Amphibole and garnet bearing mantle xenoliths in the Kaiserstuhl, Germany: relation to diatreme and carbonatite

J. Sigmund
J. Keller

Mineral.-Petrograph. Institut, Albertstr. 23b, D-79104 Freiburg, Germany

Introduction

Amphibole and garnet bearing mantle xenoliths occur in diatremes with close spatial and temporal relationship to the svitic carbonatites of the Kaiserstuhl. This is to our knowledge the first find of a garnet bearing mantle xenolith in the Tertiary to Quaternary Mid-European Volcanic Province (Wedepohl *et al.* 1994). The carbonatite itself is devoid of mantle xenoliths due to probably high level (crustal) fractionation and extreme low viscosity of the carbonatite melts (Treiman 1989).

Diatreme rocks

Diatreme facies rocks of the intrusive center of the volcano edifice sampled a large range of Kaiserstuhl rocks (tephrites, essexites, rare phonolites and carbonatites), mafic minerals, pyroxenites, hornblendites and xenoliths or detrital crystals (ol, opx, cr-di, spi) of spinel lherzolite composition. Two groups of mantle xenoliths are distinguished: 1. anhydrous spinel-lherzolites and 2. hydrous, pargasite bearing spinel-lherzolites. One pargasite bearing lherzolite exhibits garnet together with spinel.

Chemistry of lherzolite minerals

Olivine, opx, and cpx show only slight compositional variations between various xenoliths (tab. 1a). Cr content of cpx is up to 1.1 wt%, TiO_2 is minor. Amphiboles are Cr and Ti bearing pargasites with mg-values between 0.84 and 0.90 (Table 1a). Pargasites show only minor alteration and occur at grain boundaries of the primary, often altered mantle minerals and as a small veinlet within a lherzolite xenolith. Texture and composition of the pargasites indicate their formation due to reaction of pyroxene + spinel + H_2O. Garnet in the unique garnet bearing spinel lherzolite xenolith has a pyrope rich (py68, alm_{14} gro_{12}) composition, the Cr content is low (~ 0.7 wt%). Coexisting spinels are also low in Cr (tab. 1a). Olivine and pyroxene are completely altered.

T-P conditions of equilibration

Geothermometry for spinel lherzolites yields equilibrium temperatures of 950 to 1100ÅC. No characteristic differences in equilibrium temperatures between the pyroxene thermometers (Brey & Khler 1990; Sachtleben & Seck 1981) and the olivine-spinel thermometer of Ballhaus *et al.* (1991) were obtained. The 'Ca in olivine'-barometer of Khler & Brey (1990) yields unrealistic low pressures due to insufficient precision of Ca determination by microprobe (0.01 weight-% of CaO in olivine lead to pressure differences of about 5 kbars!). For the garnet bearing spinel-lherzolite an equilibrium pressure of about 21 kbars (O'Neill 1981) is estimated, equilibrium temperatures for this xenolith cannot be calculated because of alteration of ol, opx and cpx. Though the T-P determinations are limited, the spinel lherzolite mantle xenoliths indicate equilibration (for assumed pressures of 15 kbars) under high-heat flow conditions (Pollack & Chapman 1977) of about 70 to 80 W/m2. This is compatible with the idea of a diapiric mantle dome underneath the Kaiserstuhl (Illies 1975).

Petrography of diatreme matrix

The finegrained matrix (=juvenile melt) of the breccia is also visible in small pelletal lapilli within the breccia. The matrix contains two types of larger pheno-/xenocrysts of cpx: green core cpx (mg-value 0.5–0.6) with remarkable FAT- and CAT-substitutions are distinguished from Cr-poor diopsides (mg ~ 0.8). Both types of cpx have small rims of Ti-augite, whose composition is identical to cpx microphenocrysts in the groundmass. The fine grained, often altered and aphanitic groundmass consists of mica, magnetite, and titanite.

Magma composition

The original magmatic composition of the diatreme breccias is difficult to determine,

TABLE 1a.

	34(1)55 opx	30(5)7 cpx	34(2)47 spi	133(4)73 amp	147(4) gnt	147(8) spi
SiO_2	55.77	52.49	0.07	43.74	42.31	0.06
TiO_2	0.08	0.16	0.43	1.40	0.05	0.07
Al_2O_3	4.02	4.67	50.43	14.89	22.76	61.92
Cr_2O_3	0.41	0.78	14.56	1.00	0.66	3.16
FeO	6.14	3.08	13.72	3.92	8.70	11.86
MnO	0.21	0.08	0.00	0.03	0.42	0.08
MgO	32.20	15.39	20.23	17.67	19.42	20.03
NiO	0.00	0.00	0.13	0.17	0.00	0.26
CaO	0.56	20.57	0.00	10.60	5.76	0.02
Na_2O	0.11	1.14	0.00	3.89	0.04	0.00
K_2O	0.00	0.06	0.00	0.44	0.00	0.02
Total	99.50	98.42	99.57	97.75	100.12	97.46
oxygens	6	6	4	23	24	4
Si	1.931	1.930	0.001	6.199	6.026	0.002
Al	0.164	0.202	1.596	2.487	3.821	1.902
Ti	0.002	0.004	0.008	0.149	0.005	0.001
Cr	0.011	0.022	0.309	0.112	0.074	0.065
Mg	1.662	0.843	0.809	3.733	4.123	0.778
Fe	0.177	0.094	0.308	0.464	1.037	0.259
Mn	0.006	0.002	0.000	0.003	0.050	0.002
Ni	0.000	0.000	0.002	0.017	0.000	0.005
Ca	0.020	0.810	0.000	1.609	0.879	0.001
Na	0.007	0.081	0.000	1.068	0.012	0.000
K	0.000	0.002	0.000	0.079	0.000	0.000
Sum	3.982	3.994	3.036	15.925	16.027	3.013
mg	0.903	0.899	0.724	0.889	0.799	0.751

TABLE 1b.

	breccia 110.78 m	breccia 128.50 m	assumed comp.	olivine-melilitite	olivine-nephelinite
	1	2	3	4	5
SiO_2	33.32	34.68	42.39	39.50	40.79
TiO_2	1.59	1.78	3.22	2.51	2.55
Al_2O_3	9.49	9.52	11.45	10.45	10.16
ΣFeO	8.75	9.58	9.14	10.90	10.50
MnO	0.29	0.23	0.17	0.20	0.16
MgO	9.62	12.81	14.28	15.88	14.50
CaO	14.32	11.59	13.76	13.10	11.50
Na_2O	2.05	1.37	0.32	2.58	2.99
K_2O	5.20	5.55	3.48	1.49	0.83
P_2O_5	0.78	0.54	n.d.	0.79	0.77
H_2O	1.15	1.77	1.61	1.73	2.90
CO_2	10.50	6.84	n.d.	0.13	0.85
Σ	97.06	96.26	99.82	99.26	98.50
V	332	304	n.d.	353	242
Sc	15	20	n.d.	32	27
Ni	194	351	n.d.	390	386
Cr	343	478	n.d.	736	488
Co	38	55	n.d.	57	58
Rb	218	207	n.d.	43	20
Sr	1763	1065	n.d.	916	859
Ba	1677	1340	n.d.	1147	753
La	155	63	n.d.	84	70
Y	32	15	n.d.	23	19
Nb	163	86	n.d.	95	75
Zr	293	215	n.d.	263	193

because whole rock analyses are influenced by tiny fragments of xenoliths. Two whole rock analyses of mostly xenolith free samples of the breccia are listed in table 1b (col 1,2). A hypothetical rock composition for the juvenile melt of the diatreme can be roughly estimated by calculation from modal amounts and chemical compositions (by EMP) of phenocrysts and matrix (col. 3). The juvenile melt can be characterized as an ultrabasic, ol and melilite normative melt, although magmatic olivine and melilite are lacking. The high K_2O/Na_2O ratios for the hypothetic composition and the two breccia analyses are due to the mica rich, fine grained groundmass. This 'biotitisation' of the breccia is ascribed to the later intrusion of the carbonatites (Wimmenauer 1962). However, fresh parts of the breccia are only slightly enriched in typical carbonatite trace elements and *REE* (Table 1b, col. 2,3). Trace elements and *REE* of these analyses resemble ol-melilitites in the Rhinegraben (col. 4), 15 to 40 km apart from the Kaiserstuhl. A second occurrence of spinel lherzolite xenoliths is in ol-nephelinite lava flows of the Limberg/ Ltzelberg parasitic volcano. For comparison the chemical composition of the ol-nephelinites is given in col. 5.

Relationship between carbonatite and diatreme

Occurrence, time of intrusion, as well as chemical and isotopic composition (Schleicher & Keller 1991) suggest a close genetic relationship between the diatremes and the carbonatites. Both intrude within one magmatic sequence. The diatreme breccias seem to be the precursor for the svitic carbonatites and the alvikitic dykes, although the breccias 'sampled' some existing carbonatites as xenoliths. The juvenile melt was probably an ultrabasic, olivine and melilite normative magma with trace and *REE* similar to ol-melilitites in the vicinity of the Kaiserstuhl. The 'missing link' between the genesis of the diatreme melt and the carbonatites can be seen in rare small carbonate droplets, which occur in least altered parts of the diatreme matrix. Cathodoluminescence investigations exhibit growth-zoning and chemical variations in the carbonate droplets, luminescence colour is similar to carbonatite calcites. These carbonate droplets are interpreted as trapped inclusions of an 'immiscible' (?) carbonatitic melt in the juvenile diatreme magma.