Tomek, C., Peate, D.W., 2006. Alkaline magmatism in SW  
753 Poland – An example of asthenosphere-lithosphere interactions? . *Mineralogia Polonica*  
754 *Special Papers* 29, 40-47.

755 Lustrino, M., Wilson, M., 2007. The circum-Mediterranean anorogenic Cenozoic igneous  
756 province. *Earth-Science Reviews* 81 (1-2), 1-65.

757 Mazur, S., Aleksandrowski, P., Kryza, R., Oberc-Dziedzic, T., 2006. The Variscan Orogen in  
758 Poland. *Geological Quarterly* 50 (1), 89-118.

759 McDonough, W.F., Sun, S.S., 1995. The composition of the Earth. *Chemical Geology* 120 (3-  
760 4), 223-253.

761 Mercier, J.C.C., Nicolas, A., 1975. Textures and fabrics of upper-mantle peridotites as  
762 illustrated by xenoliths from basalts. *Journal of Petrology* 16 (2), 454 - 487.

763 Morimoto, N., 1989. Nomenclature of pyroxenes. Subcommission of new minerals and mineral  
764 names. *International mineralogical association. Canadian Mineralogist* 27, 143 –  
765 156.

766 Napieralska, M., Muszyński, A., 2006. Peridotite enclaves in picrobasalts from Wolek Hill  
767 near Nowy Kościół ( SW Poland) - preliminary data. *Mineralogia Polonica - Special*  
768 *Papers* 29, 63-65.

769 Norman, M.D., 1998. Melting and metasomatism in the continental lithosphere: laser ablation  
770 ICPMS analysis of minerals in spinel lherzolites from eastern Australia. *Contributions*  
771 *to Mineralogy and Petrology* 130 (3-4), 240-255.

772 Oliver, G.J.H., Corfu, F., Krogh, T.E., 1993. U-Pb ages from SW Poland: evidence for a  
773 Cadomian suture zone between Baltica and Gondwana. *Journal of Geological*  
774 *Society* 150 (2), 355-369.

775 Presnall, D. C., Gudfinnsson, G. H., Walter, M. J., 2002. Generation of mid-ocean ridge  
776 basalts at pressures from 1 to 7 GPa. *Geochimica et Cosmochimica Acta* 66, 2073-  
777 2090.

778 Puziewicz, J., 2005. Litospheric mantle beneath SW Poland. In: J. Puziewicz (Ed.), VI  
779 meeting of the Mineralogical Society of Poland. *Mineralogical Society of Poland,*  
780 *Krościenko*, 184-187.

781 Sawicki, L., 1995. Geological map of Lower Silesia with adjacent Czech and German  
782 territories (without Quarternary deposits). Polish Geological Institute, Warszawa.

783 Shaw, C.S.J., 1999. Dissolution of orthopyroxene in basanitic magma between 0.4 and 2  
784 GPa: further implications for the origin of Si-rich alkaline glass inclusions in mantle  
785 xenoliths. *Contributions to Mineralogy and Petrology* 135 (2-3), 114-132.

786 Shaw, C.S.J., Dingwell, D.B., 2008. Experimental peridotite-melt reaction at one atmosphere:  
787 a textural and chemical study. *Contributions to Mineralogy and Petrology* 155 (2),  
788 199-214.

789 Šibrava, V., Havlíček, P., 1980. Radiometric age of Plio - Pleistocene volcanic rocks of the  
790 Bohemian Massif. *Věstník Ustředního Ústavu geologického* 55, 129-139.

791 Tournon, S., Renac, C., O'Reilly, S.Y., Cottin, J.Y., Griffin, W.L., 2008. Characterization of the  
792 metasomatic agent in mantle xenoliths from Deves, Massif Central (France) using  
793 coupled in situ trace-element and O, Sr and Nd isotopic compositions. *Geological*  
794 *Society, London, Special Publications* 293, 177-196.

795 Turniak, K., Mazur, S., Wysoczański, R., 2000. SHRIMP zircon geochronology and  
796 geochemistry of the Orlica – Śnieżnik gneisses (Variscan belt of Central Europe) and  
797 their tectonic implications. *Geodinamica Acta* 13, 293 – 312.

798 Wells, P.,R.,A., 1977. Pyroxene thermometry in simple and complex systems. *Contributions*  
799 *to Mineralogy and Petrology* 62, 129-139.

800 Wierzchołowski, B., 1993. Stanowisko systematyczne i geneza sudeckich skał  
801 wulkanicznych. *Archiwum Mineralogiczne* 49, 199- 235.

802 Wilson, M., Downes, H., 2006. Tertiary-Quaternary intra-plate magmatism in Europe and its  
803 relationship to mantle dynamics. *Geological Society, London, "European Lithosphere*  
804 *Dynamics" Memoir*, 147 - 166.

805 Zangana, N.A., Downes, H., Thirlwall, M.F., Hegner, E., 1997. Relationship between  
806 deformation, equilibration temperatures, REE and radiogenic isotopes in mantle  
807 xenoliths (Ray Pic, Massif Central, France): An example of plume-lithosphere  
808 interaction? *Contributions to Mineralogy and Petrology* 127 (1-2), 187-203.

809 Zangana, N.A., Downes, H., Thirlwall, M.F., Marriner, G.F., Bea, F., 1999. Geochemical  
810 variation in peridotite xenoliths and their constituent clinopyroxenes from Ray Pic  
811 (French Massif Central): implications for the composition of the shallow lithospheric  
812 mantle. *Chemical Geology* 153 (1-4), 11-35.

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Table 1. Modal composition of xenoliths from Lutynia.

xenolith	OI [%]	Opx [%]	Cpx [%]	Sp [%]	Cpx trace element group
MM11	75.56	16.01	6.62	1.81	A
MM21	87.67	8.93	2.37	1.03	
MM22	62.34	33.44	2.73	1.49	
MM39	78.84	16.31	2.01	2.85	
MM03	51.60	38.91	5.00	4.48	B
MM08	71.97	13.26	12.87	1.90	
MM15	84.40	9.37	2.97	3.26	
MM29	57.64	30.44	8.39	3.53	
MM31	69.71	21.77	6.00	2.52	
MM09	68.05	20.37	10.27	1.32	C
MM25	75.29	18.37	4.03	2.30	
MM28	80.54	16.07	1.74	1.66	
MM04	80.27	16.12	2.02	1.59	D
MM30	72.96	19.44	5.35	2.25	MM30

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848 Table 2. Representative analyses and structural formulae ( $O^{2-}=4$ ) of olivine from Lutynia  
849 xenoliths.

No.	1	2	5	3	4	6	6	7	8
Generation	OI I	OI I	OI I	OI I	OI I	OI I	OI II	OI II	OI II
Group	A	B	B <sub>MM29</sub>	C	D	MM30			
SiO <sub>2</sub>	41.43	40.81	41.21	40.90	40.75	41.79	40.79	41.15	40.84
TiO <sub>2</sub>	b.d.l.	0.01	b.d.l.	b.d.l.	0.01	0.03	0.02	0.01	0.02
Al <sub>2</sub> O <sub>3</sub>	0.02	0.01	b.d.l.	0.01	0.03	0.01	0.02	0.01	0.03
Cr <sub>2</sub> O <sub>3</sub>	0.01	b.d.l.	0.04	b.d.l.	0.05	0.13	0.03	0.03	0.07
FeO	8.93	8.62	8.57	10.02	8.98	7.50	11.47	8.13	10.25
MnO	0.12	0.12	0.11	0.18	0.16	0.11	0.22	0.16	0.18
NiO	0.34	0.39	0.41	0.41	0.36	0.37	0.21	0.28	0.40
MgO	50.34	49.62	50.39	49.36	49.25	51.42	47.53	50.43	48.54
CaO	0.05	0.08	0.08	0.10	0.09	0.03	0.18	0.10	0.26
Total	101.24	99.66	100.81	100.98	99.68	101.39	100.47	100.30	100.59
Si <sup>+4</sup>	0.999	0.999	0.997	0.994	1.000	1.001	1.004	0.998	0.999
Ti <sup>+4</sup>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Al <sup>+3</sup>	0.001	0.000	0.000	0.000	0.001	0.000	0.001	0.000	0.001
Cr <sup>+3</sup>	0.000	0.000	0.001	0.000	0.001	0.002	0.001	0.001	0.001
Fe <sup>+2</sup>	0.180	0.177	0.172	0.204	0.184	0.150	0.236	0.165	0.210
Mn <sup>+2</sup>	0.003	0.003	0.002	0.004	0.003	0.002	0.005	0.003	0.004
Ni <sup>+2</sup>	0.007	0.008	0.008	0.008	0.007	0.007	0.004	0.005	0.008
Mg <sup>+2</sup>	1.810	1.811	1.817	1.788	1.801	1.835	1.744	1.823	1.770
Ca <sup>+2</sup>	0.001	0.002	0.002	0.003	0.002	0.001	0.005	0.003	0.007
Total	3.000	3.000	3.000	3.000	2.999	2.999	2.999	2.998	3.000
	90.948	91.116	91.331	89.776	90.724	92.432	88.074	91.705	89.405

	Fo									
	Ca [ppm]	329	543	586	729	665	243	1279	722	1844
850	*total iron as FeO									
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863 Table 3. Representative analyses and structural formulae ( $O^{2-}=6$ ) of orthopyroxene from  
864 Lutynia xenoliths.

No.	1	2	3	4	5	6	7	8
Generation	Opxl	Opxl	Opxl	Opxl	Opxl	Opxl	Opxl	Opxl
Group	A	B	B <sub>MM29</sub>	C				
SiO <sub>2</sub>	55.72	55.59	57.15	56.10	56.59	56.69	55.57	
TiO <sub>2</sub>	0.03	0.03	b.d.l.	0.03	0.04	0.07	0.01	0.05
Al <sub>2</sub> O <sub>3</sub>	3.66	3.95	1.71	3.72	2.70	2.67	3.69	4.24
Cr <sub>2</sub> O <sub>3</sub>	0.46	0.44	0.36	0.48	0.34	0.3	0.49	0.52
FeO*	5.73	6.30	5.63	5.81	5.77	5.69	5.74	6.13
MnO	0.12	0.17	0.18	0.13	0.14	0.16	0.12	0.14
NiO	0.12	0.08	0.07	0.11	0.07	0.10	0.10	0.09
MgO	33.93	33.81	34.90	34.01	34.83	34.81	33.81	33.74
CaO	0.67	0.65	0.42	0.64	0.45	0.40	0.64	0.69
Na <sub>2</sub> O	0.06	0.02	0.01	0.03	0.03	0.03	0.03	0.02
Total	100.50	101.04	100.43	101.06	100.96	100.92	100.20	101.29
Si <sup>+4</sup>	1.907	1.897	1.956	1.909	1.926	1.928	1.909	1.895
Ti <sup>+4</sup>	0.001	0.001	0.000	0.001	0.001	0.002	0.000	0.001
Al <sup>+3</sup>	0.148	0.159	0.069	0.149	0.109	0.107	0.149	0.170
Cr <sup>+3</sup>	0.012	0.012	0.010	0.013	0.009	0.010	0.013	0.014
Fe <sup>+2</sup>	0.164	0.180	0.161	0.165	0.164	0.162	0.165	0.174
Mn <sup>+2</sup>	0.004	0.005	0.005	0.004	0.004	0.005	0.003	0.004
Ni <sup>+2</sup>	0.003	0.002	0.002	0.003	0.002	0.003	0.003	0.002
Mg <sup>+2</sup>	1.732	1.720	1.780	1.730	1.767	1.765	1.731	1.712
Ca <sup>+2</sup>	0.025	0.024	0.016	0.024	0.016	0.017	0.024	0.025
Na <sup>+1</sup>	0.004	0.001	0.001	0.002	0.002	0.002	0.002	0.002
Total	4.000	4.000	3.999	4.000	4.000	4.000	4.000	4.000

	#mg	0.914	0.905	0.917	0.913	0.915	0.916	0.913	0.908
865	*total iron as FeO								
866	b.d.l. – content below detection limit								
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879 Table 3. continued

No.	9	10	11	12	13	14
Generation	OpxI	OpxI	OpxI	OpxI	OpxIII	OpxIII
Group	D		MM30			
SiO <sub>2</sub>	55.87	56.15	57.24	57.88	55.61	56.69
TiO <sub>2</sub>	0.09	0.08	0.02	0.01	0.04	0.04
Al <sub>2</sub> O <sub>3</sub>	3.03	2.98	2.50	1.63	4.12	2.64
Cr <sub>2</sub> O <sub>3</sub>	0.50	0.48	0.50	0.29	0.44	0.36
FeO*	5.96	5.91	5.56	5.41	5.56	5.74
MnO	0.15	0.16	0.13	0.14	0.13	0.15
NiO	0.11	0.11	0.13	0.11	0.10	0.11
MgO	33.82	33.89	35.30	35.62	33.81	34.76
CaO	0.68	0.67	0.40	0.32	0.76	0.51
Na <sub>2</sub> O	0.02	0.03	b.d.l.	0.02	0.060	0.05
Total	100.23	100.46	101.78	101.43	100.63	101.05
Si <sup>+4</sup>	1.922	1.927	1.931	1.958	1.901	1.928
Ti <sup>+4</sup>	0.002	0.002	0.000	0.000	0.001	0.001
Al <sup>+3</sup>	0.123	0.121	0.099	0.065	0.166	0.106
Cr <sup>+3</sup>	0.014	0.013	0.013	0.008	0.012	0.010
Fe <sup>+2</sup>	0.172	0.170	0.157	0.153	0.159	0.163
Mn <sup>+2</sup>	0.005	0.005	0.004	0.004	0.004	0.004
Ni <sup>+2</sup>	0.003	0.003	0.004	0.003	0.003	0.003
Mg <sup>+2</sup>	1.734	1.733	1.776	1.796	1.723	1.763
Ca <sup>+2</sup>	0.025	0.025	0.014	0.011	0.028	0.019
Na <sup>+1</sup>	0.001	0.002	0.000	0.001	0.004	0.003
Total	4.000	3.999	3.999	4.000	4.000	4.000

880 #mg 0.910 0.911 0.919 0.922 0.916 0.915

881 \*total iron as FeO

882 b.d.l. – content below detection limit

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Table 4. Basic chemical features of Cpx I from Lutynia xenoliths.

	#mg	Al [a.pfu]	Ca [a.pfu]	Na [a.pfu]	Cr [a.pfu]	Ti [a.pfu]
<b>CpxI</b>	0.912-0.932	0.104-0.197	0.842-0.902	0.035-0.074	0.016-0.199	0.000-0.008
<b>Cpx I B<sub>MM29</sub></b>	0.927-0.930	0.119-0.123	0.887-0.902	0.035-0.039	0.016-0.018	0.002-0.003
<b>Cpx I MM30</b>	0.943-0.948	0.079-0.097	0.901-0.924	0.036-0.047	0.012-0.022	0.000-0.001
<b>Cpx II coexisting with alkali Fsp</b>	0.921-0.932	0.018-0.070	0.779-0.845	0.038-0.070	0.023-0.059	0.000-0.018
<b>Cpx II coexisting with Pl</b>	0.907-0.925	0.046-0.261	0.691-0.912	0.032-0.079	0.028-0.056	0.003-0.074
<b>CpxIII</b>	0.903-0.923	0.106-0.202	0.760-0.872	0.036-0.065	0.010-0.027	0.001-0.022
<b>Cpx III MM30</b>	0.913-0.940	0.091-0.140	0.756-0.909	0.024-0.039	0.016-0.021	0.000-0.002

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916 Table 5. Representative analyses and structural formulae ( $O^{2-}=6$ ) of clinopyroxene from  
917 Lutynia xenoliths

No.	1	2	3	4	5	6	7	8
Generation	Cpxl	Cpxl	Cpxl	Cpxl	Cpxl	Cpxl	Cpxl	Cpxl
Group	A	A	A	B	B	B	B <sub>MM29</sub>	B <sub>MM29</sub>
	core	→	rim					
SiO <sub>2</sub>	52.57	52.70	52.70	54.22	52.81	53.95	53.52	53.76
TiO <sub>2</sub>	0.16	0.16	0.17	0.02	0.09	0.11	0.11	0.09
Al <sub>2</sub> O <sub>3</sub>	3.97	3.99	3.99	2.45	3.81	2.83	2.88	2.83
Cr <sub>2</sub> O <sub>3</sub>	0.88	0.85	0.89	1.01	0.76	0.56	0.55	0.58
FeO*	2.54	2.50	2.57	2.29	2.47	2.42	2.29	2.43
MnO	0.08	0.09	0.07	0.08	0.08	0.06	0.08	0.11
NiO	0.03	0.08	0.06	0.03	0.04	0.05	0.06	0.05
MgO	16.88	16.76	16.81	16.88	16.75	17.40	17.11	17.16
CaO	21.91	21.86	22.02	22.42	22.47	23.13	23.33	23.25
Na <sub>2</sub> O	0.79	0.77	0.78	0.95	0.68	0.57	0.51	0.56
Total	99.81	99.76	100.06	100.35	99.96	101.08	100.44	100.82
Si <sup>+4</sup>	1.904	1.911	1.905	1.955	1.912	1.931	1.929	1.931
Ti <sup>+4</sup>	0.004	0.004	0.005	0.000	0.003	0.003	0.003	0.002
Al <sup>+3</sup>	0.169	0.170	0.170	0.104	0.163	0.119	0.122	0.120
Cr <sup>+3</sup>	0.025	0.024	0.025	0.029	0.022	0.016	0.016	0.016
Fe <sup>+2</sup>	0.077	0.076	0.078	0.069	0.075	0.072	0.069	0.073
Mn <sup>+2</sup>	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003
Ni <sup>+2</sup>	0.001	0.002	0.002	0.001	0.001	0.002	0.002	0.001
Mg <sup>+2</sup>	0.911	0.906	0.906	0.907	0.904	0.929	0.920	0.919

Ca <sup>+2</sup>	0.850	0.849	0.853	0.866	0.872	0.887	0.901	0.895
Na <sup>+1</sup>	0.055	0.054	0.055	0.066	0.048	0.039	0.036	0.039
Total	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
#mg	0.922	0.923	0.921	0.929	0.924	0.928	0.930	0.927

918 \*total iron as FeO

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930 Table 5. continued

No.	9	10	11	112	13	14	15
Generation	Cpxl	Cpxl	Cpxl	Cpxl	Cpxl	Cpxl	Cpxl
Group	C	C	C	D <sub>MM04</sub>	D <sub>MM04</sub>	MM30	
SiO <sub>2</sub>	52.99	52.48	53.07	53.19	52.92	54.78	54.28
TiO <sub>2</sub>	0.06	0.12	0.25	0.28	0.27	0.01	0.02
Al <sub>2</sub> O <sub>3</sub>	4.12	4.60	3.53	3.51	3.54	2.00	2.29
Cr <sub>2</sub> O <sub>3</sub>	0.74	0.73	0.88	0.89	0.85	0.60	0.75
FeO*	2.55	2.60	2.68	2.67	2.70	1.73	1.69
MnO	0.05	0.07	0.09	0.12	0.09	0.06	0.07
NiO	0.04	0.06	0.07	0.07	0.05	0.06	0.04
MgO	16.73	16.64	17.01	17.03	16.90	17.64	17.25
CaO	22.20	21.87	22.62	22.51	22.60	23.95	24.01
Na <sub>2</sub> O	0.75	0.85	0.71	0.73	0.71	0.59	0.62
Total	100.23	100.02	100.91	101.00	100.63	101.42	101.02
Si <sup>+4</sup>	1.912	1.896	1.905	1.907	1.905	1.952	1.942
Ti <sup>+4</sup>	0.002	0.003	0.007	0.008	0.007	0.000	0.000
Al <sup>+3</sup>	0.175	0.196	0.149	0.148	0.150	0.084	0.097
Cr <sup>+3</sup>	0.021	0.021	0.025	0.025	0.024	0.017	0.021
Fe <sup>+2</sup>	0.077	0.079	0.080	0.080	0.081	0.051	0.051
Mn <sup>+2</sup>	0.002	0.002	0.003	0.004	0.003	0.002	0.002
Ni <sup>+2</sup>	0.001	0.002	0.002	0.002	0.001	0.002	0.001
Mg <sup>+2</sup>	0.900	0.896	0.910	0.910	0.907	0.937	0.920
Ca <sup>+2</sup>	0.858	0.846	0.870	0.865	0.871	0.914	0.921

Na <sup>+1</sup>	0.053	0.060	0.049	0.051	0.050	0.041	0.043
Total	4.000	4.000	4.000	4.000	4.000	4.000	4.000
#mg	0.921	0.919	0.919	0.919	0.918	0.948	0.948

931 \*total iron as FeO

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944 Table 5. continued

No.	16	17	18	19	20	21	22	23	24
Generation	CpxII	CpxII	CpxII	CpxII	CpxII	CpxIII	CpxIII	CpxIII	CpxIII
Group	in contact with Pl		in contact with alk. Fsp			A	B	C	MM30
SiO <sub>2</sub>	53.84	52.77	54.14	55.34	52.43	53.45	52.45	52.76	54.25
TiO <sub>2</sub>	0.41	0.14	0.09	0.14	1.28	0.13	0.09	0.09	0.01
Al <sub>2</sub> O <sub>3</sub>	6.07	2.92	1.64	0.42	2.16	4.16	3.74	4.19	2.15
Cr <sub>2</sub> O <sub>3</sub>	0.97	1.11	2.09	0.87	1.70	0.86	0.80	0.81	0.600
FeO*	2.67	2.74	2.52	2.66	2.18	2.97	2.76	2.76	2.04
MnO	0.12	0.08	0.08	0.08	0.07	0.10	0.08	0.07	0.07
NiO	0.03	0.04	0.03	0.08	0.03	0.06	0.05	0.05	0.05
MgO	15.60	17.52	18.08	18.96	16.38	17.93	17.30	16.89	17.45
CaO	17.82	22.14	20.51	21.40	22.66	20.33	21.28	22.02	23.66
Na <sub>2</sub> O	1.76	0.45	1.00	0.67	0.89	0.70	0.70	0.81	0.54
Total	99.29	99.91	100.18	100.62	99.78	100.69	99.25	100.45	100.82
Si <sup>+4</sup>	1.949	1.913	1.953	1.985	1.913	1.915	1.908	1.899	1.946
Ti <sup>+4</sup>	0.011	0.004	0.003	0.004	0.035	0.004	0.002	0.002	0.000
Al <sup>+3</sup>	0.259	0.120	0.070	0.018	0.093	0.176	0.160	0.178	0.090
Cr <sup>+3</sup>	0.028	0.030	0.059	0.025	0.049	0.024	0.023	0.023	0.017
Fe <sup>+2</sup>	0.081	0.083	0.076	0.080	0.066	0.089	0.084	0.083	0.061
Mn <sup>+2</sup>	0.004	0.002	0.002	0.002	0.002	0.003	0.003	0.002	0.002
Ni <sup>+2</sup>	0.001	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.002

Mg <sup>+2</sup>	0.842	0.947	0.972	1.014	0.891	0.958	0.938	0.906	0.933
Ca <sup>+2</sup>	0.691	0.860	0.793	0.823	0.886	0.781	0.830	0.849	0.909
Na <sup>+1</sup>	0.124	0.032	0.070	0.047	0.063	0.049	0.050	0.056	0.037
Total	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
#mg	0.912	0.919	0.927	0.927	0.931	0.915	0.918	0.916	0.938

945 \*total iron as FeO

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957 Table 6. Representative analyses and structural formulae (C=3) of spinel from Lutynia  
 958 xenoliths.

No.	1	2	3	4	5	6	7	8
Generation	Spl	Spl	Spl	Spl	Spl	Spl	Spl	Spl
Group	A	A	B	B	B <sub>MM15</sub>	B <sub>MM15</sub>	C	C
SiO <sub>2</sub>	0.04	0.03	0.05	0.06	0.08	0.03	0.04	0.05
TiO <sub>2</sub>	0.05	0.07	0.06	0.08	0.67	0.37	0.08	0.06
Al <sub>2</sub> O <sub>3</sub>	50.17	45.96	47.77	45.55	28.61	30.14	52.52	47.11
Cr <sub>2</sub> O <sub>3</sub>	16.87	21.44	20.41	21.22	38.12	38.08	15.84	19.51
FeO*	13.41	12.37	12.10	12.49	15.75	15.28	10.63	12.72
MnO	0.13	0.09	0.11	0.10	0.18	0.13	0.12	0.12
NiO	0.36	0.29	0.28	0.30	0.19	0.17	0.30	0.32
MgO	19.22	19.33	19.07	19.20	15.37	15.83	20.20	19.58
Total	100.25	99.58	99.85	99.00	98.97	100.03	99.73	99.47
Si <sup>+4</sup>	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001
Ti <sup>+4</sup>	0.001	0.001	0.001	0.002	0.015	0.008	0.002	0.001
Al <sup>+3</sup>	1.572	1.468	1.516	1.464	1.002	1.039	1.630	1.497
Cr <sup>+3</sup>	0.355	0.459	0.435	0.457	0.896	0.880	0.330	0.416
Fe <sup>+3**</sup>	0.069	0.068	0.045	0.072	0.068	0.064	0.036	0.081
Fe <sup>+2**</sup>	0.229	0.212	0.227	0.213	0.324	0.310	0.198	0.206
Mn <sup>+2</sup>	0.003	0.002	0.002	0.002	0.004	0.003	0.003	0.003
Ni <sup>+2</sup>	0.008	0.006	0.006	0.007	0.004	0.004	0.006	0.007
Mg <sup>+2</sup>	0.762	0.781	0.765	0.781	0.681	0.690	0.793	0.787
Total	3.000	2.998	2.998	3.000	2.996	2.999	2.999	2.999



#mg	0.769	0.786	0.771	0.238	0.472	0.459	0.800	0.793
#cr	0.184	0.238	0.223	0.786	0.678	0.690	0.168	0.217

959 \*total iron as FeO

960 \*\* Fe<sup>2+</sup> and Fe<sup>3+</sup> calculated by charge balance

961 b.d.l. – content below detection limit

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974 Table 6. continued

No.	9	10	11	12	13	14	15
Generation	Spl	Spl	Spl	Spl	SplI	SplI	SplI
Group	D	D	MM30	MM30			
SiO <sub>2</sub>	0.03	0.04	0.01	0.01	0.78	0.09	0.07
TiO <sub>2</sub>	0.30	0.31	0.01	0.02	0.99	0.40	0.35
Al <sub>2</sub> O <sub>3</sub>	37.02	36.79	38.92	41.12	31.67	46.28	43.32
Cr <sub>2</sub> O <sub>3</sub>	28.95	29.00	30.24	28.38	30.38	22.16	24.74
FeO*	14.82	14.44	12.74	11.07	18.83	12.30	12.49
MnO	0.14	0.12	0.12	0.09	0.19	0.13	0.13
NiO	0.25	0.22	0.21	0.21	0.28	0.23	0.27
MgO	17.70	17.44	17.70	18.80	14.96	19.76	18.20
Total	99.21	98.36	99.95	99.70	98.08	101.35	99.57
Si <sup>+4</sup>	0.001	0.001	0.000	0.000	0.023	0.002	0.002
Ti <sup>+4</sup>	0.006	0.007	0.000	0.000	0.022	0.008	0.007
Al <sup>+3</sup>	1.236	1.239	1.284	1.340	1.100	1.453	1.407
Cr <sup>+3</sup>	0.648	0.655	0.669	0.620	0.708	0.467	0.539
Fe <sup>+3**</sup>	0.102	0.090	0.046	0.039	0.105	0.060	0.036
Fe <sup>+2**</sup>	0.249	0.255	0.252	0.217	0.359	0.214	0.252
Mn <sup>+2</sup>	0.003	0.003	0.003	0.002	0.005	0.003	0.003
Ni <sup>+2</sup>	0.006	0.005	0.005	0.005	0.007	0.005	0.006
Mg <sup>+2</sup>	0.747	0.743	0.739	0.775	0.658	0.785	0.747
Total	2.998	2.998	2.998	2.998	2.987	2.997	2.999

#mg	0.344	0.346	0.746	0.781	0.647	0.786	0.748
#cr	0.750	0.745	0.343	0.316	0.392	0.243	0.277

975 \*total iron as FeO  
 976 \*\* Fe<sup>2+</sup> and Fe<sup>3+</sup> calculated by charge balance  
 977 b.d.l. – content below detection limit

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 991 Table 6. continued

No.	16	17	18	19	20	21	22	23	24
Generation	SpIII	SpIII	SpIII	SpIII	SpIII	SpIII	SpIII	SpIII	SpIII
Group	A	A	B	B	C	C	D <sub>MM04</sub>	D <sub>MM04</sub>	MM30
SiO <sub>2</sub>	0.02	0.06	0.06	0.05	0.03	0.07	0.08	0.13	0.06
TiO <sub>2</sub>	0.06	0.12	0.05	0.06	0.06	0.09	0.07	0.23	0.01
Al <sub>2</sub> O <sub>3</sub>	49.05	45.45	46.86	50.79	50.79	41.60	51.19	36.69	42.46
Cr <sub>2</sub> O <sub>3</sub>	17.16	24.25	20.18	16.28	16.33	22.83	14.61	27.79	26.01
FeO*	13.29	10.30	12.70	11.32	11.40	14.47	12.14	15.31	10.98
MnO	0.13	0.12	0.11	0.09	0.10	0.13	0.06	0.16	0.06
NiO	0.37	0.25	0.29	0.33	0.38	0.29	0.38	0.23	0.27
MgO	19.25	19.12	19.34	20.53	20.04	18.32	20.17	18.28	18.93
Total	99.33	99.67	99.59	99.45	99.13	97.80	98.70	98.82	98.78
Si <sup>+4</sup>	0.001	0.002	0.002	0.001	0.001	0.002	0.002	0.004	0.002
Ti <sup>+4</sup>	0.001	0.003	0.001	0.001	0.001	0.002	0.001	0.005	0.000
Al <sup>+3</sup>	1.552	1.456	1.491	1.585	1.594	1.370	1.603	1.219	1.385
Cr <sup>+3</sup>	0.364	0.521	0.431	0.341	0.344	0.505	0.307	0.619	0.569
Fe <sup>+3**</sup>	0.081	0.015	0.074	0.069	0.058	0.118	0.083	0.145	0.043
Fe <sup>+2**</sup>	0.218	0.219	0.213	0.181	0.196	0.221	0.187	0.216	0.211
Mn <sup>+2</sup>	0.003	0.003	0.002	0.002	0.002	0.003	0.001	0.004	0.001
Ni <sup>+2</sup>	0.008	0.006	0.006	0.007	0.008	0.006	0.008	0.005	0.006
Mg <sup>+2</sup>	0.770	0.775	0.778	0.810	0.796	0.763	0.799	0.768	0.781

Total	2.998	3.000	2.998	2.997	3.000	2.990	2.991	2.985	2.998
#mg	0.780	0.779	0.785	0.817	0.177	0.269	0.161	0.337	0.291
#cr	0.190	0.264	0.224	0.177	0.803	0.776	0.811	0.780	0.787

992 \*total iron as FeO

993 \*\* Fe<sup>2+</sup> and Fe<sup>3+</sup> calculated by charge balance

994 b.d.l. – content below detection limit

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1007 Table 7. Representative analyses and structural formulae (O<sup>2-</sup>=8) of feldspar from Lutynia  
 1008 xenoliths.

No.	1	2	3	4	5	6	7	8	
Generation	Patch Fsp								
	← one xenolith			→ Af		Af	Pl	Pl	→
SiO <sub>2</sub>	57.33	62.74	65.78	64.06	66.48	66.34	55.63	58.00	
TiO <sub>2</sub>	0.21	0.19	0.54	0.41	0.18	0.13	0.07	0.24	
Al <sub>2</sub> O <sub>3</sub>	26.71	22.68	19.59	21.07	19.14	19.15	28.11	26.46	
FeO*	0.31	0.24	0.24	0.36	0.48	0.31	0.20	0.22	
MgO	0.02	0.02	0.02	0.04	0.02	0.01	0.02	0.06	
CaO	8.00	3.95	0.67	2.24	0.06	0.14	9.96	8.08	
Na <sub>2</sub> O	6.48	8.40	6.99	6.79	5.92	6.84	5.45	6.51	
K <sub>2</sub> O	0.58	1.55	6.29	5.17	8.01	7.13	0.35	0.42	
Total	99.64	99.77	100.12	100.14	100.29	100.05	99.79	99.99	
or	3	9	36	30	14	51	2	2	
ab	57	72	61	59	47	48	49	58	
an	39	19	3	11	53	1	49	40	
Si <sup>+4</sup>	2.579	2.579	2.792	2.942	2.984	2.966	2.498	2.601	
Ti <sup>+4</sup>	0.007	0.007	0.007	0.018	0.006	0.004	0.002	0.008	
Al <sup>+3</sup>	1.416	1.416	1.189	1.032	1.012	1.009	1.497	1.398	
Fe <sup>+2</sup>	0.012	0.012	0.009	0.009	0.018	0.011	0.013	0.008	

Mg <sup>+2</sup>	0.001	0.001	0.001	0.001	0.001	0.001	0.004	0.004
Ca <sup>+2</sup>	0.386	0.386	0.188	0.032	0.003	0.01	0.485	0.388
Na <sup>+1</sup>	0.565	0.565	0.724	0.605	0.515	0.593	0.478	0.566
K <sup>+1</sup>	0.033	0.0333	0.088	0.359	0.459	0.407	0.020	0.024
Total	4.999	4.999	4.998	4.998	4.998	5.001	4.997	4.997

1009 \*total iron as FeO

1010 b.d.l. – content below detection limit

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1023 Table 7. continued

No.	9	10	11	12	13	14	15	16
Generation	←	Vein Fsp		→	←	Host rock Fsp		→
	Af	Af	Pl	Pl	Af	Af	Pl	Af
SiO <sub>2</sub>	65.28	64.230	56.07	62.14	65.59	64.29	56.81	54.56
TiO <sub>2</sub>	0.26	0.24	0.23	0.20	0.23	0.18	0.15	0.13
Al <sub>2</sub> O <sub>3</sub>	19.87	22.19	27.82	24.95	19.71	22.07	26.92	28.48
FeO*	0.31	0.26	0.26	0.30	0.31	0.40	0.47	0.45
MgO	b.d.l.	b.d.l.	0.01	0.05	b.d.l.	b.d.l.	0.02	0.02
CaO	0.86	2.97	9.62	6.19	0.57	2.68	8.07	9.82
Na <sub>2</sub> O	5.66	8.27	5.91	7.02	5.58	8.58	5.93	5.24
K <sub>2</sub> O	7.93	2.57	0.37	0.61	8.25	2.24	0.74	0.44
Total	100.17	100.73	100.29	101.46	100.24	100.44	99.11	99.14
or	46	15	2	4	48	13	4	3
ab	50	71	52	65	49	74	55	48
an	4	14	46	32	3	13	41	50
Si <sup>+4</sup>	2.935	2.835	2.513	2.746	2.949	2.84	2.578	2.483
Ti <sup>+4</sup>	0.009	0.008	0.008	0.007	0.008	0.006	0.005	0.004
Al <sup>+3</sup>	1.053	1.154	1.470	1.300	1.044	1.149	1.440	1.527
Fe <sup>+2</sup>	0.012	0.010	0.001	0.011	0.003	0.015	0.018	0.017
Mg <sup>+2</sup>	0.000	0.000	0.001	0.003	0.000	0.000	0.002	0.00

Ca <sup>+2</sup>	0.042	0.141	0.462	0.293	0.027	0.127	0.393	0.479
Na <sup>+1</sup>	0.494	0.708	0.514	0.601	0.486	0.735	0.522	0.463
K <sup>+1</sup>	0.455	0.144	0.021	0.035	0.473	0.126	0.043	0.025
Total	5.000	5.000	4.990	4.996	4.999	4.998	5.001	4.998

1024 \*total iron as FeO

1025 b.d.l. – content below detection limit

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1039 Table 8. Representative analyses and structural formulae (O<sup>2-</sup>=23) of amphibole from Lutynia  
 1040 xenoliths.

No.	1	2	3	4
Group	D			
SiO <sub>2</sub>	43.27	42.87	43.31	43.24
TiO <sub>2</sub>	1.17	1.08	1.08	1.09
Al <sub>2</sub> O <sub>3</sub>	13.76	13.86	13.86	13.85
Cr <sub>2</sub> O <sub>3</sub>	1.78	1.87	1.85	1.84
FeO*	4.18	4.08	3.97	3.90
MnO	0.07	0.05	0.07	0.05
NiO	0.11	0.09	0.10	0.10
MgO	17.57	17.76	18.02	18.09
CaO	11.33	11.24	11.60	11.54
Na <sub>2</sub> O	3.35	3.32	3.07	3.11
K <sub>2</sub> O	0.89	0.90	0.84	0.86
Total	97.48	97.12	97.80	97.67
Si <sup>+4</sup>	6.140	6.090	6.104	6.098
Ti <sup>+4</sup>	0.125	0.116	0.114	0.115
Al <sup>+3</sup>	2.302	2.321	2.303	2.302
Cr <sup>+3</sup>	0.200	0.210	0.206	0.205

Fe <sup>+2</sup>	0.496	0.485	0.468	0.460
Mn <sup>+2</sup>	0.008	0.006	0.008	0.006
Ni <sup>+2</sup>	0.012	0.011	0.011	0.011
Mg <sup>+2</sup>	3.717	3.761	3.786	3.803
Ca <sup>+2</sup>	1.723	1.712	1.751	1.743
Na <sup>+1</sup>	0.923	0.913	0.840	0.852
K <sup>+1</sup>	0.16	0.164	0.151	0.154
Total	15.806	15.789	15.742	15.749
#mg	0.882	0.886	0.890	0.892

1041 \*total iron as FeO

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1053 Table 9. Trace element compositions of Cpx I from Lutynia xenoliths

Element	MM11	MM21	MM22	MM39	LU 50	LU 28	LU 8
Ba	0.11	0.12	0.11	0.19	0.04	0.02	0.01
Th	0.67	1.40	0.63	1.02	2.99	7.06	11.80
U	0.22	0.41	0.19	0.33	3.22	6.55	9.36
Ta	0.06	0.12	0.10	0.10	1.17	2.05	0.87
La	5.56	11.29	6.36	10.44	9.92	10.05	17.04
Ce	12.14	19.75	12.09	22.67	11.61	8.82	16.17
Sr	61.35	100.41	62.16	94.56	10.91	12.11	22.41
Nd	5.34	8.50	4.90	9.01	11.15	5.84	9.02
Zr	20.14	18.65	19.18	9.07	8.22	1.16	0.73
Hf	0.12	0.28	0.45	0.19	3.44	0.28	0.76
Sm	1.26	1.89	1.24	1.85	7.69	3.75	4.04
Eu	0.34	0.51	0.39	0.51	6.45	2.96	3.30
Ti	558.78	310.93	756.27	476.31	b.d.l.	b.d.l.	b.d.l.
Gd	1.05	1.20	1.28	1.39	4.55	2.32	1.97
Dy	1.26	1.09	1.40	1.44	2.95	1.42	1.13
Ho	0.27	0.22	0.29	0.29	2.36	1.16	0.86
Er	0.80	0.64	0.85	0.90	2.06	1.00	0.88
Yb	0.79	0.65	0.86	0.89	1.47	0.85	0.94
Lu	0.12	0.10	0.13	0.13	1.19	0.75	0.81

1054 b.d.l. – content below detection limit

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1071 Table 9. continued

Element	MM03	MM08	MM15	MM29	MM31	MM09	MM25	MM28
Ba	0.52	0.11	0.94	0.13	0.13	0.06	0.09	0.10
Th	2.18	0.85	2.29	0.96	0.90	0.67	0.39	1.10
U	0.63	0.32	0.78	0.32	0.20	0.28	0.12	0.27
Ta	0.03	0.02	0.00	0.01	0.06	0.06	0.01	0.02
La	30.78	8.73	35.25	14.52	11.36	3.91	3.81	10.99
Ce	62.83	17.30	61.36	21.13	28.29	5.03	5.82	17.48
Sr	220.46	80.02	484.92	147.54	156.98	19.53	26.85	88.94
Nd	9.00	4.85	14.34	4.91	8.94	0.79	0.80	3.09
Zr	2.73	1.67	2.81	0.78	2.24	0.38	0.53	2.31
Hf	0.07	0.04	0.09	0.14	0.06	0.19	0.16	0.14
Sm	1.10	0.79	2.33	0.86	1.54	0.24	0.20	0.42
Eu	0.25	0.24	0.46	0.22	0.40	0.13	0.09	0.12
Ti	401.47	361.26	110.76	562.53	341.04	604.75	697.65	399.44
Gd	0.80	0.81	0.90	0.69	0.92	0.62	0.48	0.48
Dy	1.12	1.07	0.69	0.84	1.01	1.11	0.86	0.89
Ho	0.26	0.25	0.14	0.19	0.24	0.28	0.21	0.21
Er	0.75	0.74	0.42	0.59	0.76	0.91	0.69	0.65
Yb	0.72	0.75	0.44	0.62	0.78	0.91	0.74	0.66
Lu	0.11	0.11	0.07	0.10	0.12	0.13	0.12	0.10

1072 b.d.l. – content below detection limit

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1089 Table 9. continued

Element	MM04	LU 50	MM30
Ba	0.64	0.04	0.04
Th	0.99	2.99	0.01
U	0.41	3.22	b.d.l.
Ta	0.22	1.17	b.d.l.
La	9.30	9.92	0.02
Ce	23.54	11.61	0.03
Sr	133.10	10.91	2.30
Nd	15.72	11.15	0.02
Zr	96.18	8.22	0.08
Hf	1.39	3.44	b.d.l.
Sm	3.82	7.69	b.d.l.
Eu	1.23	6.45	0.00
Ti	1.39	b.d.l.	59.88
Gd	3.07	4.55	0.03
Dy	2.66	2.95	0.09
Ho	0.46	2.36	0.04
Er	1.09	2.06	0.15
Yb	0.96	1.47	0.16
Lu	0.13	1.19	0.02



1090 b.d.l. – content below detection limit  
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1107 Table 10. Calculated temperatures for Lutynia xenoliths. For Brey and Köhler (1990) the  
 1108 assumed pressure is P=10kbar

METHOD	Opxl/Cpxl		CpxlIII lamellae in Opxl		OpxlIII lamellae in Cpxl	
	Brey and Köhler (1990) [°C]	Wells (1977) [°C]	Brey and Köhler (1990) [°C]	Brey and Köhler (1990) [°C]	Brey and Köhler (1990) [°C]	Brey and Köhler (1990) [°C]
GROUP A						
MM11	955	923	956		958	
MM21	995	952	n.d.		n.d.	
MM22	1000	944	993		974	
MM39	965	931			966	
AVERAGE	979	938	974		966	
GROUP B						
MM03	985	947	no equilibrium		957	
MM08	985	942	984		965	
MM15	no equilibrium	no equilibrium	1003		832	
MM29	no equilibrium	no equilibrium	no equilibrium		866	
MM31	957	930	957		933	
AVERAGE	976	940	981		911	
GROUP C						
MM09	995	947	no equilibrium		986	
MM25	983	937	991		1008	

MM28	1000	960	981	1009
AVERAGE	993	948	986	1001
GROUP D				
MM04	970	933	no equilibrium	nd
MM30				
MM30	no equilibrium	no equilibrium	n.d.	760-830

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1122 Tab.11. The experimental Cpx-alkali basalt partition coefficients. Data after (Norman, 1998)

Element	D <sub>Cpx/melt</sub>
La	0.055
Ce	0.075
Nd	0.150
Sm	0.250
Eu	0.300
Gd	0.400
Dy	0.450
Ho	0.450
Er	0.450
Yb	0.400
Lu	0.350

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