# Mineral Chemistry and Petrogenesis of Ultramafic Alkaline Lamprophyre Dyke from the Klunst Quarry in Ebersbach (Lusatia, Germany)

Axel Dieter RENNO<sup>1</sup>, Sabine HASER<sup>2</sup>, Klaus Peter STANEK<sup>2</sup> and Jens GÖTZE<sup>1</sup> <sup>1</sup>Institute of Mineralogy, Freiberg University of Mining and Technology, D-09596 Freiberg, Germany, <sup>2</sup>Institute of Geology, Freiberg University of Mining and Technology, D-09596 Freiberg, Germany

ABSTRACT: A representative set of samples of ultramafic alkaline lamprophyre (UML) dykes from Ebersbach (Lusatia, Germany) has been studied to determine the mineralogical composition of calcites, apatites and micas. Calcite can be subdivided into two groups, Sr-rich and Sr-poor calcite. Apatite shows a significant enrichment in Si and CO<sub>3</sub>, and noteworthy concentrations of SO<sub>3</sub>, Sr, Ba and Na. The studied micas are mainly phlogopites and tetraferriphlogopites. Three different types of mica were recognized: (Cr, Ti, Al)-rich cores of megacrysts, (Ti, Ba, Al)-rich rims of megacrysts as well as Fe-rich and Al-poor groundmass mica. Apatite crystallized from a segregated carbonatitic melt together with Sr-rich calcite and Al-poor and Fe-rich groundmass mica. Rounded cores of mica megacrysts represent xenocrysts from a phlogopite-enriched mantle. The rims and groundmass micas represent products of magmatic crystallization. Sr-poor calcite was formed during hydrothermal alteration of the UML rocks.

KEY WORDS: ultramafic alkaline lamprophyre, carbonatite, phlogopite, apatite, Sr-rich calcite.

# Introduction

The ultramafic alkaline lamprophyre dykes (UML) from Ebersbach (Lusatia) were discovered in 1995. Lösch et al. (2000) and Renno et al. (2000 and in press) gave the first description of the petrographic and geochemical features of these rocks. It was the first description of this rock type from the Lusatian part of the Bohemian Massif. Regardless of their general scarcity, these rocks are widespread in the wings of the Eger Rift. Similar melilitic rock associations represent the Zeughausgangzug (Germany) and the Osečná Complex (Czech Republic), and the carbonatite ultramafic lamprophyre complex of Delitzsch (Germany). Age determinations showed (Renno et al. in press), that the Lusatian UML can be assigned to the pre-rift series according to Ulrych and Pivec (1997).

The aim of this paper is to provide first data on compositional variations of characteristic rock-forming minerals, such as phlogopite, apatite and calcite, and to reconstruct the crystallization history of the UML dykes.

# Geological setting

The Lusatian Granodiorite Massif (LM) consists of mostly undeformed Cadomian granodiorites with intrusive ages of about 550 Ma (see Fig. 1). Widespread minor intrusions of mafic plugs and dyke swarms as well as rare rhyolitic bodies have been described from the region. Ages of these intrusions have not been well constrained yet. The youngest magmatic activity is characterized by three volcanic series of the latest Cretaceous to Late Neogene ages at the southern and eastern border of the LM associated with the Eger Rift (Ulrych and Pivec 1997).

The active quarry of Klunst in Ebersbach exploits pre-Cretaceous microgabbro. The presence of several cross-cutting dyke swarms allow the study of the age relations of the individual dykes.

The Cadomian granodiorite was penetrated by plugs of ophitic microgabbro. These plugs reach several hundred metres in diameter and show thermal-metamorphic effects on the



Fig. 1. A sketch map of the Lusatian granodiorite massif and the location of the Klunst quarry.

granodiorite. The granodiorite and the gabbro plugs are intersected by several dyke systems.

The older swarm consist of three sets of basaltic dykes. Lamprophyre dykes cutting the basaltic dykes, represent the youngest dykes in the Klunst quarry. The general thickness of the dykes reaches several meters. Mica megacrysts are orientated parallel to the sharp contacts, indicating the flow direction in the dyke.

## Petrography

The modal composition of the lamprophyres is variable. The most outstanding feature is the high amount of centimetre-sized mica megacrysts in thin dykes sometimes not broader than five centimetres. All mica megacrysts are characterized by resorbed margins (Fig. 2). They show clear signs of mechanical stress like kink bands, opened cleavage planes, filled with carbonate



**Fig. 2.** Typical appearance of ultramafic alkaline lamprophyres. The phlogopite megacryst in the centre shows resorption structures and bears a rounded core (change in pleochroism). The filling of a cleavage plane with calcite (arrows) took place after the crystallization of the rim. The groundmass is composed of calcite (1), opaque minerals (2) and pseudomorphs of calcite + serpentine + chlorite after clinopyroxene (3). Plane-polarized light, width of photomicrograph ca. 5 mm.

minerals, and "fringed-out" rims. The phlogopite shows a weak zoning in the marginal parts, characterized by a stronger but not reverse pleochroism as described by Farmer and Boettcher (1981). Abundant clinopyroxenes also occur, showing a different degree of preservation. There are either fresh, having the form of euhedral and rarely broken crystals, or rounded and almost completely pseudomorphosed. Typical forms of the clinopyroxene alterations are uralitization, serpentinization and carbonatization. Many of the clinopyroxenes are tiny zoned in marginal parts and show an expressive sectorial zoning in the cores of the crystals. In contrast to the nearly inclusion-free micas, the pyroxenes bear inclusions of spinel, apatite and carbonate. No olivine crystals but some pseudomorphs after olivine were found. Typical feature of the microstructure of the lamprophyres are the ocelli, formed of carbonate minerals and apatite (Fig. 3). These ocelli were interpreted as segregation of a carbonatitic melt from the silicate lamprophyric melt. The groundmass is mainly composed of carbonate minerals, mica, apatite, magnetite, and pyrite. In contrast to the mica megacrysts, the groundmass micas are euhedral, showing sometimes a broad zoning, and are unaltered. Strong alteration of the glass phase resulted in the development of a fine-grained assemblage of amphibole, chlorite, serpentine-like minerals and calcite.

The contacts of these dykes with the wall-rock are formed as chilled margins. These chilled margins are today recrystallized, but in the form of extremely fine-grained aggregates (< 1  $\mu$ m). Euhedral magnetite, mica and apatite were identified.

In some parts of the dykes, a flow-banding texture is pronounced by the parallel arrangement of mica megacrysts.

Cathodoluminescence microscopy allowed to distinguish two types of carbonate minerals. Carbonates in the ocelli and



Fig. 3. Typical ocellus in the UML. The ocellus is formed by Sr-rich calcite (1) and surrounded by euhedral groundmass micas. Calcite (2), opaque minerals (3) and mica are present in the groundmass. Crossed-polarized light, width of photomicrograph ca. 3 mm.

a majority of carbonates in the groundmass show clear orange luminescence colours. This colour is also displayed by carbonate minerals in opened cleavage planes of mica megacrysts. Carbonates in the pseudomorphs of calcite after clinopyroxene and olivine have a pale yellow luminescence colour. These pseudomorphs are filled with a lot of very small inclusions of non-luminescing minerals. Apatite is concentrated in the ocelli and in selected parts of the groundmass. No inclusions of apatite in micas were found.

## Analytical methods

The characteristic cathodoluminescence (CL) features of carbonate minerals and apatites were investigated by CL-microscopy using a "hot cathode" CL microscope at 14 kV. The CL images were captured on-line by means of an adapted video-camera.

Analyses of the minerals were made with a JEOL JXA-8900R electron microprobe operated with five wavelengthdispersive spectrometers at an accelaration voltage of 20 kV and beam currents between 5 nA and 15 nA. We used a ZAF matrix correction. The problem of the fluorine diffusion during exposure to the electron beam (Stormer et al. 1993) was minimized through the use of a low beam current (max. 8 nA) and by avoiding apatite sections perpendicular to the *c*-axis. Beam diameter, 10 µm on average, depended on the size of the analysed apatites. The smallest analysed crystals were not larger than 12 by 8 µm. The unknown amount of REE and yttrium affected the calculation of the occupancy of the Ca-site. The second problem is the estimation of the OH and CO<sub>3</sub> contents in the apatites. Both components were calculated on the basis of ideal stoichiometry only. Especially the uncertainties in the fluorine, phosphorus and sulphur determinations influenced the calculations. A possible non-ideal stoichiometry is also able to affect the calculations of OH and CO<sub>3</sub> contents.

# Mineral chemistry Calcite

Chemical analyses indicated the occurrence of two different calcite types. Calcite with orange luminescence colour is characterized by a noteworthy enrichment in SrO (max. 6 mol.% SrCO<sub>3</sub>). FeCO<sub>3</sub>, MnCO<sub>3</sub> and MgCO<sub>3</sub> components occur in nearly all analysed samples but generally do not exceed 1 mol.%. BaO and Na<sub>2</sub>O contents are negligible.

Pale yellow luminescing calcite is nearly pure calcite. The SrCO<sub>3</sub> component generally does not exceed 1 mol.%. Some of the analyses included inclusions of Mg- and Si-rich phase, probably of serpentine mineral. Inclusion-free analyses exhibited that this calcite is only slightly enriched in MgCO<sub>3</sub> (up to 4 mol.%) and FeCO<sub>3</sub> and MnCO<sub>3</sub> (1 mol.%) components. The variations are illustrated in the SrCO<sub>3</sub> vs. CaCO<sub>3</sub> diagram (Fig. 4). On the other hand Ulrych et al. (1997) determined primary Sr-poor carbonates (0.02–0.05 wt.% Sr) from melilitic rocks of the Osečná Complex.



Fig. 4. Calcites plotted in CaCO<sub>3</sub> vs. SrCO<sub>3</sub> diagram in mol.%. Field I represents Sr-rich calcites formed by crystallization from the carbonatitic melt, field II represents Sr-poor calcites from the pseudomorphs after clinopyroxene. These calcites are slightly enriched in MgCO<sub>3</sub>, MnCO<sub>3</sub> and FeCO<sub>3</sub>. Only uncontaminated analyses (SiO<sub>2</sub> <0.3 wt.%) were plotted.</p>

#### Apatite

The representative microprobe analyses and formulas of apatites are presented in Table 1. We assumed an ideal stoichiometry and calculated the formulas on the basis of 10 Ca-site (A-site) cations. The general apatite formula is  $A_{10}[TO_4]_6(OH,$ F, Cl)<sub>2</sub>, where the A-site can be occupied by Ca<sup>2+</sup>, Sr<sup>2+</sup>, Ba<sup>2+</sup>, Fe<sup>2+</sup>, Mn<sup>2+</sup>, Mg<sup>2+</sup>; LREE<sup>3+</sup>, Y<sup>3+</sup>, and Na<sup>+</sup>, whereas the T-site stands for P<sup>5+</sup>, Si<sup>4+</sup>, C<sup>4+</sup>, and S<sup>6+</sup>. The content of C<sup>4+</sup> is estimated by a difference assuming T=6. In addition, we calculated OH assuming (F + Cl + OH) = 2. This procedure is generally used for microprobe analyses according to Comodi et al. (1999) and Seifert et al. (2000). Other possible substitution mechanism like O<sup>2-</sup> for OH<sup>-</sup> (Young and Munson 1966) was disregarded.

	98-18-26-1	99-KL-1-3-6	99-KL-4-6-1
$P_2O_5$	36.52	39.92	39.44
SiO <sub>2</sub>	1.71	1.13	1.21
$SO_3$	0.19	0.25	0.22
CaO	52.87	55.11	53.75
SrO	1.24	0.71	0.59
BaO	0.16	0	0.24
Na <sub>2</sub> O	0.78	0.05	0
MgO	0.18	0.13	0.15
MnO	0.01	0.02	0.04
FeO	0.35	0.27	0.25
F	2.54	0.45	0.65
Cl	0.10	0.16	0.16

Ν	umber	of ions	in	apfu o	n the	base	of	structural	formul	a
			А	10 TO4	$]_{6}(O)$	H, F,	Cl	),		

	110[104]6(011,1	, 0.1)2	
Р	5.20	5.80	5.71
Si	0.28	0.21	0.21
S	0.02	0.03	0.03
C <sub>calc</sub>	0.49	0.00	0.06
Ca	9.52	9.84	9.84
Sr	0.12	0.10	0.06
Ва	0.01	0.00	0.02
Na	0.25	0.02	0.00
Mg	0.05	0.03	0.04
Mn	0.00	0.00	0.01
Fe	0.05	0.04	0.03
Хон	0.31	0.88	0.80
$X_{F}$	0.67	0.09	0.18
X <sub>Cl</sub>	0.01	0.02	0.02
$X_{\rm F}$ / $X_{ m OH}$	2.17	0.10	0.22
TSI	15.45	3.44	5.11

Tab. 1. Representative apatite compositions and structural formulas on the basis of the general apatite formula A<sub>10</sub> [TO<sub>4</sub>]<sub>6</sub> (OH, F, Cl)<sub>2</sub> from 3 different UML samples. TSI – tetrahedral substitution index after Stoppa and Liu (1995).

Contents of F range between 0.3–3.8 wt.%, Cl contents are negligible. According to the  $X_{\rm F}$  /  $X_{\rm OH}$  ratio, both hydroxylapatites ( $X_{\rm OH}$  > 0.5) and fluorapatites ( $X_{\rm F}$  > 0.5) occur in the UML. This distribution is shown by both apatite types from the ocelli and from the groundmass.

Contents of SrO are substantial (0.5-2.5 wt.%); i.e., 0.25 Sr apfu). The highest concentrations of other elements in the A-site were revealed for Na<sub>2</sub>O: 1.84 wt.% (0.62 apfu), BaO 1.84 wt.% (0.03 apfu), MnO: 0.12 wt.% (0.02 apfu), FeO: 1.87 wt.% (0.28 apfu) and MgO 0.12 wt.% (0.49 apfu).

Apatites are characterized by significant concentrations of  $SiO_2$  (0.03–5.68 wt.%) and  $SO_3$  (0.05–0.75 wt.%). The calculated  $CO_3$  representation reaches 0.4 apfu.

Different substitution mechanisms are proposed for apatite in carbonatites and alkaline rocks:

$$\begin{split} & P^{5+} + P^{5+} \,\Omega\;(Si+C)^{4+} + S^{6+}(\text{Hogarth},\,1989)(1) \\ & P^{5+} + P^{5+} \Omega\;Si^{4+} + S^{6+}(\text{Dihn and Klement},\,1942)(2) \\ & \text{Ca}^{2+} + P^{5+} \Omega\;\text{REE}^{3+} + Si^{4+}(\text{Comodi et al. 1999})(3) \\ & \text{Ca}^{2+} + P^{5+} \Omega\;S^{6+} + \text{Na}^+(\text{Dihn and Klement},\,1942)(4) \\ & \text{Sr}^{2+} \Omega\;\text{Ca}^{2+}(\text{Comodi et al. 1999})(5) \\ & \text{Ca}^{2+} + \text{Ca}^{2+} \Omega\;\text{REE}^{3+} + \text{Na}^+(\text{Rønsbo},\,1989)(6) \end{split}$$

The tetrahedral substitution index [TSI = 100(Si+S+C)/P]sensu Stoppa and Liu (1995) is a measure of the degree of substitution in the T-site. High TSI-values together with the high

	Phl 2-4 C	Phl 1-1 R P	Phl 4-1 M	
SiO <sub>2</sub>	37.40	35.85	39.10	36.96
$Al_2O_3$	15.52	16.35	11.88	12.42
TiO <sub>2</sub>	5.63	4.17	2.90	4.54
$Cr_2O_3$	1.28	0.02	0.06	0.08
FeO	5.77	6.37	17.06	16.81
MgO	19.34	20.67	15.57	14.45
MnO	0.02	0.04	0.09	0.03
BaO	0.62	1.69	0.21	0.35
CaO	0.03	0.05	0.17	0.36
Na <sub>2</sub> O	0.29	0.34	0.53	0.07
K <sub>2</sub> O	9.93	9.48	8.81	9.43
F	0.15	0.11	b.d.l.	b.d.l
Cl	0.02	b.d.l.	0.03	0.01
$H_2O_{calc}$	4.06	4.89	3.58	4.48
Total	95.94	95.11	96.42	95.52

Number of ions in apfu on the base of the structural formula  $XY_3[Z_4O_{10}](OH,F,Cl)_2 \label{eq:2.1}$ 

	- E		-			
Si	2.79	2.59	2.94	2.77		
Al <sup>IV</sup>	1.21	1.39	1.05	1.09		
$Fe^{3+\mathrm{IV}}$	-	0.02	0.01	0.13		
Al <sup>VI</sup>	0.16	0.42	-	-		
Ti	0.32	0.23	0.16	0.26		
$Fe^{2+}$	0.36	0.37	1.06	0.92		
Mg	2.16	2.22	1.74	1.62		
Cr	0.08	0.00	0.00	0.00		
Ba	0.02	0.05	0.01	0.01		
Ca	0.00	0.01	0.01	0.03		
Na	0.04	0.05	0.08	0.01		
Κ	0.95	0.87	0.85	0.9		
OH	1.01	1.18	0.90	1.12		
F	0.04	0.03	0.00	0.00		
0	0.76	1.18	1.10	0.88		

Tab. 2. Representative microprobe analyses of mica. C – core of megacryst; R – rim of megacryst; R - C – rim of megacryst with chemical composition similar as the groundmass mica; M – groundmass.

amounts of calculated C in the apatite formulas indicate that the dominant tetrahedral substitution mechanisms follows scheme (1) – see Fig. 5. But this substitution is not ideal, as shown by the indistinct correlation in the  $Ca^{2+} + P^{5+} vs. S^{6+} + Na^+$  diagram (see Fig. 6) and the substantial correlation between Ca and Sr. It can be therefore assumed that the substitution in the apatite was influenced by schemes (4) and (5), too.

Substitutions including REE were not justified due to the lack of REE data. However, the clear and homogeneous blue cathodoluminescence colour of apatite is – according to Kempe and Götze (2002) – due to activation by trace quantities of ions of LREE, like  $Ce^{3+}$  and  $Eu^{2+}$ .



Fig. 5. Apatites plotted in the T-site cations  $[PO_4]^{3-} - [SO_4]^{2-} - [SiO_4]^{4+} + [CO_3]^{2-}$  diagram (data in apfu) indicating the dominant substitution scheme  $P^{5+} + P^{5+} W (Si + C)^{4+} + S^{6+}$  in the UML apatites.



Fig. 6. Apatites plotted in the Ca<sup>2+</sup> + P<sup>5+</sup> vs. S<sup>6+</sup> + Na<sup>+</sup> diagram (data in apfu). The indistinct correlation proves the effect of the substitution mechanism Ca<sup>2+</sup> + P<sup>5+</sup>  $\Omega$  S<sup>6+</sup> + Na<sup>+</sup> in addition to the dominating P<sup>5+</sup> + P<sup>5+</sup>  $\Omega$  (Si + C)<sup>4+</sup> + S<sup>6+</sup> substitution scheme.

The apatites are unzoned, with only slight core-rim variations in the intensity of backscattered electrons.

#### Micas

Three types of micas can be distinguished: (i) cores of the megacrysts, (ii) rims of the megacrysts and (iii) groundmass micas. Representative microprobe analyses of all types are presented in Table 2. The formulas were calculated according to the general formula of micas XY<sub>3</sub> [Z<sub>4</sub>O<sub>10</sub>] (OH,F,Cl)<sub>2</sub> (Rieder et al. 1998). The total amount of OH was calculated by assuming (OH + F + Cl) = 2. Some of the micas revealed Si + Al < 4.00 apfu. In these cases we used Fe<sup>3+</sup> to fill the deficiency in the Z-position. The remaining Fe was added as Fe<sup>2+</sup> to the Y-position. End-member calculations defined the majority of the micas as phlogopite and tetraferriphlogopite with rare biotite and tetraferribiotite (Fig. 7). The occurrence of tetraferriphlogopite in carbonatites and alkaline lamprophyres is not uncommon (e.g., Gaspar and Wyllie 1987, McCormick and LeBas 1996, Dunworth and Wilson 1998, Seifert et al. 2000) but is not a condition for micas in carbonatites and melilitites (Lloyd et al. 2002). Ulrych et al. (1996) recognized tetraferriphlogopite in zoned phlogopites of melilitic volcanic rocks of the Osečná and Dvůr Králové complexes.



Fig. 7. Micas plotted in the  $Fe^{VI}/(Fe^{VI} + Mg) - [4-(Si + Al_{total})]*$ 10 diagram.

All micas were found to be Ti-bearing (> 4 wt.% TiO<sub>2</sub>). Cr<sub>2</sub>O<sub>3</sub> contents are mostly low (<0.1 wt.%), but rarely in cores of the megacrysts exceeding 1 wt.%. Both fluorine and chlorine contents are remarkably low (rarely >0.1 wt.%). In some samples BaO contents in the rims of the megacrysts reached values of 1.7 wt.%, otherwise it shows values about 0.5 wt.% in the cores and in the groundmass micas. The megacrysts have markedly higher Al<sub>2</sub>O<sub>3</sub> contents than the micas of the groundmass. The groundmass micas show Al-poor chemical compositions. Indirect Al<sub>2</sub>O<sub>3</sub> and FeO contents relations in the groundmass micas are characteristic.

### Discussion

The three rock-forming minerals from the UML studied in this work have variable forms and significant chemical compositions. In general terms, the observed calcite–apatite ocelli prove the coexistence of a carbonatitic melt and a silicate melt. As suggested by petrographic criteria, the calcite–apatite ocelli were formed by the segregation of carbonatitic magma from the lamprophyric one. Fig. 8 shows a flow-chart for the evolution of the UML.

The presence of micas in all phases of the UML development is indicative for the high activity of K during the evolution of these rocks. Titanium-rich micas with 10–14 wt.% Al<sub>2</sub>O<sub>3</sub> from lamproites were considered relatively unevolved phases by Mitchell and Bergman (1991), indicating an early crystallization at high pressure. Experiments made by Tronnes et al. (1985) and Foley (1990) showed that high-Ti micas crystallized under conditions of decreasing pressure and increasing temperature in lamproitic melts.

Significant contents of  $Cr_2O_3$  in rock-forming minerals are commonly regarded as an indicator of mantle provenance. The highest  $Cr_2O_3$  values of the UML micas are of the same order as in Matsoku vein micas (Delaney et al. 1980) at higher Al<sub>2</sub>O<sub>3</sub>. We interpret the cores of the phlogopite megacrysts as xenocrysts from a metasomatically affected phlogopite-enriched mantle. The wide range of Cr contents indicates either the incorporation of micas from a heterogeneous mantle or the remobilization of  $Cr_2O_3$  by a later recrystallization.

The compositions of phlogopite in rims and the groundmass is sensitive to the availability of Al, as well as the Mg/(Mg+Fe) value of the crystallizing magmas. The Al content in phlogopite crystallizing in carbonatite is low (ca. 12 wt.%), see McCormick and Le Bas (1996). Therefore, the most obvious explanation for the change in the chemical composition in the groundmass micas is associated with the segregated carbonatitic melt.

Due to the characteristic substitutions in the anion and cation sites of apatites, these are considered to be sensitive indicators of magma evolution. Stoppa and Liu (1995) subdivided apatites from ultra-alkaline rocks into three groups. The studied apatites from the UML fit into Group II, i.e., apatites with high Si, OH, C and low S contents, characteristic for extrusive calcite carbonatites. This classification supports our CL-microscopic observations that apatite crystallized together with Sr-rich calcite from the carbonatitic melt.

Two groups of calcites were distinguished by their SrO contents. Sr-rich calcite is also a typical mineral of carbonatitic origin. Sr-poor calcite was formed by the hydrothermal alteration of the UML rocks. Pseudomorphs of calcite + serpentine minerals  $\pm$  chlorite  $\pm$  opaque minerals resulted in the enrichment of calcites in FeCO<sub>3</sub>, MnCO<sub>3</sub> and MgCO<sub>3</sub>; negligible amount of the SrCO<sub>3</sub> component is typical.

The study of the UML dykes documented the magmatic history of these ultra-alkaline rocks. We suppose that this rock type plays a key role in the interpretation of the starting conditions of the Tertiary magmatism in the eastern part of the Bohemian



Fig. 8. A scheme of the crystallization history of the UML rocks from Ebersbach. A: Incorporation of phlogopite and clinopyroxene xenocrysts from a metasomatically transformed mantle by ultraalkaline melt. B: Partial resorption of the xenocrysts. C: Crystallization of phlogopite and clinopyroxene from ultraalkaline melt. D: Segregation of carbonatitic melt and crystallization of the groundmass micas. E: Formation of calcite-apatite ocelli, and penetration of mica megacrysts by carbonatitic melt. F: Hydrothermal alteration of the UML. Formation of calcite + serpentine + chlorite + opaque minerals pseudomorphs after clinopyroxene.

Massif in the Eger Graben region similar to the complexes of Osečná (Czech Republic) and Delitzsch (Germany).

# Acknowledgements

We thank Mr. Ch. Haase from Oppach for the first report on "large biotite-bearing dykes" in the Klunst quarry in 1995 and Mr. Neitsch (Lukas Gläser – Naturstein GmbH & Co KG) for the friendly support during sampling and R. Lobst (Stufa Bautzen) for discussion. The work benefited from discussions with the participants of the Hibsch 2002 meeting. J. Ulrych supported us with information about interesting details of melilitic rocks from the Czech Republic. Detailed and constructive reviews by J. Ulrych and an anonymous reviewer helped to improve the original manuscript.

# References

- COMODI P., LIU Y., STOPPA F. and WOOLLEY A.R., 1999. A multi-method analysis of Si-, S- and REE-rich apatite from a new find of kalsilite-bearing leucitite (Abruzzi, Italy). *Mineral. Mag.*, 63 (5): 661-672.
- DELANEY J.S., SMITH J.V., CARSWELL D.A. and DAW-SON J.B., 1980. Chemistry of micas from kimberlites and xenoliths. II. Primary- and secondary-textured micas from peridotite xenoliths. *Geochim. Cosmochim. Acta*, 44: 857-872.
- DIHN P. and KLEMENT R., 1942. Isomorphe Apatitarten. Z. f. Elektrochem. angew. phys. Chemie, 48 (6): 331-333.
- DUNWORTH E.A. and WILSON M., 1998. Olivine Melilitites of the SW German Tertiary Volcanic Province: Mineralogy and Petrogenesis. J. Petrology, 39 (10): 1805-1836.
- FARMER G.L. and BOETTCHER A.L., 1981. Petrologic and crystal-chemical significance of some deep-seated phlogopites. *Amer. Mineral.*, 66: 1154-1163.
- FOLEY S., 1990. Experimental constraints on phlogopite chemistry in lamproites: 2. Effect of pressure-temperature variations. *Europ. J. Mineral.*, 2: 327-341.
- GASPAR J.C. and WYLLIE P., 1987. The phlogopite from the Jacupiranga carbonatite intrusions. *Mineral. Petrol.*, 36: 121-134.
- HOGARTH D.D., 1989. Pyrochlore, apatite and amphibole: distinctive minerals in carbonatite. In K. BELL (Editor), *Carbonatites: Genesis and Evolution*. Unwin Hyman, London, pp. 105-148.
- KEMPE U. and GÖTZE J., 2002. Cathodoluminescence (CL) behaviour and crystal chemistry of apatite from rare-metal deposits. *Mineral. Mag.*, 66 (1): 151-172.
- LLOYD F.E., WOOLLEY A.R., STOPPA F. and EBY G.N., 2002. Phlogopite-biotite parageneses from the K-mafic-carbonatite effusive magmatic association of Katwe-Kikorongo, SW Uganda. *Mineral. Petrol.*, 74: 299-322.

- LÖSCH C., RENNO A.D., STANEK K.-P. and LOBST R., (2000). Petrology of Late Cretaceous ultramafic lamprophyres in the Lausitz-Massiv (Germany). Ber. Dtsch. Mineral. Gesell., Beiheft *Eur. J. Mineral.*, 12: 115.
- McCORMICK G.R. and LE BAS M.J., 1996. Phlogopite crystallization in carbonatitic magmas from Uganda. *Canad. Mineralogist*, 34: 469-478.
- MITCHELL R.H. and BERGMAN S.C., 1991. Petrology of Lamproites. Plenum Publishing Corporation, New York.
- RENNO A.D., STANEK K., LOBST R. and PUSHKAREV Y., (in press). New aspects to the Lusatian basic dike swarms – (1) Klunst quarry Ebersbach. Z. Geol. Wiss.
- RIEDER M., CAVAZZINI G., D'YAKONOV Yu.S., FRANK-KAMENETSKII V.A., GOTTARDI G., GUGGENHEIM S., KOVAL P. V., MÜLLER G., NEIVA A. M. R., RADOSLO-VICH E.W., ROBERT J.-L., SASSI F.P., TAKEDAH., WEISS Z. and WONES D.R., 1998. Nomenclature of the micas. *Canad. Mineralogist*, 36: 905-912.
- RØNSBO J.G., 1989. Coupled substitution involving REEs and Na and Si in apatites in alkaline rocks from the Ilimaussaq intrusion, South Greenland. *Amer. Mineral.*, 74: 896-901.
- SEIFERT W., KÄMPF H. and WASTERNACK J., 2000. Compositional variation in apatite, phlogopite and other accessory minerals of the ultramafic Delitzsch complex, Germany: implication for cooling history of carbonatites. *Lithos*, 53: 81-100.
- STOPPA F. and LIU Y., 1995. Chemical composition and petrogenetic implications of apatites from some ultra-alkaline Italian rocks. *Eur. J. Mineralogy*, 7: 391-402.
- STORMER J.C. Jr., PIERSON M.L. and TACKER R.C., 1993. Variation of F- and Cl- X-ray intensity due to anisotropic diffusion in apatite during electron microprobe analysis. *Amer. Mineral.*, 78: 641-648.
- TRONNES R.G., EDGAR A.D. and ARIMA M., 1985. A high-pressure, high-temperature study of TiO<sub>2</sub> solubility in Mg-rich phlogopite: implications to phlogopite chemistry. *Geochim. Cosmochim. Acta*, 49: 2323-2329.
- ULRYCH J., POVONDRA P., PIVEC E., RUTŠEK J., BENDL J. and BILIK I., 1996. Alkaline ultramafic sill at Dvůr Králové nad Labem, Eastern Bohemia: Petrological and geochemical constraints. *Acta Univ. Carol., Geol.*, 40: 53-79.
- ULRYCH J. and PIVEC E., 1997. Age-related contrasting alkaline volcanic series in North Bohemia. *Chem. Erde*, 57: 311-336.
- ULRYCH J., PIVEC E., POVONDRA P. and BENDL J. 1997. Geochemical and isotope characteristics of representative carbonates in young alkaline volcanites from northern Bohemia J. Czech Geol. Soc., 42 (1-2): 26-32.
- YOUNG E.J. and MUNSON E.L. (1966): Fluor-chlor-oxyapatite and sphene from crystal lode pegmatite near Eagle, Colorado. *Amer. Mineral.*, 51: 1476-1493.