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Ultrapotassic plutonic rocks of the durbachite series in the Bohemian Massif: Petrology, geochemistry and petrogenetic interpretation

Ultradraselné plutonity durbachitové série v Českém masivu: petrologie, geochemie a petrogenetická interpretace

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Abstract: Ultrapotassic plutonic rocks of Hercynian age are widespread in the southern (Moldanubian) part of the Bohemian Massif. The most prominent group of them is represented by the durbachite series comprising porphyritic amphibole-biotite melasyenite (durbachite), quartz melasyenite and melagranite, usually referred to as the Čertovo břemeno type. Mafic microgranular enclaves of ultrapotassic composition occur frequently in all members of the series.

All these rocks are highly magnesian and rich in Cr (Ni) as well as in many hygromagmatophile elements (namely Rb, Cs, U, Th). Their chemical composition corresponds to relatively Si-rich minettes and related melasyenite to melagranite porphyries which are common in Central and South Bohemia.

The mafic members of the durbachite series probably represent primitive, mantle-derived ultrapotassic magma which was only slightly modified by fractionation and (or) hybridization. The ultrapotassic magma probably originated within highly anomalous domains of the lithospheric mantle which have been modified by a strong depletion and subsequent, perhaps subduction-related, enrichment in some hygromagmatophile elements. Geochemical characteristics of the more acid members of the durbachite series, namely the high Mg and Cr, linear trends in simple variation diagrams and only slight decrease of Mg/(Mg+Fe) values with increasing silica, are compatible with an origin by mixing of the ultrapotassic mafic magma with (leuco)granitic melts, perhaps derived from the continental crust.

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Introduction

Ultrapotassic rocks are defined as abnormally rich in potassium in combination with high content of MgO; according to Foley et al. (1987) both K_2O and MgO exceed 3 wt. % and K_2O/Na_2O ratio is > 2. Great majority of the ultrapotassic occurrences scattered over the world are represented by volcanic and hypabyssal rocks, whereas plutonic rocks of equivalent composition are scarce.

In contrast to other regions and to geologically younger units, some parts of the West-Central European Hercynides comprise unusually large volumes of ultrapotassic plutonic rocks besides innumerable dykes of ultrapotassic lamprophyres. These plutonic rocks are called durbachites, MgK-syenites, vaugnerites, stavrites, etc.

Among these ultrapotassic plutonic rocks, the most voluminous suite is the group of durbachitic rocks (the durbachite series) represented by porphyritic amphibole- biotite quartz-bearing melasyenites to melagranites.

The name durbachite was introduced by Sauer (1893) who has described this unusual melasyenite from the Black Forest (Schwarzwald). Rocks of this group are much more widespread in the Vosges (Jung 1955; Von Eller 1961; Gagny 1968; Fluck 1980) and in the southern part of the Bohemian Massif (Hejtman 1949; Holub 1977). All occurrences are situated within the Moldanubian zone of the Hercynian belt. In close spatial and probably also genetic association there are other ultrapotassic varieties including ultramafitites.

Peculiar appearance and composition of durbachitic rocks attracted attention of many petrologists for a long time. Consequently, a wide spectrum of petrogenetic hypotheses has been established and until now many geologists consider these rocks as rather enigmatic in origin.

The present paper is focused on petrology, chemical composition and petrogenesis of durbachitic rocks occurring in the Bohemian Massif. Nevertheless, problems of their origin are discussed regardless of geographic boundaries.

Field relations and age

In the Bohemian Massif, occurrences of durbachitic rocks are confined to the area of the Moldanubian crystalline complex (Moldanubicum). This high-grade complex comprises metasedimentary and metaigneous rocks of Early Proterozoic to Lower Paleozoic age which were strongly metamorphosed during the Hercynian orogeny under conditions of high-P, high-T, to low-P granulite and amphibolite facies (Vrána 1989).

This metamorphic complex has been intruded by vast amounts of Hercynian granitoid rocks forming the Central Bohemian Plutonic Complex (CBPC) and the South Bohemian or Moldanubian Batholith (SBB), as well as by many masses of the ultrapotassic suite. The ultrapotassic masses range in surface areas from very small bodies (<1 km in diameter) to plutons as large as hundreds km^2 in area (Fig. 1).

In South Bohemia, the durbachitic and related rocks are concentrated within a zone of NNE-SSW direction which is about 130 km long and up to 25 km wide. This zone links the eastern part of CBPC with the western branch of SBB and runs across the Šumava part of the Moldanubian Complex. The zone comprises the Milevsko massif (about 220 km^2, sometimes called "the main complex of the Čertovo břemeno type") with several satellite masses and dykes in CBPC, the Mehelník massif and numerous small masses in the vicinity of Písek, Vodňany and Prachatice, the Netolice massif and, at the southern end of the zone, the Knížecí Stolec (or Želnava) massif (90 km^2) in the Šumava Mts.

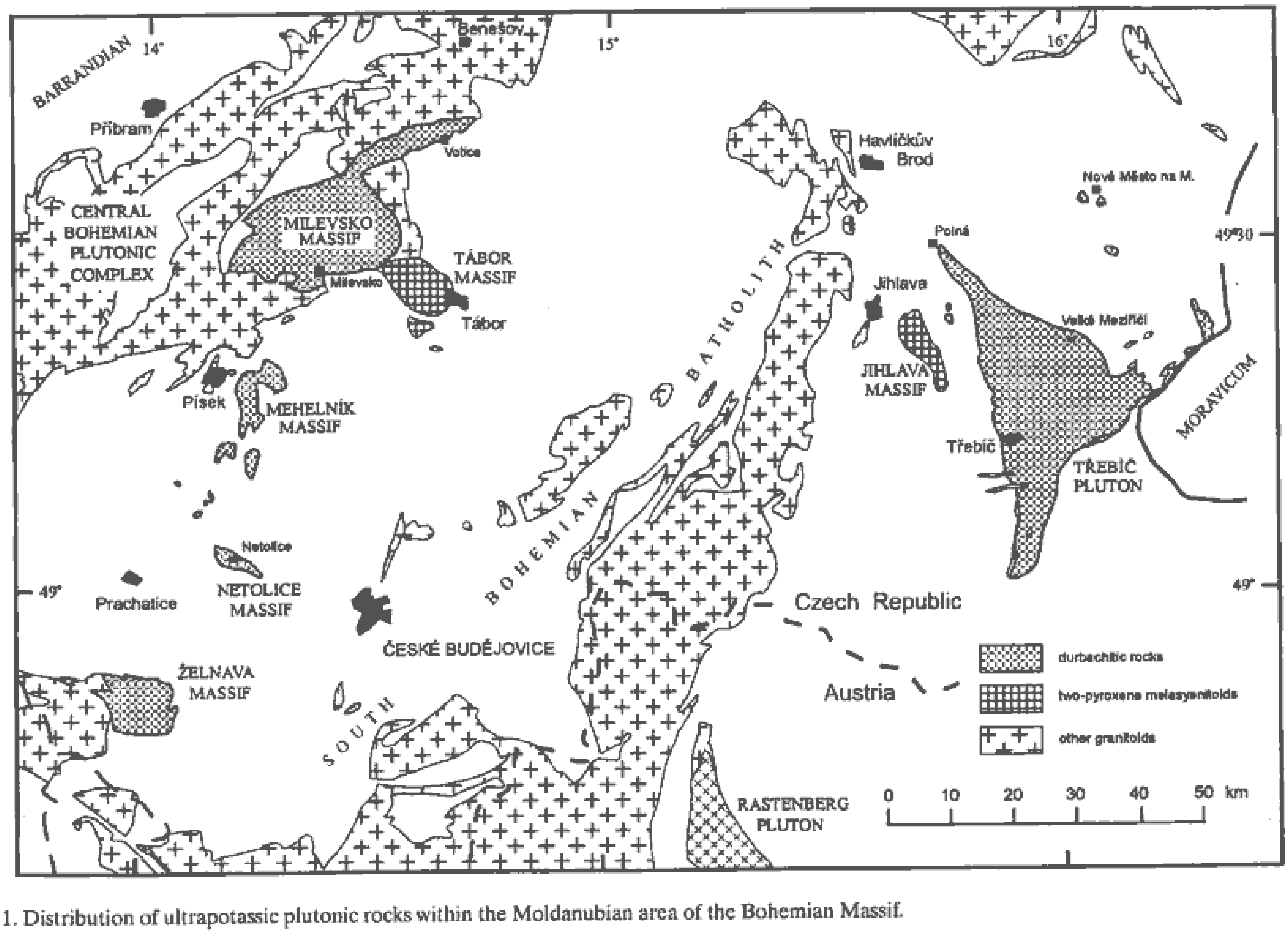
Other durbachitic bodies crop out in the eastern, i.e. Moravian, part of the Moldanubicum. The Třebíč Pluton (500 km^2) is the largest known body of durbachitic rocks. Around it, there are several small satellite bodies outcropping at Nové Město na Moravě and W of Tišnov.

Many other K-rich rocks are spatially associated to the durbachite series. In the eastern part of the Central Bohemian Plutonic Complex, the durbachitic rocks are accompanied by more acid, K-Mg-rich granites of the Sedlčany and Zbonín types (see Holub et al., this volume). In the Šumava part of the Moldanubicum, many very small bodies (typical surface area is > 0.1 km^2) occur which are built of mafic to extremely mafic ultrapotassic rocks varying from amphibole-biotite melasyenite and melagranite to quartz meladiorite and even to stavrite, i.e. the amphibole-phlogopite ultramafic rock (Vrána 1963; Hejtman 1975).

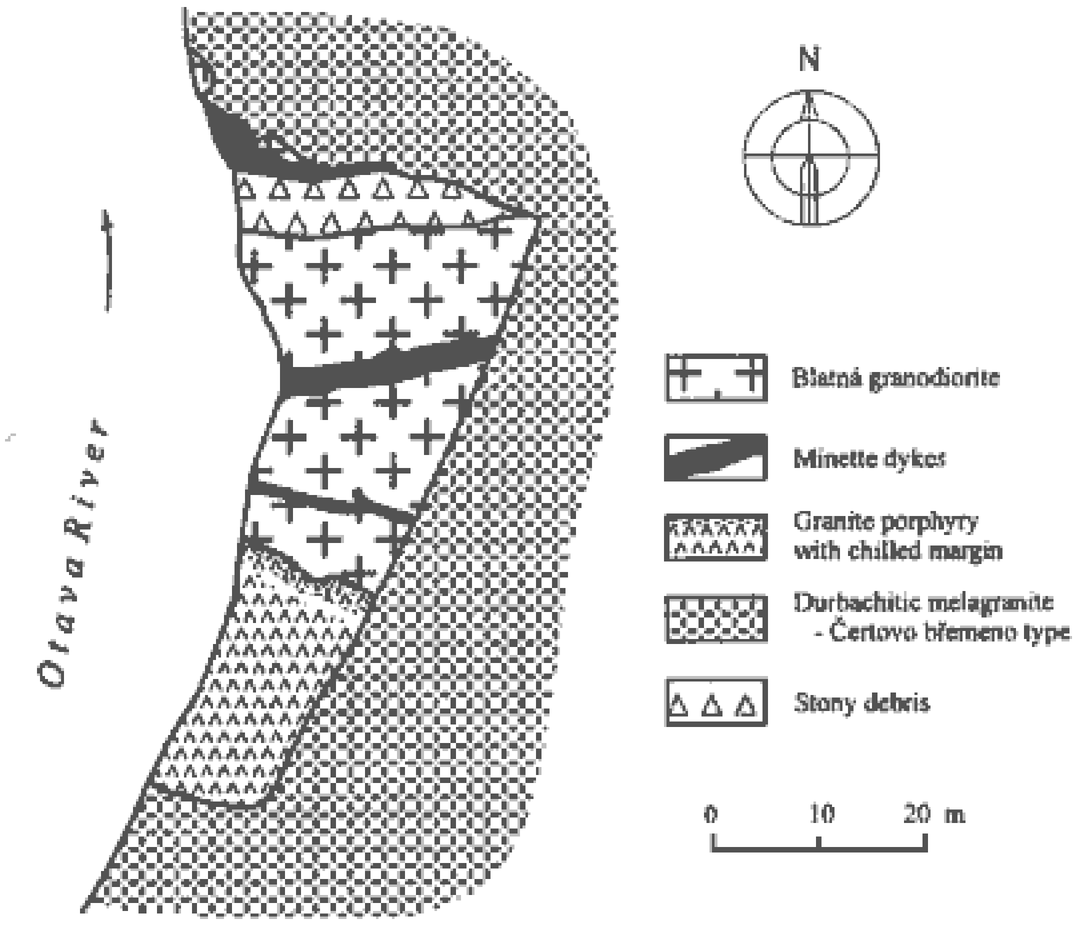
Biotite-clinopyroxene-orthopyroxene melasyenites to melagranites form the Tábor and Jihlava masses cropping out in vicinity of the Milevsko massif and the Třebíč Pluton, respectively. Moreover, numerous leucogranite dykes occur in close spatial association with many durbachitic intrusions.

As follows from the map (Fig. 1), the ultrapotassic rock occurrences are not confined to the major granitoid batholiths nor to any special type of surrounding rocks. They form rather independent rock suite which seems to be controlled by a particular structural pattern.

Large durbachitic massifs and particularly their marginal parts are relatively thin and were described as ethmoliths



1. Distribution of ultrapotassic plutonic rocks within the Moldanubian area of the Bohemian Massif.



2. Field relations of the durbachitic melagranite (the Čertovo břemeno type) in the Central Bohemian Plutonic Complex. Outcrop on the right bank of Otava River, 3 km S of Zvíkov Castle, N of Písek.

(Čech et al. 1961, 1962; Kodym jun. et al. 1961; Bubeníček 1968a). Conspicuously flat shape of the Třebíč Pluton has been proved by geophysical data (Rejl and Sedlák 1987). Shape of the Milevsko massif in CBPC was modelled gravimetrically by Dobeš and Pokorný (1988) as a subhorizontal, relatively thin tabular body with maximum thickness of about 2–3 km. From this shape it is clear that the Milevsko massif does not respect fabric of the surrounding granitoids nor the adjacent part of the Moldanubian complex with foliation planes dipping at moderate angles to NW.

Within the Moldanubian crystalline complex outside the CBPC, some spatial association of many durbachitic bodies with acid metamorphic rocks (granulites and orthogneisses, leucocratic migmatites etc.) has been reported (Marek and Palivcová 1968; Fiala et al. 1987). These acid rocks are widely assumed as forming the Gföhl nappe (terrane), transported and uplifted from the lower crust during Hercynian continental collision (e.g., Matte et al. 1990, and references therein).

In the Podolsko complex (E and S of Písek, Southern Bohemia), which is built mainly of leucocratic migmatites and migmatitic granites, the durbachitic rocks and other ultrapotassic varieties display complicated relationship to the surrounding rocks and occasionally (e.g., E of Písek) some "xenoliths of durbachites" (Röhlichová 1962) and lobate to finger-like contacts with migmatitic granites have been observed (e.g., Fišera et al. 1978).

In the area of CBPC, durbachitic rocks behave as relatively younger than granodiorites of the Blatná and Červená types (Urban 1930; Kodym jun. et al. 1963) and crosscut even some dykes of granodiorite to granite porphyries and minettes (Holub 1974; Holub and Žežulková 1978; see Fig. 2). Consequently, their intrusions postdate the calc-alkaline and high-K calc-alkaline suites of granitoids and associated mafic rocks (Holub et al., this volume).

Cooling age of about 336 Ma has been determined with Ar-Ar method on the durbachitic melagranite from the Milevsko body (Matte et al. 1990). Crystallization age of 343 to 346 Ma has been provided recently by the single-zircon evaporation method (Holub et al., in print). This age is relatively young among granitoids of the Central Bohemian Plutonic Complex but relatively old in respect to many granites of the South Bohemian Batholith.

Petrographic variability

Rocks of the durbachite series

These rocks are usually coarsely porphyritic with abundant K-feldspar phenocrysts in a dark medium-grained matrix (Fig. 3). The phenocrysts ranging from 10 to 30 mm in length with an average size of about 25 mm are tabular and twinned according to the Carlsbad law. Matrix is composed of abundant biotite, amphibole, K-feldspar, plagioclase and varying amount of quartz. Some clinopyroxene may be present as relics within amphibole crystals. Orthopyroxene has been reported rarely (Čech 1964) and its significant presence is restricted to a small durbachitic body at Písek.

In the IUGS modal classification (Le Maitre et al. 1989), the durbachitic rocks range from melasyenite to quartz melasyenite to melamonzogranite. Colour index (CI) varies from about 55 to 25. With decreasing CI, the amount of amphibole decreases more rapidly than biotite, and among felsic minerals, quartz and plagioclase become progressively more important.

Typical petrographic feature of all durbachitic rocks is the presence of scattered clots of very fine-grained, pale-green actinolite, conspicuously mantled by biotite; these clots ranging in size from < 1 to 5 mm closely resemble "pilite", well-known from many potassic lamprophyres, and may be interpreted as pseudomorphs after olivine (Holub 1974). They are different from common amphibole clots representing pseudomorphs after pyroxene in many calc-alkaline granitoids and their mafic enclaves (Castro and Stephens 1992).

The most typical accessory mineral is apatite reaching up to 3 vol. % in some durbachites and decreasing to about 1-1.5 % in melagranites. Other important accessory minerals are zircon, sphene, and frequently also allanite. Rutile, fluorite, topaz and scheelite were identified in heavy mineral assemblages (Johanová 1969; Kodymová and Vejnar 1974). Opaque minerals are rather scarce and usually represented by pyrrhotite which highly prevails over pyrite, pentlandite and other sulphides. Minute grains of chromite occur within actinolite of the pilitic pseudomorphs after olivine. Magnetite is typically absent.

Durbachitic rocks in the Bohemian Massif are usually called the Čertovo břemeno (ČB) type (Zelenka 1925). Their broad compositional variability has been recognized by Orlov (1933) who defined two principal subtypes; the darker one is more syenitic, the lighter subtype more "granodioritic" in composition. Later, the Čertovo břemeno type was subdivided into dark, "normal" and "leucocratic" facies (e.g., Zikmund 1974).

Common durbachitic rocks of quartz melasyenite and melagranite composition (some less mafic samples of the dark facies and especially the light or "normal" facies of ČB) correspond to Granite des Cretes in the Vosges (see Gagny 1968; Fluck 1980).

Sparsely porphyritic and finer-grained varieties of durbachitic rocks occur frequently in marginal parts of some bodies. A conspicuous rim of such border facies is developed in the Milevsko massif (Žežulková 1982a) and less regularly in the Třebíč Pluton (Němec 1982).

Some other varieties, which are even more different from common durbachitic rocks in texture and also in lower contents of amphibole and K-feldspar, occur in some localities very close to contacts of the Třebíč Pluton; these are referred to as "atypical durbachitic rocks".

For a long time, the name Čertovo břemeno type was used for durbachitic rocks in CBPC only, whereas the bodies within the Moldanubian complex were named the Rastenberg type (after the Rastenberg Pluton in Austria, Koller 1883) and both names were believed as synonymous (e.g., Čech et al. 1961, 1962; Kodym jun. et al 1964). The Rastenberg Pluton differs from true durbachitic rocks, however, and therefore only the Čertovo břemene type is used in the present paper.

Recently, the term durbachite is used by many authors for all members of the durbachite series and sometimes for even broader family of K-rich plutonic rocks from the Bohemian Massif irrespective of significant differences in their chemical composition, mineral assemblages and textures. In the present paper, the term durbachite is used in the original strict sense.

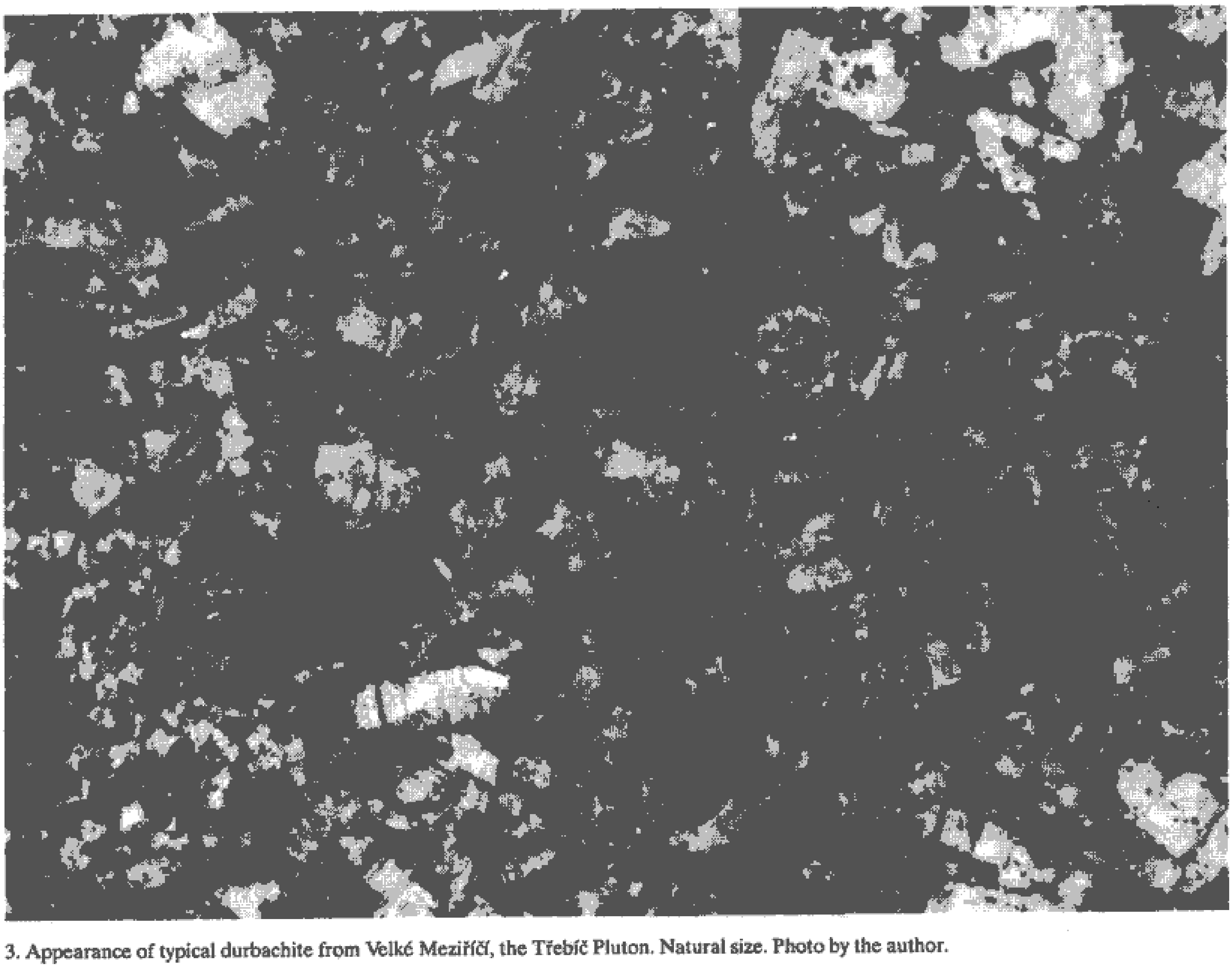
To avoid any confusion, the following paragraphs define the names of petrographic types and subtypes used in this paper:

Durbachite is very dark porphyritic amphibole-biotite melasyenite strongly resembling the rock from the type locality in the Black Forest (Sauer 1893) and durbachites from the Vosges. It represents the most mafic member of the durbachite series, i.e. the darkest variety of the Čertovo břemeno type. The CI is about 50 to 55 (cf. the excellent petrographic description by Hejtman 1949).

The *durbachite series* (DS) includes both durbachites and more acid rocks which are petrographically, mineralogically and geochemically closely related, i.e. the medium-dark and light facies of the Čertovo břemeno (ČB) type.

The *medium-dark facies of ČB* covers very common varieties of durbachitic rocks with CI from 45 to 35, usually corresponding to quartz melasyenite.

The *light facies of ČB* is represented by melagranitic varieties with CI commonly ranging from about 30 to 25.



3. Appearance of typical durbachite from Velké Meziříčí, the Třebíč Pluton. Natural size. Photo by the author.

Although some transitional rocks occur, they are relatively scarce and the principal three subtypes cover a great majority of samples.

The *border facies of ČB* includes finer-grained and less conspicuously porphyritic durbachitic rocks outcropping namely at margins of some bodies, e.g., of the Třebíč Pluton (Němec 1983).

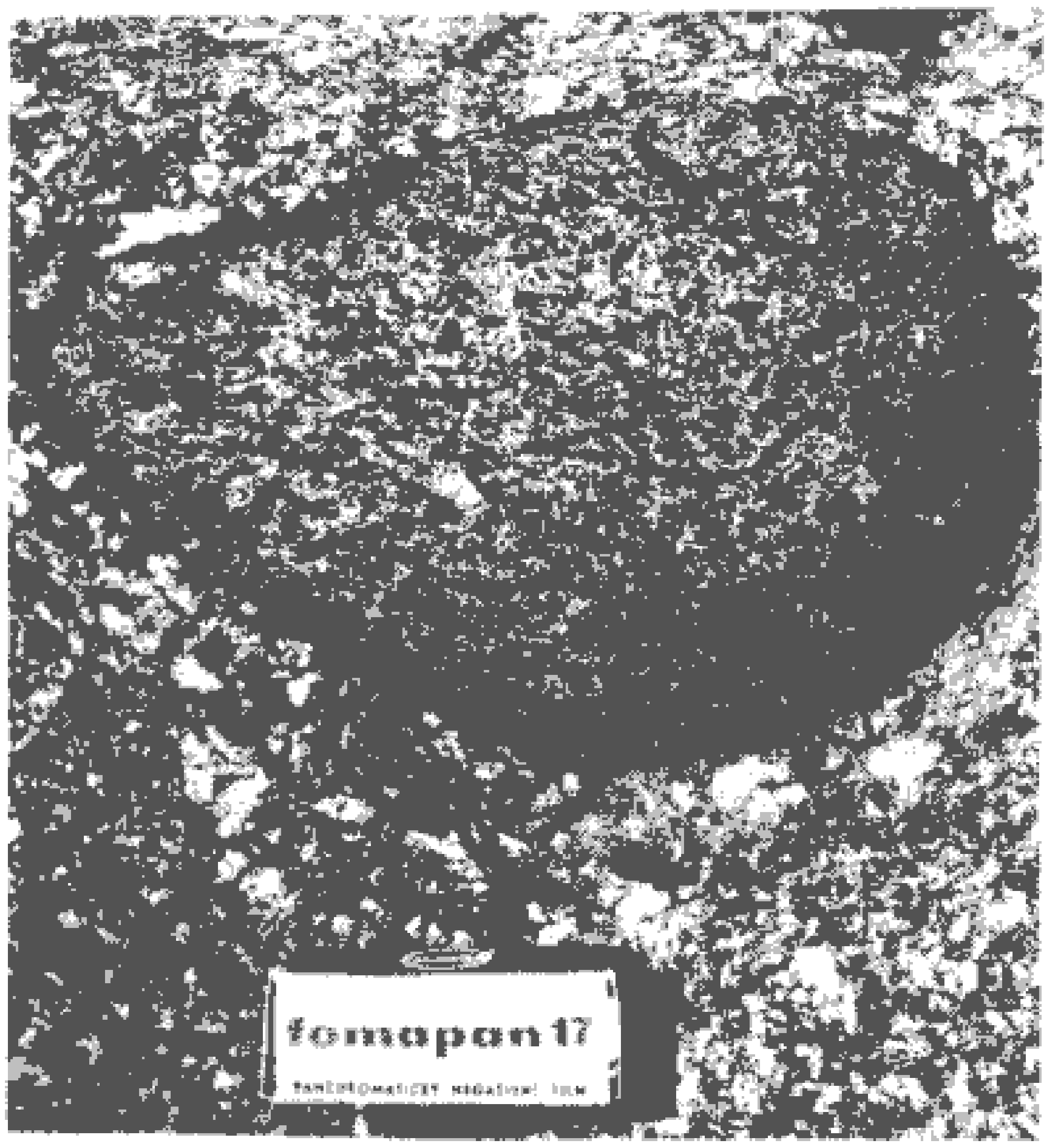
The *atypical durbachitic rocks* are local varieties occurring rarely along contacts of durbachitic bodies but differing from the border facies of ČB in composition (e.g., in scarcity of amphibole, less potassic nature, etc.).

Microgranular enclaves

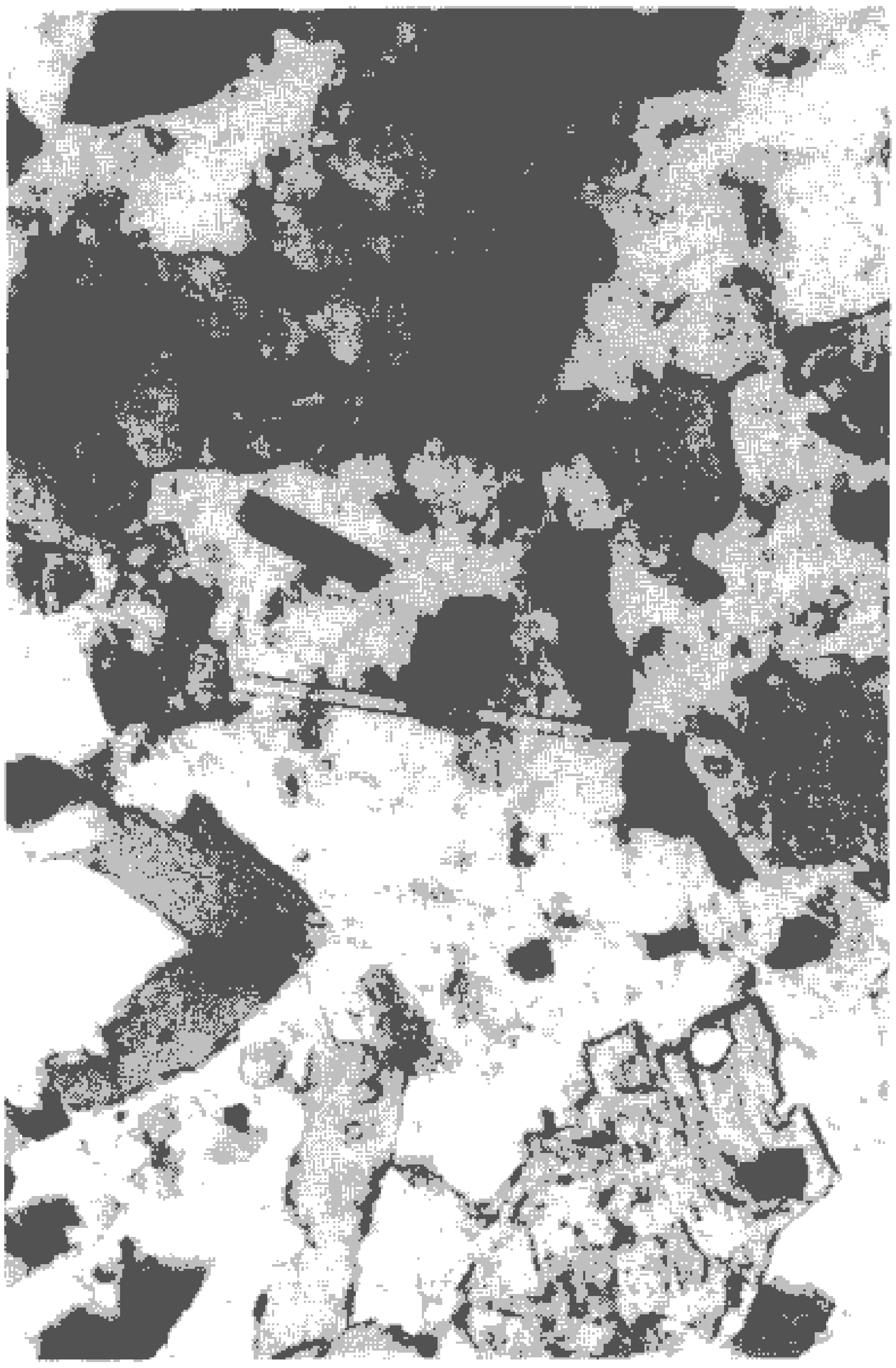
The common type of mafic microgranular enclaves ranges in composition from K-feldspar melasyenite to quartz-melasyenite (Holub 1974, 1977). The mineral assemblage is the same as that in the host durbachitic rocks but the enclaves are commonly darker, much finer-grained, and mostly free of feldspar phenocrysts or, less frequently, only sparsely porphyritic (Fig. 4). All microgranular enclaves contain small amphibole clots (replacing pyroxenes? – cf. Castro and Stephens 1992) and less frequent pilitic pseudomorphs. Very typical is presence of abundant apatite in acicular form (Fig. 5) which is so common in microgranular enclaves elsewhere.

Xenoliths

Diverse xenoliths occur frequently in all durbachitic intrusions; they cover a broad spectrum of rocks comprising fine-grained biotite gneisses to hornfelses, alumina-rich gneisses to typical surmicaceous enclaves of restitic character (Holub 1980), less frequently quartzites and calc-silicate rocks, marbles, amphibolites, sometimes also acid orthogneisses and retrogressed granulites. In CBPC, the durbachitic rocks carry blocks of older granitoids. A special group of xenoliths is represented by small inclusions of amphibolized and phlogopitized ultramafic rocks (e.g., Lensch and Rost 1966), rarely containing relics of pyroxenes, olivine, Cr-rich spinel or kelyphitic pseudomorphs after garnet.



4. Dark microgranular enclave in the medium-dark variety of the Čertovo břemeno type. Bezděkov, 12 km NE of Milevsko. Foto by the author.



5. Acicular apatite and biotite-amphibole clots in a microgranular enclave from the light variety of the Čertovo břemeno type (durbachitic melagranite), Zvíkovské Podhradí. Plane-polarized light, x50. Foto by the author.

Mineralogy

Mica

Red-brown to foxy-red biotite is the major ferromagnesian mineral of the durbachitic rocks. It is always high in magnesium (*mg* 62–72) and namely in durbachites it may reach the composition of phlogopite with Mg/Fe >2 (Table 1). Relatively high titanium content is characteristic (TiO_2 usually 3–4 %, only rarely in the darkest rocks below 3 %)

Table 1. Representative microprobe analyses and structural formulas of mafic minerals (in %)

No.	1	2	3	4	5	6	7	8	9	10	11
Rock	LČB	DČB	DČB	D	D	LČB	LČB	LČB	D	D	LČB
Mineral	cr	opx	cpx	amp	amp	amp	amp	amp	bi	bi	bi
SiO_2	0.25	54.15	53.61	52.60	56.27	54.47	51.93	56.06	37.89	37.71	37.80
TiO_2	1.70	0.22	0.08	0.55	0.08	0.16	0.54	0.04	3.36	4.19	4.06
Al_2O_3	6.21	1.12	0.53	4.12	1.03	1.05	3.53	0.60	14.89	14.36	14.12
Cr_2O_3	52.22	–	–	0.08	0.00	0.16	0.06	0.04	0.15	0.17	0.15
FeO_{tot}	36.06	19.55	8.64	10.48	8.60	10.45	10.64	9.23	13.86	14.79	15.38
MnO	0.67	0.37	0.30	0.32	0.32	0.51	0.30	0.16	0.13	0.13	0.20
MgO	1.40	23.90	14.91	17.18	19.16	18.87	17.75	18.59	16.25	15.12	15.11
NiO	0.04	–	–	0.04	0.00	0.07	0.01	0.00	0.02	0.02	0.04
CaO	0.91	0.48	22.02	11.38	12.26	12.08	12.25	12.97	0.00	0.04	0.03
BaO	0.00	–	–	0.00	0.00	0.00	0.00	0.03	0.00	0.07	0.00
Na_2O	0.00	0.00	0.17	0.81	0.25	0.31	0.74	0.05	0.08	0.06	0.15
K_2O	0.00	0.00	0.00	0.34	0.07	0.10	0.30	0.04	9.55	9.20	9.58
Si	0.07	1.99	1.99	7.43	7.89	7.75	7.41	7.92	5.58	5.59	5.59
Al(IV)	–	0.01	0.01	0.57	0.11	0.18	0.59	0.08	2.42	2.41	2.41
Al(VI)	2.09	0.04	0.01	0.11	0.06	–	0.00	0.02	0.16	0.10	0.05
Ti	0.37	0.01	0.00	0.06	0.01	0.02	0.06	0.00	0.37	0.47	0.45
Cr	11.80	–	–	0.01	0.00	0.02	0.01	0.00	0.02	0.02	0.02
Fe^{3+}	1.22	0.00	0.00	0.41	0.10	0.00	0.20	0.07	–	–	–
Fe^{2+}	7.40	0.60	0.27	0.87	0.91	1.24	1.07	1.02	1.71	1.83	1.90
Fe tot.	8.62	0.60	0.27	1.28	1.01	1.24	1.27	1.09	1.71	1.83	1.90
Mn	0.16	0.01	0.01	0.04	0.04	0.06	0.04	0.02	0.02	0.02	0.03
Mg	0.60	1.31	0.83	3.62	4.00	4.00	3.78	3.91	3.57	3.34	3.33
Ni	0.01	–	–	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Ca	0.27	0.02	0.87	1.70	1.82	1.82	1.85	1.94	0.00	0.01	0.00
Ba	0.00	–	–	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na	0.00	0.00	0.01	0.22	0.07	0.21	0.01	0.02	0.02	0.02	0.04
K	0.00	0.00	0.00	0.06	0.01	0.02	0.06	0.01	1.79	1.74	1.81
mg	6.5	68.5	75.5	74.5	79.9	76.3	74.8	78.2	67.6	64.6	63.7

Fe^{3+} and Fe^{2+} were calculated from stoichiometry
D – durbachite, DČB – medium-dark facies of the Čertovo břemeno type, LČB – light facies of the Čertovo břemeno
cr – chromite, opx – orthopyroxene, cpx – clinopyroxene, amp – amphibole, bi – biotite or phlogopite
Localities: 1, 6, 7, 8, 11 – Vepice (CBPC); 2, 3 – Písek; 4, 5, 9, 10 – Chlumek (Třebíč Pluton)

and is responsible for reddish colour in the Y, Z direction (Fiala et al. 1976; Minařík et al. 1988). The octahedral Al is very low or even negligible, much lower than Ti.

Amphibole

Amphibole is conspicuously pale green showing only weak pleochroism. According to "wet" analyses (Poubová 1971, 1974; Vaněčková 1984; Minařík et al. 1988), its composition is relatively Si-rich, corresponding in the Leake's (1978) classification to actinolitic hornblende to actinolite. In comparison to common mafic and granitic rock types from CBPC, amphibole of durbachitic rocks is not only Al-poor but also much more magnesian (*mg* 71–78) and relatively rich in Cr and Ni (Poubová 1974).

Microprobe data exhibit some important compositional variations within amphibole crystals. Inner parts of well-developed crystals consist of actinolitic hornblende, whereas the rims and also some small spots within grains (presumably replacing original clinopyroxene) correspond to actinolite which is more magnesian and very low in Ti and alkalis (Table 1). Actinolite of similar composition constitutes also the pilitic pseudomorps which may contain some chromite inclusions (Table 1, no. 1).

Amphiboles of the durbachitic rocks have their counterparts in some dyke rocks from the CBPC and its southern vicinity (Žežulková 1982b); actinolitic hornblende seems to be true magmatic mineral in melagranite porphyries whereas actinolite replaces original pyroxenes and olivine in many minettes.

Pyroxenes

Although pyroxenes are not very characteristic minerals of the durbachite series, small relics of diopside may occur frequently in cores of relatively large amphibole crystals. However, content of clinopyroxene may increase in some places, particularly in the finer-grained, less porphyritic border facies. The rare pyroxene-bearing porphyritic variety from Písek contains both ortho- and clinopyroxene poor in alumina. Orthopyroxene is weakly zoned with 64 to 73 mol. % enstatite. Clinopyroxene corresponds to diopside $En_{41-44}Fs_{12-15}Wo_{44}$.

Potassium feldspars

Bulk composition of K-feldspar phenocrysts from the durbachitic rocks of the Milevsko massif was studied by Minařík and Povondra (1976). They reported very narrow range of major components (Or 65.5 to 79.1 mol. %) and some relationship between minor elements in K-feldspars and colour index of the rock; K-feldspars in dark varieties are higher in Ba and Sr but lower in Rb relative to the light facies. Němec (1975) reported increasing Ba contents with increasing size of individual phenocrysts from the Třebíč Pluton and interpreted this phenomenon as an evidence of their magmatic origin.

Triclinity of K-feldspar phenocrysts was investigated by Němec (1976), Neužilová (1978) and Vaněčková (1984). The values derived from X-ray diffraction study range from $\delta = 0.00$ (orthoclase) to almost maximum microcline with δ about 90, regardless of the colour index of the host rock. In the Třebíč Pluton, triclinity seems to vary systematically with higher values in the central part of the massif.

Plagioclase feldspars

Hamtilová (1969, 1971) reported average An contents ranging from 34 to 36 % for all varieties of durbachitic rocks from the Milevsko massif. Plagioclases in other durbachitic bodies are very similar. Compositional zoning of individual crystals is rather weak with the highest An-contents rarely exceeding 40 mol. %.

Geothermometry and geobarometry

Minařík and Povondra (1976) calculated equilibration temperatures of K-feldspar and biotite as about 740 °C in the dark facies and about 650 °C in the light facies of the Milevsko massif.

Minařík et al. (1988) estimated crystallization temperatures of biotite and amphibole in the range between 650 and 750 °C applying diagrams. They pointed out some disequilibrium symptoms and variations in Fe^{3+}/Fe^{2+} ratio which they interpreted as an evidence of a wide range of crystallization conditions including variable values of oxygen fugacity during assumed metamorphic-recrystallization processes.

In fact, the high and variable values of Fe^{3+}/Fe^{2+} ratio reported by Minařík et al. (1988) are rather doubtful as follows from contradicting results of other analyses of the same minerals (e.g., Fiala et al. 1976) and numerous bulk analyses of the rocks which show very low oxidation ratios of Fe.

Hejtman (1975) applied the same method to amphibole-biotite pairs of much more mafic ultrapotassic rocks from the vicinity of Prachatice. The resulting equilibration temperatures are higher (above 700 °C) and most of them range between 750 and 850 °C.

Temperature of primary magmatic crystallization can be determined on the pair orthopyroxene-clinopyroxene. The two-pyroxene geothermometer calibrated by Wells (1977) provides equilibration temperatures of 900-950 °C for pyroxenes in the pyroxene-bearing body at E margin of Písek (see Table 1).

In contrast to pyroxenes, the actinolitic hornblende probably crystallized from the magma relatively late in the crystallization history under increasing activity of water. Actinolite replacing relics of pyroxenes inside the actinolitic hornblende and forming relatively thin rims appears to be of post-magmatic origin.

Estimation of pressure conditions under which the durbachite rocks crystallized is problematic. The Al-in-hornblende geobarometer for biotite-hornblende granitoids, for instance the recent experimental calibration by Schmidt (1992), yields extremely low and unlikely pressures (0–0.5 kb). Either the correlation of Al^{tot} with pressure is not linear bellow about 3 kb (and the low-Al amphibole does, indeed, indicate rather low-pressure conditions), or the calibration is quite unsuitable to these potassium-rich rocks though their mineral assemblage is almost the same as in common calc-alkaline granitoids except for absence of magnetite.

Geochemistry

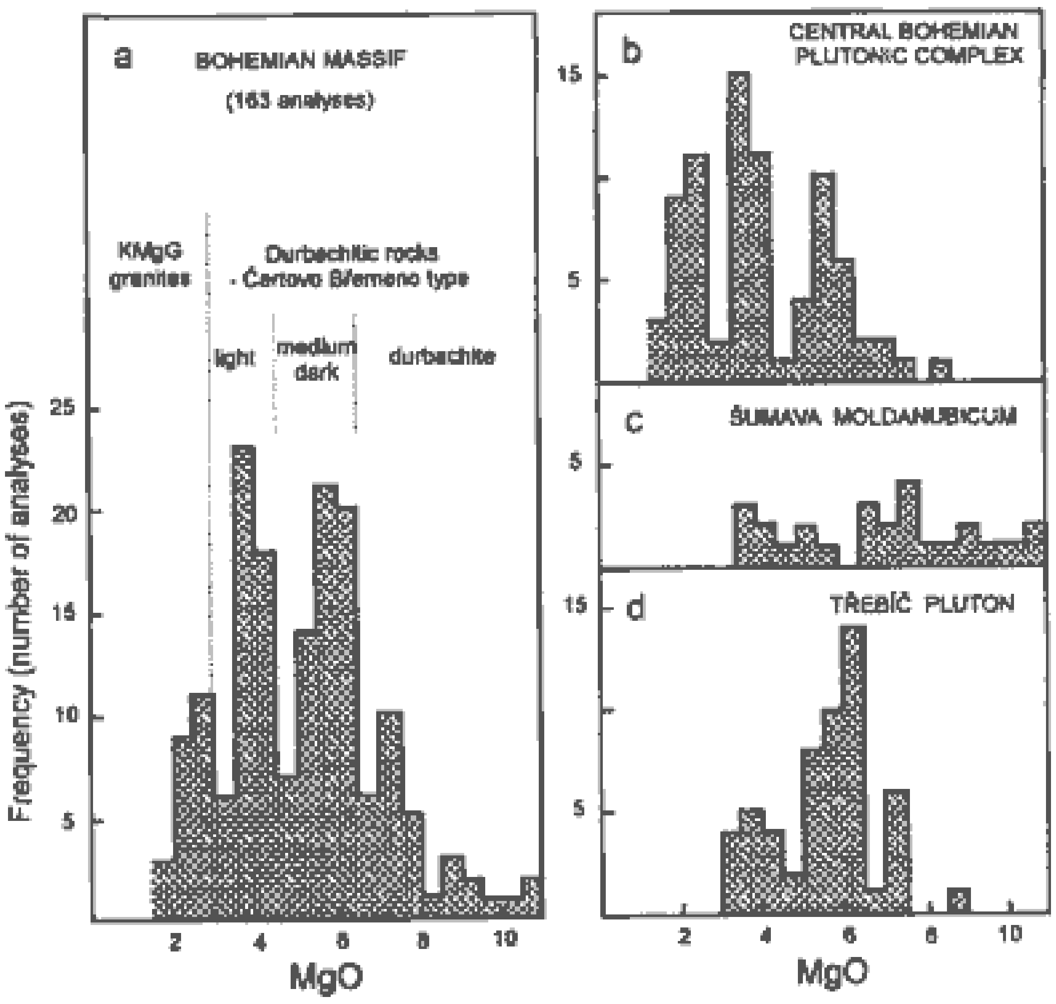
Representative whole-rock analyses of durbachitic rocks from the Bohemian Massif are listed in Table 2. These and numerous other analyses were used for construction of histograms of MgO contents (Fig. 6) and variation diagrams (Fig. 7, 8, 9). Also shown are analyses of selected microgranular enclaves and ultrapotassic rocks forming small bodies related to the durbachite series.

Major oxides

Typical ultrapotassic composition of the durbachitic rocks is characterized by high but variable MgO (10 to 3 %) and high K_2O (4.5–7.5 %, mostly 6–7 %). Markedly low are contents of Na_2O and CaO; the CaO/MgO ratio is always low, being < 1 (usually < 0.5) regardless of the silica content. Silica is relatively high even in the most mafic varieties (about 51 to 54 % in rocks containing more than 8 % MgO) and increases up to 66 % in the most acid melagranites containing 4–3 % MgO (Fig. 7). Typical is a narrow range of relatively low alumina contents with only small local deviations.

Inter-element relations are simple and the type of chemical variation is uniform despite of geographic distances between individual bodies and of some degree of bimodality to polymodality in abundance of many elements, e.g., MgO (Fig. 6).

Common element-element variation diagrams display linear trends between the most mafic and most acid members of DS, i.e. the durbachite and melagranite. The best



6. Histograms showing distribution of MgO (wt %) in ultrapotassic plutonic rocks of the durbachite series and associated potassic magnesian granites (KMgG) from a) southern part of the Bohemian Massif as a whole, b) area of the Central Bohemian Plutonic Complex, c) area of the Šumava Moldanubicum S of CBPC, and d) the Třebíč Pluton and satellite bodies.

linear correlation is shown by MgO, total FeO, TiO_2, and P_2O_5, which are inversely proportional to silica.

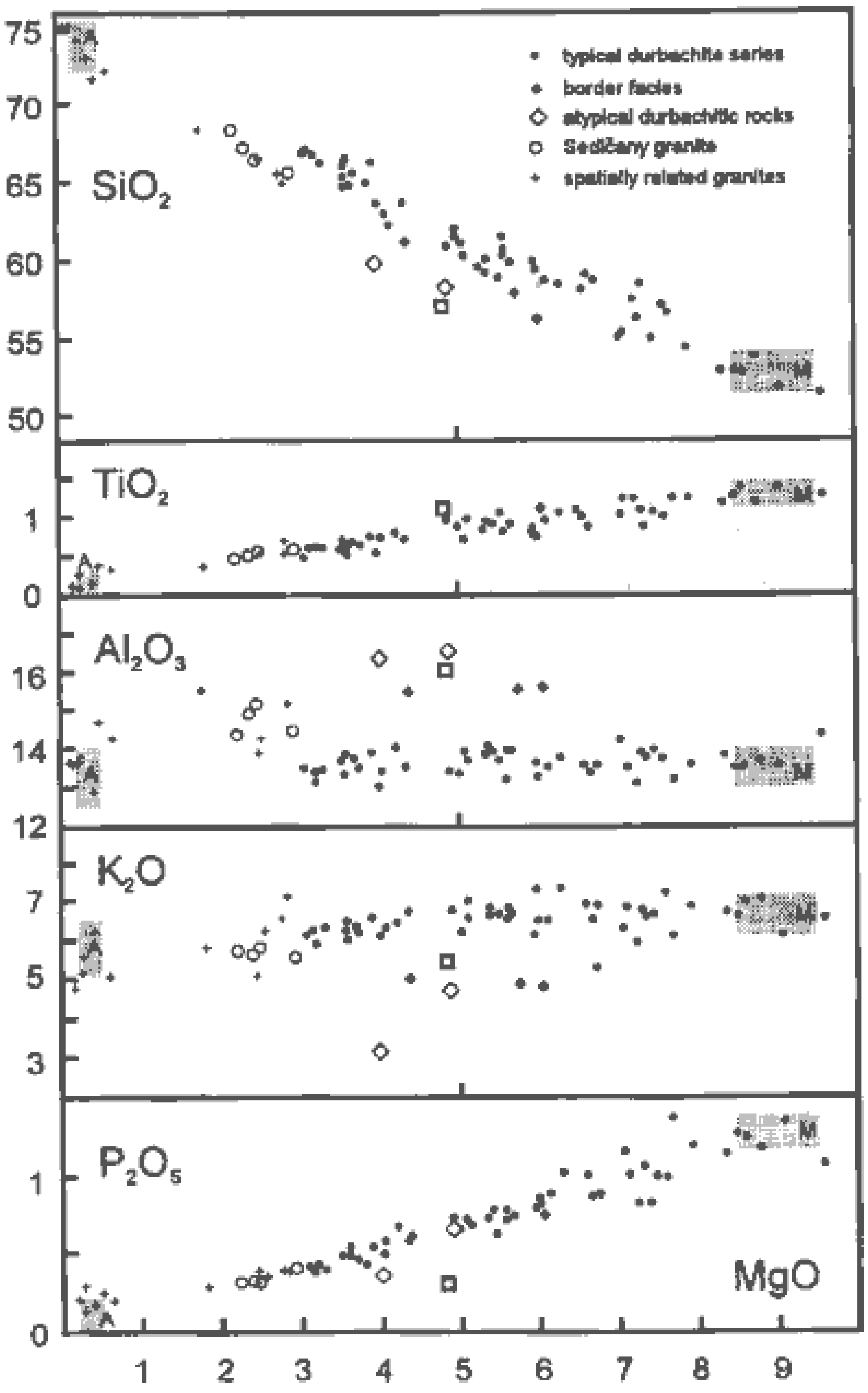
Typical durbachitic rocks are metaluminous with increasing molar $Al_2O_3/(CaO+Na_2O+K_2O)$ towards more acid varieties up to values close to 1. The CIPW norms display a slightly undersaturated (Ol+Hy normative) character of durbachites, whereas the medium-dark facies of the Čertovo břemeno type is saturated to slightly oversaturated and the light facies considerably oversaturated in silica (normative Q about 12 to 18 %).

Atypical rocks from endocontacts of some durbachitic bodies with paragneisses are lower in K_2O and higher in Na_2O and Al_2O_3; sometimes they are slightly peraluminous (C-normative) and their *mg*-values are lower than those in typical durbachitic rocks of similar SiO_2 content.

Dark microgranular enclaves display generally high MgO combined with relatively high SiO_2 and very high K_2O/Na_2O (3-6). Many samples are more magnesian (MgO 9–12 %, mg-value 69-76) and lower in alumina compared to durbachites and, though still metaluminous, approach composition of some lamproites (cf. Foley 1992). Such enclaves correspond to the "ultrapotassic rocks with high-MgO, high-SiO_2 affinities" which were discussed by Foley and Venturelli (1989).

Trace elements

Trace element patterns in durbachites are peculiar in respect to common mafic rocks but more or less similar to many other ultrapotassic varieties. Durbachitic rocks as a group are characterized by markedly high contents of Cr and Ni as well as many hygromagmatophile elements, namely Rb, Cs, Ba, Th, and U.

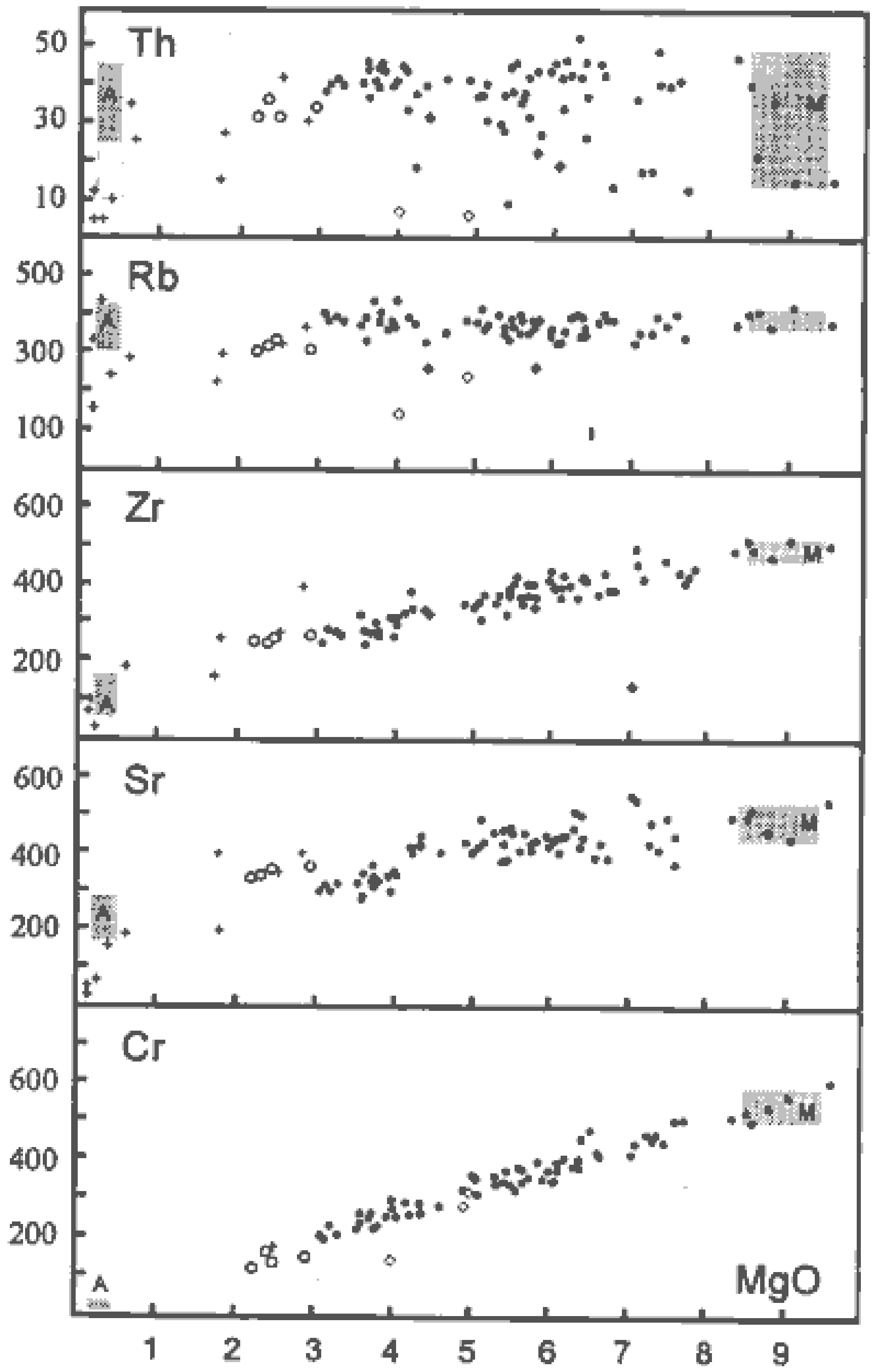


7. Variation diagrams of selected major and minor elements (wt % oxides) for durbachitic rocks and related potassic magnesian granites M and A are compositional fields of hypothetical mafic and acid end-members, respectively (see p. 19).

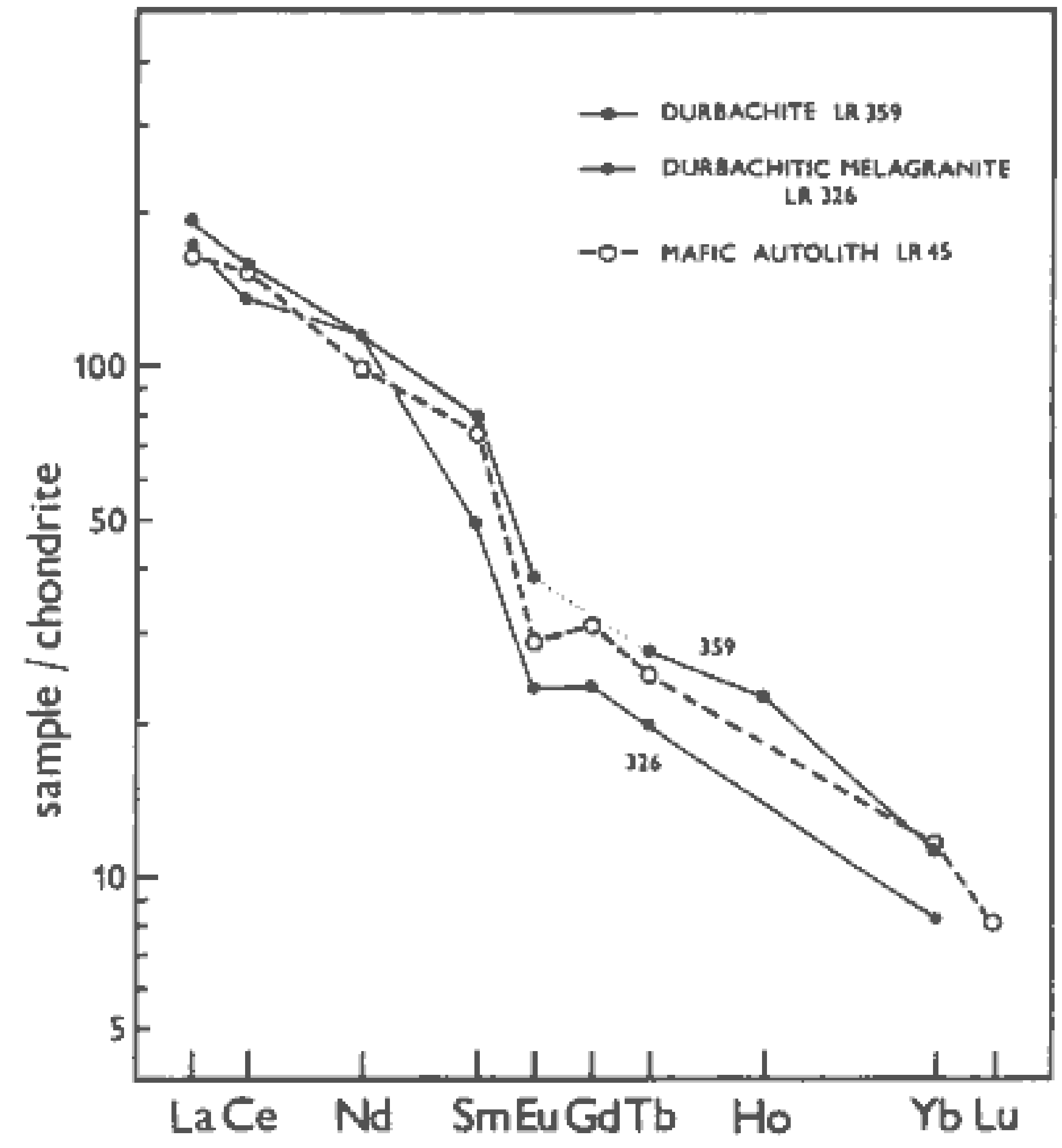
Contents of Cr and Ni in durbachites are as high as 500 and 180 ppm, respectively, and decrease linearly with increasing SiO_2 (Fig. 8). Even in the most acid members of DS (65–66 % SiO_2), contents of Cr are above 200 ppm and Ni about 70 ppm, the values comparable to many basalts. The Cr/Ni ratio varies in a narrow range of 2.5 to 3.5. Contents of Co, V, and Sc are rather low in respect to Cr and decrease with decreasing MgO.

Some other elements like Zr, Hf, Ba, and Sr decrease with increasing silica and, consequently, they correlate positively with Cr and MgO and show linear trends. Both Ba and Sr display broader scatter in variation diagrams relative to other elements, however (Fig. 8).

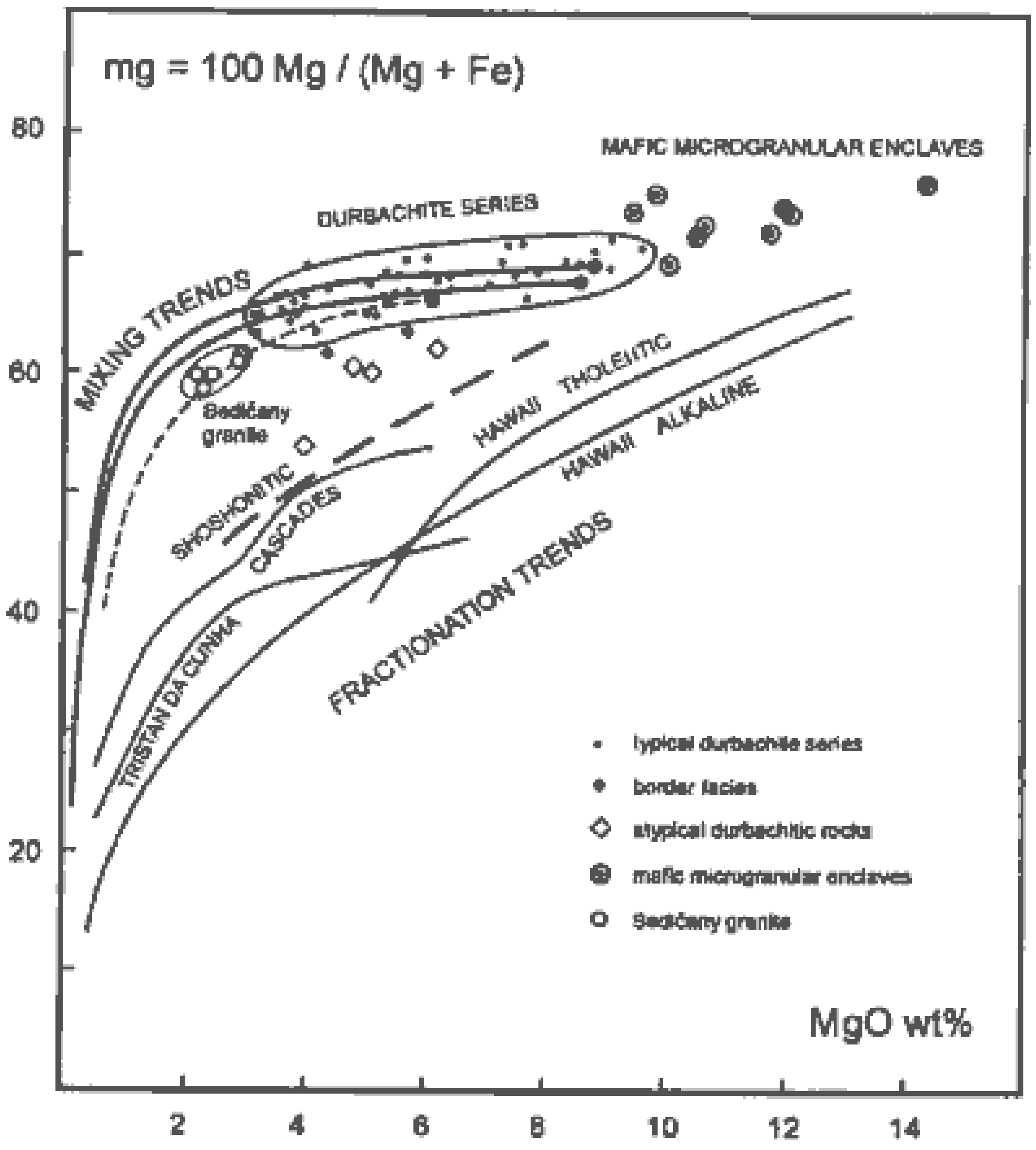
Concentrations of Rb are very high (in the range of 330–430 ppm) and drop below 300 ppm only in some relatively Al-rich samples of the border facies and atypical rocks from endocontacts. The K/Rb ratio is fairly low and almost uniform (120–160). Durbachitic rocks are unusually rich in Cs and K/Cs ratio is much lower than in common rocks.



8. Variation diagrams of selected trace elements (ppm) versus wt % MgO for the durbachitic rocks and related potassic magnesian granites.



9. Chondrite-normalized REE pattern for typical durbachite, durbachitic melagranite and a microgranular enclave. Normalizing values are from Boynton (1984).



10. The *mg*-number versus MgO (wt %) plot for rocks of the durbachite series and some related potassic granites. Three calculated mixing-curves and some trends of typical fractionation series are shown for comparison.

Strontium is markedly deficient relative to other lithophile elements and, consequently, Rb/Sr values are considerably high even in the mafic members of DS.

Chondrite-normalized REE patterns display a conspicuous enrichment in light REE (Fig. 9) with Ce_N/Yb_N about 10 to 14, and a weak negative Eu-anomaly (Eu/Eu^* about 0.8–0.9). Contents of REE vary only slightly although there is some tendency to higher contents of light REE in more mafic members of DS (Ce is typically above 110 ppm in durbachites and below 105 ppm in the light facies of ČB).

Durbachitic rocks are known as highly radioactive due to very high contents of K, Th and U (Matolín 1970; Manová 1975; Holub 1978; Fiala et al. 1983). The Th/U ratio is rather low (mostly between 2.8 and 1.5). Contents of radioactive trace elements vary significantly but without any clear relation to the silica content. Individual bodies or some parts of large plutons may differ from each other in the level of Th contents; for instance, durbachites of the Milevsko and Mehelník massifs are characterized by Th contents ranging between 45 and 53 ppm whereas much lower contents (about 15 ppm) are typical for durbachites of the Netolice massif and some small bodies E of Písek. These variations cannot be correlated with other elements and probably belong to primary features of individual magma portions.

Table 2. Representative major- and trace-element analyses for plutonic rocks of the durbachite series and some associated rocks from southern Bohemia

No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Rock	D	D	D	D	DČB	DČB	LČB	LČB	LČB	ZbG	SdG	MR	MR	ME	ME
Sample	251	6	53	23	36	12	29/270	271	250	905	158	257	57	7	262
SiO_2	51.50	52.84	53.77	55.97	58.43	59.65	64.16	64.83	65.39	66.42	66.52	50.48	53.52	50.98	54.72
TiO_2	1.26	1.20	1.20	1.10	1.06	0.89	0.73	0.68	0.67	0.55	0.52	1.13	0.80	1.17	0.89
Al_2O_3	14.41	13.82	13.69	13.81	13.76	13.86	13.38	13.73	13.82	14.31	15.11	9.41	10.65	9.88	10.94
Fe_2O_3	8.03*	1.07	7.47*	1.17	6.58*	5.33*	0.68	0.51	0.68	0.79	3.29*	1.32	1.74	0.87	7.95*
FeO	–	5.65	–	4.73	–	–	3.26	3.14	2.84	2.21	–	5.66	5.92	6.59	–
MnO	0.11	0.11	0.10	0.10	0.09	0.08	0.07	0.067	0.061	0.049	0.054	0.132	0.121	0.14	0.163
MgO	9.58	8.35	8.81	7.32	6.29	5.32	4.04	3.71	3.61	2.53	2.48	14.37	13.23	11.89	10.59
CaO	5.04	4.57	4.58	4.00	3.71	3.19	2.92	2.18	2.22	1.37	2.23	5.74	4.39	7.26	5.12
Na_2O	1.90	2.14	1.54	2.03	1.7	1.97	2.51	2.45	2.38	2.45	2.9	1.15	1.12	0.99	1.3
K_2O	6.69	6.81	7.17	6.82	7.33	6.92	6.25	6.39	6.40	6.22	5.76	6.15	4.97	5.75	6.29
P_2O_5	1.07	1.13	1.17	1.05	1.01	0.73	0.57	0.45	0.48	0.36	0.32	1.34	0.74	1.35	1.06
H_2O^+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
mg	70.3	69.2	70.0	69.3	65.4	66.4	65.0	64.8	65.1	60.7	59.9	78.9	76.0	74.0	72.5
Ba	2450	2360	2410	2160	1980	2255	1210	1330	1420	1215	1200	1660	1520	2090	500
Ce	129	120	129	118	119	120	97	112	98	108	90	178	101	171	159
Cr	600	500	540	455	380	365	280	250	259	206	125	685	1350	825	745
Cs	–	17	22	18	22	18	40	–	–	–	34	15	58	17	95
Hf	–	15	14	–	11	–	10	–	–	–	–	11	8	11	11
La	–	52	55	–	–	–	–	–	–	50	–	71	47	66	66
Ni	165	184	184	151	160	101	75	–	–	58	29	493	210	318	286
Pb	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Rb	383	378	381	402	400	396	385	437	396	328	330	400	311	290	595
Sc	–	24	25	18	19	16	13	14	–	–	–	22	21	23	19
Sr	543	498	461	480	480	458	342	322	350	334	357	240	288	313	81
Ta	–	1.2	1.2	–	–	–	2.5	–	–	–	2.2	1.2	1.6	1.2	2.6
Th	15.8	47.7	38.5	49.1	52.6	29.5	41.5	40.8	45.5	41.5	31.4	26.0	38.0	49.8	65.5
U	7.9	18.8	–	17.9	18.5	11.5	20.9	19.3	13.2	19.2	17.8	10.5	–	16.5	16.6
U	–	15.5	14.7	–	–	–	26.6	–	12.3	–	–	10.1	11.1	18.0	–
V	112	83	80	75	80	–	50	46	45	33	36	74	100	60	68
Zn	–	127	100	107	–	–	70	72	69	52	62	94	110	136	123
Zr	513	500	475	449	389	352	311	269	301	284	260	443	280	384	349
K/Rb	145	150	156	141	151	145	135	121	134	162	145	125	133	164	89
Rb/Sr	0.71	0.76	0.83	0.84	0.85	0.86	1.12	1.36	1.13	0.92	0.92	1.7	1.1	0.94	7.3

* – total Fe as Fe_2O_3

D – durbachite; DČB – medium-dark facies; LČB – light facies; ZbG – Zbonín granite; SdG – Sedlčany granite; MR – mafic ultrapotassic rock; ME – microgranular enclave; BF – border facies of Čertovo břemeno type; ADR – atypical durbachitic rock; LG – leucogranite.

Area of the Central Bohemian Plutonic Complex and the Šumava Moldanubicum:

Durbachite series: 1/251 – E margin of Netolice (Netolice massif); 2/6 – Talín (Mehelník massif); 3/53 – Květuš (Milevsko massif, CBPC); 4/23 – Chyšky (Milevsko massif, CBPC); 5/36 – Chlum hill near Velká u Milevska (Milevsko massif, CBPC); 6/12 – pyroxene-bearing facies, E margin of Písek; 7/29 – quarry Vepice (Milevsko massif, CBPC); 8/271 – quarry Jistec (CBPC); 9/250 – Bavorovské Svobodné Hory (small body S of Vodňany).

Potassic granites: 10/905 – Zbonín granite, Zvíkovské Podhradí (CBPC); 1/1581 – Sedlčany granite, quarry Vápenice near Vysoký Chlumec (CBPC).

Melanocratic rocks of small bodies associated to durbachitic rocks: 12/257 – Prachatice; 13/56 – Svatá Anna S of Zvíkov. Microgranular enclaves: 14/7 – Talín; 15/262 – Kostelec nad Vltavou; 16/21 – Zvíkovské Podhradí.

and western Moravia (major oxides in eight per cent, trace elements in ppm)

16	17	18	19	20	21	22	23	24	25	26	27
ME	D	DČB	DČB	DČB	LČB	LČB	LČB	BF	ADR	ME	LG
21	359	322	354	341	326	27	352	338	349	45	345
58.87	52.70	58.69	58.67	60.53	65.64	66.22	67.11	61.14	58.31	57.71	74.30
1.06	1.27	0.88	0.95	0.79	0.62	0.63	0.58	0.84	0.96	0.75	0.05
13.69	13.53	13.79	13.52	13.94	13.51	13.34	13.39	15.49	16.55	11.21	13.80
0.52	0.98	6.01*	0.59	0.87	3.76	0.75	3.36	0.49	6.23	6.44*	0.37
5.16	6.02	–	4.63	3.69	–	2.70	–	4.33	–	–	0.36
0.10	0.11	0.08	0.085	0.075	0.05	0.06	0.045	0.078	0.076	0.115	0.033
6.49	8.51	7.37	6.13	5.61	3.77	3.60	3.15	4.38	4.90	9.83	0.25
3.70	4.92	3.37	3.88	2.91	2.68	2.54	2.30	3.41	4.04	4.27	0.60
2.11	1.63	1.90	1.97	2.44	2.70	2.64	2.40	2.52	3.00	1.08	3.32
6.18	6.67	6.66	6.59	6.55	6.24	6.00	6.20	4.93	4.72	6.91	5.47
0.59	1.25	0.81	0.87	0.71	0.43	0.55	0.40	0.61	0.66	0.83	0.29
–	1.20	–	0.91	1.01	–	–	–	1.04	–	–	0.38
67.3	68.7	70.8	67.9	69.1	66.5	65.5	65.0	62.1	60.9	75.2	39
1960	2300	2000	1985	1720	1255	1000	1115	1775	1975	2030	64
128	128	122	121	116	111	108	84	116	81	122	20
490	550	467	355	330	215	225	190	265	280	590	–
–	21	–	–	–	45	29	–	–	–	22	–
–	16	–	–	–	9	–	–	–	–	8	–
–	60	–	–	–	55	–	38	–	–	50	–
86	179	179	121	140	58	62	67	–	–	326	–
419	–	45	–	–	54	–	57	–	–	44	–
–	402	408	357	386	375	386	384	261	242	340	429
419	27	–	23	18	14	12	–	–	–	18	–
–	501	414	443	407	335	278	311	415	480	370	63
28.1	1.4	–	–	–	2.2	–	–	–	–	1.4	–
14.5	40.6	40.8	46.4	37.0	39.4	43.9	40.3	31.9	6.4	42.0	4.5
–	14.0	19.1	18.3	13.9	20.8	26.7	21.6	10.5	5.0	18.4	2.8
–	–	–	–	–	–	–	–	–	–	–	–
93	90	65	72	52	45	41	41	66	80	50	< 10
–	125	89	96	86	57	–	50	94	–	100	58
342	520	422	432	366	277	280	283	333	425	285	50
123	138	136	153	141	138	129	134	157	162	169	106
1.0	0.80	0.99	0.81	0.95	1.15	1.39	1.23	0.63	0.50	0.92	6.8

Area of the Třebíč Pluton:
Durbachite series: 17/359 – Chlumek; 18/322 – Kožichovice; 19/354 – Osové; 20/341 – Střítež; 21/326 – quarry near Kamenná; 22/27 – Kojatín; 23/352 Budišov; 24/338 – Jersín.
Atypical durbachitic rocks: 25/349 – Ohrazenice.
Microgranular enclaves: 26/45 Velké Meziříčí.
Leucogranites: 27/372 – Březka.

Uranium contents in fresh samples vary from about 12 to 27 ppm in typical durbachitic rocks and usually are below 10 ppm in the "atypical rocks" and sometimes also in the border facies.

Microgranular enclaves are geochemically similar to durbachites but their Cr and Ni are frequently even higher. Compared to durbachites, the most magnesian enclaves are lower in Sr, Zr and often in Ba, whereas Rb and Th are very high (Table 2).

Comparison with other K-rich plutonic rocks of the Hercynian belt

Table 3 provides comparison of chemical composition between durbachitic rocks from the Bohemian Massif and those from the Vosges and the Black Forest. Particularly for durbachites, the compositional uniformity regardless of geographic distances is striking. The Granite des Cretes is usually poorer in Rb relative to the Čertovo břemeno melagranites but in the Vosges there are many local varieties whose content of Rb is as high as 400 ppm (Fluck 1980). Also REE show similar concentrations including a weak negative Eu anomaly (Pagel 1982).

Table 3. Comparison of major-element chemistry of representative durbachitic rocks from the Bohemian Massif, the Black Forest, and the Vosges

No	1	2	3	4	5	6	7	8	9
Rock	D	D	D	D	D	MDF	MDF	LF	LF
Sample	251	6	–	–	101	VA38	–	29	–
Region	BM	BM	Sch	V	V	BM	V	BM	V
SiO_2	51.50	52.84	51.05	51.00	52.03	59.25	60.50	64.16	62.85
TiO_2	1.26	1.20	1.76$^{1)}$	1.45	1.54	0.94	0.92	0.73	0.79
Al_2O_3	14.41	13.82	14.49	14.40	14.29	14.01	13.80	13.38	14.40
Fe_2O_3	8.03*	1.07	4.16$^{2)}$	1.65	7.98*	5.60*	5.48*	0.68	1.16
FeO	–	5.65	4.37	6.20	–	–	–	3.26	3.13
FeO_{tot}	7.23	6.61	8.11	7.68	7.18	5.04	4.93	3.87	4.17
MnO	0.11	0.11	–	0.11	0.13	0.08	0.09	0.07	0.08
MgO	9.58	8.35	8.16	8.80	7.88	5.40	5.63	4.04	4.13
CaO	5.04	4.57	5.11	6.30	5.42	3.19	3.31	2.92	2.80
Na_2O	1.90	2.14	1.85	1.25	1.81	2.36	2.27	2.51	2.41
K_2O	6.69	6.81	7.24	6.35	7.29	6.71	6.67	6.25	6.48
P_2O_5	1.07	1.13	0.70	1.20	–	0.77	–	0.57	0.57

* – total Fe as Fe_2O_3

1) – including ZrO_2

2) – anomalously high Fe_2O_3 in the historical analysis of durbachite from Durbach probably represents an analytical artifact

BM – Bohemian Massif; Sch – Black Forest (Schwarzwald); V – Vosges

References: 3 – Sauer (1893); 4 – Jung and Chenevoy (1951); 5 – Fluck (1980); 7 – Gagny (1968), 9 – de la Roche (1962/63); others – Holub (1990)

Chemical composition of two-pyroxene melasyenitoids of the Tábor type from CBPC is chemically similar to durbachitic rocks except for their lower water, markedly lower Ni contents and some subtle differences in inter-element ratios. Some local varieties, e.g. the fine-grained melasyenite of the Dražice subtype (central part of the Tábor massif), are much lower in U, Th (Fiala et al. 1983), Cs, Rb and Zr (cf. Tauson et al. 1977).

Among acid K-rich granitoids of CBPC, the Sedlčany and Zbonín granites are closely related to the light facies of the Čertovo břemeno type (Table 2, Fig. 7, 8). Both granite types are higher in silica and lower in magnesia (< 3 %), however, and their composition fall out of the ultrapotassic group. There are also some subtle chemical differences in respect to prolonged trend of the typical durbachite series: The Sedlčany granite has lower MgO/CaO ratio, slightly higher alumina and enhanced Sr, whereas the Zbonín granite is poorer in Ca and often very rich in K_2O, with variable alumina content.

Chemical composition of the Rastenberg type from Austria varies considerably and generally it is less potassic and much less magnesian relative to durbachitic rocks; it mostly does not suit the definition of ultrapotassic rocks and resembles some K-rich granitoids of shoshonitic affinity. Moreover, it is higher in Al, Na, Sr, and has much lower MgO/CaO, Cr, Rb and Rb/Sr (see Luna 1972; Němec 1976; Liew et al. 1989; Vellmer and Wedepohl 1994). However, some samples of the "atypical durbachitic rocks" from margins of the Třebíč Pluton seem to be geochemically (not texturally) related to the Rastenberg type.

Also ultrapotassic syenitoids to granitoids in other parts of the Hercynian belt show some distinct features. For instance, ultrapotassic syenites of the Giuv type in the Aar massif of western Alps (Schaltegger et al. 1991) have CaO/MgO > 1 and higher Sr, Th, etc.; nevertheless, they are highly enriched in the same group of hygromagmatophile elements like durbachitic rocks.

Mafic rocks and MgK granitoids in Corsica (Rossi and Cocherie 1991) only sporadically correspond to the definition of ultrapotassic rocks and more frequently are of shoshonitic character. Their Al_2O_3, MgO/CaO ratio, and REE vary considerably whereas Rb/Sr ratio is much lower than that in durbachitic rocks. However, few samples are geochemically similar to them except for Rb and Sr.

Results of the comparison can be summarized as follows: Rocks of the durbachite series are characteristic for the Moldanubian zone where they may be accompanied by other Mg, K-rich plutonic and dyke rocks. Composition of both durbachites and the more acid members of DS from various regions within the Moldanubian zone is almost uniform. Outside the Moldanubian zone, the mafic ultrapotassic rocks of Hercynian age are less common and their composition usually differs in lower Rb/Sr and MgO/CaO.

Re-evaluation of yet published petrogenetic hypotheses

In the Bohemian Massif, it is rather difficult to find another rock type for which so many and so different petrogenetic hypotheses were established. Despite the fact that the durbachitic rocks were originally described as being of magmatic origin (Sauer 1893; Orlov 1933; Hejtman 1949), many authors considered them as originated through granitization (e.g., Jung 1955; von Eller 1961; Röhlichová 1964; Krupička 1968).

During the last 20 years, the igneous character has been proved and discussion focused on problems related the source of magma (Rossi et al. 1988, 1990; Holub 1990) and on processes of their origin (Bubeníček 1968a; Gagny 1978; Fluck 1981; Holub 1988, 1990), although the granitization hypothesis is still alive among several Czech petrologists (Palivcová et al. 1989a,b; Vlašímský et al. 1992). Opposite opinions can be illustrated by contrasting explanations of a single phenomenon like the presence of large K-feldspar crystals; according to Röhlichová (e.g., 1964; Hamtilová 1969) and Pivec (1970) these crystals represent porphyroblasts, according to Palivcová et al. (1989a,b) they are inherited phenocrysts from a granitized volcanic rock, whereas Němec (1975), Minařík and Povondra (1976), Neužilová (1978) and many others consider them as phenocrysts crystallized under plutonic conditions.

Metamorphic-metasomatic origin

This group of opinions includes hypotheses published originally by French petrologists during 1950's and early 1960's. According to Jung (1955), durbachites originated due to a "basic front" preceding a zone of granitization in the sense of Reynolds (1946). Von Eller (1961) proposed their origin by potash metasomatism affecting some amphibolite bodies within a gneiss complex.

These hypotheses were also applied to South-Bohemian durbachites (e.g., Zoubek in Bártek et al. 1973), and to NW part of the Třebíč Pluton, whose origin was ascribed to metasomatic ultrametamorphism of Moldanubian gneisses (Krupička 1968).

Such speculative hypotheses require an extreme influx of K, Mg, P, Cr and many other elements into "common" metamorphic rocks and their total recrystallization. They cannot explain the field relations, typical geochemical variations, nor igneous textures of durbachitic rocks and their microgranular enclaves.

Metamorphic-recrystallization origin from metasediments

Röhlichová (1962, 1964; Hamtilová-Röhlichová 1967; Hamtilová 1969) believed the durbachitic rocks to have originated through more or less isochemical recrystallization of metasedimentary "hornfelses", perhaps containing some tuffitic admixture (Hamtilová 1969). Her interpretation was accepted also by Lensch and Rost (1966) who interpreted the ultramafic xenoliths as inherited pebbles in a transformed metasediment.

This hypothesis was based on misinterpretation of textural and structural phenomena. Typical microgranular enclaves with their igneous textures including pilitic pseudomorphs after olivine and acicular apatite were interpreted as relics of metasedimentary hornfelses, phenocrysts of K-feldspar containing epitaxitic inclusions as porphyroblasts, local accumulations of xenoliths and cognate inclusions as metaconglomerates. Peculiar chemical composition of the rocks was not discussed.

Metamorphic-recrystallization origin from a volcanic protolith

Palivcová and Šťovíčková (1968), Marek and Palivcová (1968), Tauson et al. (1977), Palivcová et al. (1989b) and Vlašímský et al. (1992) considered durbachitic rocks as recrystallization products of older volcanic rocks, which could belong to a "weakly alkalic volcanism of a Moldanubian continental rift" and originated in the "Moldanubian crustal source".

Field relations (intrusive contacts, contact metamorphism around them, spatial distribution of the bodies, etc.) as well as petrography do not provide any evidence for such origin from a volcanic precursor. Moreover, geochemistry of these rock contrasts with both the proposed crustal source and the continental rift setting.

Crustal origin of the durbachitic magmas

Jakeš (1969) suggested origin of durbachitic magma by partial or even complete melting of some "mafic granulites", represented by rocks of the Tábor massif (sic!). Also Vejnar (1974) considered the durbachitic rocks as "products of palingenesis of crustal rocks". Bouška et al. (1984) believed that such origin is supported by high concentrations of lithophile elements and low K/Rb ratio.

Rossi et al. (1988, 1990) assumed that the intermediate durbachitic magma and other Mg-K-granitoids have originated through about 40 % melting of metagreywackes at a base of the Gondwana crust under conditions of $PCO_2 > PH_2O$. However, this model (similarly to the previous hypotheses) cannot explain the very high MgO, mg-values and Cr and Ni abundances, i.e. the features requiring a mantle source.

Origin by gravitational differentiation of a granitic magma

Model of gravitational crystal settling which does not contradict the previous hypothesis has been proposed for the origin of durbachitic and related rocks in the Vosges (Gagny 1978; Fluck 1980). However, the observed narrow range of mg-values as well as linear co-variations of elements like Cr, Ni, Zr, Sr, Ba, and MgO seem to contradict such explanation. Even the igneous layering described by Blanchard et al. (1978) from one locality of the Granite des Cretes cannot prove a fundamental role of such a process for the origin of the entire rock group.

Differentiation by diffusion in a granitic magma reservoir

Rajlich and Vlašímský (1983) assumed chemically distinct parts of CBPC to have originated through an elemental diffusion in a large magma body due to thermal gradient between the "cool" contact with the Barrandian zone and the "warm" contact with the Moldanubicum; thus, the durbachitic rocks should represent an extreme result of this process at the Moldanubian side of the batholith.

This model is unacceptable from geological as well as geochemical points of view (e.g., it ignores geological relations among various rock types, involves effective diffusion to horizontal distances of many kilometers, and long-lasting existence of a steep thermal gradient without crystallization, etc.).

Contamination of a granitic magma

Bubeníček (1968a, b) suggested the origin of dark durbachitic rocks in the Třebíč Pluton through contamination of an original acid magma by the host Moldanubian gneisses with subordinate bodies of metabasites.

Any simple mixing calculation can exclude such an origin as any proportions of a common granite magma and the surrounding rocks do not give the ultrapotassic composition of typical durbachite or durbachitic melagranite. Moreover, an assimilation process responsible for increasing MgO content in a siliceous magma up to 8–9 % is rather difficult to accept.

Origin from a special type of mantle-derived magma

Holub (1974, 1977, 1978 etc.), Hejtman (1975) and Fiala et al. (1983) recognized the geochemical affinity of durbachitic rocks with K-rich mafic magmas corresponding to potassic lamprophyres (minettes) and lamproites, and suggested their mantle-derived origin. Such explanation is consistent with new data but can be refined considerably in the following chapter.

Bowes and Košler (1993) compared durbachitic rocks with appinitic intrusives and came to conclusion that both the rock groups of shoshonitic affinity and lamprophyre-like composition originated by similar processes of mantle melting and several subsequent stages of freezing, remelting, and remixing of fractionation products. Though some geochemical characteristics are broadly similar, many important differences in chemistry and mineralogy between durbachitic and appinitic rocks should be emphasized as well as absence of any features symptomatic for the processes of remelting, advanced fractionation and remixing in rocks of the durbachite group.

Origin of durbachitic and related rocks

Genetic relationship between mafic and more acid varieties

Fractionation of early mineral phases (e.g., olivine and pyroxenes) cannot explain chemical variations in DS with the linear co-variance of many trace elements and MgO or SiO_2 (Fig. 8). Also the curvilinear trend in the mg versus MgO plot (Fig. 10) is different from common fractionation trends. On the other hand, the linear trends in variation diagrams may indicate the principal role of mixing processes in the evolution of the whole DS.

The very large compositional variation of the durbachite series excludes both the restite unmixing and the bulk assimilation of solid rocks. Such variation, however, may result from mixing of two geochemically contrasting magmas, i.e. from progressive hybridization of a mafic magma with an acid magma.

Such origin of DS is in accord with the "anomalous" behavior of durbachitic rocks in the mg versus MgO plot, namely the too high mg-numbers in the intermediate members (Fig. 10), the "basaltic" abundances of Cr and Ni in the light facies, and may be responsible for the presence of pilitic pseudomorphs after Mg-rich olivine even in the most acid samples with about 65 % silica.

Mafic end-member

Ultrapotassic nature of the mafic end-member is beyond any doubt. Such magma must have been rich in K, Rb, Th, U etc. It also carried abundant Mg, Cr, Ni and considerable amounts of Ca, Sr, Ba, which were progressively diluted by hybridization.

Real composition of the mafic end-member could correspond to the most mafic rock still fitting the linear trend of DS, i.e. to the durbachite itself. Nevertheless, we cannot fully exclude another possibility that the mafic end-member was even more mafic relative to durbachite and that the latter represents a magma already hybridized.

There is no other geochemically appropriate composition among the known varieties of durbachitic rocks, however. Many mafic microgranular enclaves as well as the extremely mafic melasyenites and stavrites of small masses have suitable contents of some elements like Mg, Cr, and Ni, but are poor in Al, Ca, Sr, Zr (Table 2); these geochemical discrepancies exclude them from further consideration about the mafic end-member of simple mixing.

Typical durbachites with their mg-numbers about 70, Cr> 500 ppm and Ni > 150 ppm, correspond to primitive magmas originated within peridotitic upper mantle. If they were derived from some even more mafic parental magma by a limited degree of fractionation (involving olivine, see Ni), then geochemistry of the parent could be in many respects more similar to (though probably not identical with) the very dark melasyenites and some microgranular enclaves which are lower in Al, Ca, Sr, Zr, etc. but higher in Mg, Cr and Ni (see Table 2).

Limited but variable degree of fractionation may be responsible for some variation in alumina content and mg-numbers among the most mafic durbachites; for instance, the most mafic sample of the Třebíč Pluton (No. 359 in Table 2) cannot be the best mafic end-member for many less mafic samples from the same body because of its slightly lower mg-value and, consequently, a less primitive character. This line of evidence suggests some role of fractionation processes prior to the major mixing episode.

On the other hand, some geochemical variations, namely the contents of some hygromagmatophile elements, may represent also primary differences among individual portions of the ultrapotassic mafic magma. For instance, variations in Th concentrations may represent a feature inherited from rather heterogeneous source, or they might have resulted from early fractionation of a Th-bearing mineral (e.g., thorite).

Acid end-member

It is highly unlikely that the acid end-member could be represented by the light facies of ČB itself because of its peculiar composition indicating a hybrid character. Consequently, the composition of the acid end-member is expected to plot in variation diagrams onto the trend line of

DS somewhere beyond the most acid durbachitic rock, and to contain fairly more silica than 66 %.

The higher content of silica in the acid end-member, the smaller amount of this magma is necessary for deriving chemical variations within the durbachite series. The upper limit to silica content is given by zero content of any inversely correlated element in a variation diagram; it is about 75 % SiO_2 when P_2O_5 or MgO are equivalent to zero.

Search for the acid end-member should be oriented toward rocks which have common composition and which can originate within the continental crust in relatively large volumes. As comes out from Fig. 10 and variation diagrams, the normal mg values and Cr contents can be reached only at very high content of silica (SiO_2 72 %) and very low MgO and Fe-oxides. Fairly low Mg and Fe in the acid member are indicated also by the narrow variation in mg-values within the durbachite series itself.

Consequently, a potassium-rich leucogranite appears to be theoretically the best representative of the acid end-member. Its assumed composition is shown in Table 4 and marked in variation diagrams (Figs. 7, 8 and 10). This composition is similar to many common S-type orogenic granites; for instance, it partly overlaps with the compositional variability of the Eisgarn granite in the South Bohemian Batholith.

The high content of K_2O in the hypothetical leucogranite magma does not correspond to the "wet" granite eutectic in the Qz-Or-Ab-An-H_2O system (cf. Winkler 1979). This feature may indicate a water-undersaturated nature of the acid magma. According to Ebadi and Johannes (1991), reduced activity of water due to presence of CO_2 can shift the melt towards more potassic (Or-rich) composition.

The acid end-member was rich in Rb, Cs, Th and U, i.e. in those elements which are typical also for the mantle-derived ultrapotassic end-member. This geochemical feature, however, does not correspond to partial melts of a refractory lower crust (Taylor and McLellan 1985).

Table 4. Calculated compositional ranges of the mafic and acid end-members

Member	mafic	acid
SiO_2	51.5 – 54.0	72.0 – 75.5
TiO_2	1.2 – 1.4	0.1 – 0.3
Al_2O_3	13.0 – 14.0	12.5 – 14.0
FeO tot	6.5 – 7.3	0.4 – 1.3
MnO	0.10 – 0.12	0.2 – 0.5
MgO	8.5 – 9.5	0.2 – 0.5
CaO	4.5 – 5.0	0.7 – 1.5
Na_2O	1.5 – 2.0	2.7 – 3.3
K_2O	6.2 – 7.2	6, 5.0 – 6.5
P_2O_5	1.2 – 1.4	0.05 – 0.2
mg	70	20 – 40
V	80 – 100	< 20
Cr	500 – 600	< 20
Ni	160 – 200	< 10
Zn	100 – 130	20 – 50
Rb	380 – 420	300 – 420
Sr	440 – 540	170 – 270
Zr	470 – 520	40 – 150
Cs	17 – 22	(40?)
Ba	2100 – 2700	100 – 500
Ce	110 – 130	75 – 105
Th	15 – 50	(10)-25 – 45
U	10 – 20	10 – 30

Major elements in weight per cent, trace elements in ppm.

Consequently, the source rocks are believed to have been either geochemically undepleted (in contrast to present composition of the Moldanubian acid granulites which are rich in K_2O but poor in Th and U – cf. Fiala et al. 1987), or even enriched in radioactive and some other highly hygromagmatophile elements in similar way as was the mantle source of the ultrapotassic mafic magma itself. The latter hypothesis has been proposed by Van Bergen (1985) for the origin of an acid end-member of geochemically very similar young volcanic rocks occurring in Italy. It can also explain the origin and source of a fluid phase which is needed for a large-scale anatexis of crustal rocks. This problem, however, is difficult to solve unless isotopic data are available.

Conditions and course of mixing

Large volumes of durbachitic rocks are fairly homogeneous although mixing calculations indicate that the most acid varieties (65–66 % silica) contain more than 50 (up to 60) wt % of the acid end-member. Consequently, the principal role of mechanical mixing of the two magmas is suggested because of its much higher efficiency relative to diffusion processes at a mafic/acid interface.

The high degree of homogenization also indicates that the major mixing processes occurred in greater depths relative to the present intrusion level of durbachitic plutons. Intruding magmas are thought to have been already hybridized. Nevertheless, some subordinate hybridization and contamination episodes could affect the composition of durbachitic magmas during their ascent through the hot Moldanubian complex and cause some local geochemical variations.

Some problems lie in the weak deviations from linear trends in variations of K, Ba and Sr. They may be due to limited fractionation of K-feldspar in highly hybridized magma as well as to subtle changes in composition of the acid end-member during final stages of hybridization.

Origin of microgranular enclaves

The ultrapotassic microgranular enclaves in durbachitic plutonites are in many respects (namely the shape and textures) comparable to microgranular enclaves in common granitoid rocks. The current hypothesis that the enclaves represent small portions or drops of more mafic magma mingled with and chilled against the granitic host (Vernon 1984 and many others) seems to be applicable also for our rocks with well developed quenching textures.

However, any simple petrogenetic model for these ultrapotassic enclaves and their role in development of the durbachitic magmas is still obscured by their extremely variable geochemistry; these variations may reflect highly heterogeneous mantle source and could be affected by processes of fractionation, hybridization and also partial interaction with the host.

Origin of atypical durbachitic rocks

The hybridized durbachitic magma may have interacted during its ascent with neighbouring rocks regardless of whether they were in partially melted or completely solid state prior to interaction. Such contamination could have been responsible for the observed local deviations from the major trend of the durbachitic series, particularly in the border facies and the so-called atypical durbachitic rocks.

Although such contamination by a wall-rock material seems to be highly probable, some role of a different (perhaps shoshonitic?) magma cannot be excluded either. Such magma may represent the third, only locally important, end-member taking part in the complex hybridization processes. Its role in genesis of the atypical durbachitic rocks seems to be supported by presence of geochemically distinct mafic enclaves in NW part of the Třebíč Pluton where they have been sampled by Scharbert and Veselá (1990); according to their data, these rocks are much higher in Sr and lower in Rb (with Rb/Sr 0.40) than typical ultrapotassic microgranular enclaves elsewhere, and their initial $^{87}Sr/^{86}Sr$ ratio is lower than that of common durbachitic rocks from the Třebíč Pluton.

Origin of associated leucogranites

Leucogranites spatially associated with durbachitic rocks are chemically variable and still poorly known. Their composition usually differs from that of the hypothetical acid end-member of the hybridization series in lower K_2O/Na_2O ratio, lower contents of U (Bubeníček 1968b), Th, and light REE, rather low but varying contents of Ba, etc.

Composition of these leucogranites argues for their origin under lower pressure and rather wet conditions, probably at shallower levels of the continental crust as compared with the acid end-member of DS. The close spatial affinity of leucogranites and ultrapotassic rocks can be explained by thermal perturbance and anatexis due to the ascent of voluminous, more mafic ultrapotassic magmas through relatively hot post-collisional crust. Nevertheless, at least some leucogranites may be related to a distinct, younger magmatic event.

Mantle processes

Geochemical constraints indicate an anomalous composition of the mantle source which was different from common lherzolites. Markedly low Ca and Na argue for a source very poor in clinopyroxene, perhaps corresponding to harzburgite. Enhanced silica is also typical for mafic magmas originated in a strongly depleted, refractory mantle source, and may indicate relatively low-pressure and wet conditions of partial melting (cf. Foley and Venturelli 1989).

Abundant hygromagmatophile elements except Sr are in sharp contrast with the assumed refractory nature of the mantle source and together with peculiar inter-element ratios cannot be explained by even very low-degree partial melting of a common peridotite. The high and nearly uniform potassium content indicates the presence of a substantial amount of phlogopite in the source rock which may, indeed, correspond to phlogopite harzburgite. Such rock could have originated through a strong enrichment of previously depleted region of the lithospheric mantle and is regarded as appropriate magma-source for many lamproites (e.g., Foley 1992).

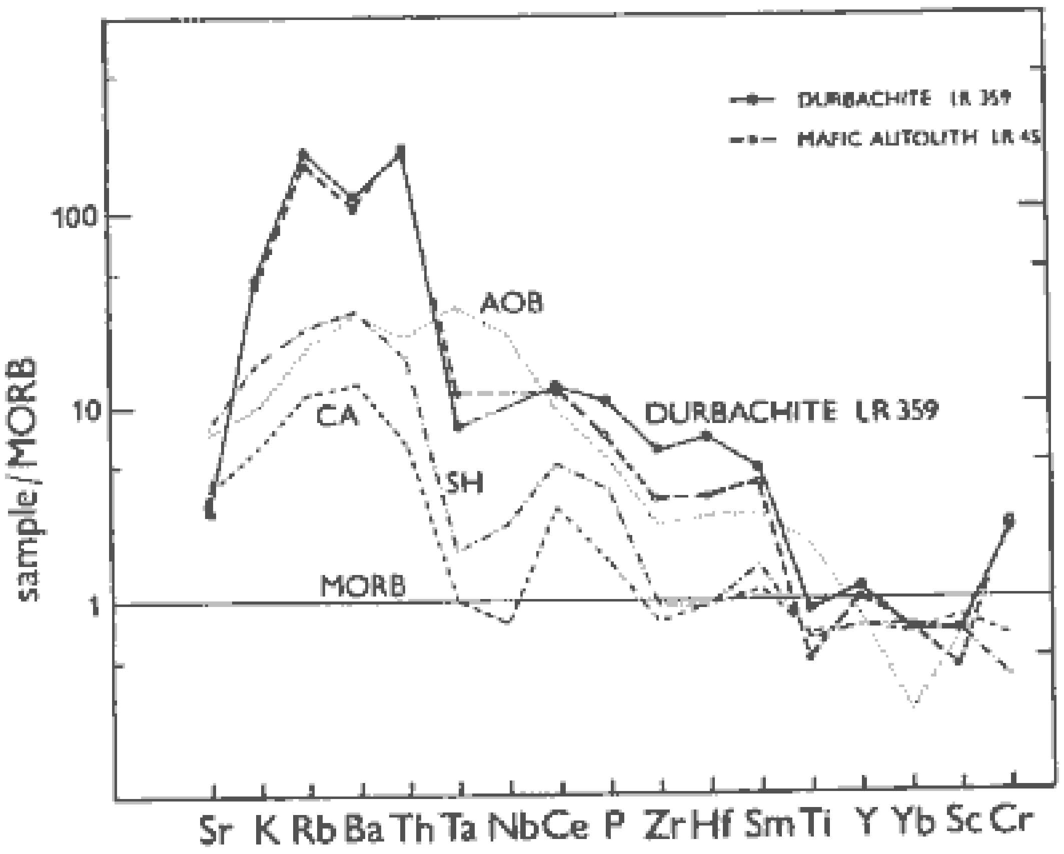
Normalization spidergrams after Pearce (1982) display peculiar inter-element relations which are typical for both the durbachites and their microgranular enclaves (Fig. 11). Normalized abundances of some large-ion-lithophile elements, namely K, Rb, Cs, and Ba, as well as Th and U, are much more enhanced than REE and some high-field-strength elements like Zr, Nb, Ta, and Ti. This feature is usually considered to be typical for magmas originated in those mantle domains which have been metasomatized by hydrous fluids. Such fluids are widely believed to be derived from the subducted slab, namely the hydrated oceanic basalts and deep-sea sediments, or a detritic material derived from the continent.

When compared with calc-alkaline and shoshonitic series, the durbachitic rocks are much more enriched in the most indicative hygromagmatophile elements (Fig. 10). The very high Rb, Cs, Rb/Sr, and low K/Rb may indicate substantial involvement of subducted continental crust in the enrichment processes.

According to experimental works, very high-pressure metamorphism and dehydration of granitic crust may yield highly potassic hydrous fluids which, consequently, enrich the overlying shallow lithospheric mantle (Schreyer 1988; Massone 1992). Some role of the continental crustal material in origin of the ultrapotassic rocks from the Moldanubian area is supported by considerably high initial $^{87}Sr/^{86}Sr$ values in durbachitic rocks and the chemically related Jihlava melasyenite (about 0.712, Scharbert and Veselá 1987), minettes and the Mg-K-rich granite of the Sedlčany type from the CBPC (Janoušek and Rogers 1994).

Geodynamic setting

The type of enrichment discussed above should not be interpreted in terms of a close temporal relation between



11. Spidergram of selected major, minor and trace elements in typical durbachite compared to common mafic rocks of the alkali-basaltic (AOB), calc-alkaline (CA) and shoshonitic (SHO) series. Normalizing values of MORB and other averages are from Pearce (1982).

the active subduction and melting of the modified mantle. Shoshonitic magmas are usually related to a failure of subduction activity (Morrison 1980) and ultrapotassic magmas may originate considerably later from sources which remained isolated within the lithospheric mantle for a long time (Varne 1985; Nelson 1992).

Discrimination diagrams after Müller et al. (1992) for distinguishing geodynamic setting of potassic and ultrapotassic rocks give results which are rather disputable and ambiguous: typical durbachites plot at the border of fields denoted as the within-plate and continental arc plus post-collisional arc settings. Though it is doubtful whether the geochemical data themselves can solve problems of actual geodynamic setting, those results are consistent with rather complicated and more or less transitional conditions indicated by field geology.

Nearly linear alignment of durbachitic bodies in South Bohemia may reflect existence of a deep fault which controlled ascent of ultrapotassic magma batches from the mantle, perhaps under extensional conditions. Such extension could be early post-collisional as well as only episodic within framework of highly complex continental collision.

Emplacement of large and generally flat intrusions located within the Moldanubian complex could have been controlled by some subhorizontal discontinuities; the most prominent one seems to be the base of the Gföhl nappe with its acid metamorphic rocks, which could serve as ”traps“ for magma due to their composition, relatively low density and at least local anatectic state. Considerably different situation in the Central Bohemian Plutonic Complex, where durbachitic rocks intruded near the roof of the older granitoids, may be explained in terms of magmatic stoping and perhaps cauldron subsidence (see the shape of the Milevsko massif).

Conclusions

(1) The durbachite series (DS) ranges in composition from very dark amphibole-biotite melasyenite (= durbachite) to melagranite.

(2) Rocks of DS display ultrapotassic composition with very high abundances of K, Rb, Cs, Th, U, Cr, and markedly low contents of Ca, Na, and Sr.

(3) In close spatial association there are other types of mafic ultrapotassic rocks, as well as some more acid K-rich granites and leucogranites.

(4) Durbachitic rocks from the Bohemian Massif correspond in mineral and chemical composition to the same rock types in the Black Forest (the original durbachite) and the Vosges (durbachites, Granite des Cretes). These rocks are not identical with the Rastenberg type from the Waldviertel area in Austria, however.

(5) Hypotheses considering the origin of the durbachitic rocks by metasomatic or isochemical recrystallization of metasediments and metavolcanic rocks are inconsistent with field relations, petrographical and geochemical data.

(6) The most mafic members of DS characterized by high *mg*-values, Cr, and Ni abundances, correspond to primitive mantle-derived magmas, which could be only slightly modified by fractionation or hybridization.

(7) More acid rocks of DS can be explained as products of progressive hybridization (mixing) of the ultrapotassic mafic magma with acid crustal melts of leucogranitic composition.

(8) Highly anomalous composition of the mantle source is proposed. Such source should have rather complicated history involving an early depletion due to previous melting episode(s) and subsequent enrichment in strongly hygromagmatophile elements.

(9) The enrichment may be related to high-pressure metamorphism and dehydration of a subducted plate from which the water-rich fluids carrying K, Rb, Cs, Ba, Th, U, and some other elements could have been released.

(10) Ascent of the ultrapotassic magmas could be enhanced by deep radial tectonics during crustal extension. Location of large and usually flat plutons of the already hybridized durbachitic magmas seems to be controlled by some geological structures originated during the Hercynian collision, e.g. the base of the Gföhl nappe.

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Ultradraselné plutonity durbachitové série v Českém masivu: petrologie, geochemie a petrogenetická interpretace

(Resumé anglického textu)

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Ultradraselné plutonity hercynského stáří jsou rozšířeny v jižní, tj. moldanubické části Českého masivu. Jejich nejvýznamnější skupinu představuje durbachitová série, tvořená porfyrickými amfibol-biotitickými melasyenity (durbachity) až melagranity a označovaná obvykle jako typ Čertovo břemeno. Všechny členy durbachitové série obsahují mafické mikrogranulární enklávy melasyenitového až mela-kvarcsyenitového složení (obr. 4). S porfyrickými durbachitickými plutonity jsou těsně spjata i drobná tělesa neporfyrických variet.

Všechny tyto horniny jsou vysoce hořečnaté a bohaté Cr (Ni) stejně jako mnoha hygromagmatofilními (litofilními) prvky jako Rb, Cs, U, Th atd. Charakteristická je anomálně vysoká přirozená radioaktivita těchto hornin. Celkové chemické složení přibližně odpovídá relativně Si-bohatým minetám a příbuzným melasyenitovým až melagranitovým porfyrům, rozšířeným v oblasti středočeského plutonického komplexu a v šumavském moldanubiku.

Durbachity z lokalit v Českém masivu odpovídají petrograficky i chemicky originálnímu durbachitu ze Schwarzwaldu a durbachitům ve Vogézách, světlejší variety typu Čertovo břemeno jsou dobře srovnatelné s granitoidy typu Cretes z Vogéz. Zastoupení tmavých durbachitových variet je však v Českém masivu vyšší a přechodní členy mezi klasickými durbachity a světlejšími varietami v durbachitové sérii jsou zde rovněž mnohem více zastoupeny (obr. 6), i když celková variační šíře je obdobná. Naproti tomu mezi durbachitovou sérií a granitoidy typu Rastenberg z Rakouska existují významné petrografické a geochemické rozdíly, a oba typy hornin proto nelze ztotožňovat.

Hypotézy, které se v 60. letech pokoušely vysvětlit vznik durbachitických plutonitů metasomatickými procesy ze staršího bazického nebo rulového substrátu, nebo nověji izochemickou transformací předhercynských alkalických vulkanitů apod., lze na základě dosavadních znalostí geologického vystupování, struktur i látkového složení těchto hornin zcela odmítnout. Složení durbachitických hornin však nelze odvodit ani frakcionací nebo kontaminací běžných (tzn. nikoliv ultradraselných) typů magmat, ať už mafických nebo granitoidních.

Složení mafických členů durbachitové série odpovídá značně primitivnímu ultradraselnému magmatu plášťového původu, které bylo jen slabě modifikováno procesy frakcionace a (nebo) hybridizace a jehož dílčí porce se přes celkově velmi stálý charakter mohly lišit v koncentracích některých hygromagmatofilních prvků, např. Th.

Geochemický charakter ultradraselného magmatu (obr. 11) indikuje jeho vznik v anomálních doménách litosférického pláště. Tyto domény musely dříve prodělat silné ochuzení bazaltickými komponentami, protože byly velmi chudé Na, Ca, Sr apod. Dodatečně však musely být obohaceny hygromagmatofilními prvky, zejména K, Rb, Cs, Th, U, kterými jsou i velmi primitivní ultradraselná magmata abnormálně bohatá. Tyto prvky byly nejspíše přinášeny prostřednictvím superkritických roztoků, uvolňovaných při devolatilizaci nějaké subdukované litosférické desky. Vzniklý silně modifikovaný plášťový zdroj ultradraselného magmatu měl nejspíše složení flogopitického harzburgitu.

Přestože durbachitický magmatismus je spodnokarbonského stáří, nelze předpokládané procesy spjaté se subdukcí zatím časově zařadit, neboť mezi obohacením plášťového zdroje a vznikem ultradraselného magmatu mohl být i značný časový odstup. Složení intermediálních až acidních členů durbachitové série se výrazně liší od produktů „čisté“ frakcionace výchozího mafického magmatu a dokonce i nejacidnější variety s obsahy SiO_2 mírně nad 65 % mají obsahy Cr na úrovni dosti primitivních bazaltů. Jejich geochemické charakteristiky, zejména abnormálně vysoké obsahy Mg a Cr, lineární trendy v mnoha jednoduchých variačních diagramech (obr. 7, 8), stejně jako abnormálně mírný pokles poměru Mg/(Mg+Fe) s rychle rostoucím obsahem SiO_2 (obr. 10), lze vysvětlit procesy mísení ultradraselného mafického magmatu s (leuko)granitickými taveninami, patrně pocházejícími z kontinentální kůry. Magmatickému mísení odpovídá také přítomnost pilitických pseudomorfóz po olivínu, často s akcesorickým chromitem, v celé sérii od mafických po acidní členy. Nejsvětlejší členy durbachitové série obsahují až přes 50 % předpokládaného acidního koncového členu. Vlivy frakcionace magmatu a kontaminace okolními horninami byly celkově spíše podružné, i když lokálně mohly způsobit odchylky od ideálního průběhu mixingového trendu.

Leukogranitické horniny, vystupující na dnešním povrchu v prostorové asociaci s durbachitickými plutonity, se většinou geochemicky mírně liší od hypotetického acidního koncového členu hybridizační durbachitové série, mají např. nižší obsahy K, Th, U apod. Představují nejspíše produkty tavení kůry za odlišných podmínek a snad v menší hloubce.

Pro výstup ultradraselných magmat z pláště lze předpokládat extenzní režim, následující po hlavní etapě kontinentální kolize. Tvar vesměs značně plochých masivů durbachitických hornin je pravděpodobně predisponován určitými plochami nespojitosti ve svrchní kůře, především bází gföhlského příkrovu.

Vysvětlivky k obrázkům

1. Distribuce těles ultradraselných hornin v moldanubické oblasti Českého masivu.

2. Terénní vztahy durbachitického melagranitu typu Čertovo břemeno ve středočeském plutonickém komplexu. Výchoz na pravém břehu Otavy, 3 km jižně od hradu Zvíkov, sev. od Písku.

3. Makroskopický vzhled typického durbachitu z třebíčského plutonu od Velkého Meziříčí. Téměř původní velikost.

4. Tmavá mikrogranulární enkláva ve středně tmavé varietě typu Čertovo břemeno. Bezděkov u Nadějkova, 12 km sv. od Milevska.

5. Jehlicovitý apatit a biotit-amfibolové shluky v mikrogranulární enklávě ze světlejší facie typu Čertovo břemeno (durbachitického melagranitu), Zvíkovské Podhradí. Mikrofoto bez analyzátoru, zvětšeno 50x.

6. Histogramy obsahů MgO (hmot. %) v ultradraselných plutonitech durbachitové série a sdružených K a Mg-bohatých granitech (KMgG) pro a) jižní část Českého masivu souhrnně, b) oblast středočeského plutonického komplexu, c) oblast šumavského moldanubika jižně od středočeského plutonického komplexu, d) třebíčský pluton a drobná satelitní tělesa v jeho okolí.

7. Variační diagramy vybraných hlavních a vedlejších oxidů (hmot. %) durbachitických hornin a příbuzných K- a Mg-bohatých granitů. Pole M označuje pravděpodobné složení mafického koncového členu, pole A označuje hypotetický acidní koncový člen.

8. Variační diagramy vybraných stopových prvků (obsahy v ppm) proti MgO (hmot. %) v durbachitických horninách a příbuzných K- a Mg-bohatých granitech. Pole A a M jako v obr. 7.

9. Obsahy vzácných zemin normalizovaných na průměr chondritů (Boynton 1984) v typickém durbachitu, durbachitickém melagranitu a mafické mikrogranulární enklávě, vše z třebíčského plutonu (lokalizace – viz tabulka 2).

10. Variační diagram mg-hodnot proti obsahu MgO (hmot. %) v horninách durbachitové série a některých příbuzných draselných granitech. Pro srovnání jsou zde vyznačeny tři varianty teoretické mixingové křivky pro různé dvojice ultradraselných a granitových koncových členů a dále trendy několika typických frakcionačních sérií.

11. Normalizační diagram vyjadřující obsahy některých prvků v typickém durbachitu a mafické enklávě, vztažené k průměrným obsahům v bazaltech středooceánských hřbetů (MORB). Pro srovnání: jsou znázorněny křivky běžných horninových sérií: AOB – alkalickobazaltové, CA – vápenatoalkalické, SHO – šošonitické.
Normalizační hodnoty MORB i průměry jsou podle Pearce (1982).

Vysvětlivky k tabulkám

1. Reprezentativní mikrosondové analýzy mafických minerálů. Obsahy Fe^{3+} a Fe^{2+} byly vypočteny na základě ideální stechiometrie. D – durbachit, DČB – středně tmavá facie Čertova břemene, LČB – světlá facie Čertova břemene.

2. Reprezentativní analýzy hlavních a stopových prvků v plutonitech durbachitové série i některých prostorově asociovaných horninách jižních Čech (sloupec 1–15) a západní Moravy (16–27). Hlavní prvky jsou v hmot. %, stopové prvky v ppm (0.000X hmot. %).

3. Srovnání makrochemismu reprezentativních durbachitických hornin z Českého masivu (BM), Schwarzwaldu (Sch) a Vogéz (V).

4. Možné intervaly složení mafického a acidního koncového členu durbachitové série podle mixingových výpočtů. Hlavní oxidy jsou v hmot. %, stopové prvky v ppm.